Response to referee #1

This paper examines the physical processes that influence the nitrate seasonal cycle in the equatorial Atlantic cold tongue region using observations (PIRATA/EGEE cruise and PIRATA mooring data) and a numerical model (NEMO + PISCES run for the tropical Atlantic). The biogeochemical results are very interesting to this physical oceanographer, and the paper reads very nicely and is well organized. In particular, I found the results about the role of vertical processes in controlling the seasonal evolution and spatial distribution of nitrate and the interplay between the low frequency advection and advection due to tropical instability waves and eddies most fascinating. The results presented here are important and with some minor revisions this paper will be suitable for publication.

We thank the referee for his/her careful reading and comments. Below are our responses to the different points. Changes in the manuscript are also indicated.

Abstract: The abstract text about the different role of horizontal advection (extends and shapes the bloom off equator, brings nitrate low water below mixed layer, EUC brings low-nitrate water but still rich enough) on lines 19-23 seems a little contradictory and some wordsmithing could be applied to make clear the competing roles of zonal and horizontal advection. In contrast, the description of vertical advection and diffusion were clear.

We changed lines 19-23 to "Below the mixed layer, observations and model show that the Equatorial Undercurrent brings low-nitrate water (relatively to off-equatorial surrounding waters) but still rich enough to enhance the cold tongue productivity. Our results also give insights on the influence of intraseasonal processes in these exchanges. The submonthly meridional advection significantly contributes to the nitrate decrease below the mixed layer."

Figure 1. Possibly enlarge Figure 1 and/or make SST contours darker/thicker so that they are easier to read.

We thickened the SST contours.

Line 49: Suggest "1960s, as well as satellite measurements since the 1980s" instead of "60s and satellite measurements"

Done.

Line 79 (and elsewhere): Suggest acronym "TIWs" instead of "TIW"

Done.

Line 83: It is important to note here or elsewhere in the paper that TIWs exhibit seasonal variability similar to the nutrient seasonal cycle (specifically they are present with peak variance in May-July and sometimes re-emerge and there is a secondary peak in variance in the fall). This is in response to seasonal changes in the winds and the background circulation (which is drive the low-frequency vertical advection signal) but might also be contributing to the eddy vertical advection signal. Might be good to cite a study or two that shows evidence of this reemergence of TIWs in the tropical Atlantic (Caltabiano et al. 2005 OS, Athie and Marin, 2007 JGR; Perez et al. 2019 JGR, ...)

The semiannual cycle of activity of TIWs should be mentioned. We added this information in the first paragraph of the discussion on intraseasonal processes: "They are active in boreal summer, decrease in fall, emerge again at the end of the year with lesser intensity than in summer, and disappear in spring (Jochum et al., 2004; Catalbiano et al., 2005; Perez et al, 2019)."

Line 85 (and elsewhere): wording "low productive and productive seasons" is unclear, and you could perhaps switch the order or use something like "low productivity and high productivity seasons"

We used the referee's suggestion "low productivity and high productivity seasons".

Line 90: Here do you mean "equatorial upwelling" instead of "equatorial divergence" since you are specifically referring to vertical processes in the parentheses?

Yes. We changed to "equatorial upwelling".

Line 133-134: Perhaps indicate here or in Table 1 which years you include in the "low productive"/"no upwelling" averages and the "productive"/"upwelling" averages for Figure 2a-c. Are they cruise transect composites for years which productive vs. not productive but in the same season?

We clarify in table 1 which cruises are used for each period. We reworded lines 133-134 as "Vertical sections of nitrate, chlorophyll, and zonal current along 10° W measured during the PIRATA cruises and averaged separately in no-upwelling/low productivity and upwelling/high productivity seasons (table 1) are shown in Fig. 2a-c."

Line 135: Suggest "1970s and 1980s" instead of "70s and 80s"

Done.

Line 181: Suggest "three-dimensional" instead of "three-dimension"

Done.

Line 192: The second term on the right hand side in equation (2) is just the eddy part of the advection rather than the residual (sum of three terms involving an eddy term) that you describe using in the text.

Now, we clearly state that it is the eddy advection. We changed lines 194-197 by "The left hand side term is the monthly average of zonal advection. On the right hand side, the first term is the monthly zonal advection calculated from monthly averages of zonal current ($\bar{u}$) and nitrate concentrations ($\overline{NO3}$). The second term is the eddy advection term. It includes all the submonthly advection contributions which, in this region, may include influences of inertia-gravity waves, mixed Rossby-gravity waves, Kelvin waves, and eddies or tropical instability waves (e.g. Athié et al. 2009; Jouanno et al. 2013). It is calculated as the residual between…"

Line 196: Suggest "residual" instead of "residue"

Done.

Line 202: Please identify which term in equation 1 corresponds to the "entrainment term" either on this line, or earlier in the discussion of equation 1 terms.

Now, we specify more clearly what is the entrainment term: "We use the method described in Vialard and Delecluse (1998) to investigate nitrate budgets in the mixed layer and in the euphotic layer. An entrainment term appears when integrating Eq. (1) over a time-varying layer:

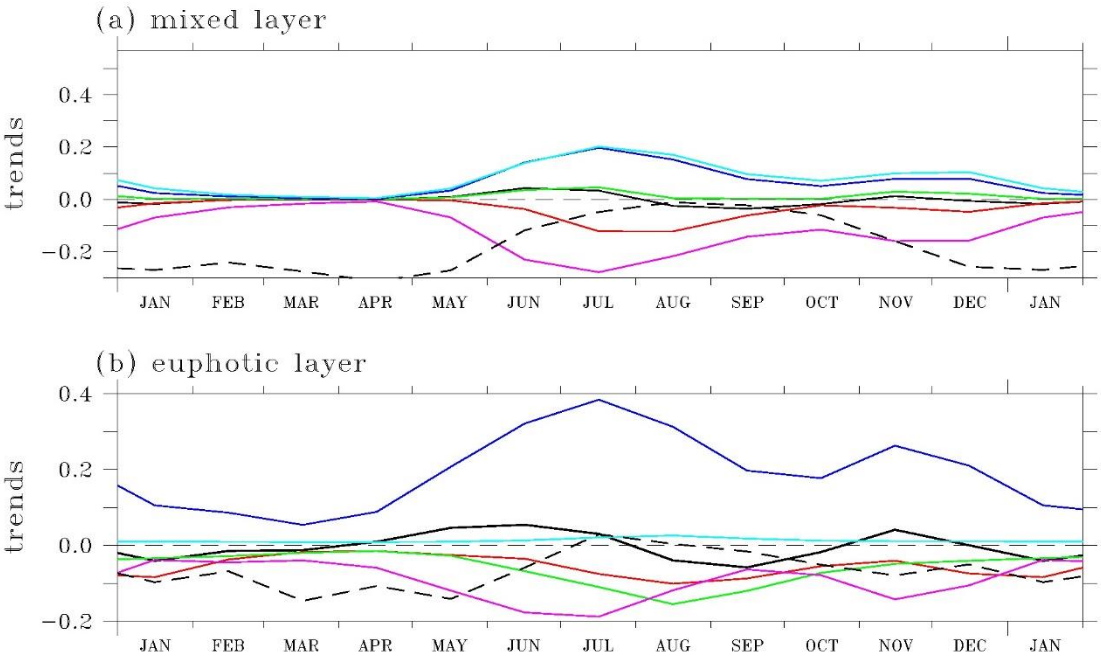
$$\frac{\partial\langle NO_3\rangle}{\partial t} = -\left\langle u\frac{\partial NO_3}{\partial x}\right\rangle - \left\langle v\frac{\partial NO_3}{\partial y}\right\rangle - \left\langle w\frac{\partial NO_3}{\partial z}\right\rangle$$

$$+\langle D_l(NO_3)\rangle + \frac{1}{h}\left(K_z\frac{\partial NO_3}{\partial z}\right)_{z=-h} + \langle SMS\rangle$$

$$-\frac{1}{h}\frac{\partial h}{\partial t}\left(\langle NO_3\rangle - NO_{3_{z=-h}}\right) \qquad (3)$$

where brackets indicate the vertical average over the layer depth h. The last term arises from time-variations of the integration depth h. This term is often referred to entrainment at the base of the layer (e.g. Vialard and Delecluse, 1998) and computed as a residual of the other terms of Eq. (3). Here we verified that this term is small and we chose not to show it. The mixed layer depth is…"

The following figure shows that the contribution of entrainment is several order of magnitude smaller than the contribution of other trends: nitrate change rate (black), zonal advection (red), meridional advection (green), vertical advection (dark blue), vertical diffusion (light blue), SMS (purple) in the mixed layer (a) and in the euphotic layer (b). The black dashed line is 1000 × entrainment, illustrating that entrainment is 3 order of magnitude smaller than the other trends.



Line 224: "Too elevated" reads awkwardly. Please consider rewording.

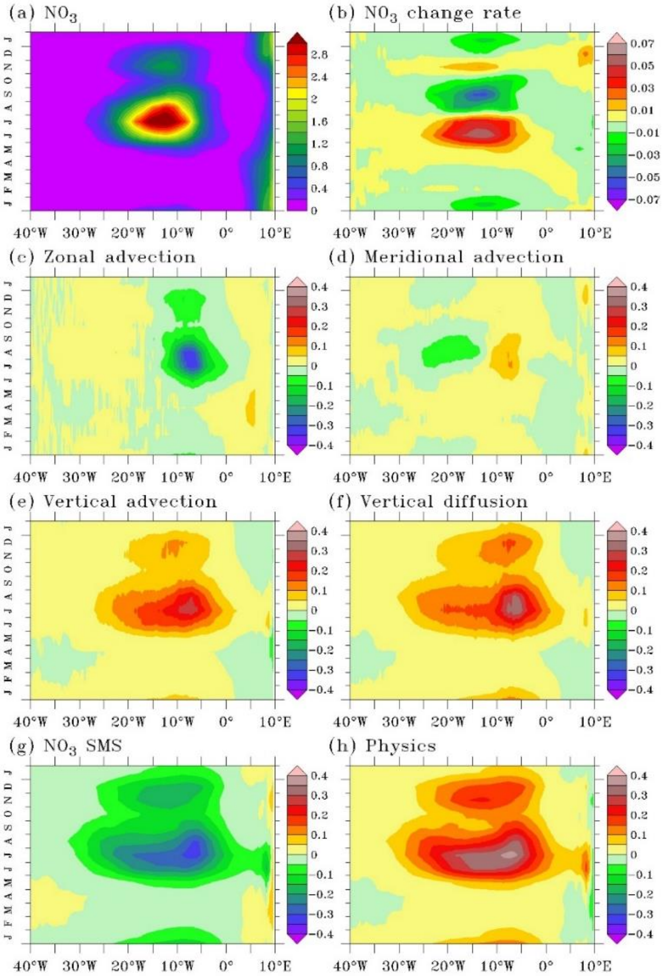
We changed to "too high simulated chlorophyll".

Figure 4: Panel e makes it easier to compare Z20 and ZEUC between model and observations. Could a similar line plot be used to compare depth of the nitracline and DCM between model during the "no upwelling season"? It could be a panel f and fill the white space.

Studying oligotrophic conditions is not the goal of this article and we prefer not to include such a plot. We specify now (lines 222-223) "In the equatorial zone, the position of the simulated DCM in the upper nitracline is in agreement with observations while its magnitude is more elevated by about 0.1 mg m^{-3} (Fig. 4b)."

Line 261: There is compensation between zonal and meridional advection. Question: Which term wins and during which time of year? Which term is most responsible for bringing nitrate low waters to the cold tongue area, presumably zonal advection?

Thank you for this remark. It points out that the latitude range used in figure 5 of the submitted manuscript is wrong. When the average is applied with the correct latitude range, it is clear that variations of zonal advection drive variations of horizontal advection and that it brings nitrate low water during most of the year. The new figure 5 is the following one:



We changed the text to “Variations of zonal advection drive variations of horizontal advection (Fig. 5c, d) that acts to bring some low-nitrate water to the cold tongue area during most of the year. The main peak occurs in July-August and a secondary peak in December. Horizontal advection is close to zero in February-May.”

Line 281. In December, is the compensation between meridional and zonal advection different than in July? How do they contribute to the secondary maxima?

This remark is linked to the preceding one. The reduction of vertical processes is mainly responsible for the reduction of nitrate supply in December. So, the lesser decrease in December is mentioned in line 261 instead of adding details in this paragraph.

Line 310 Suggest “as an interplay” instead of “as interplays”

Done.

Line 331: Don't you mean zonal advection (rather than horizontal advection) removes nitrate all year long? Meridional advection seems to add nitrate in the mixed layer, at least in Figure 7e. You do say this later, but the statement on line 331 is in conflict with that.

Yes, this is an oversimplification. We reordered this paragraph in order to better separate processes in the mixed layer and below. It is now written as:

"Below the mixed layer, horizontal advection (Fig. 7d, e) removes nitrate all year long. It drives the strong nitrate loss in August-September and the lesser one in December-January (Fig. 7c) when the contributions of both zonal (Fig. 7d) and meridional (Fig. 7e) advections are the largest. The contribution of the low frequency zonal advection (Fig. 8a) compares to that of the eddy advection (Fig. 8d) while the eddy signal (Fig. 8e) controls the meridional advection. Negative low frequency zonal and meridional advections indicate the transport of low-nitrate water from the west by the EUC and from the north by the low frequency southward component of the subsurface current (Perez et al., 2014). In the mixed layer, zonal advection acts to decrease the nitrate concentration and meridional advection is a weak source of nitrate. The low frequency advection of nitrate poor water from the east is the largest where the zonal nitrate gradient is the strongest. The low frequency meridional advection (Fig. 8b) reveals the influence of the equatorial cell: the northward transport of nitrate rich upwelled water dominates the meridional advection in the mixed layer on average in the 20° W-5° W, 1.5° S-0.5° N region."

Line 322-340: Some of Figure 7 labels are shifted (e.g., Fig. 7c instead of Fig. 7d) in the text in these 2 paragraphs.

We corrected labels 7b, 7c, 7d (now 7c, 7d, 7e).

Lines 358, 360. Two sentences begin with "Its" and "It" and I'm not 100% whether "It" means the EUC or nitrate concentrations or something else.

We changed to "**The semiannual cycle** of the nitracline depth follows the basin wide adjustment of the thermocline to the wind forcing via interactions between wind forced Kelvin waves and boundary reflected Rossby waves (Merle, 1980; Ding et al., 2009). **This adjustment** conditions the depth of the thermocline and associated nitracline that varies from 60 m in spring to about 20 m in July-August while the upwelling core remains in the upper part of the EUC, at 20-30 m, all year long (Fig. 4e)."

Line 447-449: The sentence beginning with "Although..." is a bit unclear as written.

We changed this sentence to "This simulation was initially designed to study the large scale processes and it does not allow concluding about the role of the different intraseasonal processes. However, our results strongly suggest that large scale processes cannot totally explain the seasonal evolution of the nitrate budget and that the role of intraseasonal processes should be clarified."

General question that pertains to the last two sections in the text: How strong or realistic are the TIWs in the model? In the real ocean, do you think the eddy contribution to advection will be basically the same as what you found in the model?

We did not perform a specific validation of the TIW field in this study. Nevertheless, our experience from previous studies with this model configuration (NEMO, ¼ and 75 vertical levels) is that it reproduces the level of energy of the TIWs and their equatorial signature in terms of sea surface temperature (e.g. Athié et al. 2009; Jouanno et al. 2013). This suggests that the eddy advection contribution to the nitrate budget is well resolved. Nevertheless, this cannot be fully demonstrated from an observational basis since the only available nitrate data in the cold tongue area are from the PIRATA cruises which do not provide high-frequency information on the nutrient distribution.

We included this information in the last paragraph of the discussion. Now it reads as "This simulation was initially designed to study the large scale processes and it does not allow concluding about the role of the different intraseasonal processes. However, our results strongly suggest that large scale processes cannot totally explain the seasonal evolution of the nitrate budget. Previous studies (e.g. Athié et al.; 2009; Jouanno et al., 2013) show that this model reproduces the level of energy of the TIWs and their equatorial signature in terms of sea surface temperature. It suggests that their contribution to the nitrate budget is well resolved, but this cannot be fully demonstrated from an observational basis since the only available nitrate data in the cold tongue area are from the PIRATA cruises which do not provide high-frequency information on the nutrient distribution. A dedicated study allowing better separating the large scale and eddying signals is needed in order to identify the nature of intraseasonal processes at work and their impact on the seasonal nitrate budget in the Atlantic cold tongue area."