

We are very grateful to the Editor and the Reviewers for their constructive and relevant comments, which have helped us improve the quality and clarity of this work.

Please find below our detailed responses to each of the comments.

Figures prepared specifically for the review process are labeled as Figure RW X. Some of these figures will also be included in the revised manuscript; when applicable, this is indicated in the corresponding figure caption.

The paper considers tidal effects on the distribution and growth of phytoplankton in response to transports, mixing, nitrate supply over the Brazil shelf near the Amazon outflow. It presents a very interesting picture of how internal tides affect biogeochemistry in the seasonally-variable presence of the Amazon plume. The work uses a NEMO-PISCEv4 framework with 3 km horizontal resolution, which is sufficient to resolve low-mode internal tidal waves.

The Introduction ends with a very clear description of the 3 key questions to be addressed.

The model is validated against climatological data for nitrate and chl (see general issues below). Most of the work focuses on the differences between the model with and without tides. Some of the strongest results are on the cross-shelf/shelf edge sections where internal tidal influences are very clear.

The analysis focuses on mean, seasonal and spring-neap changes. All of these are interesting, and there are both common (internal tides and mixing) and different (plume changes) physical drivers. The paper feels very descriptive. There are lots of interesting contrasts between tides/notides but the explanations of why these contrasts occur are largely asserted or linked to previous work. But this is an impressive modelling experiment that must also include model outputs that would allow thorough, objective explanations of the results.

I have made a lot of comments below, but it all summarises to two main suggestions: (1) provide more physical data (e.g. density) to help understand the nitrate and chlorophyll patterns, and (2) make better use of the model output to identify *causal* links (e.g. what does a map of nitrate flux to the DCM or diapycnal diffusivity look like – the tides/notides anomaly of this could be very informative and strengthen much of the explanations). Without (2) the paper feels very descriptive. If a more detailed analysis of model fields is used to identify causal links, then there may be more than one paper in all this (e.g. mean and seasonal fields, and spring-neap tidal behaviour). Or, keep it as one paper but simplify the results section and use the discussion section to demonstrate the causal relationships. Either way – this is good, novel material. High-resolution models that get internal tide mixing are rare and with a better focus on modelled processes and causal relationships there is potentially a very strong paper here.

Thank you for this constructive suggestion. We agree that the original version was too descriptive and did not make sufficient use of the model diagnostics to investigate the physical mechanisms underlying the nitrate and chlorophyll patterns.

We have chosen to retain the study as a single manuscript, but have substantially reorganized it following your second suggestion. The Results section has been simplified and will now focus

primarily on the main spatial, seasonal, and spring–neap patterns. We have also added physical information, including the density structure and flux, to better interpret the vertical distribution of nitrate and chlorophyll.

General points to address:

1. The Abstract could be better organised. Perhaps explain first the seasonality, then the modification by tides (including spring-neap). At the moment the abstract is quite long, and talks about tides, then seasonality, then returns to tides.

Thank you here a revised version of the Abstract :

The Amazon shelf–offshore continuum is a dynamic biogeochemical region of the tropical Atlantic, where river discharge, ocean circulation, and energetic tides interact to shape nutrient and phytoplankton distributions. While the influence of the Amazon plume and regional circulation is well documented, the contribution of tidal forcing to seasonal and intraseasonal biogeochemical variability remains poorly constrained. Here, we investigate how tidal dynamics modify nitrate and chlorophyll distributions from the Amazon shelf to offshore waters using a high-resolution coupled physical–biogeochemical model ($1/36^\circ$) with and without tidal forcing, evaluated against climatological, satellite, and in situ observations.

Seasonally, surface nitrate and chlorophyll are higher over the Amazon shelf during April–June than during August–October, whereas the opposite tendency occurs offshore, producing a marked cross-shelf contrast. Tidal forcing substantially modifies this seasonal pattern. Differences between the TIDES and NO-TIDES simulations show enhanced surface nitrate over the northern shelf, along the shelf break, and extending offshore along the main internal-tide propagation region. These nitrate anomalies are accompanied by chlorophyll changes of approximately 15–50% offshore and decreases of 30–40% near the Amazon mouth. Tidal forcing also accounts for a substantial fraction of the April–June to August–October nitrate contrast. The vertically integrated chlorophyll response further illustrates the strong spatial heterogeneity of the tidal effect. Near the internal-tide generation region at P1, chlorophyll increases by approximately 8.4 mg m^{-2} in TIDES relative to NO-TIDES, corresponding to an enhancement of about 63%. Farther offshore at P2, the increase is more moderate, approximately 2.5 mg m^{-2} or 7%. This marked decrease from P1 to P2 is consistent with a stronger tidal influence on upper-ocean biogeochemistry near the generation region and a weaker response along the offshore propagation pathway.

At intraseasonal timescales, the tidal simulation exhibits a clear spring–neap variability of approximately 15 days in both nitrate and chlorophyll. This signal extends from the shelf break toward offshore waters and is particularly pronounced near the deep chlorophyll maximum, where variability in the upper nitracline is associated with changes in nitrate availability and chlorophyll. Additional transport diagnostics indicate that this modulation is accompanied by a pronounced MSf-band signal in vertical nitrate transport. The vertical advective nitrate flux shows a substantial tidal enhancement along the internal-tide propagation pathway, reaching approximately $10 \text{ mmol N m}^{-2} \text{ d}^{-1}$ locally and about $7 \text{ mmol N m}^{-2} \text{ d}^{-1}$ within the region of strongest internal-tide activity. Along the selected transect, the tide-related advective transport is also large relative to the upper-75-m nitrate inventory anomaly, with inventory-equivalent rates of $48.15 \text{ \% d}^{-1}$ at P1, $22.95 \text{ \% d}^{-1}$ at P2, and $15.84 \text{ \% d}^{-1}$ on average between the two locations. The MSf-band turbulent nitrate flux additionally shows a localized positive enhancement near the main internal-tide generation region, although its magnitude is more difficult to quantify because vertical diffusivity is available only as a daily mean.

These results show that tidal forcing contributes substantially to biogeochemical variability across the Amazon shelf–offshore continuum, from seasonal changes in nutrient distributions to recurrent spring–neap variability, and highlight the potential importance of internal tides in transmitting tidal influence from the shelf break toward the open ocean.

2. Multi-panel figures I think work best if you label them (a), (b) etc, rather than “top right”, “lower left” etc.

Thank you for this suggestion. We agree that labelling multi-panel figures using (a), (b), etc. is clearer than referring to panels as “top right”, “lower left”, and similar descriptions. We have revised the multi-panel figures and the corresponding references in the text accordingly.

3. In the model description it would help to understand how the vertical mixing works in the presence of internal tides with such a high resolution set-up. Do the modelled internal tides generate extra shear, and does that shear transfer into diapycnal mixing?

This is a very good question that has not been quantified so far and maybe could/should be the topic of study. We can only hypothesise that the high frequency currents as North Brazilian Current and the associated vertical shear with high modes (see Kouogang et al 2026 <https://os.copernicus.org/articles/22/1545/2026/os-22-1545-2026.pdf>) can create such an extra shear that may increase induced mixing done by the IT. An average of this mixing over one day and its impact on nutrients has been quantified below (Figure RW 10) and it is shown that it is quite important. However as mixing induced by IT is highly intermittent and hot spots of mixing might occur within less than one hour, the average over one day may underestimate the mixing effect. In addition, the problem is not so simple as other terms might be of some importance such as the diffusion term in the advection scheme that will work at high frequency and may generate additional mixing. In our case the advection scheme is upstream biases (UBS) From Shchepetkin and McWilliams (2005) and this may produce additional mixing where current are strong. Nugroho et al. (2016) have quantified previously in NEMO at coarser resolution ($1/12^\circ$) that UBS was responsible of 30% of the mixing when including explicit forcing by the tides (comparing twin experiments with and without tides). We are expecting that at $1/36^\circ$ this number may be smaller, as processes are better resolved at higher resolution, but this remains to be quantified precisely by calculating all the tendency terms of the evolution equation of momentum. This is beyond the scope of this study and will be addressed in a future study.

4. The comparison with observations is sometimes unclear, and overly optimistic.

Thank you for this comment. We agree that some of the comparisons with observations were not presented clearly enough and that our interpretation was occasionally too optimistic.

5. The comparison of the model nitrate field with CARS is not convincing. Figure 3 should also show the CARS nitrate climatology, otherwise it is difficult to accept that the model does a reasonable job at simulating the broad distributions. The comparison (Notides-CARS) shows a coherent pattern of discrepancies that too me suggest the model results on the shelf are quite poor (e.g. high nitrate in coastal waters north of the Amazon, low nitrate over most of the rest of the shelf).

I feel I still need to be convinced that the model is doing OK. Getting nitrate to the right order of magnitude does not seem like a difficult bar to get over. Later (line 297) it is stated that the model

shows a moderate but statistically significant correlation with CARS – this seems to be a much more reasonable claim.

However, the mean errors are still high and I feel are telling us something more interesting than the simple argument that CARS is relatively low resolution.

We agree that showing only the model–CARS difference did not provide sufficient information to assess the spatial distribution of nitrate in the model. We have therefore revised (Figure 3 in the manuscript to Figure RW 1) to include the CARS nitrate climatology alongside the NOTIDES simulation, allowing a direct comparison of the large-scale spatial patterns.

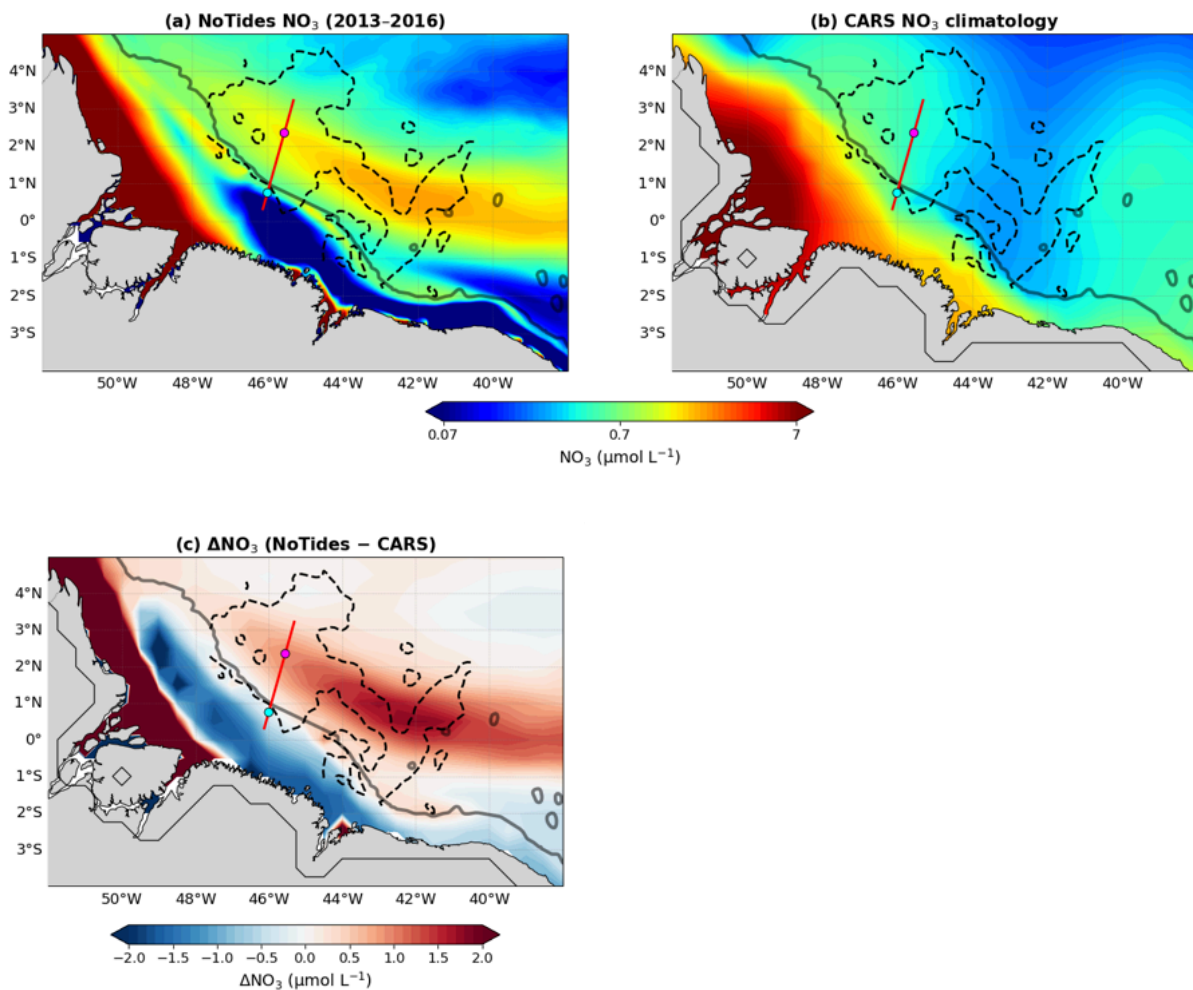
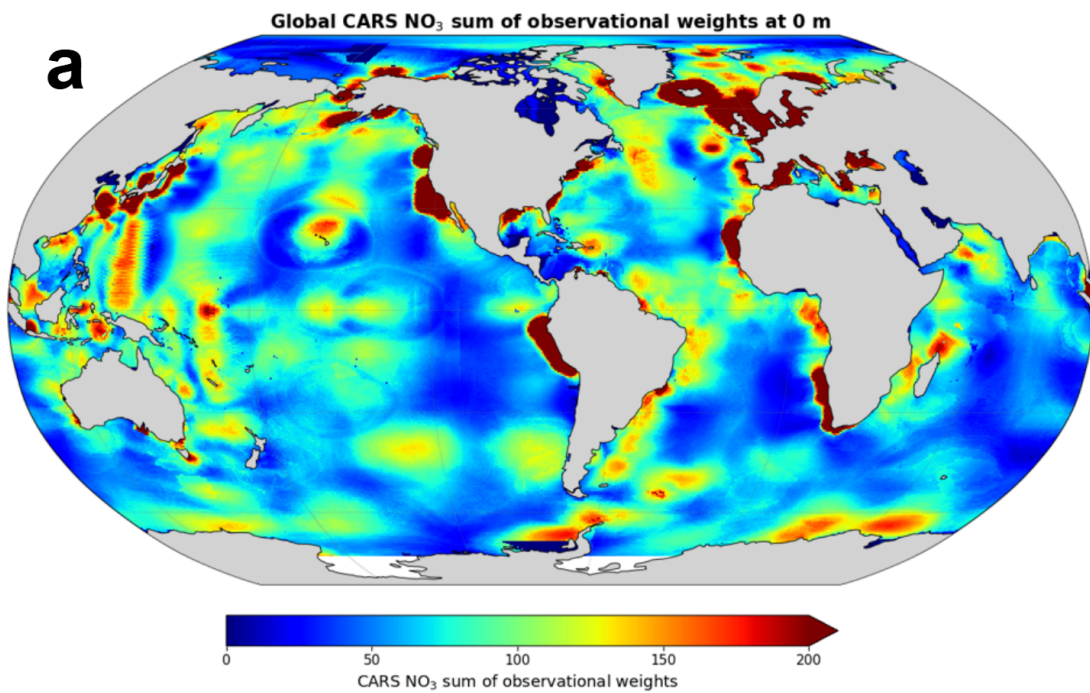


Figure RW 1 : Spatial distribution of surface nitrate concentration (NO_3^-) in the Amazon shelf-continent region.(a) mean nitrate concentration simulated by the NoTides configuration over 2013–2016 (log₁₀ scale). mean nitrate concentration from CARS configuration over 2013–2016 (log₁₀ scale).(c) Difference between the NoTides simulation and the CARS climatology ($\Delta\text{NO}_3 = \text{NoTides} - \text{CARS}$). **(TO BE INCLUDE IN MANUSCRIPT)**

An important limitation of this comparison is that CARS2009 is an objectively mapped climatology constructed from historical in situ observations collected between 1985 and 2009, rather than a synoptic observational field. Observational coverage is particularly sparse in parts of the western tropical Atlantic, with only approximately one hundred nitrate observations available

within our study region while region like europe are around more than eight hundred(Figure RW 2). These observations are also unevenly distributed across seasons, which may limit the ability of the climatology to fully represent the strong seasonal and spatial variability characteristic of this region.



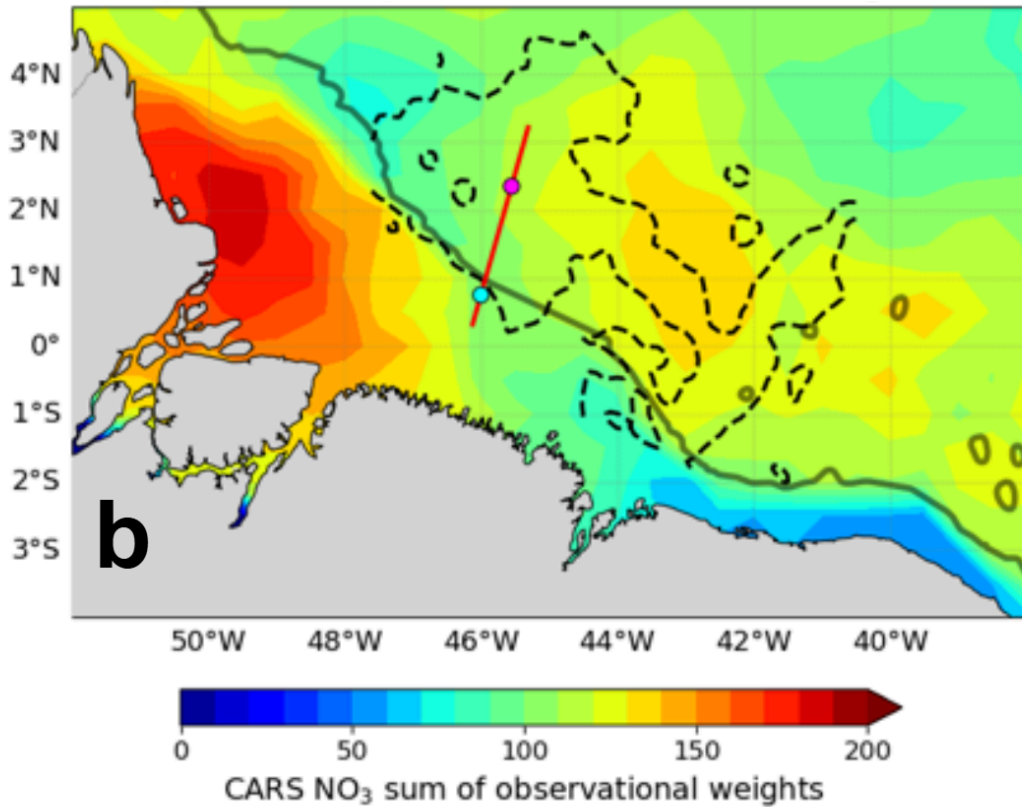


Figure RW 2: CARS2009 nitrate climatology and associated observational constraint at the global scale (a) and over the study region (b).

Moreover, the CARS nitrate RMS reaches approximately $0.4 \mu\text{mol kg}^{-1}$ (Figure RW3) over part of the offshore region corresponding to the main internal-tide propagation pathway. This value is of the same order of magnitude as the model–CARS discrepancy in this area, suggesting that the mismatch remains within an acceptable interval relative to the variability associated with the CARS mapping. Overall, the sparse and unevenly distributed observations underlying the climatology limit its usefulness for a detailed regional model evaluation. A more robust assessment is provided by the comparison with the contemporaneous AMAZOMIX in situ nitrate observations, for which the model reproduces the observed concentrations and spatial variability well.

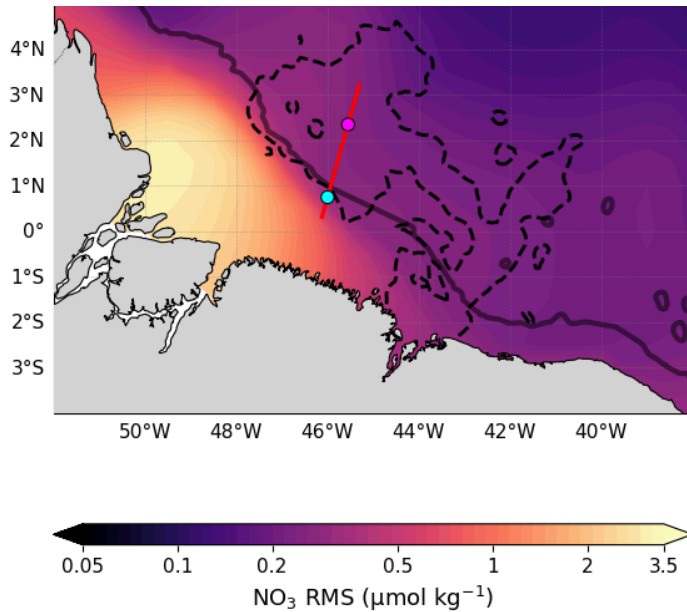


Figure 3 RW : CARS2009 nitrate root-mean-square (RMS) l ($\mu\text{mol kg}^{-1}$) over the study region. The RMS provides an indication of the variability associated with the objectively nitrate climatology.

Part of the large-scale background nitrate distribution, particularly toward the equatorial and offshore portions of the domain, may also be influenced by the biogeochemical initial and lateral boundary conditions. AMAZON36-BIO is initialized and forced at its open boundaries using the Mercator Ocean GLOBAL_MULTIYEAR_BGC_001_029 global PISCES hindcast, whose quality assessment identifies regional limitations in the western tropical Atlantic.

We therefore acknowledge that AMAZON36-BIO does not reproduce the regional biogeochemical state perfectly. However, the primary objective of this study is not to provide a fully bias-free reconstruction of the nitrate field, but rather to quantify and understand the role of tidal forcing. Our analysis is based mainly on the difference between two otherwise identical simulations, TIDES and NO-TIDES, which allows the tidal contribution to be distinguished from biases that are common to both experiments. Consequently, although biases in the mean biogeochemical state may affect the absolute nitrate concentrations, the twin-experiment framework remains appropriate for assessing the relative impact of tides on nutrient distributions.

More generally, previous coupled physical–biogeochemical modeling studies have shown that nutrient distributions in the tropical Atlantic are highly sensitive to the representation of equatorial circulation, thermocline and nitracline depth, upwelling, and vertical mixing (Radenac et al., 2020; Koseki et al., 2024). In the Amazon region specifically, biogeochemical modeling also remains challenging. Regional studies have shown that state-of-the-art models may not accurately reproduce the offshore extension of the productive plume, suggesting that some regional biogeochemical processes remain unresolved or imperfectly represented (da Cunha and Buitenhuis, 2013; Louchard et al., 2021; Gévaudan et al., 2024). Gévaudan et al. (2024) further report persistent biases in the NBC–NECC region, including an underestimation of productivity

in the eastern extension of the plume despite a reasonably well represented eastward advection by the NECC.

6. The comparison of the vertical profiles is overly optimistic, and confusing. Are the figure legends correct? The description of modelled and observed chl in the main text implies the observations are the green line and model the dashed line. Using the labels in the figures, the observations show a very clear subsurface chl maximum (45m depth), while the *model* has a very weak max at 25m and higher concentrations of surface chl (I would not agree that the model gets the subsurface max at the same depth as the observations). So, if the legends are correctly identifying which line is which, then I suspect too much nitrate is getting into surface waters in the model (e.g. at 40m there looks to be about x3 more nitrate in the model compared to the observations – again assuming the figure legend is correct). Might some of this discrepancy be caused by the wide range on environments covered by the observations, perhaps undermining a simple mean-profile approach? The observation locations cross some of the major gradients in model-obs discrepancies (Fig. 3). Or were the observed chl profiles based on fluorescence, so there might be some quenching in the surface? You could test the latter point by only selecting nighttime observations. Or, if the legends are incorrect (implied by the descriptions in the main text), then the observations have higher nitrate and chl in the surface – which would make me want to look at how the model vertical mixing works in stratification.

We thank the reviewer for pointing this out. The figure legend is correct: the observations correspond to the solid green line and the model to the dashed line. The inconsistency resulted from an error in the description in the main text, which will be corrected in the revised manuscript.

We agree that the initial discussion was overly optimistic. In particular, the model does not reproduce the observed subsurface chlorophyll maximum at the same depth. The observations show a pronounced maximum at approximately 40–50 m, whereas the modelled maximum is weaker and shallower, at approximately 20–30 m, together with higher chlorophyll concentrations in the upper water column. The model also slightly overestimates nitrate concentrations at intermediate depths relative to the observations. In the revised manuscript, we will therefore revise the corresponding text accordingly to describe these discrepancies more explicitly, rather than presenting the model–observation agreement as satisfactory.

For chlorophyll, we additionally tested the possible influence of daytime fluorescence quenching by retaining only nighttime profiles along the transect (Figure 4 RW). The resulting nighttime mean profile still shows a clear and deeper subsurface chlorophyll maximum than in the model, indicating that surface fluorescence quenching alone cannot explain the discrepancy. Part of this mismatch may therefore arise from limitations in the representation of phytoplankton biomass and its vertical distribution in the biogeochemical model.

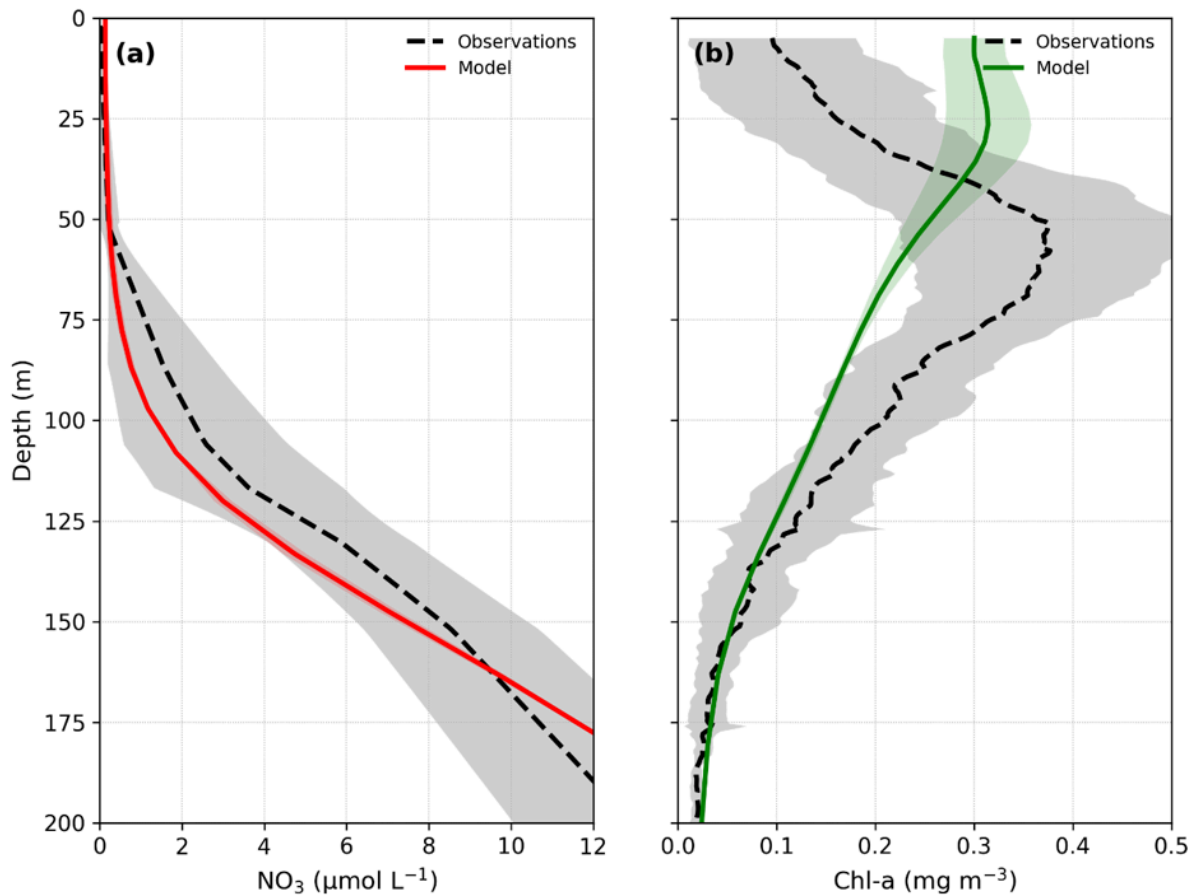


Fig 4 RW : Comparison model (mean Aug-Sep-Oct 2013-2016) vs Amazomix profiles (Aug - Sep - Oct 2021) of NO₃ (a) concentration ($\mu\text{mol NO}_3 \text{ m}^{-3}$) and Chlorophyll-a (b) (mg CHL-a m^{-3}). Along Internal Tides pathway (**To Be Included**)

7. Was any tuning of PISCES attempted to improve the fit? I accept that the vertical nitrate gradients are OK, which is vital for subsequent calculations of nitrate fluxes, but I would want to be more convinced that the phytoplankton are also in the right places.

No specific tuning of PISCES was performed for this study. We used the standard PISCES parameterization and the original namelist, without adjusting biological parameters to improve agreement with the observations. The objective of this study was not to develop an optimized regional biogeochemical configuration, but rather to quantify the first-order impact of tides on nitrate and chlorophyll distributions using an existing model configuration.

We agree with the reviewer that the phytoplankton vertical distribution is less well reproduced than the nitrate structure. In particular, the modelled deep chlorophyll maximum is shallower and weaker than observed. We will describe and discuss this bias more explicitly in the revised manuscript.

Importantly, the shallower position of the modelled chlorophyll maximum may influence its sensitivity to internal-tide-driven vertical displacements and nutrient supply. Because the phytoplankton maximum is located higher in the water column in the model, internal tides may have a reduced ability to affect chlorophyll through vertical displacement and nutrient injection

near the base of the euphotic layer. Therefore, this bias could affect the magnitude, and potentially the vertical structure, of the simulated chlorophyll response to tides.

Nevertheless, our analysis primarily relies on the difference between two otherwise identical simulations, with and without tides. Both simulations share the same biogeochemical parameterization and associated biases, allowing us to isolate the response induced by tides within the model framework. In addition, the reasonably well-represented vertical nitrate gradients provide confidence in the simulated tidal modulation of nutrient supply, which is one of the main mechanisms investigated here.

We therefore consider that the present configuration is suitable for assessing the first-order effect of tides on nitrate and chlorophyll distributions, while acknowledging that the quantitative magnitude of the chlorophyll response should be interpreted with caution. A future regional tuning of PISCES, supported by additional observations, could improve the representation of the phytoplankton vertical distribution and refine these quantitative estimates. We will make this limitation clearer in the revised manuscript and avoid over-interpreting the absolute magnitude of the simulated chlorophyll response.

8. Figure 4: It would also be useful to see comparison of the vertical density structure as this is an important part of where nitrate and chl are found.

We agree with the reviewer that the vertical density structure is important for interpreting the vertical distributions of nitrate and chlorophyll. We have therefore added a comparison of the observed and modelled density profiles to Figure 5 RW.

The comparison shows that the vertical density structure is relatively well reproduced by the model, with better agreement than for nitrate. In particular, the model captures both the overall stratification and the depth of the main density gradient.

This better agreement may be explained by two factors. First, the observational dataset available for density is substantially larger than that for nitrate and chlorophyll, potentially providing a more representative seasonal sampling and reducing sampling-related biases in the comparison. Second, the physical model may be better constrained by its forcing and parameterization than the biogeochemical model, resulting in a more accurate representation of the vertical density structure.

The good agreement in density, together with the reasonably well-reproduced vertical nitrate gradient, provides additional confidence that the model adequately captures the main physical structure governing the vertical distribution of nutrients, particularly the position of the nutricline. Nevertheless, larger discrepancies remain in the simulated vertical distribution of chlorophyll, as discussed in our response to Comment 7.

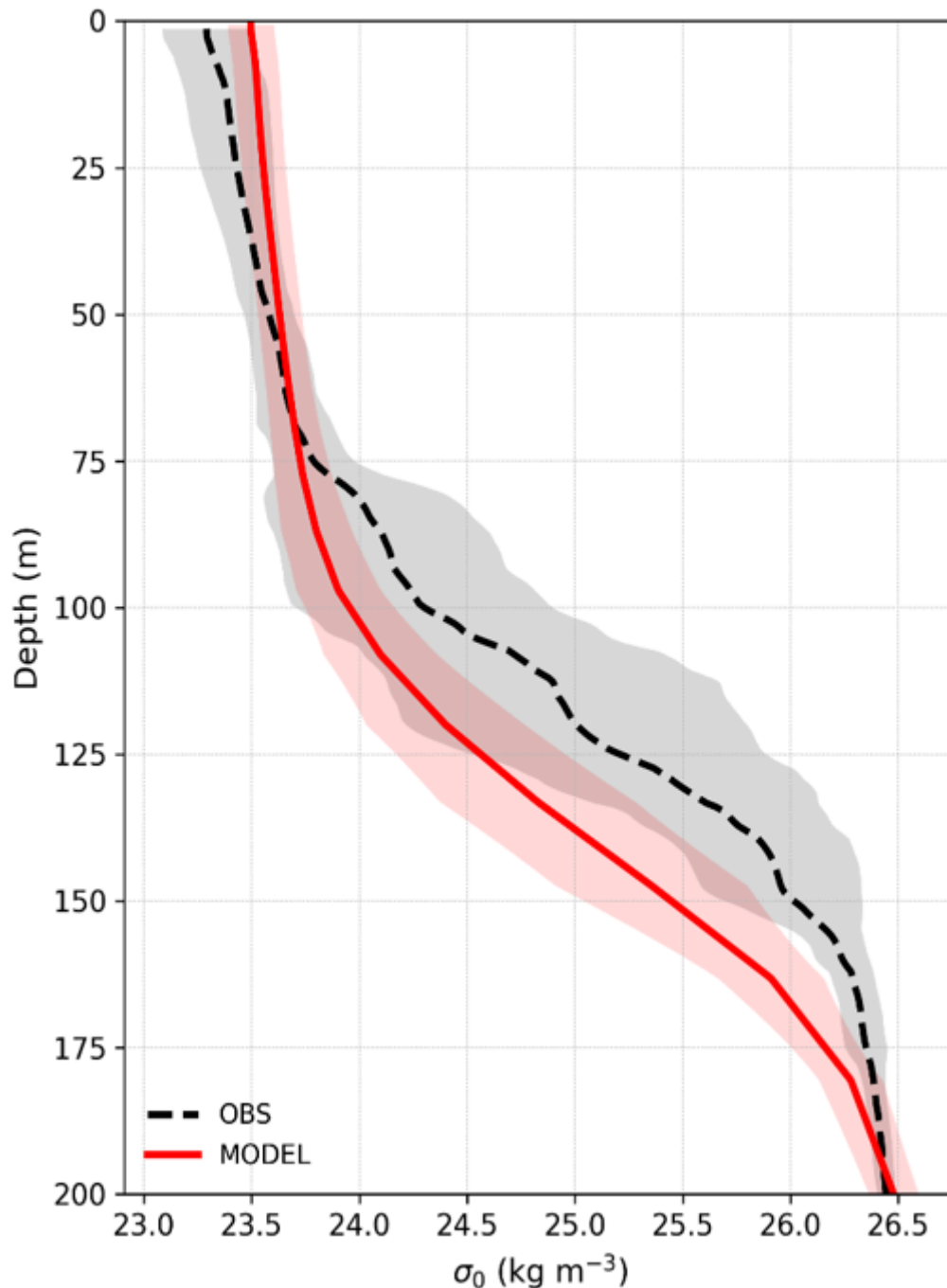


Figure 5 RW : Comparison model (mean Aug-Sep-Oct 2013-2016) vs Amazomix profiles (Aug - Sep - Oct 2021) of density profiles (to be included)

9. Figure 5: as with Fig. 3 it would be useful to also see the CCI observed chl field as the discrepancy plot possibly masks any consistency in model patterns. The precision of the bias and error in chl is too high – 1 decimal place is all that is justifiable.

Figure 5 has been revised to include the CCI observed chlorophyll-a field alongside the No-Tides simulation and the model–CCI discrepancy. We can see that the model is too productive off shore by about a relatively constant bias of 0.3mg.m-3 however it catches a global pattern with higher

chlorophyll

at

the

equator.

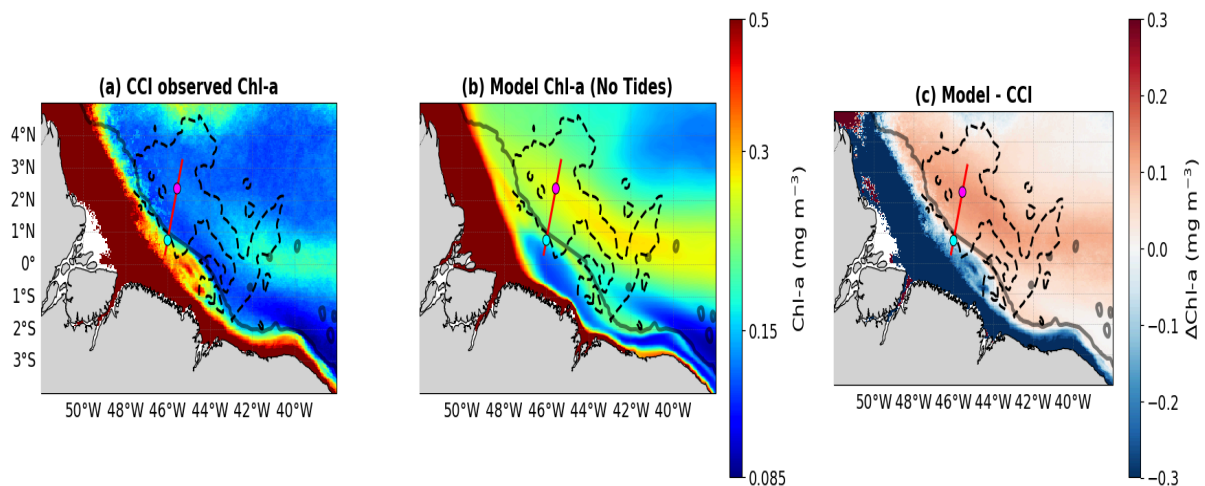


Figure 6 RW : (a) Mean surface chlorophyll-a field from Satellite CCI, expressed in mg m^{-3} (logarithmic scale), over the western equatorial Atlantic margin. (b) Mean surface chlorophyll-a field simulated by the model without tides (No Tides), expressed in mg m^{-3} (logarithmic scale), over the western equatorial Atlantic margin. (c) Difference in chlorophyll-a between the No Tides simulation and CCI satellite observations ($\Delta\text{CHL} = \text{No Tides} - \text{CCI}$).

10. Having said all that, the importance of the model results later mainly sits on the model-model comparisons with/without tides. So, getting the broad, approximate spatial patterns in nitrate and chl reasonable compared to the observations is fine –

10.1. The work could make better use of the model data when interpreting how tides affect the biogeochemistry. Almost all the model/model comparisons are based on nitrate and chl fields, and the reasons for the tides-notides differences are inferred based on literature. But presumably the model produced data that would allow you to test these ideas objectively? For instance, high nitrate anomaly in the northern shelf is attributed to tidal mixing, but a low nitrate anomaly in the southern shelf is blamed on mixing diluting the surface nitrate. Does interrogation of the model data confirm this?

We thank the reviewer for this important comment. We agree that, in the original manuscript, some of the explanations for the TIDES–NOTIDES biogeochemical differences were attributed too directly to specific mechanisms, whereas the distinction between what is directly diagnosed from the present simulations and what is inferred from the physical response of the model was not sufficiently clear.

Ideally, a complete nitrate budget would allow the respective contributions of vertical mixing, vertical and horizontal advection, and biological uptake to be quantified directly. Such a term-by-term nitrate budget was not computed because of the computational cost associated with storing and analysing these diagnostics at the temporal resolution required for a robust budget. Consequently, the sign of a local surface nitrate anomaly cannot be attributed unambiguously to a single process from the available biogeochemical fields alone, since nitrate reflects the combined

effects of physical transport, plume redistribution, and biological uptake, which may act simultaneously and partly compensate each other.

However, the physical response to tidal forcing in this model has already been investigated in detail. Assene et al. (2024) used the same AMAZON36 NEMO configuration at $1/36^\circ$ resolution and specifically analysed the physical mechanisms associated with the TIDES–NOTIDES differences. They showed that tides strongly enhance vertical mixing over the Amazon shelf, where mixing is largely associated with barotropic tidal dissipation, while internal-tide dissipation controls enhanced mixing along the shelf break and offshore propagation pathways. They further showed that the effect of this mixing depends on the local stratification and water-column structure, and that its impact can therefore differ spatially across the shelf

In addition, Ruault et al. (2020) demonstrated that tidal forcing strongly modifies the Amazon shelf circulation and plume dynamics. In particular, tide-induced vertical mixing weakens the northwestward alongshore current and modifies plume retention, dilution, and offshore export. Ruault et al. - 2020 - Role of ... Their process analysis shows that tidal mixing affects not only the vertical structure of the plume but also its horizontal redistribution across the shelf. Ruault et al. - 2020 - Role of ...

These physical results provide an important framework for interpreting the contrasting nitrate anomalies obtained in the present biogeochemical simulations. Moreover, in our model results, the spatial structure of the TIDES–NOTIDES density anomalies (Figure RW 7 and Figure 5 RW) is broadly consistent with that of the nitrate response, supporting a dynamical link between tide-induced modifications of the water-column structure and nitrate redistribution. Nevertheless, this correspondence does not allow the individual contributions of mixing, advection, and biological uptake to be separated quantitatively.

We therefore agree that our original interpretation of the northern and southern shelf anomalies was too specific. In particular, we attributed the positive nitrate anomaly over the northern shelf to upward nitrate supply by tidal mixing, while the negative anomaly over the southern shelf was attributed to dilution of nitrate-rich surface waters by the same process. The sign of the surface nitrate response cannot be interpreted from mixing intensity alone; it also depends on the local vertical nitrate gradient, stratification, tide-induced modifications of shelf circulation and plume structure, and biological nitrate uptake.

We will revise this section accordingly. Rather than assigning the positive and negative shelf anomalies to two distinct local mixing mechanisms, we will describe them as the integrated biogeochemical response to tide-induced changes in vertical mixing, circulation, plume and tracer redistribution, and biological uptake. We will also make clearer that Assene et al. (2024) provides the detailed physical analysis of the same AMAZON36 model, while Ruault et al. (2020) provides complementary evidence for the tidal control of Amazon shelf circulation and plume export.

10.2. Can you interrogate the model data to understand what is happening in the equatorial region – why is the band of chlorophyll seen there because of internal tides?

We agree that the equatorial chlorophyll band deserves further interpretation. Our analysis suggests that this feature is not generated by internal tides themselves, but rather reflects a pre-existing large-scale equatorial signal that is subsequently modulated by tides.

Part of this signal is likely associated with large-scale equatorial upwelling and is already present in the GLORYS fields used to force the regional model at its open boundaries, as also suggested by the comparison presented in our response to Comment 9. In addition, previous evaluations of PISCES have shown that several versions of the model tend to overestimate net primary production in the equatorial band compared with observation-based products (Bopp et al., 2022). Thus, the elevated chlorophyll concentrations in this region may partly originate from the large-scale biogeochemical background inherited by the regional configuration.

Within our regional simulations, internal tides do not appear to create this equatorial chlorophyll band. Rather, by enhancing the upward transport of nutrients into the upper ocean, they can strengthen the phytoplankton response where chlorophyll concentrations are already elevated. The tidal signal seen in the equatorial region should therefore be interpreted as an amplification or modulation of a pre-existing large-scale chlorophyll feature, rather than as the generation of the equatorial band by internal tides.

10.3. Fig 7 – can we also see density structure and its anomaly? Having the basic physical field will make the interpretation of the nitrate and chl much easier. This is a general point relevant to many of the figures – some physical context would help in many places.

The density transect shows a spatial structure that is broadly consistent with that seen in nitrate. This comparison supports our interpretation that a substantial part of the nitrate response is dynamically linked to internal-tide-driven diapycnal vertical motions rather than representing an isolated biogeochemical feature

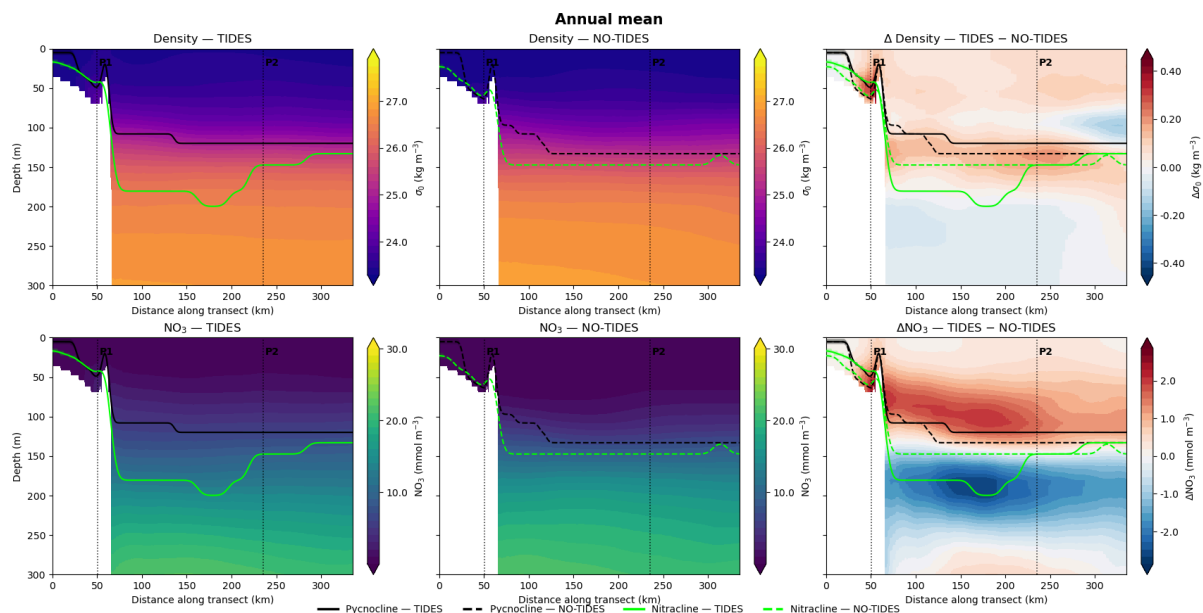


Figure 7 RW : Annual mean vertical transects of density and nitrate (To Be Included)

10.4. “Cone-shaped structure” is noted several times. I think this is simply the angle that the shelf edge makes to the equatorial region? It would be worth noting this – there is nothing fundamental about the cone-shaped pattern.

We agree with the reviewer that there is nothing fundamental about the cone-shaped geometry itself. The spatial pattern appears to reflect the regional circulation at 75m and geometry of the Amazon shelf rather than a distinct dynamical structure.

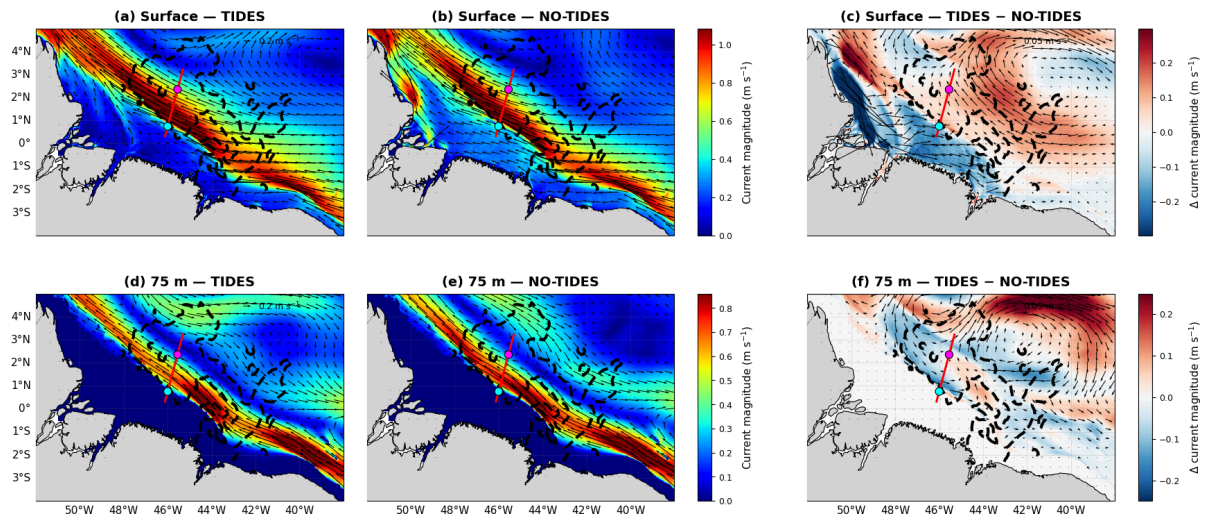


Figure RW 8 : Total current in the study region at surface and 75m

10.5. The wavelet analysis is a useful tool to use to identify the spring-neap patterns. But again, it would be good to see some supporting data on the *causes* of this (e.g. changes in DCM nitrate flux or diapycnal diffusivity).

A rigorous answer would require the complete tendency terms of the nitrate evolution equation, ideally saved at a sufficiently high temporal frequency (e.g. hourly) to resolve the semidiurnal internal tide. Such diagnostics are not available in the present simulations, for which the relevant biogeochemical and physical outputs are available only at daily frequency.

This limitation is particularly important for turbulent transport. Vertical diffusivity (K_z) is available only as a daily mean, whereas internal-tide-induced turbulence is highly intermittent and can vary substantially over the course of a tidal cycle. Daily averaging therefore smooths short-lived, high-intensity mixing events and limits our ability to accurately quantify the turbulent contribution to nitrate transport. Figure RW 10 shows the turbulent nitrate flux filtered at the MSf frequency. The spatial pattern is characterized by alternating positive and negative anomalies, with most values ranging between approximately -3 and +3 $\text{mmol NO}_3 \text{ m}^{-2} \text{ d}^{-1}$. Within the region influenced by internal tides, however, a marked positive hotspot appears close to the main generation site, reaching values of about +7 $\text{mmol NO}_3 \text{ m}^{-2} \text{ d}^{-1}$. This localized enhancement suggests a substantial tidal influence on turbulent nitrate transport near the generation region. Nevertheless, because K_z is only available as a daily average, the magnitude of the turbulent flux may be underestimated, particularly where mixing occurs through short-lived and intense events. A more robust quantification would therefore require online computation of the turbulent nitrate flux at the model time step, or at least at a sufficiently high temporal resolution to resolve the semidiurnal tidal cycle and the associated intermittent mixing events.

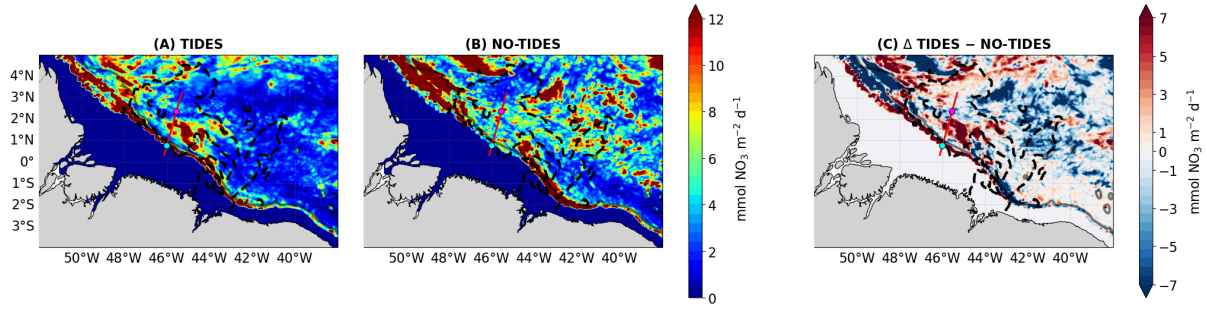


Figure RW 10 : Spatial distribution of the MSf-band (14.77 days) of the Integrated vertical diffuse nitrate flux between 0 m to 75 m . (A) TIDES simulation, (B) NO-TIDES simulation, and (C) tidal anomaly defined as $\Delta = \text{TIDES} - \text{NO-TIDES}$. The red line indicates the transect used for the subsequent analysis, with P1 and P2 shown by the cyan and magenta markers, respectively. The black dashed contour indicates the main internal-tide propagation region identified from MIOST, while the black solid contour represents the 1000 m isobath.

This limitation is less restrictive for the advective component, which can still be estimated directly from the available vertical velocity and nitrate fields (Figure 11 RW). The vertical advective nitrate flux is first calculated as:

$$F_{adv} = w \times \text{NO}_3$$

where w is the vertical velocity and NO_3 is the nitrate concentration. Because the objective here is to investigate the spring–neap modulation previously identified in the nitrate fields, the resulting daily F_{adv} time series is subsequently harmonically filtered at the MSf frequency (14.77 days). More precisely, the diagnostic used below corresponds to the amplitude of the MSf component of F_{adv} rather than to the instantaneous advective flux. For simplicity, this MSf-band component is referred to as F_{adv} throughout the following analysis.

Figure 11 RW shows the MSf-band vertical advective nitrate flux for the TIDES and NO-TIDES simulations, together with their difference. Overall, the inclusion of tides leads to an enhancement of the advective nitrate transport of approximately $5 \text{ mmol N m}^{-2} \text{ d}^{-1}$ over a large part of the region. The strongest enhancement, reaching approximately $10 \text{ mmol N m}^{-2} \text{ d}^{-1}$, occurs along the internal-tide propagation pathway, where the signal appears as elongated streak-like structures. Within the region of maximum internal-tide activity identified by the black contour, the enhancement remains substantial, with values of approximately $7 \text{ mmol N m}^{-2} \text{ d}^{-1}$.

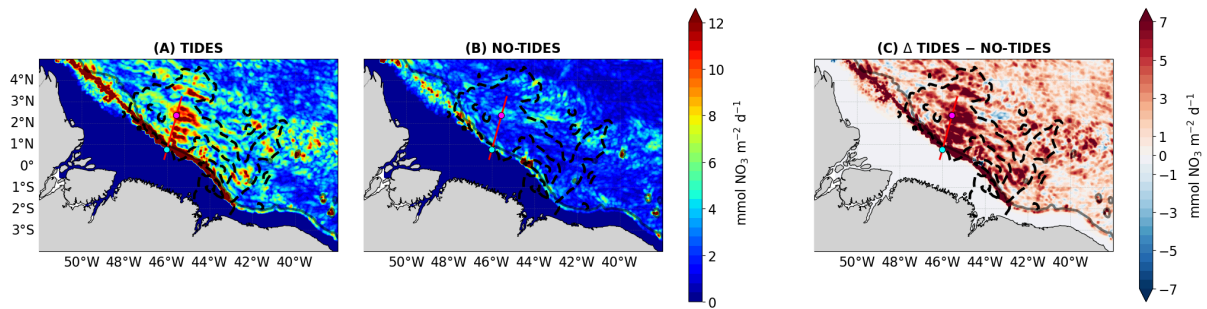


Figure 11 RW : Spatial distribution of the MSf-band (14.77 days) of the Integrated vertical advective nitrate flux between 0 m to 75 m . (A) TIDES simulation, (B) NO-TIDES simulation, and (C) tidal anomaly defined as $\Delta = \text{TIDES} - \text{NO-TIDES}$. The vertical advective nitrate flux is calculated as

$F_{adv}=w \times NO_3$ and expressed in $mmol\ N\ m^{-2}\ d^{-1}$. The red line indicates the transect used for the subsequent analysis, with P1 and P2 shown by the cyan and magenta markers, respectively. The black dashed contour indicates the main internal-tide propagation region identified from MIOST, while the black solid contour represents the 1000 m isobath. (To be included)

To further assess the role of tide-associated vertical advection in the nitrate enrichment of the upper 0–75 m layer, we adopted the following approach. First, we calculated the vertically integrated nitrate anomaly between the TIDES and NO-TIDES simulations, denoted ΔI_{NO_3} , and the corresponding anomaly in vertical advective nitrate transport, denoted ΔF_{adv} . Their ratio was then used to estimate the magnitude of the advective transport relative to the nitrate inventory anomaly.

The nitrate inventory within the upper 75 m is calculated as:

$$I_{NO_3}(x) = \int_0^{75} NO_3(x,z) dz$$

and the tidal anomaly is defined as:

$$\Delta I_{NO_3} = I_{NO_3,TIDES} - I_{NO_3,NO-TIDES}$$

Similarly, the tidal anomaly in vertical advective transport is defined as:

$$\Delta F_{adv} = F_{adv,TIDES} - F_{adv,NO-TIDES}$$

To compare the magnitude of this advective transport anomaly with the nitrate enrichment of the upper layer, we calculated an inventory-equivalent advective rate:

$$R = 100 \times \Delta F_{adv} / \Delta I_{NO_3}$$

Because ΔF_{adv} is expressed per unit time, R has units of $\% d^{-1}$ and should therefore be interpreted as the daily advective transport anomaly relative to the nitrate inventory anomaly, rather than as a direct percentage contribution of advection to the nitrate enrichment.

The results Figure 12 RW show that the relative importance of vertical advection is greatest near P1, close to the internal-tide generation region. At P1, $\Delta I_{NO_3} = 64.02\ mmol\ N\ m^{-2}$ and $\Delta F_{adv} = 30.83\ mmol\ N\ m^{-2}\ d^{-1}$, corresponding to an inventory-equivalent advective rate of $48.15\ \% d^{-1}$. This indicates that the tide-related vertical advective transport is substantial relative to the nitrate anomaly observed in the upper layer.

Further along the transect, the relative advective contribution decreases. At P2, $\Delta I_{NO_3} = 44.28\ mmol\ N\ m^{-2}$ and $\Delta F_{adv} = 10.16\ mmol\ N\ m^{-2}\ d^{-1}$, corresponding to $22.95\ \% d^{-1}$. Between P1 and P2, the spatially averaged nitrate inventory anomaly and advective transport anomaly are $44.43\ mmol\ N\ m^{-2}$ and $7.04\ mmol\ N\ m^{-2}\ d^{-1}$, respectively, yielding an average inventory-equivalent advective rate of $15.84\ \% d^{-1}$.

These results suggest that tide-related vertical advection can account for a substantial transport relative to the nitrate anomaly in the upper 75 m, particularly near the generation region, with its relative influence decreasing along the propagation pathway. However, because the calculations are based on daily outputs and on the MSf-band component of the advective flux, they should be interpreted as low-frequency estimates of the advective contribution rather than as a complete nitrate budget resolving the semidiurnal tidal cycle.

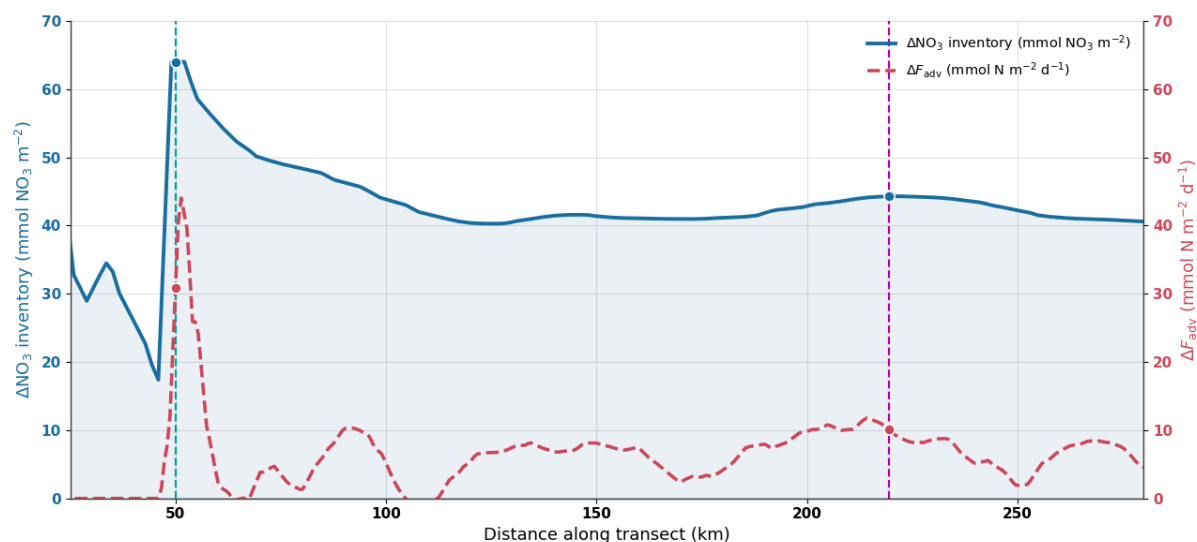


Figure 12 RW Along-transect comparison of the tidal nitrate inventory anomaly and vertical advective nitrate flux anomaly. (To be Included)

Smaller points:

1. Line 44. “The headings” ? Delete?

yes

2. Lines 46-47: The statement that internal tides affect nitrate and chlorophyll needs a couple of supporting references.

Ok

3. Line 61: Sentence beginning “This circulation exhibits:...” could be split into shorter sentences for clarity.

Ok

4. Line 82: sentence beginning “At the shelf break....” Some repetition from earlier about exchanges across density surfaces, including the same 3 references. This part would benefit from references specific to the Amazon/shelf edge rather than repeating the more general references from earlier.

Ok

5. Figure 1: some of the text (NBC, NBCR, potentially NECC) is hard to see against the background chl colours. Also, the chl colour scale washes out at 0.5 mg m⁻³, so there is little structure visible on the shelf. Can a non-linear scale be used with a higher max value? The Fig caption needs MIOST and DUACS explained.
6. Line 85: “commonly labelled A to F....”. I am not sure what this means, as only A is marked in Fig. 1.

Thank you for pointing this out. The labels A to F refer to the internal-tide generation sites previously identified in this region by earlier studies. In the present study, we focus primarily on site A because it is the main generation site examined in our analysis and is

the one explicitly shown in Figure 1. We agree that the original wording could be confusing when only site A is displayed. We will therefore add the previously identified generation sites A–F to Figure 1, while keeping site A highlighted as the main focus of the present study.

7. References are needed for NEMO and PISCES v4.

Ok

8. For clarity I would usually avoid words like “explicit(ly)”, “specific(ally)”, “particular” unless they really do alter the meaning of a sentence. For instance, at line 159/160 in the sentence beginning “This coupled configuration....” – “specifically” and “particular” could be removed, simplifying the sentence.

Ok

9. Line 206 – repeated at line 207!

Thanks ok

10. It would be better to number the equations through the manuscript.

Ok

11. Line 208: Is U_{bc} the baroclinic velocity profile? If yes, then is this calculated simply by removing the depth-mean profile? Also, I am not sure how to interpret P_{bc} .

Thank you for pointing this out. Yes, U_{bc} denotes the baroclinic velocity component. Following Kelly et al. (2010), it is obtained as the anomaly of the total velocity relative to its depth-averaged component, the latter being considered as the barotropic velocity. The same decomposition is applied to pressure. P_{bc} denotes the baroclinic pressure perturbation, obtained by removing the depth-averaged (barotropic) pressure component. It have firstly been computed by Assene et al 2024

12. Is Fig 2 mentioned in the text? I think it should appear somewhere in 2.2.3 in relation to the equation on line 208?

13. Line 225: Fig. 4 is referred to, but the figure does not appear for some time.

14. Line 395 and 404/405: what is meant by “internal tide propagation pathway”? I can understand why tides might increase surface nitrate on the shelf and along the shelf edge, but what is happening off-shelf in the equatorial region? Is there enhanced diapycnal mixing here that you can link to internal tides? You say they are consistent with tidal mixing, but does the model mixing data show this is the case?

Thank you for this comment. We agree that the expression “internal tide propagation pathway” was not sufficiently defined. Here, we refer to a literature-based offshore propagation pathway of coherent M2 internal tides, previously identified in several studies of the region (Magalhães et al., 2016; Tchilibou et al., 2022; de Macedo et al., 2023; Assene et al., 2024). This previously documented pathway is also consistent with

the spatial distribution of internal-tide energy in our model and with the MIOST product. We have clarified this definition in the revised manuscript.

15. Lines 488-489: what is meant by “seasonal reorganisation of the plume-influenced region”?

Thank you for pointing this out. By “seasonal reorganisation of the plume-influenced region”, we meant a seasonal change in the spatial extent and distribution of the chlorophyll-rich waters influenced by the Amazon plume. In particular, the chlorophyll-rich region offshore of the Amazon mouth is more spatially extended during AMJ and becomes more confined during ASO. We agree that the original wording was too vague and have replaced it with a more explicit description of this seasonal change in spatial extent.

16. Lines 494-496: what is meant by “when the upper ocean structure favours uplift”?

Thank you for this comment. By “when the upper-ocean structure favours uplift”, we specifically referred to the shallower nitracline during AMJ. In our simulations, the nitracline begins at approximately 50–60 m during AMJ, compared with about 80–100 m during ASO. Consequently, tidally induced vertical displacements and transport can bring nitrate closer to the euphotic layer more efficiently during AMJ. The TIDES – NOTIDES vertical sections are consistent with this interpretation, showing a stronger and shallower positive nitrate anomaly during AMJ. We have revised the sentence to state this explicitly.

17. Lines 500-502: a “seasonal redistribution of phytoplankton biomass” – do you mean advection or horizontal dispersion? Or (as you say later) changes in the local conditions favouring growth? I assume the latter – but the sentence seems to imply advection, which given the seasonal timescale compared to phytoplankton growth timescales feels unlikely.

We agree with the reviewer. The term “redistribution of phytoplankton biomass” was ambiguous and could incorrectly imply direct horizontal advection of phytoplankton from the nearshore region toward offshore waters. We did not diagnose such a horizontal transport of biomass. What our results show is a spatial shift in the chlorophyll response, with negative tidal anomalies near the coast and positive anomalies farther offshore.

18. Lines 557-559: similar to the previous point – the implication seems to be a wholesale advection of the chlorophyll (“redistribution”) rather than a shift in the aspects of the environment that support growth.

Thank you for this comment. We agree that the term “redistribution” could be misleading here, and we agree that is a wholesale advection.