Authors response to comments by reviewer #1 to the manuscript "Physical processes in the upwelling regions of the tropical Atlantic" by Brandt et al. (pbrandt@geomar.de).
We would like to thank the reviewer for the detailed and helpful comments to improve the manuscript. Below, we use black text for the reviewer's comments and green text for our response.

RC1: 'Comment on egusphere-2022-1354', Anonymous Referee #1, 13 Jan 2023

General comments:

This is an interesting, extensive, and relevant compilation of knowledge about (upwelling in) the tropical Atlantic climate system. I find the introduction to be a bit disconnected which at times makes it hard to follow, the reader could be helped by working on the flow of the text and explaining why specific parts of the system are being introduced. Additionally, later on in the text statements are made that are not easily verifiable by the reader, e.g. wrt figure 3 and 4 and 5. More direction as to where the reader should focus and more explanation in the text would be helpful, especially to make this work accessible to a wider audience than the established tropical Atlantic community. Similarly the text at times mentions specific terms without either showing the equations or explaining what the terms represent. Either would be helpful here for completeness. Specific incidents are indicated below.

I recommend adding a connection to primary productivity / nutrient supply to the title, since it is discussed a lot in the text.

We added biological productivity to the title.

Specific comments

L50: add citation Yang, Yun, et al. "Suppressed Atlantic Niño/Niña variability under greenhouse warming." Nature Climate Change 12.9 (2022): 814-821.

Included the reference (Yang et al., 2022)

Ll 80-85 The areas GGUS tAUS and EAUS should be indicated in the figure, the focus here is said to be on inner upwelling and not coastal upwelling. Indication of the region would help the reader understand which areas are being discussed and which are not.

We now included the upwelling areas in Fig. 1, Fig. 3, and Fig.4. Areas are now defined in the caption and in the text.

Ll 88- 103 The discussion on where the water masses are coming from and going to : please add a sentence or two to the relevance of this discussion, potentially relating to primary productivity, OMZ, etc. Since this also is discussed in the individual sections (e.g. Ll243-245) this discussion here might be removed in favor of flow of the paper.

We reworked the section, removed the first sentence and added a sentence relating the supply of upwelling to oxygen.

L 104: connection between upwelling and ITCZ unclear, I recommend mentioning the relevance of this section to the upwelling in the tropical Atlantic in the beginning of this section

We now start that section as follows: The tropical Atlantic and its upwelling systems undergoes a strong seasonal cycle. Main driver are the seasonally changing winds associated with the meridional migration of the Intertropical Convergence Zone (Fig. 2).

Ll 133-135 please mark the upwelling favoring easterly winds in the figure, it is hard to see the variability in strength from Figure 1. When the winds are purely easterly they seem very weak (compared to September / October), should the reader focus solely on the region west of 40W? Please indicate in the figure and / or describe in the text.

We now mark upwelling-favourable winds in Figs. 3 and 4 by black arrows, downwelling-favourable winds by grey arrows. We also changed the text to clarify that for the EAUS easterly winds almost along the whole equator are discussed.

Ll 138-140 Is the region between Cuanza and Kunene meant here with particularly weak winds? The winds further south seem strong. Please indicate maybe with a different colour the arrows of the area under discussion, and / or add more description to the text.

It is the region between Congo and Kunene. The region is now marked in Fig. 4 to make this clearer. We now also mention the Kunene upwelling cell at the southern boundary of the TAUS that is part of the northern Benguela upwelling system when introducing the TAUS.

L 144 I am confused by the mention of inner tropical Atlantic upwelling, while the GGUS seems to follow the coast, similar to the tAUS. Again, indication of the areas in Fig 1 would help, and maybe a sentence on the differentiation between inner and coastal upwelling as it is used in this study.

With inner tropical Atlantic we referred to the region of the tropical Atlantic closer to the equator excluding part of the tropics close to the subtropics. This region includes the equatorial and coastal upwelling regions. However, we see that the term is not well defined and we removed “inner” completely, now always stating tropical Atlantic between 10°N and 20°S.

Ll 174-176 Which part of Figure 5 is indicated here? Maybe an extra figure with Thermocline movement in conjunction with temperature change should be shown here. Or alternatively Fig 3 / 4 are meant, using the SSH as proxy for thermocline? Related: the Figure caption of Figure 5 should mention the source of the data as do the other figures

We now included in Fig. 5 two new panels (temperature and zonal velocity). The seasonal temperature evolution (panel a) now shows the movement of the 20°C isotherm (as a proxy of the thermocline) as well as changes of the sea surface temperature. Furthermore, it is now mentioned that the model output is taken from Radenac et al. (2020).

Ll 188-201 Since the focus of this paper is seasonal variability, a note on what we (do not) know about the variability of the STCs and TCs as they relate to equatorial upwelling would be helpful.

We now include in the conclusion and outlook a short statement on STCs:
Off-equatorial winds that drive the STCs acting on longer time-scales, mostly larger than 5 years (Schott et al., 2004; Tuchen et al., 2020). How their changes affect stratification and nutrient distribution is still an open question (Duteil et al., 2014).

L 200-202 "The different forcing terms.." it seems odd that in a review of the forcing terms of the tropical Atlantic upwelling the physical processes forcing the upwelling are only mentioned in a short sentence with a reference. I recommend expanding on this sentence and ideally drawing a connection to the next paragraph, turbulent mixing. Alternatively, a differentiation between the current work and Giordani and Caniaux 2011 would be helpful. Also since this review is on upwelling (and its impact on nutrient availability and primary production) the connection between upwelling and mixing could be explained.

We now expand on the wind forcing of the upwelling velocity as follows:
The upwelling velocity in the equatorial Atlantic is often calculated from the wind forcing as the sum of the Ekman pumping due to the zonal wind stress, meridional wind stress, wind stress divergence and wind stress curl (Caniaux et al., 2011). By using a realistic model of the equatorial Atlantic particularly including the full dynamic response to the wind forcing, Giordani and Caniaux (2011) show that the dominant term driving the equatorial upwelling is still the forcing by zonal wind stress. The importance of the forcing by the wind stress divergence and the wind stress curl is, however, overestimated and underestimated, respectively, in the Ekman theory compared to the used model.

L 223 Fig 3 or 4 can be referenced in addition to figure 5 since they show the surface and 5 the column, might be more intuitive for the reader

Thank you is mentioned.

Ll223 Radenac reference, later on it is stated that the authors analysis PIRATA and models, please specify which dataset these results are based on as done later in e.g. L 241, 245

We now include in the caption to Fig. 5 a statement that the results are obtained from model output taken from Radenac et al. (2020).

L 255 Fig 5 ; EUC and 20C are shown in all panels

changed

L 277 December maximum is not clear in Fig 5d, looks similar throughout September - January. Fig 5c shows vertical advection maximum in November, how does this relate?

We mentioned in the text the near-surface diffusive nitrate flux that shows a maximum in July-August and a secondary maximum in November-December, which can be identified in Fig. 5f.

L 290 again confusion about inner vs coastal upwelling, explicit mention of coastal upwelling here (and throughout the text)

See above, “inner” is not used anymore.

Ll 296-297 I suggest indicating the cells in Figure 1

We now indicate the three upwelling systems in Fig. 1

Ll 313 “associated to the non-linear dynamics and its detachement..” Please add (half) a sentence on how this influences the upwelling

We added: The inclusion of the nonlinearity in the momentum equations of their model results in an inertial detachment of the Guinea Current from the coast after passing Cape Palmas. The geostrophic adjustment at the coastward flank of the current then leads to thermocline upwelling downstream of Cape Palmas.

Ll 325 what do these non-linear terms represent? In this overview being more specific about the physical process would be helpful

See point above regarding the nonlinearity in the momentum equations.

Ll 331-332 this is a bit more explicit “when the nonlinear terms are removed and the Guinea Current is trapped” but more explanation would again be helpful. Since this paper summarizes the physical processes behind upwelling it should be explicit about these processes.

We hope that the explanation regarding the role of the nonlinear terms for the inertial overshoot and the detachment of the Guinea Current clarified that point.

Ll 333-343 The discussion about the thermocline being closed to the surface in the simulation with least upwelling is difficult to follow. Earlier upwelling and upward movement of the thermocline have been positively correlated, how do they relate here? Seemingly the thermocline is shallower in the western upwelling cell while that cell has less upwelling (than the east), isn’t this counterintuitive?

We clarify that statement as follows (it is the relative change of the thermocline depth in the sensitive experiment relative to the reference simulation that is important):
In the simulation without nonlinear terms, the deepening of the thermocline relative to the reference simulation is stronger in the western upwelling cell than in the eastern upwelling cell (west and east of Cape Three Points, respectively).

L 358 “that is mostly wind driven” can this be seen in Fig 3? It would be good to refer back to the (relevant section of that) figure

We now mark in Figs. 3 and 4 upwelling-favouring wind with black arrows and downwelling-favouring winds with grey arrows and reference Fig. 3a. However, the relatively stronger wind forced upwelling east compared to west of Cape Three Points is shown best by the Ekman coastal upwelling index plotted in Fig. 9.

L 397 again please indicate the tAUS in Fig 1

See above, is included.

L 407 "are generally weak throughout the year" makes me think that it would also be good to indicate the tAUS region in Fig 4 or highlight the arrows in a different color (color coding arrows per upwelling zone might be a really good idea)

See above, is included.

Ll 415-416 "..four remotely forced CTWs throughout the year (Fig 4b)" can these be indicated in the figure, as arrows or similar

We think that it would overload the figure. However, we smoothed the somewhat noisy field in Fig. 4b to emphasize the phases of anomalously high and low sea level.

Ll 448-449 Indicate tAUS in figure 2? Is the very very narrow coastal strip e.g. in 4b meant here, or solely Fig 4c where the colder coastal SSTs seem more obvious? Again how do the authors distinguish between coastal and interior upwelling?

We now mention that SST is reduced in a narrow strip along the coast compared to further offshore (Fig. 2). We additional state that this region refers to water depths smaller than 75m.

Ll 451-455 description of coastal upwelling? It seems that the word inner in the beginning should be omitted or well defined.

It is omitted now.

Ll 489-490 "the spatially-averaged generation" of turbulence?

Should be clear (we don't see the misunderstanding): it is the spatially-averaged generation of internal tide energy

L 493 also evident in Figure 10?

In Fig. 10 mostly the isotherms upwelling (JJA) or downwelling (FMA) toward the coats are visible. The reduced SST near the coast is not the main point of that Figure.

L 496-497 related to increased mixing?

No, it is not related to mixing. As was written before: mixing acts on seasonally different background stratification. We try to make this clearer by adding:
However, the energy available for mixing acts on seasonally different background stratifications that varies due to the passage of CTWs as well as due to surface heat and

freshwater fluxes (Körner et al., 2022; Kopte et al., 2017). Zeng et al. (2021) showed that the variations in the background stratification lead to different effects of mixing on temperature: the sea surface in shallow waters near the coast is cooling stronger during phases of weak stratification than during phases of strong stratification.

Ll 502-504 what is the causal relationship here? More mixing = more cooling and therefore less stratification, but here the argument seems to be more mixing => less stratification => more cooling, can you be more explicit about the suggested series of events?

We hope that with the changes mentioned right above that this becomes clearer. The relationship is: less stratification => more effective mixing => more cooling. Here, we changed the text as follows:
While the sea surface cooling depends on the background stratification (Zeng et al., 2021; Körner et al., 2022), the upward nutrient supply additionally depends on the background distribution of nutrients.

L 514 suggest removing "it is"

Changed

L 522 additional forcing

Changed

Ll 522-524 this causality is not clear, please clarify

We changed the text as follows:
Atlantic Niños and Niñas are associated with SSS variability as well (Awo et al., 2018) suggesting additional forcing of the equatorial and eastern boundary upwelling in the eastern tropical Atlantic as the coupling between subsurface and surface is reduced for enhanced near-surface stratification. During an Atlantic Niño, the southward shift of Intertropical Convergence Zone (ITCZ) brings maximum rainfall in the eastern tropical Atlantic and potentially increases the flow of surrounding rivers, affecting near-surface stratification (Awo et al., 2018; Nyadjro et al., 2022).

L538 what is the timescale of the AMOC weakening? Decadal?

Included: on decadal to multidecadal timescales

L 540 add citation same as above Yun Yang

Done

Ll 544 "or productivity" maybe better to phrase "also indicated by trends in productivity"

That is not what we meant. We mean indeed stratification or productivity as two independent parameters for which decadal trends just emerging.

L 556 Please remind the reader how the influence of Ekman transport fits in with the seasonal modulation

We included the phrase: on decadal to multidecadal timescales

L 586 what does inner mean here

"inner" is removed. We now refer to "the tropical Atlantic (10°N-20°S)"

Minor:

Some inconsistencies with the plural and singular in the text, e.g. Ll 241-242 ..waters… has ..

Changed

References

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