Response to reviewer of manuscript

egusphere-2026-2092

"Thermohaline gradients and frontal regimes in the northwestern Tropical Atlantic"

by Napolitano et al.

Reviewer: Maya Jakes, University of Southampton

General comments

The manuscript provides a thorough assessment of submeoscale frontal characteristics in the northwestern Tropical Atlantic, where the North Brazil Current interacts with the Amazon River freshwater plume.

Using surface observations from four saildrones, the authors compute horizontal velocity and buoyancy gradients ithin and outside the Amazon plume and assess the relative contributions of temperature and salinity in setting the strength of the density gradients. Density gradients are stronger at small scales and are dominated by salinity gradients within the plume region.

The saildrone observations are complemented by a high-resolution model, revealing the spatiotemporal variability of submesoscale fronts both within the plume region, driven by variability in the NBC and Amazon outflow, as well as outside the plume region driven by the seasonal mixed-layer cycle.

Overall, the manuscript is detailed and well-written. The combination of observations and a high-resolution model provides confidence in the model representation of surface fronts in this region, while also providing insights into the spatial and seasonal variability of submesoscale fronts that are difficult to obtain from observations alone. It makes a valuable contribution to our understanding of submesoscale variability in general, as well as the specific dynamics in the region.

The manuscript is of high quality and should be accepted following some very minor technical corrections. Most of the comments below are just suggestions or questions to consider.

We thank the reviewer for their kind comments and the interest shown in our work. Below we address the comments and corrections proposed. Line numbers refer to the track-changed version.

Specific comments

1. You show the seasonal variability of submesoscale fronts very clearly in the model. What was the basis behind the choice of 2008 and 2009? Is this due to the availability of the model output? I am wondering how often the NBC and Amazon plume configuration match that of EUREC4A-OA? Did you consider doing an EOF analysis to assess the dominant configurations of the NBC and Amazon Plume (using model/satellite data)? Is it dominated by seasonal variability or is there also strong interannual/decadal variability?

   Answer: The model dates comes from realistic forcing and boundary conditions. We use the available timeseries for the 1 km simulation of the GIGATL series (Gula et al., 2021).

The NBC-Amazon Plume configuration during EUREC4A-OA matched what is expected for the season (Jan-Feb), with a growing plume in the end of the “dry season” pushed by a retroflecting NBC entering it’s eddying season (Feb-Sep.; e.g., Johns et al., 1998). With conditions during EUREC4A-OA usually described in the literature, we did not perform an EOF analysis.

With marked seasonal variability in both the Amazon plume and the NBC, the interannual variability would play a role during anomalous large-scale meteorological conditions that imprint in the Tropical Atlantic and influences both the SSS distribution (Da and Foltz, 2022) and the NBC (Johns et al., 1990).

2. Did you look at the depth extent of the submesoscale fronts in the model?

   Answer: We briefly looked at the vertical structure and depth extent of fronts in the model. We are preparing a follow-up study focusing on the velocity structure and dynamics from both the saildrones and the model. Outside the plume, fronts are oriented vertically and reach deeper levels, with typical enhancement of cyclonic motions. Within the plume, fronts are often tilted and shallower, constrained by the plume, and present strong shear at the subsurface.

3. You compute the along-track mean gradients across the four saildrone tracks. How much difference does it make if you use this approach compared to if you had along-track gradients from only one saildrone?

   Answer: For the analysis presented in Figure 2 of the manuscript, we used the density gradients computed from the mean temperature and salinity values obtained from Equation 1 using all saildrones. To compare with one saildrone, we take SD1026, the drone used as reference for the mean trajectory showed in Figure 1b.

   Below, we show a duplicate of Figure 2, with data from SD1026 only (Fig. R1). The magnitude of the gradients remain consistent, with the sharp increase at small scales and overall higher variance within the PLUME. Therefore, using four drones provided statistical confidence without compromising the results from along-track gradients of a single saildrone.

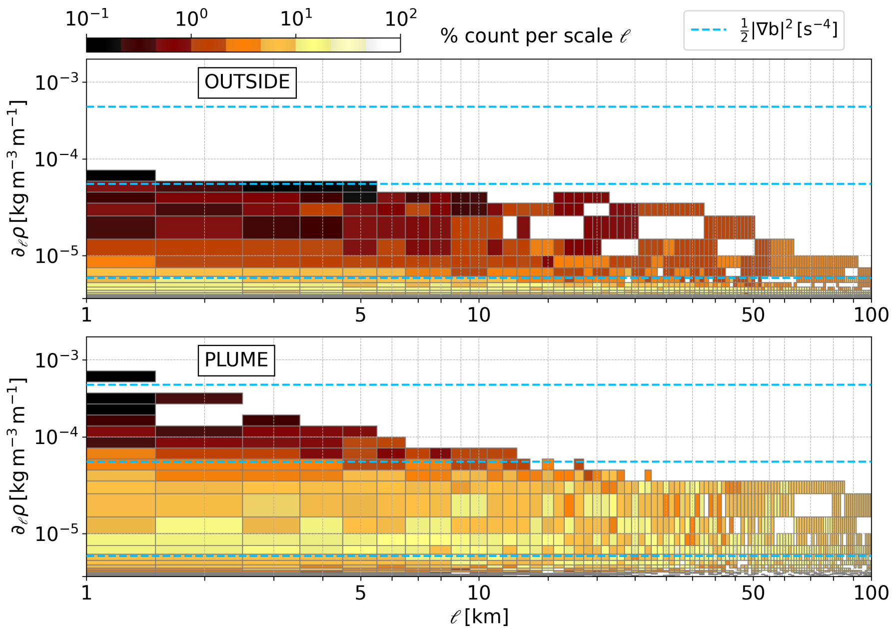

Figure R 1: Observed magnitude of surface along-track density gradients per horizontal scale ℓ along Saildrone SD1026 trajectory (a) OUTSIDE and (b) inside the Amazon PLUME. Colors represent the percentage of gradients for a given scale ℓ (each column sum up to 100% for every ℓ) and dashed lines represent the buoyancy frontal sharpness $\mathcal{B}$ reached for given density gradient thresholds.

4. Do the assigned errors account for the angle at which the saildrones cross the fronts?

   No. Our error estimate follows that of Bhuyan et al. (2026), which only accounts for random errors. The bias due to the angle at which the drones cross the fronts is not considered. We added this limitation in the new version, where we mention that the angle between the fleet route and the fronts could impact our results (L121–123).

5. In the model analysis of 1D gradients, you use density differences along zonal transects. What difference does it make if you use meridional transects instead? Or 2D gradients?

   Answer: Meridional transects (Fig. R2), as well as 2D gradients, still show stronger gradients and greater variability within the plume. However, the Saildrone tracks being usually nearly zonal, we opt to show zonal gradients from the model to ensure that the contrast between the PLUME and OUTSIDE regions depicted from observations at fine-scales was well represented by the simulation.

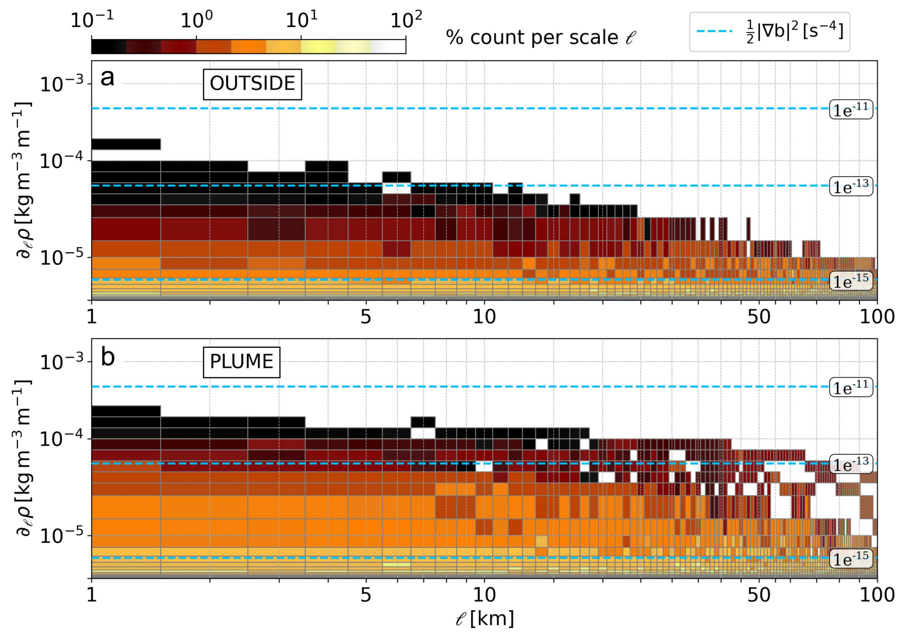

Figure R 2: Magnitude of surface density gradients, along longitudinal transects and per horizontal scale ℓ, OUTSIDE (a) and inside the Amazon PLUME (b). Colors represent the percentage of gradients for a given scale ℓ (each column sum up to 100% for every ℓ) and dashed lines represent the buoyancy frontal sharpness $\mathcal{B}$ reached for given density gradient thresholds.

6. What determines the location of the "submesoscale soup"? There is a large region between the plume edge and the "submesoscale soup" in Fig 8b with little to no small-scale fronts—why do you not get the same seasonal intensification of fronts here?

   Answer: In this study, we determine the location of the submesoscale soup visually based on the presence of anisotropic gradients associated with strong frontogenesis. In addition to the seasonal mixed-layer dynamics, the surface fronts in this regions seemed also influenced by low SSS from the plume of previous years. The plume expands to the north-northwest away from NBC domain, and when the NBC gets stronger again, it "cuts off" the plume from the western boundary, creating the temperature-driven region between the plume-NBC and the submesoscale soup (Fig. 8), with little to no fronts.

   We can see this region getting smaller (while fronts from the submesoscale soup evolve and get bigger) on a snapshot 2 months later (Fig. R3), where the plume is already larger and the NBC stronger than those depicted during EUREC4A-OA and the snapshot discussed in the paper.

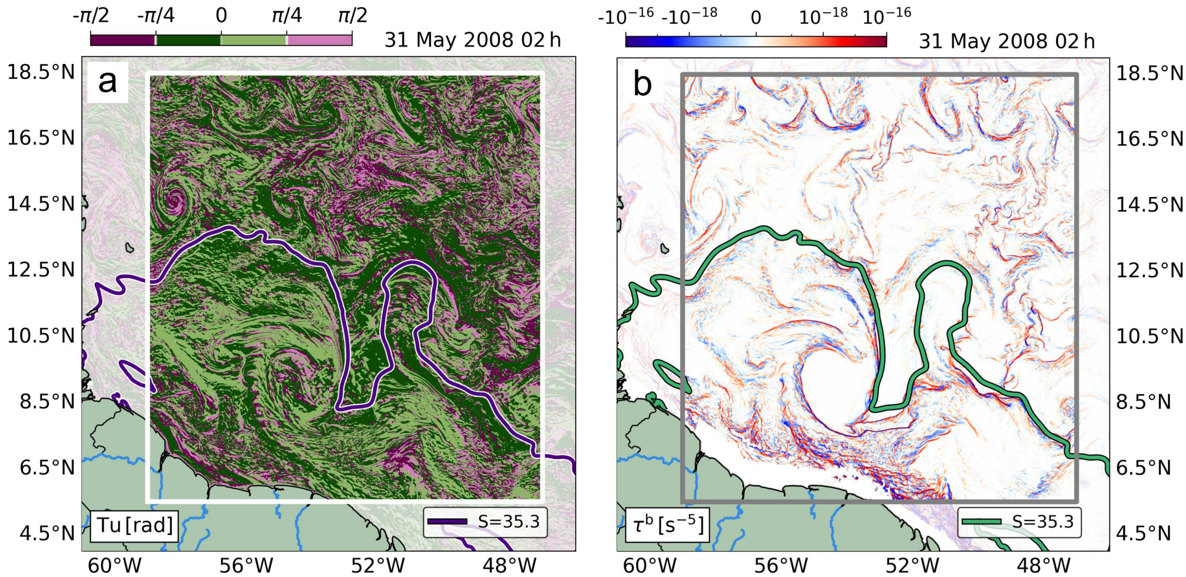

Figure R 3: Spatial distribution of (a) the Turner Angle Tu and (b) the Frontogenetic Tendency of Buoyancy τ^b for the snapshot on 31 May 2008 02h. The PLUME region is delimited by the isohaline representing the 0.25 quantile of the salinity probability distribution (dark blue and green lines).

Technical corrections

L2 - clarify *horizontal* scales Done.

L5 - I found this sentence a bit confusing, maybe rephrase as something like "density gradients are reinforced or partially compensated by temperature-salinity variability."

Answer: We have slightly edited the suggestion to avoid ambiguity, as reinforcement can also be partial. The new sentence reads "Density gradients are partially reinforced or compensated by temperature-salinity variations,…" (L6)

L10 - clarify *seasonal* mixed-layer cycle Done.

L12 - clarify *density-compensated* fronts Done.

L18 - include more references in addition to Muller-Karger et al. 1998

Answer: We added two additional references showing the propagation of low SSS in the Tropical Atlantic from observations (L19): Reverdin et al. (2021) and Olivier et al. (2024).

L19 - Coles et al. 2013 as well as Flagg et al., 1986? Done.

L39 - "we revisit density gradients observed at fine scales" Maybe another word for revisit? E.g. analyze / investigate

Answer: Thank you for the suggestion. This dataset was used in previous studies, thus the choice for "revisit". To clarify, we now say "To reach our goals, we revisit *in-situ* observations from Stevens et al. (2021), Coadou-Chaventon et al. (2024), to analyze density gradients at fine scales" (L41–42).

L46 - "hit the road" is a bit ambiguous. Maybe replace with "travel"? Done.

L94 - "saildrone observations" rather than "saildrones observations" Done.

L94 - "intensify" rather than "soar"?

Answer: Changed to "intensify rapidly"

L95 - Instead of "where more and more sharp fronts originate", what about "where buoyancy frontal sharpness is greater" or "where more sharp buoyancy fronts are present"?

Answer: We changed to option 2, "where more sharp buoyancy fronts are present". (L99–100)

L100 - "latter" rather than "later"

Answer: Good catch, thank you! Fixed.

L109 - "loss of synopticity" wording here is a bit confusing. Maybe delete and rephrase as "...interpreted with caution, since the effects..."?

Answer: We rewrote the sentence: "with caution, since the effects of temporal variability are non-negligible for $\ell \gtrsim 40$ km (i.e., the local synoptic scale; Coadou-Chaventon et al. (2024)." The sentence is now placed on the next paragraph (L120–121)

L118 - "reinforce or partially cancel each other effect on density" rephrase as "partially compensate or reinforce the density gradients"?

Answer: This was indeed a bit confusing, thank you.

L134 - ". And" - continuation of the previous sentence. Change to " ...and ..."?

Answer: Removed "And".

L145 - where does the buoyancy error = $7{\times}10^{-6}$ value come from?

Answer: This is the mean standard error of the buoyancy from the Saildrone CTD measurements. We added the information in L153–154.

L150 - use italicized / math font for "f". Also in equation 7. Done.

Figure 3 caption - "driven by salinity **(blue)** or temperature **(red)**"

Answer: Added in the caption of Figure 3 and also Figure 6

L184 - "probability density functions (pdfs)" Done.

L203 - "intensify" rather than "soar"? Done.

L208 - Sometimes plume is capitalised after "Amazon", sometimes just P is capitalised and sometimes none of the letters are.

Answer: Thank you for this remark. We adjusted the notation. In the revised version, "Amazon Plume" refers to the river plume, while Amazon PLUME appears specifically when we discuss the PLUME region defined in Section 2.

Figure 6 caption - "clockwise from $-\frac{\pi}{2}$ for frontogenesis..."

Answer: Added in the caption of Figure 6 and also Figure 3

L288 - "mesoscale and submesoscale **motions**" Done.

L296 - maybe quote the Tu values after "uncompensated front" Done.

Figure 8b - The wavelike structures along the southeast part of the plume edge are interesting.

Answer: They are, right? These structures seem to generate at the edge of the recirculating branch, or could also be associated with the strong internal tides generated at the shelf break that interact with the North Brazil Current (Tchilibou et al., 2022). Their location in the model snapshot also coincides with recent SWOT observations of these structures (Tchilibou et al., 2025).

We now mention the presence of these wavelike structures in L343–344.

L315 - delete space before comma Done.

Figure 10c caption - "compensation (orange) and reinforcement (green)"

Answer: We added "compensation (green) and reinforcement (orange)" to the caption of Figure 10.

L407 - text quotes 0.02, but caption quotes 0.01

Answer: We apologize for this oversight. The caption was the correct one. We fixed the text (L445).

L410 - "appears" Done.

L414 - "**With** the region..." Done.

L419 - "budgets **of**"? Done.

L432 - “associated **with**” Done.

We once again thank the Reviewer for their corrections and questions which showed us different possibilities to analyze and discuss our dataset and model.

References

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"Thermohaline gradients and frontal regimes in the northwestern Tropical Atlantic "

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Reviewer: Anonymous Referee

General comments

This study investigates the characteristics of submesoscale frontogenesis associated with the Amazon River freshwater plume, with particular emphasis on whether the fronts are density-compensated or density-reinforced, using both observations and model analyses. The study uses state-of-the-art methods for analyzing and observing submesoscale fronts and provides insights, particularly for regions with abundant freshwater input. The fact that such a systematic analysis has been conducted using only physical surface data is commendable.

Although this work is of clear interest and is recommended reading even for researchers who do not primarily focus on this region, there are several aspects that may be difficult for first-time readers to follow, including insufficient explanations and occasionally unclear organization of the manuscript. Therefore, I recommend publication after the structure is improved and additional explanations are provided. Specific comments for the authors' consideration are listed below.

We thank the reviewer for their comments aiming to improve the presentation of the results and discussion for a broad audience. Below, we address the comments and corrections proposed. Please note that changes in the text structure could apply to more than one comment at a time, with answers grouped into one final answer. Line numbers refer to the track-changed version.

Major comments

1. Organizing the manuscript into separate paragraph for methods, results, and discussion would make the main points much clearer.

I understand that the authors chose not to adopt a conventional structure (i.e., separate sections for methods, results, and discussion) in order to construct a narrative that transitions from observational findings to model analyses. However, there are several instances where these elements (methods, results, and discussion) are intermingled within a single paragraph. This structure unfortunately obscures the authors' main arguments.

Moreover, in some part of the manuscript, it is unclear whether the statements reflect objective results or the authors' interpretations. For example, interpretations based on observational analyses are sometimes difficult to clearly interpret conceptually until the corresponding model results are introduced.

The main relevant points are listed below. In addition to the points listed below, I encourage the authors to revise the manuscript, with attention to the roles of individual sentences and paragraphs.

- L92–93: "The accuracy of . . . ", etc.: It is important to discuss the accuracy and validity of the results, and I appreciate the authors' balanced and careful stance. However, presenting such discussions within the same paragraph as the description of the results may lead to confusion in how the results are interpreted by readers. This content would be more appropriately placed in the discussion part. see comment L113–115.

- L95: "within the PLUME": Omitting this sentence would allow the paragraph to more effectively present the scale dependence of the density gradient from a synoptic perspective. see comment L113–115.

- L113–115: "This shift suggests . . . and location).": Since results and suggestion are intermingled, it would be better to separate them. While the energetic frontogenesis might be anticipated given the eddy-rich feature of the region, such a suggestion should not be presented alongside the results at this stage, as it is not yet supported by a direct examination of the flow field.

  Answer: We have moved the sentence to the end of a new discussion paragraph (§L117), where we also discuss the caveats linked to temporal variability on our observations: "We remind that, at large scales (≥50 km), results should be interpreted with caution, since the effects of temporal variability are non-negligible for $\ell \leq 40$ km (i.e., the local synoptic scale; Coadou-Chaventon et al., 2024). The accuracy of the results could also be impacted by the direction in which the saildrones cross the fronts and changes in the fleet route, which are not considered in this study." (L120–123).

- L159: "Overall, . . . ": Is it correct to understand that this describes the symmetry between the top and bottom quadrants of Figure 3b and 3c? The same sentence also refers to a typical pattern of arched flows; does this imply that Figure 3 allows one to interpret the spatial (and/or temporal) distribution of frontogenesis and frontolysis? This is also related to the need for additional clarification regarding the spatiotemporal distribution of the data, as noted in Major Comment 2 below.

  Answer: Yes, the sentence describes the overall symmetry between the top and bottom half of the plots. Figure 3b and 3c do not give insight of the spatial distribution. The interpretation that this may be due to the presence of arched flows was moved to a separate paragraph (see comment L166–171).

- L166–171: "In Figure 3b, . . . ": This point appears to mark the beginning of the discussion specific to the plume. It may be helpful to separate this into a new paragraph.

  Answer: We reorganize the sentences in two paragraphs, for separate results (§L167) and discussion (§L175).

- L179–184: "At this point, . . . ": If this statement is presented in the context of results, it cannot be fully understood until the model-based results (specifically Figure 10) are introduced. At this stage, it should therefore be separated into a distinct paragraph and reorganized as part of the discussion, or framed as a motivation for the subsequent model analysis.

Answer: We appreciate the suggestion. We changed the sentence to avoid direct implication with the results at this point of the manuscript (L191–192). However, since the whole paragraph (§L185) is part of the discussion of Figure 3, we do not create a new paragraph this time.

- ☐ L222–233: "We first . . . its seasonal cycle.": This paragraph combines several elements, including the objective of the analysis in this section, the reason for selecting the snapshot, the philosophy behind using a single snapshot, and the definition of the PLUME in the model. The analytical objectives and factual descriptions should be clearly separated from methodological reasoning and interpretation, and presented in distinct paragraphs.

  Answer: We reorganized the sentences and split the text in two paragraphs, separating our objectives and reasoning (§L245) from methods and description (§L255). The second paragraph, which details the methods for selecting transects in the model, is now accompanied by the new Figure 5 (see also comment Figure 5a).

- ☐ L261–268: "From model . . . detailed in this study.": This paragraph includes the methodology, validation results, and interpretation. While the validation presented here is important, I feel it would be better placed in the latter part of the subsection.

  Answer: We added a new paragraph before the end of the section (§L309), detailing the validation and potential caveats separated from the results and discussion.

- ☐ L272–275: "The model also . . . of the plume.": Is this part intended as discussion? Including it within the results section could lead to confusion.

  Answer: This sentence fits more to the results than discussion, so in this case we are not changing it, but adding the reference to Figure 7c for clarity.

- ☐ L369–384: The description of the seasonal variation based on Figure 9b (results) is intermingled with interpretation and discussion of scale dependence. Simply separating the results from the interpretation would make this section much clearer.

  Answer: We rearranged the sentences and separate the results and discussion in two paragraphs (§L402 and §L411).

- ☐ L401–406: If this paragraph is intended to explain lines 179–184, stating this explicitly would help readers interpret the observational results.

  Answer: We made it explicit in L438–439 that the dynamical setup inferred from observations is the one described here.

- ◻ L447–452: "Compensated fronts, . . . and nitrogen budgets.": This discussion seems to appear for the first time at this point in the manuscript, rather than being part of the summary or conclusions.

  Answer: Indeed, we did not discuss this before in the manuscript, as we chose to focus solely on the interaction between the physical properties. In the §L484 paragraph, we introduce physical-biogeochemical interactions as an important consequence of the presence fronts in the Amazon plume, that should be considered for future work.

2. The manuscript would become more readable by adding clearer explanations of the data and figures.

There are several places where the manuscript could be improved simply by referring to figures at appropriate points, adding brief explanations to the figures, and providing additional descriptions of the data. Relevant points are listed below:

- ◻ L19–20: "Influenced by . . . in winter and spring": Referring to Figure 1 at this point would make it easier for the reader to form a clear understanding.

  Answer: We decided not to reference Figure 1 at this point. We want to avoid introducing Figure 1 without the context of the EUREC4A-OA campaign. Also, this demands the reader to move back and forth in the text, with the risk of breaking the narrative built to get to Figure 1. However, to give more context to the reader, we refer to Reverdin et al. [2021], which analyze the evolution of minimum SSS in the Amazon Plume (L22).

- ◻ L44: "boulevard de tourbillons": This should be indicated in the figure.

  Answer: Done. Please, see new Figure 1.

- ◻ L63–84: Information on how the averaged data derived from the moving circle are distributed spatially is needed. This information is important for understanding whether the analysis captures the spatial variability of frontogenesis and frontolysis, their temporal evolution, or both. Is the data arranged such that it includes both frontogenesis and frontolysis at similar locations (temporal evolution), or can it be interpreted as capturing variations in a snapshot sense—that is, as a configuration suitable for examining spatial distributions?

  Answer: We added information on why we chose the 8 km moving circle, i.e., so that the data averaged within each circle is not contaminated by temporal variability and each point represents a snapshot (L73–74).

- ◻ L175–177: "Taking every . . . mostly OUTSIDE." Should Figure 3c be referenced here?

  Answer: We now reference Figure 3b,c in L188 and Figure 3b again in L189.

- ☐ L184: "pdfs": Additional explanation is required.

  Answer: We changed it to "probability density functions (pdfs)" (L196)

- ☐ Figure 4: Can the broader tail on the reinforced side under frontolysis be explained? Does this imply that, rather than the distribution of density-reinforced water masses, the flow field that induces deformation exerts a stronger influence?

  Answer: Gathering all observations together makes it difficult to pinpoint the role of each process. Both TS and flow field should play their role in setting the curves in Figs. 4a,b. For example, another interpretation could be that reinforced TS gradients are less stable, so they would present more frontolysis than compensated gradients, which in turn are more stable and thus sustain frontogenesis for longer periods.

- ☐ L222: "We first ... campaign.": If the interpretation is that Figure 5a is similar to Figure 1a, please refer to the figure explicitly. Adding the saildrone tracks to Figure 5a would make the structural similarity easier to recognize. see comment Figure 5a below.

- ☐ Figure 5a: Since this is an important fine-scale structure, I would appreciate it if the figure could be enlarged.

  Answer: We split Figure 5 in the new Figures 5 and 6. The new Figure 5 appears after the first mention to the choice of snapshots in section 4, while the new Figure 6 shows only density gradients in section 4.1. Moreover, we merged paragraphs L236–244 with some text of section 4.1, making a new paragraph (please, see lines L245–258).

- ☐ Caption of Figure 5a "Model distribution of buoyancy sharpness": Is this correctly defined as the quantity B? Using consistent terminology and expressions throughout would help reduce confusion.

  Answer: We added the explanation "buoyancy sharpness $\mathcal{B} = \frac{1}{2}|\nabla b|^2$" to the caption of the new Figure 5.

- ☐ L273: "These gradients are mainly associated with the NBC": Would this be clear by referring to one of the figures—Figure 8, for example?

  Answer: We did not refer to Figure 8, so the reader won't have to jump through Figure 7. Instead, we referred to section 5 (L299), in which the reader will later find Figure 9 (former Fig 8).

- ☐ L357: "slowly moves poleward after a virtually stationary period between 9 and 12°N": Because the signal is not clear, it is difficult to identify which part of the figure is being referenced. Some visual guidance—such as adding dashed lines to the figure—would be helpful. see comment L357–358.

- ☐ L357–358: "probably entrained within mesoscale structures ": As noted above, if lines can be drawn on the Hovmöller diagram, an approximate propagation speed of the signal could be estimated. It would be interesting if this corresponds to the eddy propagation speed in this region.

Answer: We added dashed lines to the Hovmöller diagram to indicate different propagating branches of the plume. The estimated propagation speed is consistent with previous observations from drifters trapped within NBC rings [L382–383, see also Richardson et al., 1994].

- ☐ L369–384: Here, I understand that both the dominance of salinity versus temperature and their respective contributions to density compensation or reinforcement are key elements. Would it be possible to present a time series of Tu, similar to that shown in Figure 9b?

  Answer: The former Figure 9 (now Fig. 10) is a breakdown of Tu in temperature-salinity dominance (Fig. 9a) and compensation-reinforcement (Fig. 9b), both extracted from the interpretation of Tu (please, see §L370).

  In the new version, we now refer also to Figure Fig. 10a when mentioning the TS relations depicted from Tu (L408), but we do no believe a time series of Tu is needed here.

- ☐ L407: "The blowout of . . . 0.02 m^{-1}. ": This sentence should be moved to the caption of Figure 10.

  Answer: We repeated the sentence in the caption of new Figure 11.

- ☐ L414–415: "The region being . . . dynamical responses:": Is this description intended to refer to Figure 7?

  Answer: The description refers both to the new Figures 8 and 9, which we refer to now in L453.

3. One concern throughout the manuscript is the contribution of submesoscale current other than frontogenesis, such as mixed layer instability and forced instability. The influences of atmospheric forcing and precipitation, which could act as generation mechanisms for such flows, should be addressed at the stage of observational data analysis. The discussion that explicitly engages with the results of this study appears to be introduced in the following sections. see comment L368.

- ☐ L368: "controlled by mixed-layer cycle": Is there a contribution from variability in mixed-layer depth driven by precipitation and atmospheric forcing as well as from mixed-layer instabilities in the southern region, that is, within the PLUME and its immediate OUTSIDE?

  Answer: Precipitation and evaporation exert strong influence in the Tropical Atlantic SSS. But the Amazon River discharge is so big that it rivals precipitation in reducing salinity in the Western Tropical Atlantic [Coles et al., 2013]. Since we do not explicitly separate between different processes generating instabilities in the region, we assume that precipitation, atmospheric forcing, and mixed-layer instabilities have a similar effect within the PLUME and OUTSIDE. However, within the PLUME, they can be masked (or transformed) by conditions inherent to the plume, such as intensified stratification and density gradients fully controlled by salinity (Tu ~ 0).

In the text, we added a remark about other forcings that could generate submesoscale fronts, reinforcing that the plume effects seem strong enough to either significantly increase or decrease theses effects locally (L175–178).

Specific comments

- L116–117: "Having established ...": Has the transition region been discussed earlier in the manuscript?

  Answer: We remove the part mentioning the transition region, which in fact was not discussed in the manuscript (L124–125).

- L150: "(f) and buoyancy (N2)", etc.: Variables should be written in italics.

  Answer: Done.

- L157: "]-π/2, π/2[": The notation used for the open interval appears to be nonstandard. I recommend revising it.

  Answer: While [a,b] represents a closed interval, both (a,b) and]a,b[can be used to represent an open interval according to international standards. We use (a,b) to represent pairs of variables, and thus we chose]a,b[to represent open intervals.

- L197–200: This is an interesting point. The reinforced fronts are likely to generate strong density gradients, albeit transiently. Could the reinforced fronts be characterized as undergoing a super-exponential frontal-sharpening stage? Is it reasonable to interpret their development as being rapid, followed by a prompt breakdown due to instability?

  Answer: Thank you! This is indeed interesting. Duan et al. [2024] showed the rapid destabilization and overturning of reinforced fronts from idealized simulations. Their displayed setup started with a developed front, so there is no information about the sharpening stage; Our hypothesis agrees with the one proposed by the reviewer, of reinforced fronts boosting frontogenesis followed by a prompt breakdown. There are future plans to set up idealized simulations for such cases within our group.

- L280: "temperature-dominated gradient": Rather than being temperature-dominated, does the distribution exhibit a broader tail on the density-compensated side?

  Answer: In this distribution, we mention the effect of temperature-dominated gradients ($|\mathrm{Tu}| > \frac{\pi}{4}$) in reducing the kurtosis of the distribution compared to observations (by ocurring on both reinforced and compensated sides). In observations, temperature-dominated gradients were virtually absent and kurtosis was positive.

- ◻ L325–326: "In our region, . . . due to the NBC.": This is an interesting point. To what depth does the plume-dominated frontogenesis and its associated forward energy cascade extend? Even if these processes are confined to the surface layer, explicitly describing this would help clarify the interpretation.

  Answer: We just briefly looked at the vertical structure and depth extent of fronts in the model. We are preparing a follow-up study focusing on the velocity structure and dynamics from both the saildrones and the model. Within the plume, fronts are often tilted and shallower, constrained by the plume, and present strong shear at the subsurface, but we still did not look at the extent of frontogenetic gradients to depth and the forward energy cascade budget in the region.

- ◻ Caption of Figure 9: "within the PLUMEregion ": A space is needed between PLUME and region.

  Answer: Done. Thanks for catching this typo!

We once again thank the Reviewer for their comments. We appreciated the detailed suggestions to clarify the main results while keeping the original structure proposed by the authors.

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