Review 2

The authors would like to thank the reviewer for their thoughtful comments and suggestions. Our responses are below (reviewer's comments are indicated with black bold font).

In this paper the authors discussed the trend of ocean salinity and density profiles before and after tropical cyclones using Argo float observations and HYCOM ocean reanalysis. The upper ocean changes and the vertical structures are presented, but all figures are discussing the pre-event salinity increases and decreases with depth without much background information. There is even no example showing how much the pre-event salinity changes. That being said, the results are very well presented and the manuscript is very well written. In my opinion, the paper can be published after addressing a few minor issues.

Thank you for your comments. Each was appreciated and led to new text/figures that are described in the following.

Here is the list of my concerns:

Line 65. Why do the authors look at the vertical structures of the ocean under tropical cyclone conditions under pre-event salinity changes? The authors should mention and discuss this more explicitly in the introduction. Do you want to investigate the response of the ocean under different initial conditions?

Line 126. Can the authors show an example of increasing and decreasing cases?

Thanks for your comments and suggestions. New text and figures were included to clarify the rationale for our analysis.

New text and figures can be found in the following. Figure numbers refer to the updated set of figures. Please note that a lighter gray font indicates text in the original submission (even if edits were made in response to other reviewer's comments) and is included here for context:

→ New text in the "Introduction" to clarify the rationale for our analysis, as well as clarify that we also analyze the effect of the presence of a barrier layer on our results (the new text will appear in the revised manuscript starting at line 60 of the original pdf):

Also, Balaguru et al. (2012) shows that the TC-intensification rate is almost 50% higher over regions with barrier layers, compared to regions without. The presence of a preexisting ocean barrier layer can limit the effects of wind driven vertical mixing and the near-surface cooling response (Wang et al. 2011). This is the case, as while salinity increases from the bottom of the density based mixed layer to the bottom of the barrier layer, temperature does not change much in the barrier layer, resulting in a more favorable ocean state for e.g. the maintenance of a tropical cyclone, as the mixed layer and thermocline are decoupled. A long-term freshening of the upper ocean also tends to intensify the strongest TCs of the western North Pacific, as the increase in stratification reduces their ability to cool the upper ocean (Balaguru et al. 2016).

In this work, we use Argo float observations (Argo, 2000; Roemmich et al., 2003, 2009) to study TC-induced changes in upper ocean properties, focusing on hurricane-strength TCs, i.e., cyclones with maximum sustained winds greater or equal to 64 knots. We describe these changes and their uncertainties using the method by Hu et al., 2024 and compare cases where the pre-event salinity profile increases versus decreases with depth, i.e. we compare two different initial conditions. Our goal is to describe the association between the "increasing" versus "decreasing" vertical structures of the pre-event salinity profile and changes in upper ocean salinity and density during hurricane-strength wind events, which has potential implications for upper ocean stratification and air-sea exchanges during and after the event. If pre-event salinity increases with depth, wind-induced vertical mixing will result in an increase of near-surface salinity, as saltier waters from below are mixed in (Figure 1b); if pre-event salinity decreases with depth, wind-induced vertical mixing will result in a decrease of near-surface salinity, as fresher waters from below are mixed in (Figure 1d). The effect will be larger for pre-event salinity profiles with larger vertical gradients. The two different types of pre-event salinity profiles (Figure 1b, d; Figure S1a in the Supplemental material) and associated near surface salinity changes cannot be captured when analyzing the presence versus absence of a pre-event barrier layer and the composite pre-event profiles with and without a barrier layer both show a vertical structure that increases with depth (Figure S1b in the Supplemental material). Differences in near surface salinity changes for the "increasing" and "decreasing" case result in opposite contributions to the density changes with the weather event, with potential implications for air-sea interactions during and after the event. As part of this study, we compare Argo-based results for hurricane-strength TCs with the upper ocean response to hurricane-strength wind events in the HYCOM ocean reanalysis (Chassignet et al., 2007). The HYCOM reanalysis has been used in the past to investigate upper ocean physical and biological processes during hurricane-strength wind events (e.g., Gierach et al., 2009; Prasad and Hogan, 2007; Zamudio and Hogan, 2008) and complements our analysis as it provides time series for each event of interest, instead of sparse pairs of oceanic profiles before and after the weather event, like in the case of Argo observations. We find that results from both Argo and HYCOM are consistent with the vertical mixing of salinity playing a role in how upper ocean stratification changes with the TC passage. This is the case also for hurricane-strength wind events in general, as shown using HYCOM to investigate composites from only hurricane-strength wind events that are not co-located with observed tropical cyclones. Finally, we show that our results for hurricane-strength wind events do not change when we consider only pre-event "increasing" profiles with or without a barrier layer.

→ Mentions of the new figure in the "Methods" section:

(to include at line 126 in the original submission) We group selected events based on the pre-event vertical structure of salinity from the HYCOM reanalysis, i.e., the vertical structure 2 days before the event: "increasing" events are located where pre-event absolute salinity increases between the density based mixed layer and 50m below the mixed layer (e.g. Figure 1b); "decreasing" events, where salinity decreases between the mixed layer and 50m below (e.g. Figure 1d). The number of "increasing" events is much larger than the number of "decreasing events", with the latter mostly located in the Northern Hemisphere (Figure 2). We use 50 meters for the thickness of the layer considered below the mixed-layer, as it captures the 90th percentile (across events) of the observed mixed layer deepening (not shown). We find our conclusions in the following do not change with the thickness of the layer considered below the mixed-layer, e.g., if we consider 20m to 70m below the mixed-layer.

(to include at line 163 in the original submission As for HYCOM (and differently from Hu et al., 2024) we group Argo profile pairs based on the vertical structure of the Argo salinity profile before the weather event: "increasing" pairs include Argo pre-TC profiles with upper ocean salinity increasing with depth (e.g. Figure 1b); "decreasing" pairs include Argo pre-TC profiles with salinity decreasing with depth (e.g. Figure 1d). For each of the two groups, we estimate upper ocean changes with the TC passage and compare them to one another to characterize differences associated with the pre-event vertical structure of salinity. As for HYCOM, there are many more instances for the "increasing" case compared to the "decreasing case" (Figure 2-c, d). We note that, while the total counts in Figure 2 (white box on the top left of each map) are comparable between HYCOM and Argo, the numbers have different meanings. For HYCOM, the number indicates the count of all selected weather events, hence the number of continuous time series of ocean temperature/salinity available for the analysis, as the model output is available at the location of the weather event at all times of the model simulation. For Argo, the number indicates the count of all available profile pairs to estimate the upper ocean response to the TC passage, as we only have sparse observations from Argo floats.

Figure 1: (a, c) Paths of two tropical cyclones and location of Argo profiles close in space and time to the TC tracks and collected before (red marker) and after (purple marker) the TC passage. (b, d) Comparison between salinity profiles collected before (red line) versus after (purple line) the TC passage. One of the pre-event salinity profiles increases with depth (panel b), the other decreases with depth (panel d).

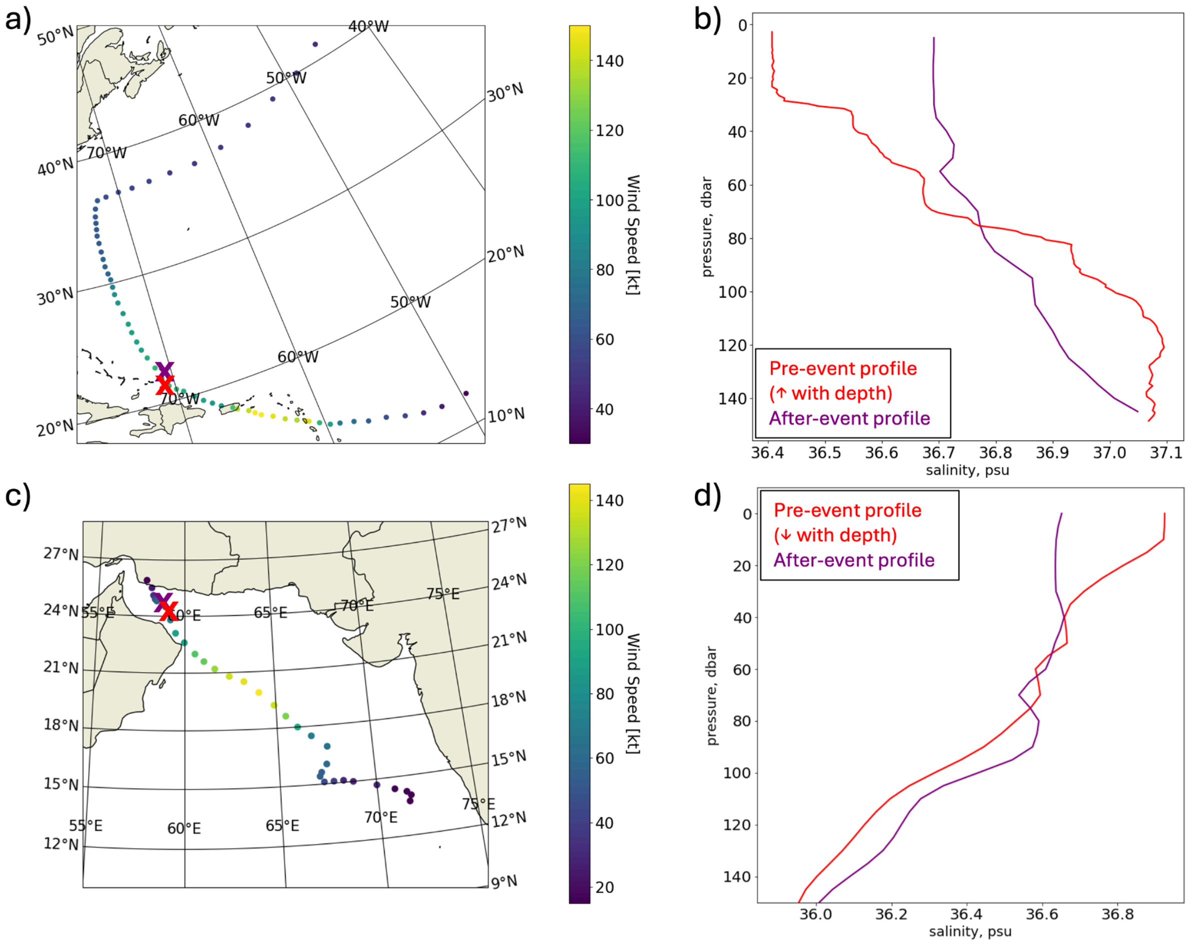
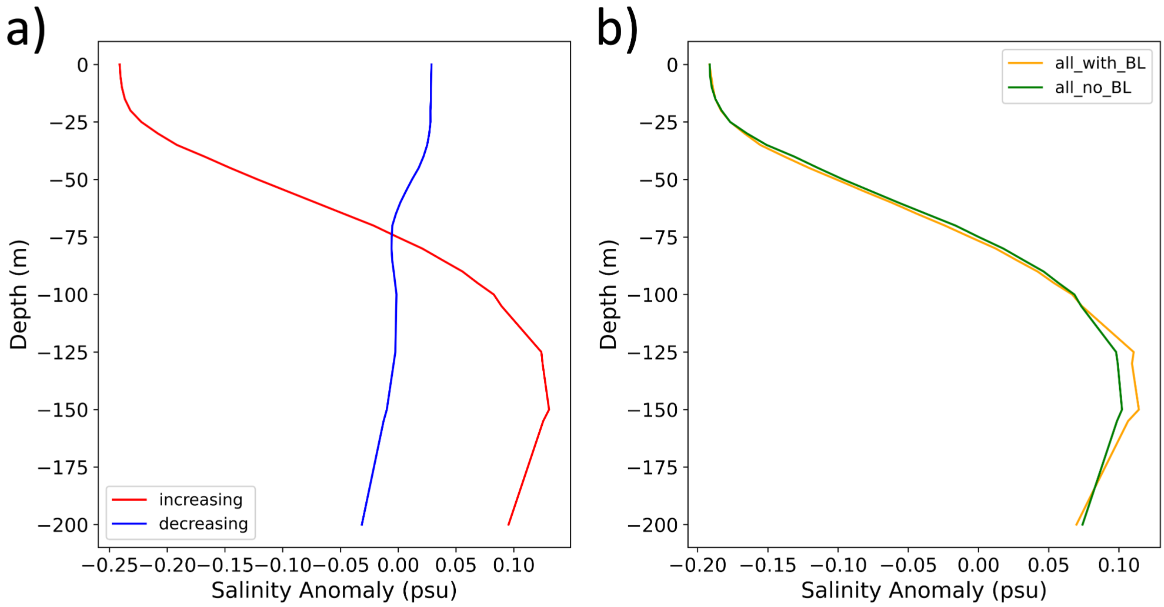


Figure S1: Composite vertical structure of pre-event salinity profiles from the HYCOM ocean reanalysis (a) with salinity increasing (red line) versus decreasing (blue) with depth, and (b) with BL (orange) versus without BL (green). While the vertical average has been removed from each profile before calculating composite vertical structures, the details of how salinity increases or decreases with depth for individual profiles in each group are different as these profiles are from different regions of the ocean and different months of the year. Hence, examples in Figure 1b, c may be more helpful than panel (a) here, to visualize differences between the "increasing" versus "decreasing" case.

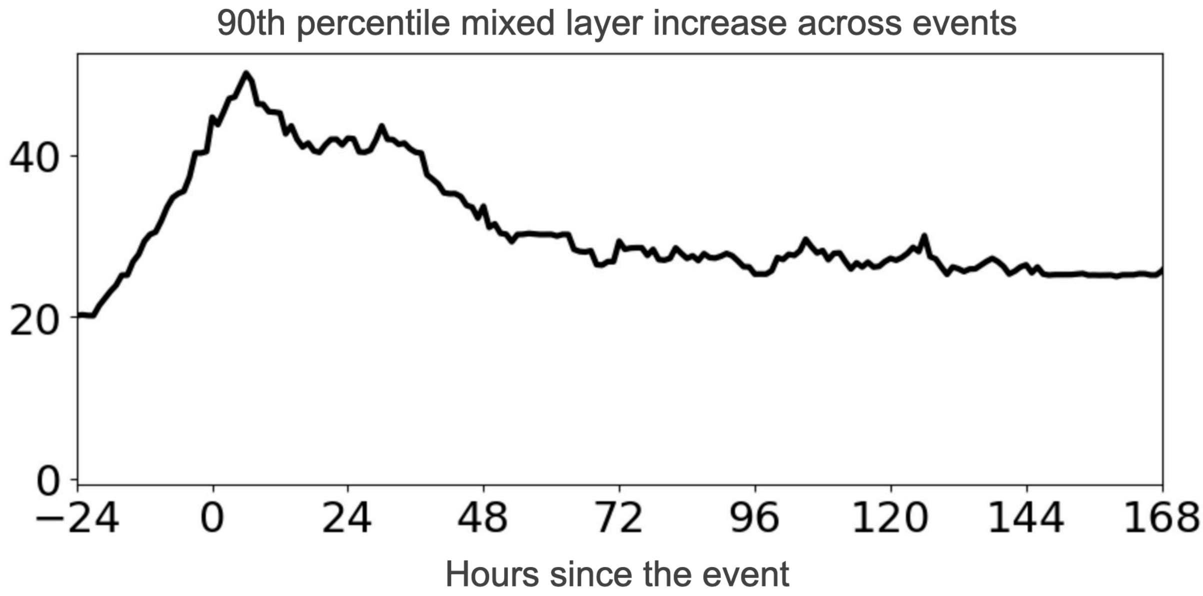


Why use 50 meters below the mixing layer?

Thanks for your question. We use 50 meters for the thickness of the layer considered below the mixed-layer, as it captures the 90th percentile (across events) of the observed mixed layer deepening (see plot below showing the time evolution of the 90th percentile mixed-layer increase across events). We also confirmed that our results do not change if we use a thickness between 20 and 70m.

We made edits to the text in the "Methods" section to clarify this point.

→ This figure shows the time evolution of the 90th percentile mixed layer increase across events.



How is the mixing layer determined in this work? What will happen if the differences for salinity or density are very small?

Thanks for your questions. Mixed layer properties are estimated using the methodology described in Holte and Talley (2009), i.e. a hybrid algorithm that models the general shape of each profile, searches for physical features in the profile, and calculates threshold and gradient MLDs to assemble a suite of possible MLD values, before selecting a final MLD estimate. This method has been shown to work well also in regions where the mixed layer exhibits great variability and the estimate of the MLD is overall challenging, e.g. winter mixed layers north of the Subantarctic Front, which can reach depths of 500 m and blend into deeper waters and remnant mixed layers (Holte et al. 2009). [This text is now included at the end of Section 2.3]

If differences in salinity between the ML and layers below are very small, waters mixed vertically have similar salinity, and the effect of wind induced vertical mixing on upper ocean salinity changes may be masked by other processes. Uncertainties in our analysis show that we observe a significant signal that is consistent with the effects of wind driven vertical mixing. A note is now included in the “Introduction” to clarify that the effect of the wind induced vertical mixing of interest is larger for events with pre-event salinity profiles characterized by larger vertical gradients.

Line 145. I think this coordinate system is only used for Fig. 6 and the definition of cross-track angle is confusing. From Hu et al. 2024, isn’t it the shortest distance between Argo float and cyclone track? The word “angle” in Fig. 6 is also confusing because it may refer to some angles between -180/pi to 180/pi. Is there any reason for not using the distance in km or meters?

Thank you for your comment. The cross-track angle is used as it offers a more accurate spherical model for measuring the distance from the TC track, compared to e.g. using distance in km. The cross-track angle is calculated by determining the angle between line segments from the sphere's center to the two points on its surface and it is equivalent to the haversine distance. When longitude is constant, the induced angle simplifies to the absolute difference in latitude. Conversely, when latitude is constant, the angle simplifies to the absolute difference in longitude, considering the cosine of latitude.

This information is now included in the “Methods” section, i.e.

The x-coordinate is the cross-track angle, which is determined by calculating the angle between line segments from the sphere's center to two surface points, equivalent to the haversine distance. When longitude is constant, this angle is the absolute difference in latitude. When latitude is constant, it is the absolute difference in longitude, adjusted by the cosine of the latitude. The cross-track angle aligns with the great circle distance and is used here as it provides a more accurate spherical model for measuring the distance from the TC track, compared to e.g. using distance in km.

Line 150. How the Argo data and HYCOM data being used is still confusing to me. It seems that most figures are plotted directly using HYCOM data, but the pre-event conditions are determined based on the Argo floats?

Thanks for your comment. The pre-event conditions in the Argo analysis are based on Argo profiles; the pre-event conditions in the HYCOM analysis are based on HYCOM profiles. We included clarifications in Section 3.1 and 3.2.2 in the manuscript.

Line 190. More technical details are needed for the statistical analysis. Are pre-TC and post-TC profiles having the same standard deviations?

As in Hu et al. 2024, only the non-tc activity is represented here as a random process, hence, the variance of the before and after profiles is the same under this model. We have added this clarification to Section 3.2.5.

Figure 2a. Any interpretation of the alternative blue red blue colors between 50 to 200 m from day -1 to day 2?

By construction, the peak wind for each event is at day zero, hence we expect to see the effects of a deeper and stronger mixing just after that. In the “increasing” case, this may result in the salinity increase reaching deeper (depending on the vertical structure of the salinity profile). Depending on how the wind increases towards the peak and what the details of the pre-event profile are, we may see the effect of mixing also before the peak wind. In the “increasing” case, this may result in a decrease in salinity at depth, as less saline waters are mixed downward. Finally, as the wind reduces after the peak, the mixing weakens again. As the effects of vertical mixing depend on both the strength of the wind and the vertical structure of the salinity profile, whether we see the sign of the composite signal alternating in time will depend on the timing and location of the events in the composite, as the vertical structure of the salinity profile changes by region and time.

How about the decrease of the density at day 0 in Figure 3a?

The decrease in subsurface density at day 0 is consistent with observed changes in temperature and salinity. As discussed in the previous answer, the peak wind for each event is at day zero, hence we expect to see the effects of this mixing just after that. Yet, depending on how the wind increases towards the peak and what the details of the pre-event profile are, we may see the effects of mixing also just before/at day 0.

If Figure 4 and Figure 2 are presenting the same result, why are the Argo data having much stronger increase at day 0?

While the overall difference in upper ocean salinity changes between the “increasing” and “decreasing” case is consistent between HYCOM and Argo, the two products show different amplitudes for the signal of interest (Figure 2c versus 4c), which may be related to e.g. how hurricane-strength wind events and related vertical mixing processes in the ocean are represented in the HYCOM model, and what the availability is of sparse ocean observations co-located with events of interest.

A clarification was included at line 269 in the original submission:

This difference may be related to how vertical mixing processes are represented in the HYCOM model, the availability of sparse ocean observations co-located with events of interest, as well as the details of the vertical structure of pre-event upper ocean properties in the model versus observations.

Thanks again for all your helpful suggestions!