Responses to Comments of Reviewer #1

We appreciate very much the comments of Reviewer #1 and have revised the manuscript accordingly. In the following, we explain our response to the comments. The relevant revisions are highlighted with red color in the marked manuscript.

Comments:

A good and timely study about properties of inertial waves. What I miss is a more detailed description of the used boundary layer model (line 106) and how the definitions of its variables relate to the analysis. Related to that is the rather poor Figure 5. Getting observed and modelled NIWs right requires good forcing and a good ML model. So please highlight and enlarge important panels of Fig 5, come up with a metric (e.g., difference in NI EKE), and discuss differences - if any.

Response:

First of all, we would like to express our sincere thanks to the reviewer for his/her constructive comments on our study. We are very pleased to learn that the reviewer considers our study being “a good and timely” one about properties of inertial waves.

In this study, we used the regional oceanic modeling system (ROMS) (Shchepetkin and McWilliams, 2005) to compute the near inertial currents. We discretized the whole depth into 35 layers in the vertical direction and refined the near-surface layers. The sea surface boundary condition is required to satisfy:

$$\nu \frac{\partial \mathbf{u}}{\partial z} = \boldsymbol{\tau}_{\mathbf{s}} \tag{1}$$

where, ν is the viscosity of seawater, which was determined by the conventional k-ε turbulence model (Rodi, 1987; Umlauf and Burchard, 2003); τ_s is the wind drag given by (Fairall et al., 1996):

$$\tau_s = \rho_a C_d u_{10}{}^2 \tag{2}$$

where, ρ_a is the density of the air; C_d is the wind drag coefficient; u_{10} is the horizontal wind speed at the 10-m level. To determine C_d, we preferred a formula that fits the numerical results obtained under extreme wind conditions with an improved wave boundary layer model

(Chen and Yu, 2016; Chen et al., 2018; Xu and Yu, 2021). So, the wave boundary model was not directly applied. The computed surface currents $\mathbf{u}$ is actually the averaged horizontal flow velocity within the top layer. The relevant modification is added in the revised manuscript [P8, L191-213].

We have improved the resolution of Figures 5 and 6, and enlarge the important panels [P16, Figure 5; P18, Figure 6]. We also introduced a metric, i.e., the classic Pearson product-moment correlation coefficient (Derrick et al., 1994), to verify the model:

$$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}} \tag{3}$$

where r is the correlation coefficient, X and Y are the computed and observed results. The correlation coefficient reaches 0.7 in this study. It is thus concluded that the numerical results are in reasonably good agreement with the HF Radar data. The relevant modifications have been added in the revised manuscript [P17, L375-377].

References:

Chen, Y. and Yu, X., 2016. Enhancement of wind stress evaluation method under storm conditions. Climate Dynamics, 47(12): 3833-3843.

Chen, Y., Zhang, F., Green, B.W. and Yu, X., 2018. Impacts of ocean cooling and reduced wind drag on hurricane katrina (2005) based on numerical simulations. Monthly Weather Review, 146(1).

Derrick, T.R., Bates, B.T. and Dufek, J.S., 1994. Evaluation of time-series data sets using the pearson product-moment correlation coefficient. Medicine and science in sports and exercise, 26(7): 919-928.

Fairall, C.W., Bradley, E.F., Rogers, D.P., Edson, J.B. and Young, G.S., 1996. Bulk parameterization of air-sea fluxes for tropical ocean-global atmosphere coupled-ocean atmosphere response experiment. Journal of Geophysical Research: Oceans, 101(C2): 3747-3764.

Freeman, N.G., Hale, A.M. and Danard, M.B., 1972. A modified sigma equations' approach to the numerical modeling of great lakes hydrodynamics. Journal of Geophysical Research 77(6): 1050-1060.

Rodi, W., 1987. Examples of calculation methods for flow and mixing in stratified fluids. Journal of Geophysical Research: Oceans, 92(C5): 5305-5328.

Umlauf, L. and Burchard, H., 2003. A generic length-scale equation for geophysical turbulence models. Journal of Marine Research, 61(2): 235-265.

Shchepetkin, A.F. and McWilliams, J.C., 2005. The regional oceanic modeling system (roms): A split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean Modelling, 9(4): 347-404.

Xu, Y. and Yu, X., 2021. Enhanced atmospheric wave boundary layer model for evaluation of wind stress over waters of finite depth. Progress in Oceanography, 198: 102664.

Responses to Comments of Reviewer #2

We appreciate very much the comments of Reviewer #2 and have revised the manuscript accordingly. In the following, we explain our response to each comment in a question-and-answer format. The relevant revisions are highlighted with red color in the marked manuscript.

General Comments:

Overall an interesting paper on an important topic with a storm that has become a wonderful test case for coastal ocean storm interactions. The study is well formed and remains largely focused on storm induced inertial currents. Some minor additions and edits are required, including a more detailed and distinct methods section for the observational data utilized. While the data was generally publicly available, more details on how the authors treated the data for QAQC, or what default QAQC if any they used from the downloaded data is required.

Response:

First, we would like to express our sincere thanks to the reviewer for his/her constructive comments on our study. We are very pleased to learn that the reviewer consider our study focusing on "an interesting paper on an important topic". Specific comments are addressed in the following contexts.

Detailed Comments:

(1) Line 32 - 35 - while an interesting comment it is disconnected from the current article.

Response:

Thanks for the comment. We have revised this comment [P2, L32-35].

(2) Line 96 - Caroline should be Carolina.

Response:

We are sorry for the mistake. We have carefully checked the entire manuscript to avoid such mistakes.

(3) Line 99 - What was the vertical gradient in temperature? This is likely more important than the surface/bottom temperature difference.

Response:

Thanks for the comment. In fact, the vertical gradient in temperature was very large before the hurricane passage. Glenn et al. (2016) and Seroka et al. (2017) analyzed the glider data and indicated that the thermocline in MAB shelf region was quite thin, e.g. the thermocline was less than 5 m where the water depth was around 40 m. Considering that the surface/bottom temperature difference was larger than 10 °C, the vertical gradient in temperature within the thermocline could be large than 2 °C/m. More detailed explanation and the relevant reference is added in the revised manuscript [P5, L98-101].

(4) Line 102 - Schofield et al., 2010 is a reference for Slocum gliders generally, however, there are multiple references for the Hurricane Irene specifically (Glenn et al., 2016) being the most prominent. There is no clear methods/data section, with some of the observational data described within what looks like results sections.

Response:

Thanks for the kind suggestion. We add the relevant references for the Hurricane Irene (Glenn et al., 2016; Seroka et al., 2016; Seroka et al., 2017) in the revised manuscript [P10, L219-220]. In addition, an introduction of the observational data, e.g., glider and HF Radar, is provided in section 2.3 [P10, L214-237].

(5) Line 234 - Why is the effective depth assumed to be 2.4m? Is there a reference for this?

Response:

Thanks for the comment. Roarty et al. (2020) indicated that the effective depth of the measurement could be estimated according to the frequency of the radar. The averaged depth was estimated to be around 2.4 by Zhang et al. (2018) and to be around 2.7 m by a more recent publication, Roarty et al. (2020). A comment and the relevant references are added in the revised manuscript [P10, L223-225].

(6) Line 236 - Is the accuracy of HF Radar here referring to this dataset in particular or more generally? A more recent publication from Roarty et al., on HF Radar in the region can be found here: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020JC016368.

Response:

Thanks for the comment. The accuracy of HF Radar here is referring to the general dataset. Following the reviewer's suggestion, we have carefully studied Roarty's publication. Roarty et al. (2020) showed a more detailed description of the accuracy of HF Radar. The RMS differences of HF Radar data were within 8 cm/s when compared with ADCP (Roarty et al., 2010; Roarty et al., 2020). Comments and references are accordingly modified in the revised manuscript [P10, L225-227].

(7) Line 239 - 264 - Were tides removed from the HF Radar fields and model current fields? I believe later in the paper they were, but it's not clear what was done for this spatial analysis.

Response:

Thanks for the comments. We are sorry for not describing it clearly. In fact, the tides were removed from the HF Radar fields and model current fields for this spatial analysis. Relevant comments are added in the revised manuscript [P12, L259].

(8) Line 266 - 274 - Please comment on data QAQC, Glider setup details, or where this information can be found e.g. previous publications or where it was downloaded. I'm assuming it was from the IOOS Glider DAC? Also an additional paper on Hurricane Irene mixing from glider and ROMS data was detailed here https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017JC012756. And a

detailed exploration of pre-storm mixing was carried out by Watkins and Whitt here: https://journals.ametsoc.org/view/journals/phoc/50/12/jpo-d-20-0134.1.xml

Response:

Thanks for the suggestion. Glider RU16 was an autonomous underwater vehicle of the Rutgers Slocum glider platform developed by Teledyne-Webb Research. It was equipped with the Seabird un-pumped conductivity, temperature, and depth (CTD) sensor and launched in Aug 10, 2011. RU16 moved vertically through the water column and typically collected data every 2 s. It was programmed to surface at nearly 3 h intervals to provide high temporal resolution data. It could measure both the vertical profiles of seawater temperature and salinity (Schofield et al., 2007; Glenn et al., 2016; Seroka et al., 2016). The accuracy of the dataset was closely related to the quality of the equipped sensors. More detailed description could be found in previous studies which used RU16 (Glenn et al., 2016; Seroka et al., 2016) or the website of Rutgers Slocum glider platform (https://rucool.marine.rutgers.edu/data/underwater-gliders/). Relevant comments and references are added in the revised manuscript [P10, L228-237].

(9) Line 290 - 301 - How did the maximum N-squared values compare between the observations and glider? It appears in Figure 3c and 3d that the observed N-squared was significantly greater than in the model ahead of the deepening and mixing, but similar during the deepening event?

Response:

Thanks for the comment. It is known that the N-squared value was calculated based on the vertical gradient of the potential density anomaly. Within the thermocline, the vertical gradient of the potential density anomaly was very large due to the large gradient of temperature T and salinity S. Therefore, N-squared values were quite sensitive to the T and S in the thermocline. It also means that, ahead of the deepening and mixing, a small error of T and S may lead to a prominent discrepancy of N-squared values in the thermocline. However, during the deepening event, the thermocline was nearly destroyed and the small error of T and S would not lead to such discrepancy any more.

Though there are discrepancies between the computed and observed values, the overall comparison was more than enough to validate our model. Both computed and observed N-squared values clearly showed the expansion of the mixed layer due to the hurricane event and capture the mixing process in seawater. The comments are added in the revised manuscript [P14, L323-325].

(10) Line 314 - I'm not clear on the use of the Zhang reference here. Is this referring to tropical cyclone shallow water mixing generally?

Response:

Thanks for the comment. The hurricane generally lead to the strong mixing and cooling in shallow waters where the initial stratification is strong. More detailed comments are added in the revised manuscript [P15, L341-343].

(11) Line 315 - Caroline should be Carolina

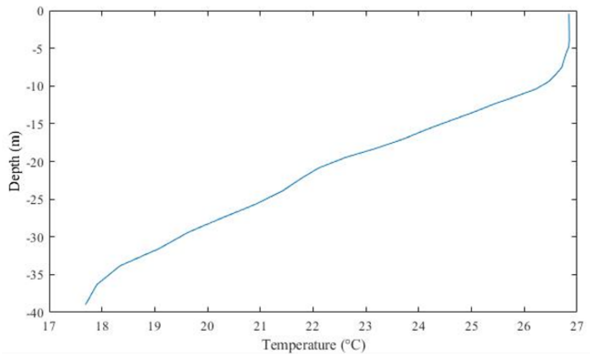
Response:

We are sorry for the mistakes. A relevant correction has been made.

(12) Line 315 - 316 - Over what time-scale did the SST recover to pre-hurricane levels? Off North Carolina there was likely very little Cold Pool water, thus mixing should result in very little cooling? Plots of bottom. Temperature pre-storm from the model will likely show this.

Response:

Thanks for the valuable suggestion. In fact, the SST recovered to pre-hurricane levels within only 1 day (Seroka et al., 2016). As the review suggested, we checked the pre-storm temperature profile at Station A2 off North Carolina. As shown in the figure, the initial temperature difference between the surface and bottom is smaller than 10 °C, and the bottom temperature is as high as 18 °C. Thus, little Cold Pool water may lead to insignificant cooling and fast recovering as the reviewer supposed. A modification is made in the revised manuscript [P15, L344-348].



(13) Line 323 - I agree that the model/data mismatches are largely not too critical for the process investigations presented here. I think the strength of stratification is likely the most important model feature to validate as it can affect the vertical mixing and generation/dissipation of NIC.

Response:

Thanks for the kind suggestion. The relevant comments are added in the revised manuscript [P16, L354-355].

(14) Line 342 - 343 - Were data dropouts documented, or could there be dynamical reason that the NIC are in poorer agreement offshore? The HF Radar data should include quality flags to identify missing or low quality data.

Response:

Thanks for the comment. The HF Radar data at each point were recorded and integrated from several radars in the observational network. Therefore, the quality of the data was largely decided by the 'coverage' of radars. Studies indicated that in shallow water regions, the coverage was larger than 90%. When compared with ADCP, the RMS difference of HF Radar was only within 8 cm/s in shallow water regions. However, the coverage dropped to ~50% outside the shelf break. Several studies have showed that data are unreliable and should be viewed with caution if the coverage is less than 50% (Roarty et al., 2010; Kohut et al. 2012; Roarty et al. 2020). Therefore, the low coverage should be the culprit causing the poor agreement outside the break. The relevant comments and references are added in the revised manuscript [P17, L378-382].

(15) Line 378 -381 - Is the 75m D3 location the beginning of the shelf-break front, a mesoscale feature impinging on the shelf, or simply too far from the main track? Adding the reference lines to additional spatial figures would be helpful doer interpretation rather than needing to flip back to figure 1 for the reader.

Response:

Thanks for the comment. In section D, NICs were quite weak from the shore to D3 due to the destruction of stratification in nearshore regions. However, the NICs were prominent outside D3. Because the stratification outside D3 was relatively well maintained due to the thicker mixed layer in these regions and the farther distance from the main hurricane track. An additional figure with the reference lines is added in the revised manuscript [P16, Figure 5].

References:

Glenn, S.M. et al., 2016. Stratified coastal ocean interactions with tropical cyclones. Nature Communications, 7(1): 10887.

Kohut, J., Roarty, H., Randall-Goodwin, E., Glenn, S. and Lichtenwalner, C.S., 2012. Evaluation of two algorithms for a network of coastal HF Radars in the mid-atlantic bight. Ocean Dynamics, 62(6): 953-968.

Roarty, H. et al., 2010. Operation and application of a regional high-frequency radar network in the Mid-Atlantic Bight. Marine Technology Society Journal, 44(6): 133-145.

Roarty, H. et al., 2020. Annual and seasonal surface circulation over the mid-atlantic bight continental shelf derived from a decade of high frequency radar observations. Journal of Geophysical Research: Oceans, 125(11): e2020JC016368.

Schofield, O. et al., 2007. Slocum gliders: Robust and ready. Journal of Field Robotics, 24(6): 473-485.

Seroka, G. et al., 2016. Hurricane Irene sensitivity to stratified coastal ocean cooling. Monthly Weather Review, 144(9): 3507-3530.

Seroka, G. et al., 2017. Rapid shelf-wide cooling response of a stratified coastal ocean to hurricanes. Journal of Geophysical Research: Oceans, 122(6): 4845-4867.

Zhang, F., Li, M. and Miles, T., 2018. Generation of near-inertial currents on the Mid-Atlantic Bight by hurricane Arthur (2014). Journal of Geophysical Research: Oceans, 123(4): 3100-3116.