Reviewer 1

This study investigates the potential impacts of urbanization and rising SSTs on tropical cyclones impacting Shanghai based on convection-permitting WRF simulations of five tropical cyclones. The authors find a significant impact from increasing SSTs, including consistent increases to cyclone radius, maximum rainfall rate, and 10-m wind speed over the cyclone area that are more variable over Shanghai itself, as well as a southward shift in the cyclone track. They also find that urbanization has only a small impact on tropical cyclones, with almost no effect on large-scale cyclone characteristics but a slight increase in rainfall and decrease in wind speed over Shanghai itself. The latter half of the paper also includes an analysis of potential mechanisms, concluding that increased SSTs enhance lower tropospheric temperatures, wind speeds, and pressure anomalies, which increase cyclone size and intensity, and produce a southward shift of the cyclone tracks through enhancement of the Fujiwhara effect.
The results are clear, well-presented, and compelling. The paper is also beautifully written and was a genuine pleasure to read. The authors did a good job of evaluating potential cyclone impacts across multiple metrics, distinguishing between large-scale changes and those affecting Shanghai in particular, and proposing and demonstrating plausible mechanisms for the effects they observed. My biggest substantive comments have to do with the figures, some of which I find to be insufficiently explained and which use color schemes that are confusing and even, in some cases, deceptive. Most of my remaining comments are looking for additional clarification on certain choices that were made in the methods or analysis rather than objections to those choices. Overall, I am recommending minor revisions.

Reply: Thank you for your positive and constructive comments. We have added further clarification and explanations as detailed below, and we hope our responses address your concerns and questions.

Reviewer Comment 1.1 — Event selection – time period. On line 86, why focus on the period from 2018-2022 for selecting TCs? Why not, for example, the five most destructive TCs impacting Shanghai in the last twenty or even thirty years instead?

Reply: We did not intentionally restrict the simulated events to the period between 2018 and 2022. As one of our goals is to understand the effects of Shanghai's urbanization on typhoons, we primarily focused on typhoon events that actually made landfall in Shanghai. Since 1990, there have only been seven such typhoons (see table below). After applying additional selection criteria, such as time of occurrence, trajectory (to ensure comparable climate conditions), and economic loss in Shanghai, we selected the five events presented in the manuscript, which happen to be clustered in 2018–2022.

Table 1: Landfalling typhoons in Shanghai since 1990 considered for selection in this study.

Year	Typhoon name	Trajectory	Inclusion in study (reason)
2014	Fung-Wong	S-N	Not included (trajectory)
2018	Ampil	SE-NW	Included
2018	Jongdari	SE-NW	Included
2018	Rumbia	SE-NW	Included
2022	Muifa	SE-NW	Included
2024	Bebinca	SE-NW	Not included (post-submission)
2025	Co-may	SW-NE, then SE-NW	Not included (post-submission)

Reviewer Comment 1.2 — Event selection – trajectory. You specified that the TCs under consideration had to directly impact Shanghai (line 87), but given the southward track shift you observed under higher SSTs isn't it possible that cyclones that would otherwise have passed north of the city could shift to hit it instead? This also comes up on line 262, as it seems to me that the southward shift may spare Shanghai from some landfalls but could equally easily expose it to cyclones that would otherwise pass harmlessly north.

Reply: Indeed, our results suggest that under higher SSTs, a southward track shift could cause typhoons that would previously have passed north of Shanghai to impact the city, while some typhoons that might otherwise have made landfall in Shanghai could shift southward. In both cases, we suggest that the typhoon risk for Shanghai increases because both the size and intensity of typhoons rise, even when the track shifts away from the city. We will add more discussion in the revised manuscript.
Following our response to Point 1.1, the event selection considered multiple criteria, allowing us to better explore how historical typhoons vary with potential city expansion and SST warming. For future work, it would be valuable to further investigate changes in general typhoon genesis and track patterns using a larger set of typhoon events.

Reviewer Comment 1.3 — WRF resolution. On line 104, you describe the vertical resolution as 45 layers going up to 50 hPa. Are those levels terrain-following, hybrid, or pressure-following? And is the layer spacing constant or does it change with height? At least a few studies (Wu et al 2019 in Acta Oceanologica Sinica; Ma et al 2012 in Asia-Pacific Journal of Amostpheric Sciences) indicate that the vertical resolution in specific parts of the atmosphere can have a noticeable effect on TC simulation with WRF.

Reply: The vertical coordinate system used is hybrid (sigma-pressure). The vertical spacing is not uniform; the model has higher resolution near the surface for a better representation of the surface-atmosphere interactions, and becomes coarser with increasing altitude. This configuration aligns with the recommendations from [Ma et al., 2012], as noted, who emphasize the importance of enhanced vertical resolution near the surface for accurately simulating typhoon intensity and structure, while noting that a large number of mid-level layers is not necessary. Configuring 35–50 vertical layers is a common practice in WRF-based typhoon simulations and has been shown to provide sufficient accuracy for reproducing typhoon tracks and associated precipitation [Wu et al., 2025, Pérez-Alarcón et al., 2024, Du et al., 2023, Hu et al., 2023]. We will revise the text accordingly.

Reviewer Comment 1.4 — Urbanization case definition. Why choose the lowest urban development scenario, SSP1, for your increased urbanization case (line 112-113)? This seems designed to under-estimate the potential impact of urbanization.

Reply: Thank you for pointing out the potential misunderstanding. To clarify, our urbanization scenario is not based on the lowest urban development pathway (SSP1). Instead, we define future urban expansion by converting grid cells within a 3 km buffer surrounding the current Shanghai city boundary to urban land. To support this design choice, we note that the resulting urban extent is consistent with the projections for the Shanghai urban area in 2040 under SSP1 or in 2030 under SSP5 based on data from [Chen et al., 2020]. We will revise the relevant sentence in the manuscript to clarify this point.

Reviewer Comment 1.5 — SST case definition. Near the end of the paper, you acknowledge a potential pattern effect of SST change which is in contrast to the uniform warming you imposed (line 280-281), so why did you go with a uniform warming case (line 118)? Particularly when you already have the pattern effect, at least in a climatological sense, in Figure S1.

Reply: Our primary motivation for using uniform SST warming was to isolate and interpret the typhoons' response to increased SST in a simplified and controlled framework. This approach is commonly adopted in WRF-based typhoon studies (e.g., [Choi et al., 2019, Yin et al., 2021]) as it provides a clear baseline for assessing the effects of sea surface warming without the added complexity introduced by spatial SST variability. However, as indicated in Figure S1, future SST warming in the East China Sea is projected to be greater than that in the South China Sea, highlighting the importance of SST heterogeneity. We fully agree with the reviewer that the pattern effect (i.e., non-uniform SST changes) can produce more realistic and complex responses (see [Wang et al., 2014, Shultz et al., 2014]), and we acknowledge that incorporating spatially varying SST should be considered in future work. We will add further discussion of this point in the Discussion section.

Reviewer Comment 1.6 — Significance or Confidence Intervals on TC metrics. Figures 5 and 6 look a lot at changes in key TC metrics from the CTR case, and line 151-152 discusses deviations from the control track in km. Is there any way to establish statistical significance of these changes, using either the bias from observations or some spread in these metrics from an ensemble of TC simulations? For example, some of the magnitudes discussed are quite small (line 186-187 discusses a "consistent" change in maximum rainfall and maximum wind speed in Figure 6, but those changes are on the order of 1-4 mm/h and 1-2 m/s, which seems very small to attribute to a significant impact of urbanization). I realize this could be challenging to quantify, but if there is any way to do so I think it would make it much easier to interpret Figures 5 and 6.

Reply: We agree with the reviewer that quantifying the significance of the changes observed in our simulations would be valuable. Unfortunately, the limited number of simulated tropical cyclones (five in total) precludes a robust statistical analysis to assess significance levels or confidence intervals. Performing statistical tests with such a small sample size may lead to misleading conclusions due to data limitations (see [Morin, 2011]).

Reviewer Comment 1.7 — Domain for calculating I_{max} and W_{max}. In Figure 6, the maximum rainfall and wind speed are calculated just over the Shanghai domain, but in Figures 5 and 7 it is

not clear to me the domain that was used to find these maxima. Is it within the radius R during the timesteps that Shanghai was also in that radius, similar to Figure 2c?

Reply: In Figures 5 and 7, at each time step, I_{max} and W_{max}^{10m} are calculated as the maximum rainfall intensity and 10-m wind speed within the typhoon radius R, following the typhoon's center. As illustrated in Figure 2c, we extract the maxima within the specified radius (whether solid or dashed circles) at every hourly time step, regardless of whether Shanghai is located within the radius at that particular time. In contrast, Figure 6 focuses exclusively on the Shanghai city domain, and the maxima are calculated only within the city boundary. We will highlight this in the figures' captions.

Reviewer Comment 1.8 — Color scale for Figures 5 and 6. I don't understand the color mapping used in these figures, and on fairly close inspection actually find them quite deceptive. As far as I can tell, each panel (single heat map) uses a shared colorbar, which has a diverging colormap where the lowest values are red and the highest are blue. But the intention of the figure seems to be to compare changes from the control simulation, so in my view there should really be a separate color scale for each row (otherwise the highest-intensity values will always be on the most and least intense TCs, so you don't really see changes even when they do exist across the middle of the pack), such that the CTR simulation is grey for each TC, any increase from that is red, and any decrease is blue, with the two sides symmetric so that the intensity of the color indicates either the absolute or relative (which may be better, since the text mostly discusses changes as a percent of the control case) change from the control case. As is, there are some very confusing cases where the text describes, for example, a three-fold increase in the radius of Jongdari in the SST3 scenario (line 160), but the corresponding box in Figure 5a is the palest shade in the Jongdari row, which would imply the opposite. Either way, the color scaling should be explained in the caption, particularly since it is not provided as a colorbar on the figure.

Reply: Thank you for this valuable suggestion. We will revise Figures 5 and 6 by using a neutral color (such as grey) for the control values, and marking positive and negative changes in each simulated scenario in blue and red, respectively, with darker shades indicating stronger signals. The figure captions will be updated accordingly.

Reviewer Comment 1.9 — Diverging colormap for uniformly increasing values. A minor point, but S1 uses a diverging red-blue colormap even though the underlying values are uniformly positive and represent a change in temperature over time. I found this unnecessarily confusing, and it took me a while to realize that the blue areas are still an increase in SST, just a smaller one.

Reply: Thank you, we will revise the colormap of Figure S1.

Reviewer Comment 1.10 — Definition of Delta in Figure 7. It was not clear to me what the Delta in rainfall and wind represents. In "after landfall", for example, is the change calculated as a change over the Shanghai domain from the moment of landfall to one time step (1 hour) after landfall? 6 hours after landfall? In that case, line 196 is confusing to me, as it states that an enhancement of rainfall both before after landfall indicates that Jongdari decays slowly after reaching land; if rainfall increases after landfall, it's not decaying at all yet, right? And if the change is actually between the CTR case and a SST/U3km case, I'm still not sure what time(s) "before" and "after" refers to. This is another case where I think a more detailed explanation in the figure caption of what the Delta I_{max} and Delta W_{max}^{10m} actually represent is needed.

Reply: Thank you for highlighting the need for clarification. In Figure 7, Delta (Δ) in rainfall and wind refers to the difference between the CTR and the other sensitivity experiments. The landfall time is defined as the first time step when the typhoon radius reaches Shanghai. "Before landfall" refers to all simulation time steps prior to landfall, while "after landfall" refers to all time steps following it. We will revise both the figure caption and the relevant text to provide a more detailed explanation.

Reviewer Comment 1.11 — Fujiwhara effect seen in all cases. The finding that the Fujiwhara effect played a role in the response of all 5 TCs to increased SSTs was particularly interesting to me (line 221-222). Was there no secondary pressure low in the CTR case, and one developed in all 5 cases under increased SSTs? Or did the secondary low already exist but just got stronger/closer to the primary TC? Is there any explanation for why this change in the effect strength happens under increasing SST? Explaining why the Fujiwhara effect gets stronger would help to support the claim made in line 296-297, particularly since about 61% of current TCs occur as doubles (line 228), which is a large number but wouldn't necessarily produce any change in the other 39% of TCs unless the increase in SSTs actually makes double-TC events more frequent rather than just changing the range/strength of interaction.

Reply: In all five cases, a secondary low-pressure system is already present in the control (CTR) simulations, and it further intensifies under the warming scenarios. Our findings do not suggest an increase in the frequency of double-TCs but rather indicate stronger interaction when such systems are already present, leading to a more pronounced Fujiwhara effect. The physical explanation is that higher SSTs provide more heat energy (increased T^{850} [°C]) and stronger wind velocity (increased W^{850} [m s^{-1}]), which promote the intensification of both primary TC and the second low (as indicated by decreased $MSLP$ [hPa]). Intensification of the two low-pressure systems leads to larger outer wind fields and increased water vapor convergence, thereby resulting in stronger interactions between them. According to [Lee et al., 2023], Fujiwhara interactions become stronger when the participating TCs are more intense or larger, which is consistent with our findings under SST warming. We agree with the reviewer that our mechanism applies only to cases where double TCs already exist. We do not observe any evidence that increased SST leads to a higher frequency of double-TC events. We will clarify this and expand the explanation in the revised manuscript.

Reviewer Comment 1.12 — Influence of El Nino. In line 266, you state "anomalously warmer SST, so-called El Nino, significantly influences typhoons on a large scale." However, the support for this point that follows seems to be based on a single El Nino year (2023) and subsequent TC season. I think you either need more references to support the claim that El Ninos in general can influence typhoons on a large scale or to soften that claim to a possibility rather than a surety.

Reply: Thank you for pointing this out. We agree that the original statement may not have been sufficiently supported. We will add some sentences to clarify that numerous studies have demonstrated that El Niño can exert large-scale influences on typhoons in the western North Pacific.

Reviewer Comment 1.13 — Line 44: "there are not many evidences" → "there is not much evidence"

Reply: Thank you. We will revise the sentence as suggested.

Reviewer Comment 1.14 — Line 92: "followed the TC central location" → "following the TC central location"? I'm not sure I understand this sentence structure, though

Reply: Thank you. We will revise the sentence.

Reviewer Comment 1.15 — Line 105 and in Table 2: "Yonsei University scheme (YSU) scheme" → "Yonsei University (YSU) scheme"

Reply: Will be corrected as suggested.

Reviewer Comment 1.16 — Figure 7 caption: "landfall from Shanghai" → "landfall in Shanghai"

Reply: Will be corrected as suggested.

Reviewer Comment 1.17 — Line 203: "T" → "T^{850}"

Reply: Will be corrected as suggested.

Reviewer Comment 1.18 — Line 225: "The typhoon" → "Typhoons" and "has been found normally moving" → "have been found to move" or similar

Reply: Will be corrected as suggested.

Reviewer Comment 1.19 — Line 238: "amount of water vapor context" get rid of "context"

Reply: Will be corrected as suggested.

Reviewer Comment 1.20 — Line 242: "enhances the upward" → "enhances upward"

Reply: Will be corrected as suggested.

Reviewer Comment 1.21 — Line 243: the citation should be in-text, no parentheses

Reply: Will be corrected as suggested.

Reviewer Comment 1.22 — Line 249-250: "marking a record-breaking four-time landfall" not sure what this refers to; did the TC make landfall four times? Or was the record broken by a factor of four?

Reply: Thank you for pointing it out. We meant that this typhoon made landfall in China four separate times, which is a new record for the most landfalls by a single typhoon. We will revise the sentence to clarify this in the manuscript.

Reviewer Comment 1.23 — Line 273: "tropical regions" New York and Tokyo (2 of the 3 listed cities) are mid-latitude, not tropical

Reply: We will remove the "tropical regions" and revise the sentence.

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