

Reply to Referee #2

This paper describes the characteristics of relatively intense tornado-scale vortices in a high-resolution numerical simulation of a mature tropical cyclone under environmental conditions resembling those of Typhoon Matsa (2005). It is found that the simulated vortices have locations and basic properties that are broadly consistent with limited observations. An effort is made to classify the vortices into 3 distinct categories. In my view, the article is well organized and provides useful information that is adequately summarized in the abstract and section 7. Moreover, I did not catch any obvious mistakes of major consequence. On the other hand, I was somewhat disappointed not to see a rigorous analysis of the generation and decay of a tornado-scale vortex belonging to any of the 3 categories. High-resolution TC simulations showing tornado-scale vortices are not unprecedented [e.g., Stern and Bryan 2014], and it seems to me that the most interesting scientific questions pertain to the formation and decay mechanisms. Below are some minor comments that might be worth considering before official publication.

We absolutely agree with you that this manuscript does not include a rigorous analysis of the generation and decay of the tornado-scale vortex. As we mentioned in the manuscript, the model output is regularly stored at 1-h intervals, and a few variables during a 22-min period from the 30th hour are also stored at 3-s intervals. In this study, we mainly used 1-hour outputs to check the structures of tornado-scale vortices. We think that considerable analysis is needed to understand the mechanisms for the generation and decay of the tornado-scale vortex. We plan to rerun the experiment by adding more variables in the 3-s output and investigate the mechanisms for the generation and decay of the tornado-scale vortex in the future. We have added some discussions in the revised manuscript.

1. The paper cites an earlier study suggesting that grid-spacing less than 100 m is necessary for simulating the development of tornado-scale vortices. However, it is not entirely clear to me that simulating the 1-2 km structures of interest requires 37-m horizontal grid spacing, especially since the vertical grid spacing is (apparently) of order 100 m in the boundary layer. A brief comment on what happens to the tornado-scale vortices when the finest horizontal grid is removed in the present numerical experiment might be worthwhile.

Our experiment contains 12 vertical levels below 1 km. We also conducted an experiment with the resolution of 111 m in the innermost domain. In the experiment, the vertical resolution and horizontal resolution are comparable in TC boundary layer. The tornado-scale vortex (TSV) mentioned in observations can also be found in the experiment. In the attached figure, we can see a simulated TSV in the experiment, similar to the TSV in Figure 6. The maximum vertical motion is 21.3 m s^{-1} at 500 m

and the maximum relative vertical vorticity is 0.11 s^{-1} . In the revised manuscript, we have added a brief description about the issue.

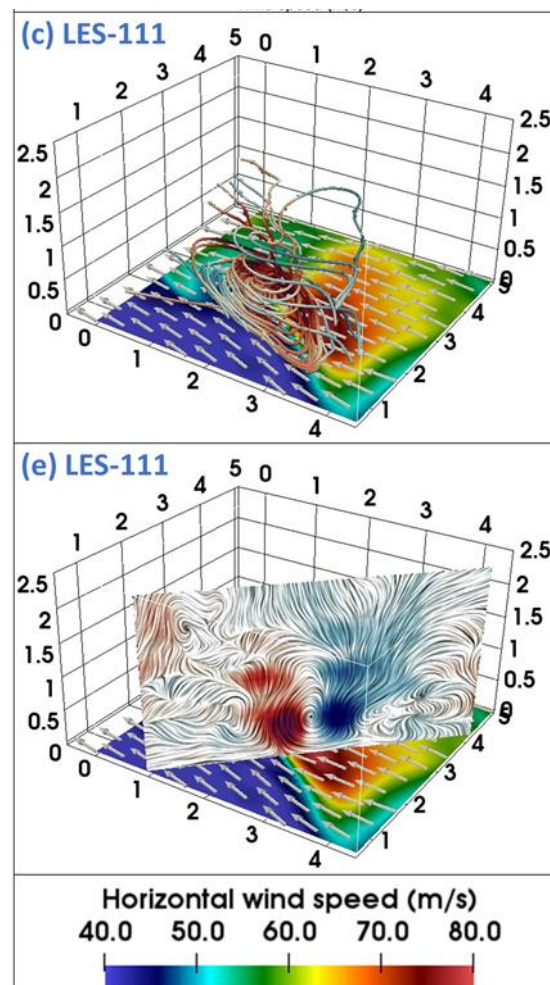


Fig. A1 A simulated TSV in the LES-111 experiment. The description of the figure is the same as Fig. 6 in the manuscript, except for LES-111 experiment.

2. *There is a recent LES study by Ito et al. [Scientific Reports, 7.1, 3798 (2017)] that addresses the variation of roll structure with location in a TC boundary layer. Perhaps the authors should to try to connect the aforementioned study to theirs.*

Thank you for providing the reference. We have introduced the research conducted by Ito et al. (2017) in the Introduction.

3. *Since this article pertains to coherent structures having large horizontal components of relative vorticity, it might be a good idea to specify upfront that the term "relative vorticity" in this paper (presumably) refers to the vertical relative vorticity.*

This is a good idea. We have done this in the revised manuscript.

4. Lines 170-171: *In my view, it seems a little awkward to introduce tornado-scale vortices as small-scale features that are distinct from horizontal rolls, but later show that they incorporate horizontal rolls (in some sense). That said, I am not sure that any changes need to be made in response to the preceding comment.*

In this manuscript, we focus mostly the tornado-scale vortices and the calculated vorticity is the vertical component of relative vorticity. The simulated tornado-scale vortices are distinct from horizontal rolls because the strong updrafts are always accompanied by strong horizontal circulations.

5. Lines 256-258: *This statement (added after the first review) needs to be rewritten. To begin with, the statement fails to clarify whether the azimuthally averaged wind speed is an azimuthal average of the total horizontal wind speed or of the tangential (azimuthal) velocity. Of lesser importance, "are directly" should be "are obtained directly", and there should probably be a comma after "time-averaging".*

Thank you. The statement has been revised.

6. Line 374: *To facilitate quantitative comparison with future studies, I think that it might be worthwhile to more precisely define the Richardson number (with an equation).*

We have added some statement on Richardson number. The gradient Richardson number, Ri , has largely been used as a criterion for assessing the stability of stratified shear flow. It is defined by

$$Ri = \frac{N^2}{S^2} \quad (1)$$

$N^2 = g \frac{\partial \ln \theta_e}{\partial z}$ is the square of Brunt–Väisälä frequency and $S^2 = \left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2$ is the square of vertical shear of the horizontal velocity, g is the gravity acceleration, θ_e is the equivalent potential temperature, u is the zonal wind speed and v is the meridional wind speed.

7. Lines 426-428: *The wording suggests (to me) that the cited studies definitively showed that the wind speed bands are connected to vertical momentum transport by the rolls, but such an interpretation is challenged by the final sentence of the paragraph. I would consider revising the paragraph so as not to mislead the reader upfront.*

The sentence has been revised.

8. Line 130: *I suggest changing "the similar features as revealed with the limited observational data" to "features similar to those revealed with limited observational data".*

The sentence has been rewritten as you suggest.

9. Lines 156-159: *This section of the paragraph tries to say too much in one sentence.*

The sentence has been rewritten as you suggest.

10. Line 275: *I believe that "France" should be "Frances".*

Corrected. Thank you!

11. Line 290: *"wind size" should be "window size".*

Corrected.

12. Line 325: *I would change "the mesovortices" to "mesovortices".*

Corrected.

13. Line 339: *I might remove "consecutive" or change it to "continuous".*

Corrected.

14. Line 350: *"close to RMW" should be "close to the RMW".*

Corrected.

15. Line 364: *"tornado-scale" should be "tornado-scale vortex".*

Corrected.

16. Line 404: *I would change "Besides" to "In addition".*

Changed.

17. Line 410: *Should "frank" be "flank"?*

Corrected.

18. Line 425: *I might change "entrained" to "locally entrained".*

Changed.

19. Line 459: *"associated strong turbulence" should be "associated with strong turbulence".*

Corrected.

20. Lines 463-465: *"nesting grids" should be "nested grids"; "shows the similar features as revealed with the limited observations" should be something like "shows features similar to those revealed with limited observations"; "favorable" should probably be "favored".*

Thank you. Corrected.

21. Lines 478-480: *These sentences seem largely redundant with the preceding paragraph.*

We have deleted some sentences in the preceding paragraph.