Effects of Horizontal Resolution and Air–Sea Flux Parameterization on the Intensity and Structure of simulated Typhoon Haiyan (2013)

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Response to referee 2

Dear Referee,

We thank the referee for the comments and suggestions to our manuscript. Please find our responses to your comments and questions below. The comments and questions are given in italics, and our responses are in blue.

This contribution aims at investigating the impacts of model horizontal resolution and surface flux formulas on structure and intensity of tropical cyclones. The authors intend to study the sensitivity of the intensity of tropical cyclones to surface fluxes parameterizations of the Weather Research and Forecasting Model (WRF) at very high resolutions (1, 3 and 6 km, when model resolution approaches the convective scale).
The paper is in general structured and scientifically sound. English should be revised by a native speaker in order to correct some typos, but also to rephrase long sentences that make the manuscript hard to read. Scientifically, there are several limitations, especially regarding the design of the simulations, that require major revisions of the submitted version.

We thank the referee's positive comments to our manuscript. We have carried out the numerical experiment of 1 km F2 in response to your comment 4. The revised manuscript has been edited by *Wallace Academic Editing* and is considered to be improved in grammar, punctuation, general readability, and native English usage. In addition, we followed the suggestion of *Wallace Academic Editing* and reworded the "impacts" to "effects" in our title, which is now:

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Below are our point-by-point replies to your comments.

1. *Is convection parameterized (K-F cumulus scheme) for all resolutions? 6 km simulations are in the grey-zone, but cumulus should be explicitly resolved when working at resolutions below 3-4 km. How this parameterization impacts the results?*

Yes, the convection parameterization (K-F cumulus scheme) was used for all resolutions. This is because we intend to keep consistency among all cases. The convective treatment was also mentioned in the comment 2 by referee 1. For typhoon Haiyan, we have carried out several tests with and without cumulus parameterization on the 3 km resolution grid. The 3 km resolution grid is for our control experiment in this study. The tests revealed that, simulations with and without cumulus parameterization produced overall similar simulated storm intensity. We did not perform any convection parameterization test on the 1-km resolution grid, because of our limited computational resource.

Numerous studies have suggested that 3-4 km resolutions without any cumulus parameterization is sufficient to represent mesoscale convections (e.g.,Weisman et al. 1997; Davis et al. 2008; Gentry and Lackmann, 2010). However, such a grid resolution is still insufficient for representing individual convective cells (e.g., Bryan et al. 2003; Miyamoto et al. 2013). The use of cumulus parameterization with the grid spacing below 3-4 km has been investigated by a number of recent studies. Some studies suggested to activate the cumulus parameterization for simulation of moist convective event with a grid resolution of 4 km (Deng and Stauffer 2006), 3 km (Lee et al 2011) and 2 km (Kotroni and Lagouvardos 2004). Some others, however, revealed that the activation of cumulus parameterization for simulation with grid spacings of 2-3 km produced overall similar simulated storm as in the simulation with explicit convection (e.g., Yu et al. 2011; Li et al. 2018; On et al. 2018). Sun et al. (2013) studied the appropriateness of a variety of cumulus parameterization schemes used in high-resolution simulations. They assumed that the cumulus scheme is closely related to the model convergence in simulating TC intensity. Here, a convergence of model solution in terms of TC intensity is that the simulated TC intensity would remain similar irrespective of any further reduction of the grid spacing. They found a weak convergence in fine resolution (from 3 to 1 km) simulations with most of the schemes, whereas the convergence is relatively strong in the simulations with a scale-aware scheme designed for any resolution. Accordingly, cumulus parameterization may still play a role in the fine resolution (3 to 1 km) simulations. The question then arises as to what is the appropriate design of cumulus parameterization for very high resolution. However, this is far beyond the scope of our present study.

2. *P. 4: What is the nesting approach followed in the simulations? Is it a one way or a two way nesting?*

No nesting approach was used for our simulations in this study. Our large single domain was chosen to cover the majority of simulated Haiyan (2013)'s convection during the period of sensitivity simulation, and to make a cleaner comparison among those experiments running at different resolutions.

Higher-resolution nested model configuration are widely used in numerical weather prediction and regional climate modelling. The main reason for this is because large area of high-resolution model simulation is computationally too expensive. However, consistency between nested grids is also important. With lateral boundaries on multiple grids, model solutions may not be smooth across nested-domain boundaries. In a nested WRF simulation, a discontinuity in precipitation and moisture fields (i.e., a sharp gradient) across the inner domain boundaries has long been recognized by the WRF community. Uncertainty related to the use of multiple nested grids can resulted from mismatched model physics across nested-domain boundaries. For example, Warner and Hsu (2000) revealed that the treatment of convection on the outer grid can affect the explicit convection on the inner grid. Their result indicated that the simulation biases related to the parameterized convection (e.g., errors in precipitation timing, precipitation intensity, and the vertical distribution of latent heating) can greatly modulate the explicit convection on the inner grid through the induced subsidence from the outer grid. The nesting issue was also mentioned in the comment 3 by referee 1.

3. *Nudging is critical for correctly representing the TC structures, their paths and intensities. So, ideally, some sensitivity runs should take nudging options into account. If not possible, further details about nudging approach followed and its impacts on the results should be elaborated.*

In this study, the simulations were performed with two stages. The nudging stage is a 24-hour period before the 78 hours sensitivity stage. No analysis nudging was applied to the model grid during the entire period of sensitivity experiment.

In this study, the analysis nudging was applied to the horizontal wind components, potential temperature, and water vapor mixing ratio. The nudging coefficients for all variables were set at 0.0003 s^{-1}. The nudging was only applied at all levels above the planetary boundary layer. We have added the information in the revised manuscript. (page 8, lines 21-23)

For typhoon Haiyan, we have carried out several tests with and without the nudging options on the 3 km resolution grid. The 3 km resolution grid is for our control experiment in this study. The tests revealed that, simulations without nudging during the '24-h pre-sensitivity stage' produced larger typhoon track errors than that with a nudging stage. Regarding the TC structure and intensity, we did not find significant differences in the Haiyan case between the experiments with and without the nudging treatment. We did not perform any nudging test on the 1 km resolution grid, because of our limited computational resource.

4. *P. 8, lines 5-10: It is not clear to the reader why 1 km F2 test is omitted. The authors indicate that the "the simulation result of F2 is somewhat between those of F0 and F1 for other resolutions, we omitted the F2 test at 1-km resolution". Can you extrapolate that for the 1 km resolution? I think the authors should elaborate on F2 at 1 km.*

We have carried out the experiment of 1 km F2 as suggested. This added experiment was also suggested in comment 1 by referee 1. Accordingly, we have modified the following figures for adding the experiments with flux option F2: Figs. 4, 6, 8, 9, 10, 11, 12, 13, 14, and 15. We have also modified some related sentences in the revised manuscript. The majority of them can be found in sub-section 2.3 (P8, Experimental designs), section 4 (P12, P14, P15, P16), section 5 (P18). Please find the respective changes in the revised manuscript.

With the new added 1 km F2, the observed typhoon intensity is located between 1 km F2 and 1 km F1 experiments. Overall, the simulated typhoon intensity (and other features presented) of F2 is again somewhat between those of F0 and F1 at the resolution of 1 km.

5. *I cannot find the observed structure of the TC in the manuscript, which would be very important for building confidence on the modelling results.*

We do not have observations for the structure of typhoon Haiyan. In the former manuscript, we have provided a reference (Shimada et al. 2018) which revealed the observational information for the structure of Haiyan (2013). Please find the information on page 11 (lines 30-34) and page 12 (lines 1-5).

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