*Response to comments of **Anonymous Referee 1 & 2** on*

# Sensitivity of simulating Typhoon Haiyan (2013) using WRF: the role of cumulus convection, surface flux parameterizations, spectral nudging, and initial and boundary conditions

Delfino et. al.

## **Anonymous Referee #1** [Report #2 Submitted on 19 Jul 2022]

| Editor's COMMENTS | Authors' RESPONSES |
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| Dear authors<br>although the manuscript has improved a lot with the provided revisions there are: (a) some technical corrections which should be made and b) most importantly a concern on the use of 2-way nesting in the sensitivity experiments. For that reason i would like to invite you to revise your manuscripts addressing the reviewers comments. Your manuscript will be further reviewed by the editor and the referees. We thank you for your efforts that aim at improving the manuscript and bring it to the NHESS standards. | Dear Editor,<br>Thank you very much for giving us the opportunity to submit an improved version of the manuscript. We appreciate the thoroughness and objectiveness of the comments and have addressed the specific concerns raised by the Reviewers, particularly the concern on the use of two-way nesting. Please note that, consistent with our original plan for this study, we are not going to attempt to build a second study based on the use of 1-way nesting, in the study of tropical cyclones: we have provided ample literature review to support our decision, as well as the expert opinion of WRF developers. Please refer to our response to Reviewer 2 for more details.<br><br>All changes are highlighted in the revised manuscript. All line numbers refer to the revised manuscript with tracked changes. |
| **Reviewer 1's COMMENTS** | **Authors' RESPONSES** |
| **General comments** | |
| **accepted subject to technical corrections.**<br>The authors have addressed successfully the suggested corrections. The article will be acceptable for publication after a few technical corrections are performed. | Thank you very much for the positive review. We have made the suggested technical corrections in the revised manuscript. Please see below our specific responses and refer to the attached revised manuscript for more details. |
| **Suggested corrections:** | |
| Line 130: please insert a bullet at the beginning of the question (similarly to the question above). | Revised in Lines 128 – 131 of the revised manuscript |
| Line 206: "… and 5-30 degrees North.". | Revised in Line 238 of the revised manuscript |

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| Table 1, 1st row (2nd column) and 2nd line of the caption of Figure 4: "Fritsch". | Revised in Table 1, 1st Row/2nd Column, of the revised manuscript |
| Line 281: "… domains, include:". | Revised in Line 322 of the revised manuscript |
| Line 283 and 10th row (right column) of Table 3: "Obukhov". | Revised in Table 3 of the revised manuscript |
| Table 3, 10th row (left column): "Surface Layer" instead of "180-hour period". | Revised in Table 3 of the revised manuscript |
| Line 342 and lines 351-352: It is mentioned in line 342 that the simulations using the TK scheme have a mean DPE of 47 km. This mean value is calculated from the average of the 3 TK simulations with nudging (TKsnONsf0, TKsnONsf1, TKsnONsf2) and the 3 TK simulations without nudging (TKsnOFFsf0 TKsnOFFsf1 TKsnOFFsf2). However, lines 351-352 mention that the mean DPE of the former TK simulations (with nudging) is 68 km while the mean DPE of the latter simulations (without nudging) is 87km. Both errors (68 km, 87 km) are above the overall TK mean of 47 km. Which errors are not correct? | Thank you very much for spotting this. We have corrected the figures in Lines 393 of the revised manuscript. |
| Lines 359-360: The sentence "The one and two black stars … land, respectively" must be removed because the single and double stars do not exist in this figure in the revised version of the article. | We have removed these in Lines 400-401 of the revised manuscript. |
| Line 366: In Figure 4b the maximum wind speed of the control simulation KFsnOFFsf0 is stronger than 45 m/s (and less than 50 m/s). After this correction, please also correct its difference from the observed max wind speed in line 367. | Thank you very much for spotting this. Revised in Lines 407-408 of the revised manuscript. |
| Line 367: There is a difference of 44 hPa (and not 38 hPa) between the min mslp of KFsnOFFsf0 (939 hPa) and the observed min mslp (895 hPa) of the typhoon. | Thank you very much for spotting this. Revised in Line 408 of the revised manuscript. |
| Figure 4: The lower row of panels is identical to the upper one. | Apologies for this, the lower and upper panels are merely duplicates. We have removed the lower panel in the revised manuscript. |
| Line 399: "… without nudging has …". | Revised in Line 441 of the revised manuscript |
| Line 517: "… KF scheme (Fig. 11 b-d) than those that used TK scheme (Fig. 11 e-g).". | Revised in Line 560 of the revised manuscript |

## **Anonymous Referee #2** [Report #1, Submitted on 6 July 2022]

| Reviewer 2's COMMENTS | Authors' RESPONSES |
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| **General comments** | |
| **reconsidered after major revisions:**<br>The revised manuscript is significantly improved. The authors were able to address the concerns of the reviewers. | Thank you very much for the positive feedback. We continue to strive for the improvement of the manuscript, particularly based on the concerns raised by the reviewer. Please see below our specific responses and refer to the attached revised manuscript for more details. |
| **Major Concerns:** | |
| Thank you for considering my 1st major comment in the literature review part of the paper. | Thank you very much. We have addressed the 1st major comment and we are happy that it has been to your satisfaction. |
| For my second concern, it is now clear that two-way nesting was used, which implies all D1 forcings are different for all sensitivity runs since WRF would not allow having different parameterizations in a two-way nesting run. Kindly address the following: | Yes, that is correct. We have used two-way nesting in the sensitivity runs following recommended practice and previous studies that looked at sensitivities to physics parameterizations in WRF (Wu et al., 2019, Biswas et al., 2014; Li and Pu, 2009; Parker et al., 2017; Spencer and Shaw 2012; Bopape et al., 2021), studies that simulated Typhoon Haiyan in the Philippines (Li et al., 2018; Nakamura et al., 2016) as well as TC cases in other basins (Parker et al., 2018; Mittal et al., 2019; Reddy et al 2020), among others. Please see Table 1 below, containing ample evidence from the literature, to support our decision to employ two-way nesting for the study of tropical cyclones.<br><br>We have tried to address the specific comments as shown below. |
| 1. Include two-way nesting WRF-related sensitivity studies in your literature review. What is the difference between 1-way and 2-way nesting methods? | Thank you for this suggestion. We have added the following discussion in Lines 190 – 199 of the revised manuscript:<br><br>*"Higher-resolution nested model configuration is widely used in numerical weather prediction and regional climate modelling. The main reason for this is because performing high resolution simulation over very large areas (e.g. an entire major oceanic basin) is computationally too expensive (Kueh et al 2019). The communication between the nested domains can be implemented using one-way or two-way nesting. One-way nesting means that the nested domains are run separately and sequentially starting with the outer domain i.e. the model is first run for the outer domain to create and output which is used to supply the inner domain's boundary file. In a two-way nesting configuration, both domains are run simultaneously and interact with each other, so that the highest possible resolution information produced by the innermost domain affects the solutions over the overlapping area of the coarser domains. The input from the coarse outer domain is introduced through the boundary of the fine inner domain, while feedback to the coarse domain occurs all over the inner domain interior, as its values are* |

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| | *replaced by combination of fine inner domain values (Alaka et al., 2022; Mure-Ravaud et al 2019; Harris and Duran 2009).”*<br><br>We have also added a short discussion on this based on the literature in the revised manuscript (Lines 200 to 215), and also shown below:<br><br>*“We have used two-way nesting in the sensitivity runs, rather than one-way nesting, following recommended practice and previous studies that looked at sensitivities to physics parameterizations in WRF (Wu et al., 2019, Biswas et al., 2014; Li and Pu, 2009; Parker et al., 2017; Spencer and Shaw 2012; Bopape et al., 2021), studies that simulated Typhoon Haiyan in the Philippines (Li et al., 2018; Nakamura et al., 2016), as well as TC cases in other basins (Parker et al., 2018; Mittal et al., 2019; Reddy et al 2020), among others. Studies of the differences in using 1-way and 2-way nesting in regional modelling have been, the topic of multiple previous papers (e.g. Spencer and Shaw 2012; Matte et al. 2016; Raffa et al., 2021; Lauwaet et al. 2013; Harris and Durran, 2010, Chen et al 2010; Gao et al., 2019). A comprehensive discussion on the differences and uncertainties associated with 1-way or 2-way nesting can also be found in Harris (2010). Studies such as those of Chen et al (2010) and Gao et al. (2019) have shown that the use of one-way or two-way nesting showed little difference in the results, but some studies showing that two-way nesting improves the simulations of TCs e.g. Typhoon Parma in the Philippines (Spencer and Shaw et al., 2012) and Typhoon Kai-tak (Wu et al., 2019). In addition, previous TC case studies in the Philippines have also used the two-way nesting configuration e.g. Mori et al. (2014), Takayabu et al. (2015), Nakamura et al (2016) and in other TC basins (Parker et al., 2018; Davis et al., 2008; Mittal et al., 2019; Reddy et al., 2020), as well as looking at sensitivity to different physics parameterizations (Wu et al 2019, Biswas et al 2014, Li and Pu 2009) as summarized in Table 1 of the Appendix. Two-way nesting is also used in operational TC forecasting (Mehra et al., 2018) and in the experimental Hurricane WRF system (Zhang et al., 2016) as well as in Convection-Permitting Regional Climate Models (Lucas-Picher et al., 2021).”* |
| 2. Again, even though all runs have the same domain settings (dx,dt,nx,ny etc.), it seems inappropriate and difficult to compare D2 sensitivities on TC track and intensity to model parameterizations if the initial forcing (D1) for KF and TK experiments do not have the same model physics. That is, KF runs have KF D1 forcings, while TK runs have TK D1 forcings. | We want to make it absolutely clear that two-way nesting was used exclusively in our experiments and that 2-way nesting underpins the communication between D1 and D2; we have not used one-way nesting in any of our experiments. One-way forcing still comes, of course, from the outer boundaries of the coarsest domain, where information from the forcing GCM enters the coarsest regional domain, D1. |

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| | The purpose of the coarsest domain, D1, is to mediate the signals originating from the entirely different physics package in the driving GCM (which enters D1 at the outer boundaries), and the physics that we are trying to study in the inner domain. We do not want to introduce a third physical parametrization between GCM and RCM, on the coarse domain, which could in principle be done with 1-way nesting, but is not a modelling strategy commonly adopted in the study of tropical cyclones (see our literature review, and below).<br><br>Therefore, the true comparison of physics performance is inside the finest domain, D2, while D1 is acting as more of a mediator. Since we are exclusively using two-way nesting and there is feedback from the outer to the inner domain at each time step and vice versa, it is crucially important that the same physics parameterization is used in both domains, otherwise we would introduce spurious noise at each time step. This is the recommended practice in using WRF with multiple and nested domains (Werner and Wang, 2017; Dudhia 2015) i.e. all physics schemes must be the same for all domains except for when cumulus scheme must be turned off in 3-4km grid intervals (Chen 2022, personal communication, 25 July 2022). Multiple other studies point out the various issues in attempting to employ two-way nesting with differing physics parameterization across the RCM nest boundaries (e.g. in precipitation fields of the mother/outer domain (Dudhia 2015, Warner and Hsu 2000) and used as in past studies e.g. Wang and Wang, 2014; Islam et al., 2015). The use of different cumulus schemes in different domains is also prohibited in WRF. |
| How much of the sensitivity is caused by the interactions of D1 and D2 (due to 2-way nesting), and how much from changing model physics/configuration? Kindly show and separate the contribution/effects of the nesting method (1-way vs. 2-way nesting) and parameterizations. | Thank you very much for pointing this out. The uncertainty related to the use of multiple nested grids can result from mismatched model physics across nested-domain boundaries, therefore consistency between nested grids is important (Kueh et al., 2019). A comprehensive discussion on the difference and uncertainties associated with 1-way or 2-way nesting can also be found in Harris (2010), and some limitations in the use of 2-way nesting in regional climate simulations for TCs are discussed in Hashimoto et al (2016). |
| If you perform a 1-way nesting simulation, how much does it differ from its two-way nesting counterpart? May I suggest 1-way nesting experiments as part of the supplementary (initial runs) or major experiments to show the nesting method's influence on the simulations? | As mentioned above, we have chosen to perform a study of TCs with 2-way nesting, because it is the predominant approach in the literature, as well as reflective of our approach in the study of scale interactions, which is only possible with 2-way nesting. Please see Table 1 below with the relevant literature review as well as the added text in Item #1 indicated in this response to support our decision. Studies of the differences in 1-way and 2-way nesting in regional modelling are, instead, the topic of multiple papers already written in the past (e.g. |

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| | Spencer and Shaw 2012; Matte et al. 2016; Raffa et al., 2021; Lauwaet et al. 2013; Harris and Durran, 2010, Chen et al 2010; Gao et al., 2019). For example, Spencer and Shaw (2012) showed that the intensity of simulated Typhoon Parma (Philippines) was found to be improved (more accurate) when two-way nesting was used than with one-way nesting. Higher accuracy and efficiency were also shown using two-way nesting in simulating Typhoon Kai-tak (Wu et al., 2019).<br><br>We feel that performing 1-way simulations would be substantial additional work and would greatly increase the length of the paper and distract from the main message. We feel that the reviewer is asking for an additional second study, both in terms of the volume of work and the length of the new text+figures, but mostly in terms of the type of study that we would be conducting if we were to re-run all experiments with 1-way nesting. We hope that the discussion above based on literature, and as included in the revised manuscript, would suffice. |
| Since two-away nesting implies D1-D2 interactions, both domain runs should be considered in the sensitivity analysis? What are the results of D1 runs? | Since we have exclusively used two-way nesting, we think that it is not necessary to show the result from the outer domain (D01) since a) in the overlapping region, the results of D01 are overwritten at each time step by the solutions of D02; b) as explained above, D01 is mostly an intermediary between GCM and RCM: as shown in most studies with a similar setup, D01 is used as a means to ensure smooth results for the inner domain (D02).<br><br>Nevertheless, for the purpose of this response, we have shown some of results from D01 as indicated in our earlier response to the first round of review (Supplementary Figure 8). But we believe that it is not necessary to show in the final manuscript. |
| **Minor suggestions** | |
| 1. Line 423-425 and other sections with surface roughness length discussion: Kindly check also other references (e.g. Montgomerry et al 2010, Smith et al 2014, their references, and other studies) on the impact of friction (Cd) to tropical cyclones. | Thank you for this suggestion. We have added a short discussion on this based on the literature in the revised manuscript (Lines 291-300), and also shown below:<br><br>*"There are limited studies on the sensitivity of TC intensity due to surface heat flux because to a lack of in-situ measurements (Montgomery et al., 2010; Green and Zhang, 2013; Smith et al., 2014), particularly under high-wind conditions (Liu et al., 2014). Emanuel (1986) put forward the idea that TC intensity is proportional to the square root of the ratio of the surface exchange coefficients of enthalpy, and momentum. According to Zhang et al. (2015), increasing surface friction would also increase boundary layer inflow, which would subsequently boost angular momentum convergence and intensify a TC. However, as surface friction also increases the momentum and heat* |

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| | *dissipation to boundary layer winds, this might result in negative impact on TC intensity (Liu et al., 2014). Despite and playing a significant role in surface heat fluxes, Chen et al. (2018) hypothesized that the influence of on TC growth was minimal because it caused moderate sea-surface cooling. Further investigation on these aspects of surface heat flux is required in the future."* |
| 2. For the maps on environmental factors, may I suggest setting the base map to high resolution. If using GrADS, set mpdset hires. | Thank you for this suggestion. We have updated the basemaps to higher resolution and replaced the figures (12,13,14) in the revised manuscript. |
| Thank you and congratulations! | Thank you as well. |

**Table 1 Summary of some studies that used two-way nesting in WRF for tropical cyclone simulations as NWP or RCM**

| Authors and Year | TC Cases | Basin / Region | Resolution (Domains) |
|---|---|---|---|
| Spencer and Shaw 2012* | TY Parma | Western North Pacific (WNP) | 12km (D01); 3k (D02) |
| Li et al 2018* | TY Haiyan | WNP | 18–45 km (D01), 6–15 km (D02), and 2–5 km (D03) |
| Nakamura et al 2016 | TY Haiyan | WNP | not specified |
| Wu et al 2019* | Typhoon Kai-tak | WNP | 15km (D01), 5km (D02) |
| Biswas et al 2014* | Hurricane Katia | Atlantic and Eastern North Pacific | HWRF ~27km (D01), ~9km (D02), ~3 km (D03) |
| Li and Pu 2009* | Hurricane Emily | Atlantic Basin | 27km (D01), 9km (D02), 3 km (D03) |
| Davis et al 2008 | Hurricane Katrina | Atlantic | 12 (D01), 4 (D02) |
| Fierro et al 2009 | Hurricane Rita | Atlantic | 15–5-, 12–4-, 9–3-, 6–2-, and 3–1-km |
| Parker et al 2017* | TC Yasi | Australia | 36 (D01), 12 (D02) |
| Parker et al 2018 | TC Yasi, Ita, Marcia | Australia | 36 (D01), 12 (D02) |
| Bopape et al 2021* | TC Idai | Africa | 6km (D01) |
| Mittal et al 2019 | TC Phailin (2013) | Bay of Bengal | 30 (D01), 10 (D02) |
| Reddy et al 2020 | TC Vardah, Madi, Hudhud and Phailin | Bay of Bengal | 27 (D01), 9 (D02), 3 (D03) |

**Focused on sensitivity studies on different physics parameterizations (including cumulus schemes)*

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## Notification to the authors from the Editorial Team [Validation, 4 July 2022]

| Notification to the authors | Authors' ACTIONS |
|---|---|
| 1. For the next revision, please rename the supplement`s figures regarding our standards: https://www.natural-hazards-and-earth-system-sciences.net/submission.html#assets / Supplements /. Please note that figures must be numbered sequentially, without reference to the numbering of subsections. | We have renamed the Supplementary Figures (see revised material) and are now numbered sequentially. |
| 2. Regarding of sources of the supplement figures: for the next revision, please check if your figures containing maps/aerial images require a copyright statement/image credit and add it to the figures (or captions) (https://publications.copernicus.org/for_authors/manuscript_preparation.html#mapsaerials). If these figures were entirely created by the authors, there is no need to add a copyright statement or credit. In that case it is important that you confirm this explicitly by email. | All Supplementary Figures were created by the authors. The source of the data in Supplementary Figure 9a has been provided in the figure title. |
| 3. Regarding the figure #8: for next revision, please add the sources from footnote to the figure`s caption. | Revised in Lines 531-532 on the revised manuscript |