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Natural Hazards and Earth System Sciences
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Discussions

Interactive comment on "Typhoon rainstorm simulation with radar data assimilation in southeast coast of China" *by* Jiyang Tian et al.

Jiyang Tian et al.

liurh@iwhr.com

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Point 1: Line 11, Page 5: Eq. (8), the RMSE is expressed as percentage? The numerator part is the RMSE and I think the equation is wrong. Please check as well as Table * and *.

Reply: Thanks for the reviewer's suggestion. The values in Table 6 and 7 is right. Equation 8 has been revised. The sentences in Line 4-6, Page 7 are revised as: "The spatiotemporal patterns of the rainfall simulation are evaluated by the critical success index (CSI) and modified root mean square error (m-RMSE), which is defined as the ratio of root mean square error (RMSE) to the mean values of the corresponding observations (Prakash et al., 2014; Agnihotri and Dimri, 2015)"

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Point 2: Why do you use FNL to drive the WRF model? Would using data from other centers like ECMWF change your final conclusion? As analysis data, FNL has also assimilated data, why do you not use GFS?

Reply: We appreciate the referee's deep insights. The initial and lateral boundary conditions provided by different centres like NCEP, ECMWF and CMA may make some difference of the rainfall forecasts. Some studies have specialised the different performances of the WRF model based on the initial and lateral boundary conditions from the different centres (Zhao et al, 2012; Zhang et al, 2018). Before the NCEP data was used in this study, we also tests ECMWF for data assimilation with storm events in the same region. Although the rainfall forecasts showed a little different, the patterns of improvements from different data assimilation modes were quite similar and the same conclusions can be obtained. In order to highlight the main purpose of this study, we only present the assimilation results using the FNL. We hope our work can inspire further studies on testing the data assimilation effects using other boundary data, such as ECMWF. For further clarification, though FNL assimilates meteorological data with low resolution, local observations such as radar data with high resolution are not included and FNL can hardly simulate the rainfall in meso-and small-scale systems. Many studies indicate radar data assimilation can improve the rainfall simulation significantly. FNL has higher applicability and accuracy than GFS for historical events simulation. GFS with no data assimilation is always used for weather forecasting. That is why we use FNL not GFS.

The following sentences are added in Line 34, Page 12 and Line 1-3, Page 13: "In reality, ECMWF is also tested for the data assimilation before FNL is used in this study. Although the rainfall simulations show some differences based on the two kinds of boundary conditions, the patterns of improvements from different data assimilation modes are quite similar and the same conclusions can be obtained." References:
Zhao P. K., Wang B., Liu J., et al. A DRP–4DVar data assimilation scheme for typhoon initialization using sea level pressure data, Mon. Weather Rev., 140, 1191-

1203, doi: 10.1175/MWR-D-10-05030.1, 2012. Zhang X., Xiong Z., Zheng J., et al. High-resolution precipitation data derived from dynamical downscaling using the WRF model for the Heihe River Basin, northwest China. Theor. Appl. Climatol., 131, 1249-1259, doi: 10.1007/s00704-017-2052-6, 2018.

Point 3: The rainfall is influenced by typhoon storms. Comparing the realistic typhoon path with the simulations can help to prove the accuracy of the assimilation results. Please add description and figures for the typhoon path simulations.

Reply: The description and figures for typhoon path simulations are added in the manuscript. According to the simulations of Saola and Nepartak, the accurate typhoon path simulation always leads to accurate rainfall simulation. However, for typhoon Hagibis, when WRF model assimilates the radar data, the actual typhoon center is far away from the Meixi catchment. Hence, the typhoon path simulations cannot help to prove the accuracy of the rainfall simulations for different assimilation modes. The actual typhoon path for Hagibis is added. In addition, the wind field and water vapor transportation for different modes are also compared in the manuscript to support the interpretation of the results.

The following sentences are added in Line 2-5, Page 11: "In order to prove the accuracy of the assimilation results, typhoon paths for different assimilation modes are also simulated (Fig. 10). According to the simulations of Saola and Nepartak, the accurate typhoon path simulation always leads to accurate rainfall simulation. However, for typhoon Hagibis, when WRF model assimilates the radar data, the actual typhoon center is far away from the Meixi catchment. Hence, only the actual typhoon path for Hagibis is added."

Point 4: The results are encouraging that shortening the assimilation time interval can improve the rainfall simulations in most cases. How about half an hour or just 6 minutes? I suggest the authors do more work in further study. The research prospects can added in section 5 Discussion.

Reply: Thanks for the reviewer's suggestion. According to the manuscript, assimilating radial velocity with time interval of 1 h can significantly improve the rainfall simulations and the REs are all lower than 10%. The rainfall simulations are satisfactory for flood forecasting in small and medium basins. That is why we have no further reduction in the assimilation time interval. However, as the reviewer mentioned, shortening the assimilation time interval can improve the rainfall simulations and further shortening the assimilation interval is worth exploring. On the one hand, radial velocity can correct the initial and lateral boundary condition more timely with higher assimilation frequency, and the rainfall simulations should be better in terms of theory. On the other hand, the observation errors of radial velocity may be amplified with high assimilation frequency in WRF model. There may be an "inverted u" relationship between accuracy of rainfall simulation and assimilation time interval (Myung et al., 2009). Further study should be carried out to investigate the optimal assimilation time interval.

The following sentences are added in Line 7-11, Page 12: "Do further shortening the assimilation interval obtain better rainfall simulation? In terms of theory, the answer is yes, because improving the assimilation frequency can correct the initial and lateral boundary condition timely. However, the observation errors of radial velocity may be amplified with high assimilation frequency in WRF model. There may be an "inverted u" relationship between accuracy of rainfall simulation and assimilation time interval (Myung et al., 2009). Further study should be carried out to investigate the optimal assimilation time interval." References: Myung, J. I. The importance of complexity in model selection, J. Math. Psychol., 44, 190-204, doi:10.1006/jmps.1999.1283, 2000.

Point 5: Abstract, the 'radial velocity' is repetition.

Reply: Revised. The repetitions are removed.

Point 6: Plots showing the orography and the location of rain gauges would be desirable. You can add the information in Fig.2.

Reply: As the reviewer mentioned, the orography and the location of rain gauges are added in Fig.2.

Point 7: It would be helpful to summarize all physical parameterizations in a table.

Reply: The physical parameterizations are listed in table 1. Physical parameterization Scheme Microphysics WRF Single-Moment 6 (WSM 6) Planetary boundary layer (PBL) Yonsei University (YSU) Longwave and shortwave radiation Rapid Radiative Transfer Model for application to GCMs (RRTMG) Land-surface model (LSM) Noah Cumulus Kain-Fritsch (KF)

Point 8: Please provide references for the two evaluation statistics, CSI and RMSE.

Reply: Two references are added. References: Agnihotri G., Dimri A. P. Simulation study of heavy rainfall episodes over the southern Indian peninsula, Meteorol. Appl., 22, 223-235, doi: 10.1002/met.1446, 2015. Prakash S., Sathiyamoorthy V., Mahesh C., et al. An evaluation of high-resolution multisatellite rainfall products over the Indian monsoon region, Int. J. Remote Sens., 35, 3018-3035, doi: 10.1080/01431161.2014.894661, 2014.

Point 9: Line 24, Page 5: km2 should be km2. Please correct.

Reply: Revised.

Point 10: Line 16, Page 10: add references for these data assimilation model.

Reply: Two references are added. References: Shen F., Min J., Xu D. Assimilation of radar radial velocity data with the WRF Hybrid ETKF-3DVAR system for the prediction of Hurricane Ike (2008), Atmos. Res., 169, 127-138, doi: 10.1016/j.atmosres.2015.09.019, 2016. Wang X., Barker D. M., Snyder C., et al. A hybrid ETKF–3DVAR data assimilation scheme for the WRF model. Part II: real observation experiments, Mon. Weather Rev., 136, 5132-5147, doi: 10.1175/2008MWR2445.1, 2012.

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$$m\text{-}RMSE = \frac{\sqrt{\frac{1}{M}\sum_{j=1}^{M}\left(P_j' - P_j\right)^2}}{\frac{1}{M}\sum_{j=1}^{M}P_j}$$

1

Fig. 1. Equation 8

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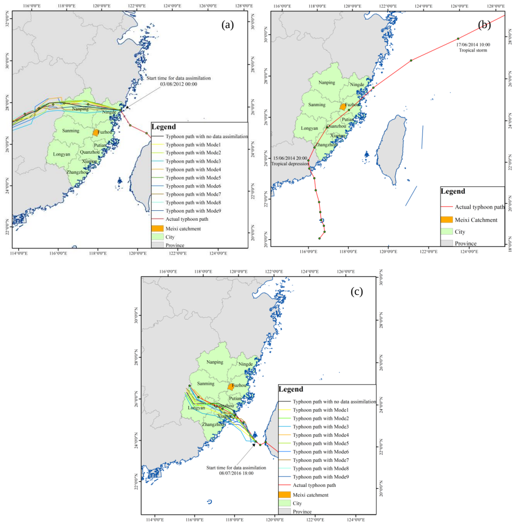

Figure 10. Typhoon path and simulations for (a) Saola, (b) Hagibis and (c) Nepartak.

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Fig. 2. Figure 10

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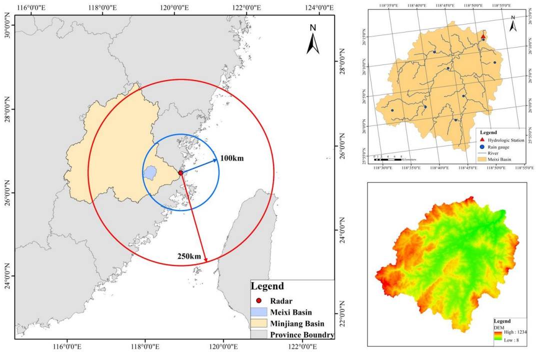

Figure 2. Radar scan area and Meixi basin.

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Fig. 3. Figure 2

Table 1. Physical parameterizations used in the WRF model.

Physical parameterization	Scheme
Microphysics	WRF Single-Moment 6 (WSM 6)
Planetary boundary layer (PBL)	Yonsei University (YSU)
Longwave and shortwave radiation	Rapid Radiative Transfer Model for application to GCMs (RRTMG)
Land-surface model (LSM)	Noah
Cumulus	Kain-Fritsch (KF)

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Fig. 4. Table 1

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