Evaluation and Improvements of Cloud and Precipitation Physics in the Operational Hurricane WRF Model at NOAA/EMC

US Weather Research Program/Joint Hurricane Testbed
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Grant Number: NA09OAR4310081
Report Period: August 2009-January 2010

OVERALL GOAL

The overall goal of this project is to evaluate and improve the cloud and precipitation physics used in the operational Hurricane Weather Research and Forecast (HWRF) model developed in the Environmental Modeling Center (EMC) at the National Centers for Environmental Prediction (NCEP) of NOAA, achieving improved prediction of hurricane structure and intensity, including the size, by the HWRF model at NCEP/EMC.

SPECIFIC OBJECTIVES

We will first evaluate and identify possible discrepancies in the current cloud and precipitation physics used in the HWRF model and understand how these discrepancies may affect the hurricane structure and intensity. This will be done by implementing the current schemes into the hurricane model TCM4 developed by the PI and conduct sensitivity experiments that are designed with both real cases and idealized simulations. The focus is given to both grid-scale moist processes and subgrid scale convective processes in the HWRF model. Both are critical to the realistic representation of three-dimensional (3D) diabatic heating, which is believed to be the key to both the structure and intensity of hurricanes. We will then closely work with the members of the HWRF model development team at NCEP/EMC to improve the relevant aspects of the cloud and precipitation scheme used in the HWRF model at NCEP/EMC. The following four specific objectives will be achieved:

- To diagnose the discrepancies of the current cloud and precipitation physics and the interaction between grid-scale moist processes and subgrid-scale convection in the HWRF model and to understand how they affect hurricane intensity and structure, including size;
- To improve the representation of the cloud and precipitation physics in the HWRF model based on the PI and co-I's previously results and evaluate the performance of the modified schemes through model inter-comparison between the HWRF model and TCM4;
- To test and tune the modified schemes in the experimental prediction mode and to evaluate their overall improvements in predicting hurricane structure and intensity using the HWRF model hindcasts for the cases in the 2010 hurricane season;
- To document the modified schemes with both technical and scientific details and to provide training to the members of the HWRF model development team at NCEP/EMC.

APPROACH

The approach to achieve our goal is to conduct numerical experiments using the HWRF model, the hurricane model–TCM4, and the single-column parcel model–SCPM with bulk and spectral microphysics schemes. The SCPM will be used to create a multi-dimensional lookup table for the supersaturation as a function of vertical velocity and other model parameters, refining the bulk scheme to be used operationally, and will be embedded in the convection scheme. The TCM4 will be used to diagnose the discrepancies of the current schemes used in the HWRF model in simulating hurricane intensity and size changes. We will implement the current cloud and precipitation schemes used in the HWRF model into TCM4 and perform a suite of idealized numerical experiments to help isolate the effects of individual processes and understand their combined impacts. In this regard, TCM4 can be regarded as a diagnostic tool to help identify the key physical processes. Based on the inter-model evaluation, we will modify the current relevant modules in the HWRF model or replace them with more advanced/improved schemes to better represent the cloud and precipitation physics in the HWRF model and to achieve improved prediction of hurricane intensity and structure at NCEP/EMC.

WORKS COMPLETED

The major task in the report period (08/01/2009-01/31/2010) are To diagnose the discrepancies of the current cloud microphysics physics and the interaction between grid-scale moist processes and subgrid-scale convection in the HWRF model and to understand how they affect hurricane intensity and structure, including size (08/01/2009-01/31/2010)

As the first step, we have implemented the current cloud microphysics scheme and convective parameterization scheme used in the HWRF model into TCM4 and conducted sensitivity experiments to identify those aspects that considerably affect the spatial distribution of diabatic heating and thus on the model hurricane structure and intensity, including the storm size. The 3D distribution of diabatic heating from both subgrid cumulus convection and grid-scale moist processes are the key to the hurricane structure and intensity. We have compared the structure, intensity, and diabatic heating of the HWRF model cloud microphysics scheme with that in used in TCM4. We have examined the possible effect of cumulus convective parameterization scheme in coarse model domains on the fine-resolution explicit simulations of hurricanes in TCM4. These comparisons have helped us identify the potential discrepancies of the current cloud and precipitation physics used in the HWRF model and elucidate the physical mechanisms and also provide the basis for our improvements of the HWRF cloud and precipitation physics in the coming project years.

HIGHLIGHTS OF RESULTS

To diagnose the discrepancies of the current cloud microphysics and the interaction between grid-scale moist processed and subgrid-scale convection in the HWRF model and to understand how they affect hurricane intensity and structure, we have implemented both HWRF cloud microphysics scheme and the simplified Arakawa-Schubert (SAS) cumulus convective parameterization scheme into the hurricane model TCM4 and conducted a series of numerical experiments. Here we will highlight some of our results and their implications for the rest of our project years.

a. Comparison of the Ferrier scheme in HWRF with the TCM4 mixed-phase scheme

Currently TCM4 uses a bulk mixed-phase cloud microphysics scheme. It predicts mixing ratios of water vapor, cloud water, rainwater, cloud ice, snow and graupel, with thirty six microphysics processes. The HWRF model uses the Ferrier microphysics scheme, which considers four hydrometeors, namely, suspended cloud liquid droplets, rain, large ice, and small ice. It only calculates the horizontal and vertical advections of the total condensate, namely, the sum of all four hydrometeors and thus the scheme is relatively more economical in computation. The components of hydrometeors are then diagnosed based on some semi-empirical formulations. We have performed two idealized simulations using the two schemes in TCM4. The experimental design follows Wang (2007) except for 32 vertical levels and relatively larger nested meshes and finer finest mesh resolution (2 km) are used in this project. This aims at to see whether the HWRF cloud microphysics may result in any unexpected systematic difference from more sophisticated bulk cloud microphysics scheme, such as the mixed phase cloud microphysics scheme used in TCM4.

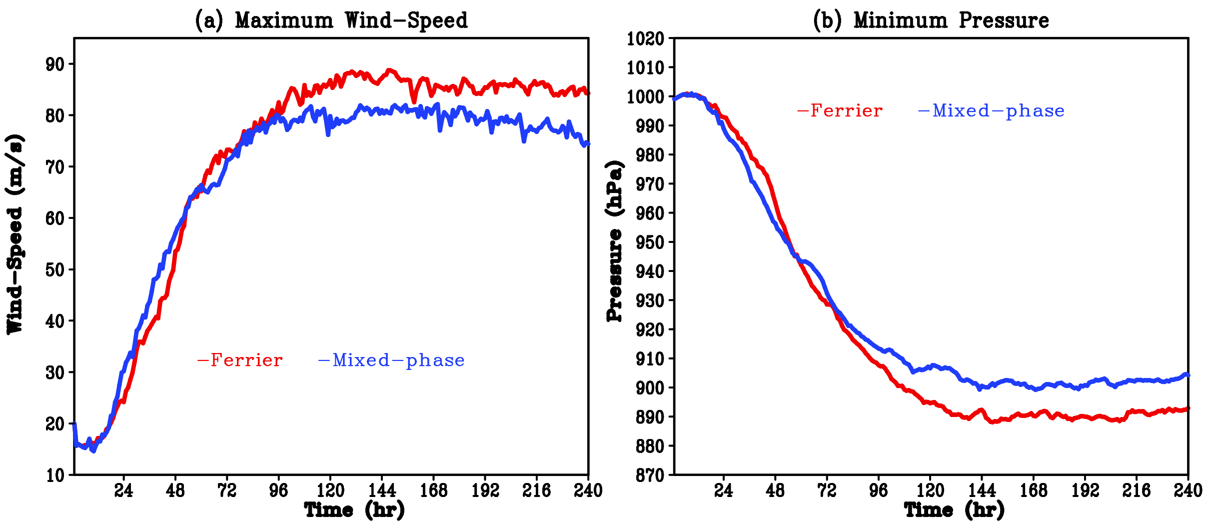

Figure 1. (a) The maximum azimuthal mean wind speed at the lowest model level (about 35 m above sea level); (b) the minimum sea level pressure of the simulated storms using Ferrier (red) and Wang (blue) cloud microphysics schemes in TCM4.

Figure 1 shows the time evolution of the maximum azimuthal mean wind speed at the lowest model level and the minimum sea level pressure of the simulated storm in TCM4 using the HWRF and TCM4 cloud microphysics schemes. It is interesting to see that the initial spin-up of the model storm using the Ferrier cloud microphysics scheme is slower than the TCM4 mixed phase scheme in the first 48 h of simulation. However, the subsequent intensification rate is large with the Ferrier scheme, which eventually produces a stronger storm than that with the TCM4 cloud microphysics scheme. Further the storm simulated with the Ferrier scheme does not show any increase in the radius of maximum azimuthal mean wind. This is in contrast with that simulated with the TCM4 cloud microphysics scheme (Fig. 2).

The results thus suggest that too big hurricanes predicted by HWRF model are unlikely due to the cloud microphysics scheme used. Consistent with the findings by Wang (2009), the larger storm with the TCM4 cloud microphysics corresponds to the rainfall (Fig. 3) and diabatic heating rate (Fig. 4) extending to larger radii. Further the azimuthally averaged diabatic heating rate by the TCM4 scheme tilt radially outward more than the Ferrier scheme because the latter simulated smaller radius of maximum wind (Fig. 2). Detailed examinations show that the simulated ice hydrometeors using the two schemes are quite different. For example, the Ferrier scheme produces much less stratiform clouds as well as much less anvil clouds outside the eyewall than the mixed phase scheme used in TCM4 (Fig. 5). This is also consistent with much smaller heating rate outside the eyewall and smaller radius of maximum azimuthal mean wind due to the lack of strong spiral rainbands (Figs. 3 and 4).

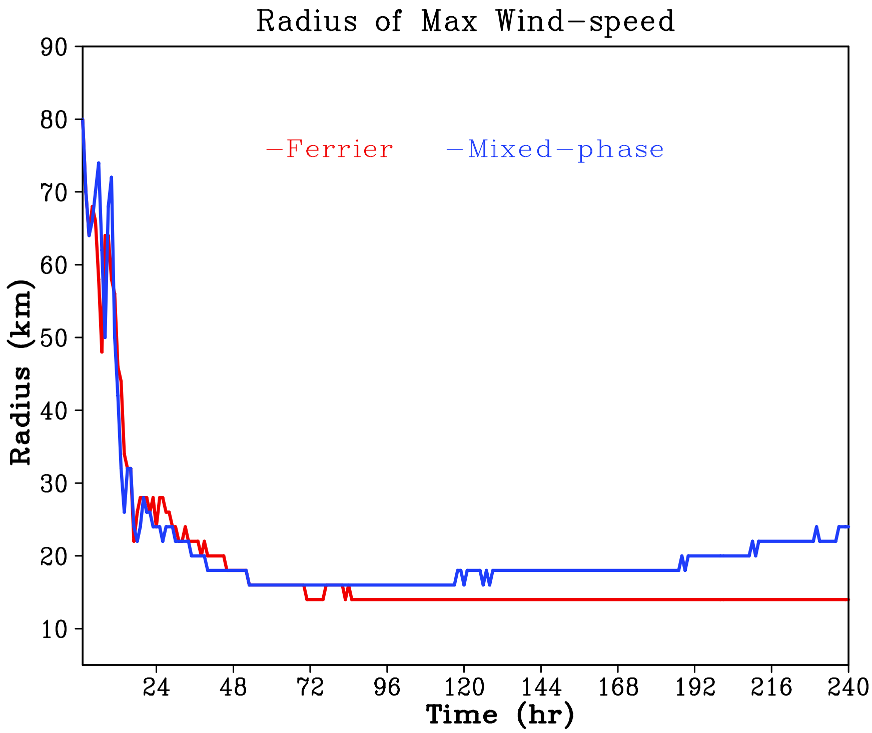

Figure 2. Time evolution of the radius of maximum azimuthal mean wind speed of the simulated storms in TCM4 with different microphysics scheme (red: Ferrier scheme, blue: TCM4 mix-phase scheme).

In summary, the Ferrier cloud microphysics scheme performs reasonably well in TCM4. Results show that the initial spin up of the model storm is slower using the Ferrier scheme than the Wang scheme used in TCM4. However, the subsequent storm is stronger in the former than in the latter. The Ferrier scheme produces much less stratiform clouds and anvil clouds outside the eyewall due to the lack of strong spiral rainbands. As a result, the diabatic heating and ice hydrometeors are concentrated mainly in the eyewall region. This is also responsible for the simulated smaller radius of maximum azimuthal mean wind. These results suggest that the slow intensification and fast growth of the storm size in the operational HWRF model may not result from the discrepancies in the cloud microphysics scheme used. However, caution needs to be taken for this statement. The results we show are based on 2 km mesh simulation. It is not clear the difference would become smaller or larger if the horizontal resolution similar to that used in the operational HWRF is used. We plan to do sensitivity experiments to learn about the resolution dependency.

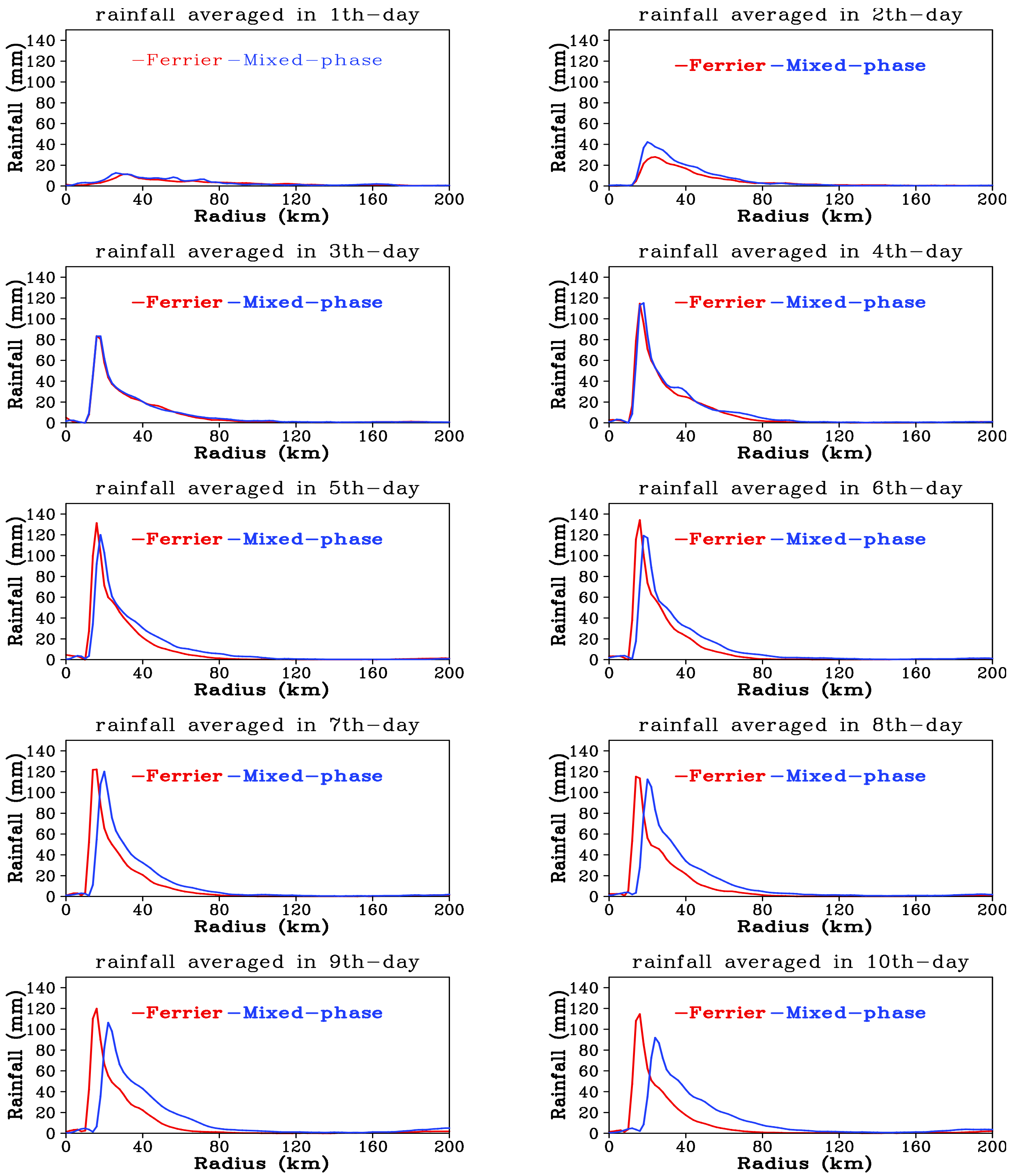

Figure 3. The azimuthal mean rainfall averaged in each 24h of simulation (red: Ferrier, blue: TCM4 mixed-phase).

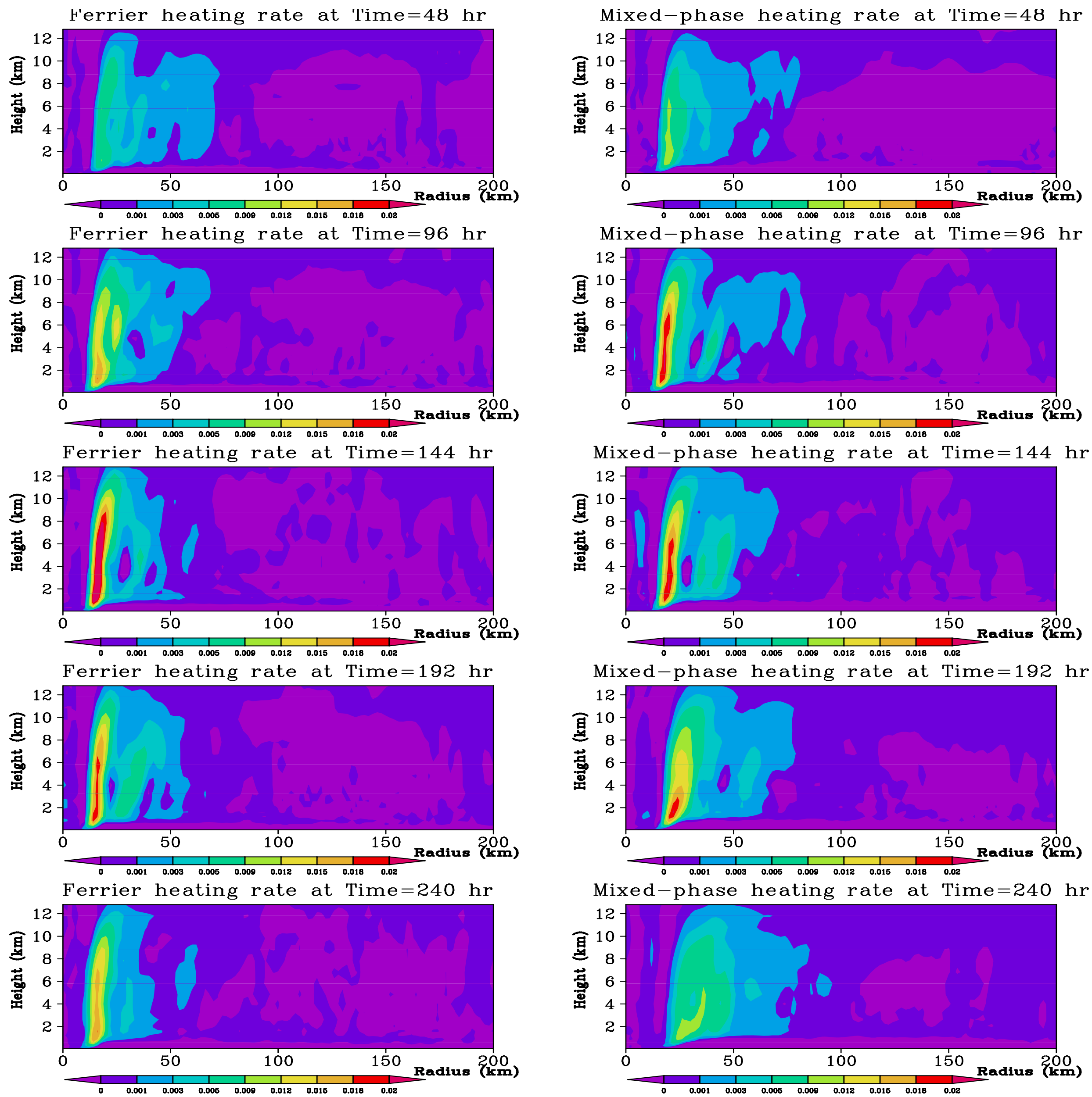

Figure 4. Radius-height distribution of the azimuthal mean diabatic heating at given times in the simulated storm with the Ferrier (left) and TCM4 (right) cloud microphysics schemes.

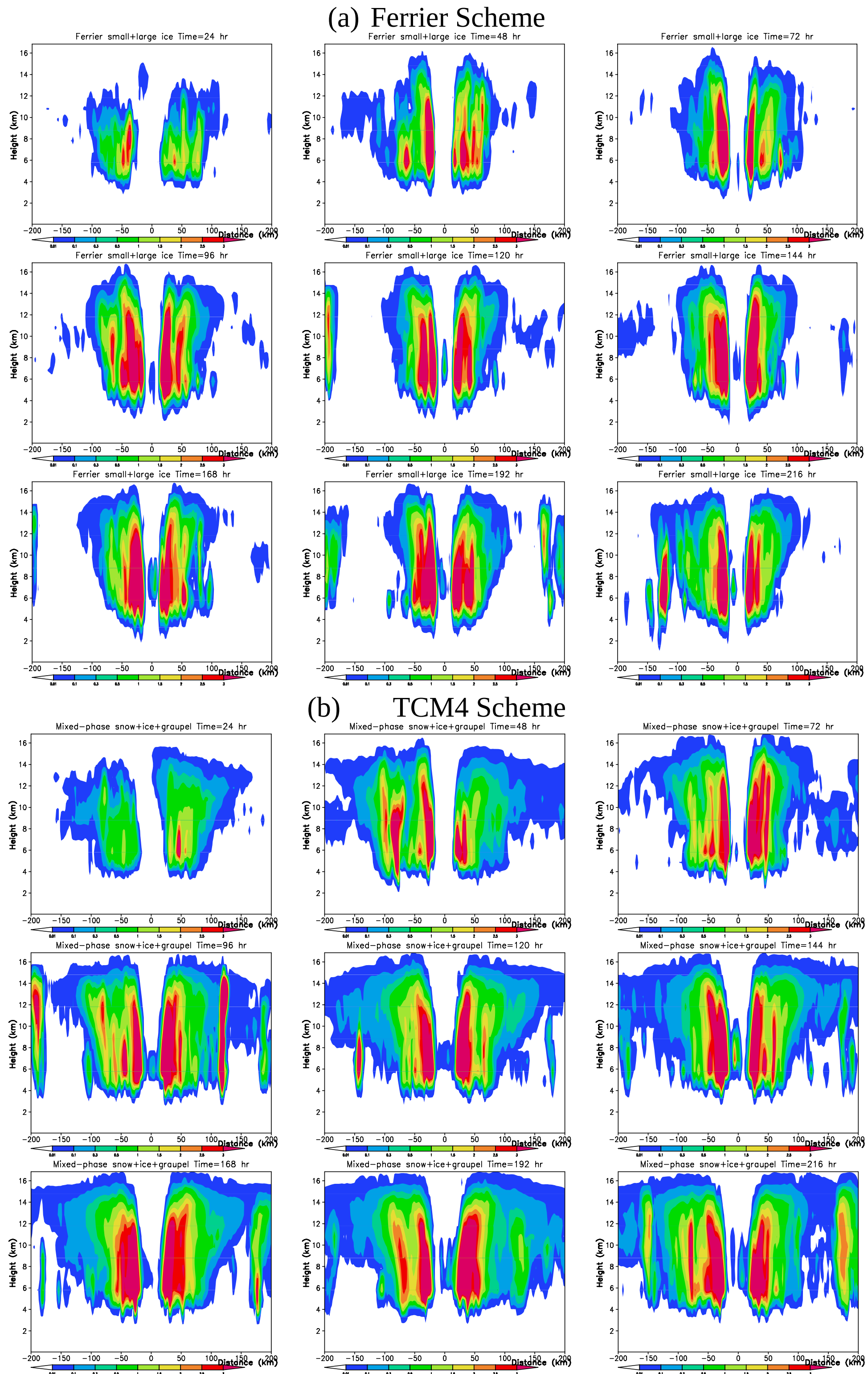

Figure 5. vertical cross-section of total ice along the east-west across the storm center simulated by Ferrier scheme (a) and TCM4 cloud microphysics scheme (b).

b. Effect of the SAS cumulus parameterization scheme in TCM4

In order to examine the effect of the use of a convective parameterization scheme in the outer coarse meshes on the simulated hurricane structure and intensity, we have implemented the Simplified Arakawa-Schubert (SAS) cumulus parameterization scheme into TCM4 and performed two experiments using TCM4 with the finest mesh resolution of 2.5 km (note that a little bit coarser than that used for the simulations discussed above). Note that the SAS cumulus parameterization scheme is currently used in the operational HWRF model. In one experiment, the SAS cumulus parameterization scheme is used. Considering the horizontal resolution of TCM4, we only activated the SAS cumulus convection scheme in the two outer coarse meshes (with resolutions of 67.5 km and 22.5 km). In the other experiment, no any cumulus parameterization scheme is used in any model meshes.

Figure 6 shows the time evolution of the maximum azimuthal mean wind speed at the lowest model level and the minimum sea level pressure in the two simulations using TCM4. What we can see is the different evolutions of the storm intensity at some later stages while with little difference in the early intensification stage. This can be explained by the fact that the use of the cumulus parameterization in the coarse meshes takes time to affect the innermost mesh where most active convection occurs. Nevertheless, the differences still become visible and significant at later stages. In particular, the storm without the use of convective parameterization in the outer meshes becomes not only stronger and but also larger, as inferred from the radial distribution of rainfall rate shown in Fig. 7. The results from these sensitivity experiments thus demonstrated that the use of cumulus convective parameterization in the operational HWRF may need to be tested further. The interaction between the grid-scale and subgrid scale moist processes is also complicated. This is implicated further by the use of the implicit subgrid scale processes in different meshes in a nested model, such as the one used in the HWRF model.

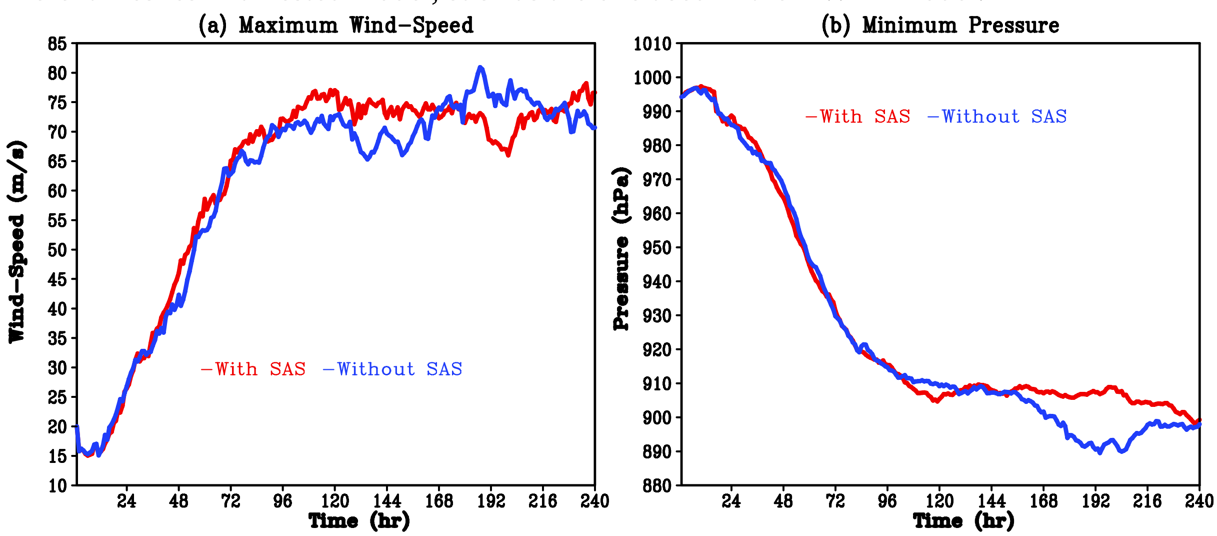

Figure 6. (a) The maximum azimuthal mean wind speed at the lowest model level (about 35 m above sea level); (b) the minimum sea level pressure of the simulated storms using Wang cloud microphysics scheme with (red) and without (blue) the use of the SAS convective parameterization scheme in the outer coarse meshes in TCM4.

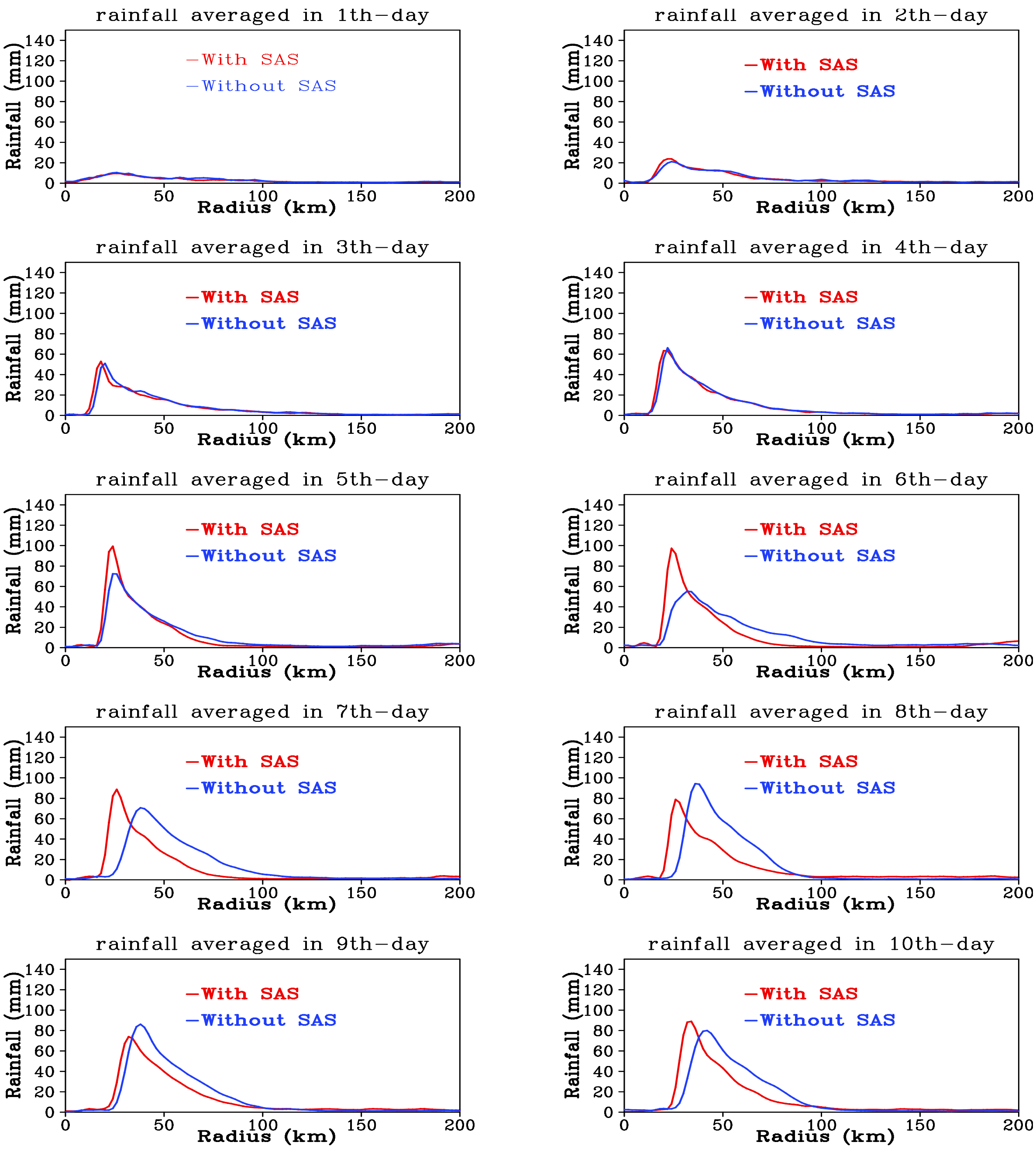

Figure 7. The azimuthal mean rainfall averaged in each 24h of simulations (red: with, blue: without the use of SAS convective scheme in the outer coarse meshes in TCM4).

References

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