608 SENSITIVITY OF TYPHOON PARMA TO VARIOUS WRF MODEL CONFIGURATIONS

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1. Introduction

During November 2010, Weather Decision Technologies, Inc. (WDT) installed for the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) a Mesoscale Forecast Decision Support System (MesoDSS) that includes the Advanced Research WRF (ARW) version 3.2.1 modeling system for real-time weather forecasting. The WRF model currently is configured to generate 72-hour forecasts each hour. As part of the WDT/PAGASA agreement, WDT personnel were tasked with providing recommendations regarding the various tunable parameters that are available to the modeler in order to maximize the performance of the WRF modeling system. As part of that effort, we have performed several sensitivity tests using typhoon Parma as a singular case study. In particular, we have performed more than a dozen 228-hour forecasts of typhoon Parma, assessing the model's sensitivity to—among other things—the choice of the microphysics scheme, the convective parameterization scheme, and the planetary boundary layer (PBL) scheme. Of particular interest is how the model performed in terms of adequately predicting the track, minimum sea-level pressure, and maximum 10 meter wind speed associated with typhoon Parma.

In section 2, we will briefly describe the current operational configuration used by the WRF model as it performs its operational forecasts for PAGASA. Section 3 describes the various sensitivity studies and presents the results. Finally, we provide a brief summary and some concluding remarks in section 4.

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2. Operational WRF configuration

Currently, WRF is configured to create forecasts for the nested grid structure shown in Fig. 1. The dimensions of the outer grid are 182 x 214 with a nominal grid spacing of 12 km; the dimensions of the inner grid are 361 x 593 with a nominal grid spacing of 3 km. The model is run with 28 vertical levels. One-way nesting describes the currently-configured interaction between the inner and outer grids. In this type of interaction, the inner grid solution has no impact upon the outer grid.

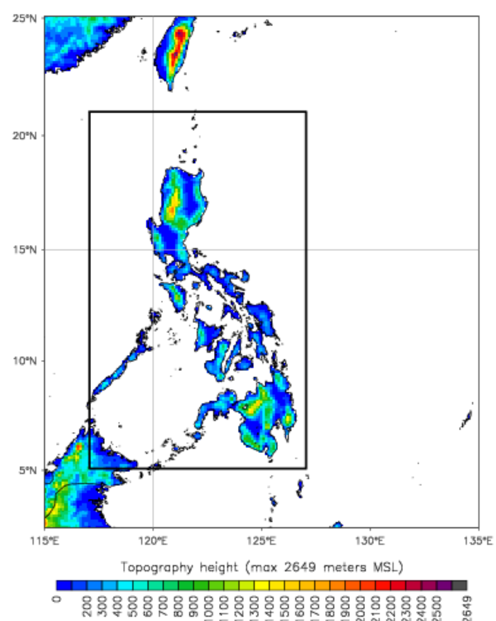

Fig. 1. Grid structure for the current operational WRF configuration. The inner domain is delineated by the thick, black lines. Topography height is contoured.

3. Sensitivity studies

To assess the model sensitivity to various physics parameterizations and other model choices, we have systematically altered—among other things—the choice of microphysics, cumulus, and PBL schemes. For example, to assess how well the model performs for various choices of the microphysics scheme, all other physics options are held constant while the choice of the microphysics scheme is changed with successive WRF runs.

In performing our assessment, WRF is run during the 228-hour period from 00 UTC 1 October 2009 – 12 UTC 10 October 2009 so as to encompass a very large portion of the life cycle of typhoon Parma, which struck the northern Philippines, killing hundreds and causing hundreds of millions of dollars in damages. Global Forecast System (GFS) analyses are used for both the initial and boundary conditions. The following subsections contain results describing the model performance and sensitivity to the listed schemes and model settings. All results described and shown herein are valid for the outer (12 km) grid.

3.1 *Microphysics schemes*

Seven different microphysics schemes were run: Ferrier (currently used operationally), Lin et al., Thompson, Morrison, WSM 3-class, WSM 5-class, and WSM 6-class. Results from each of the seven simulations are summarized in Fig. 2. The simulations were in rather good agreement regarding the track of Parma, although the width of the loop in the simulated tracks appear to have been exaggerated somewhat when compared to the observed track (Fig. 2a). The errors in the position of the center of Parma generally were less than 200 km throughout each of the simulations (Fig. 2b). Wind speeds from most of the simulations were in fairly good agreement, although the early-stage wind speeds generally were too low compared to observations and the late-stage wind speeds were much too high (Fig. 2c). The two notable exceptions were the wind speeds associated with the Lin et al. and Thompson schemes. Although the wind speeds associated with these two schemes were much too low during the early stages of the period, these schemes were associated with 10 meter winds speeds that were in general agreement with the observations during the latter half of the simulation period. Although the simulations of the minimum pressure are in fairly close agreement with each other (within about 10 mb; Fig. 2d), we believe that the strength of the typhoon was grossly underestimated during the model initialization phase due to the coarseness of the GFS analysis (1° x 1° resolution[1]). In addition, the observed decrease in the intensity of the wind speeds throughout the period suggests that the minimum central pressure is rising, contradicting the central pressure tendencies from the WRF simulations.

3.2 *Convective schemes*

Four different convective schemes were run: Kain-Fritsch (currently used operationally), Betts-Miller-Janjic, Grell-Devenyi ensemble, and New Grell. Results from each of the four simulations are summarized in Fig. 3. Unlike the microphysics, variations in the convective scheme produced significant variations in the track of the typhoon (Fig. 3a). The Kain-Fritsch scheme produced a simulation that was generally within 150 km of the actual track, whereas the other convective schemes produced track errors that were about twice that, quickly veering the simulated typhoon path to the north and east of the actual track before recovering somewhat later in the simulation (Fig. 3b). The initial wind speeds were well below typhoon status for each of the simulations, although the simulations associated with the New Grell and Grell-Devenyi ensemble schemes produced maximum winds speeds that were in general agreement with the observations over the latter half of the simulated period (Fig. 3c). The Kain-Fritsch simulation quickly ramped up typhoon strength wind speeds, but erroneously maintained typhoon strength wind speeds throughout the period. The minimum sea-level pressures associated with the Kain-Fritsch simulation are significantly lower than those associated with the other convective schemes (Fig. 3d), consistent with the higher wind speeds of the Kain-Fritsch simulation.

3.3 *PBL schemes*

Three different PBL schemes were run: YSU (currently used operationally), Mellor-Yamada-Janjic (MYJ), and ACM2. Results from each of the three simulations are summarized in Fig. 4. The simulated tracks from each of the three schemes were in rather good agreement with each other, although the width of the loop in the simulated tracks is somewhat wider than that observed (Fig. 4a). The errors in the simulated position of the center of Parma were less than

[1] 0.5° x 0.5° resolution GFS forecasts are used operationally for lateral boundary conditions.

200 km throughout each of the simulations (Fig. 4b), with no PBL scheme clearly establishing itself as the superior scheme in this regard. Wind speeds, also, were in rather good agreement with each other throughout the course of the simulation, although the wind speeds were generally too low during the early part of the simulation period and consistently too high during the latter part of the period (Fig. 4c). Minimum sea-level pressures are in general agreement regarding the trend, although the simulation using the ACM2 PBL scheme produced lower central pressures of the typhoon (up to 15 mb) throughout most of the simulation period (Fig. 4d).

3.4 *Number of vertical levels*

Three different simulations, each with a different number of vertical levels were run: 20 levels, 28 levels, and 36 levels. Results from each of the three simulations are summarized in Fig. 5. The simulated tracks from each of the three simulations were in rather good agreement with each other, although the width of the loop in the simulated tracks is too wide from the two runs with the least amount of vertical levels (Fig. 5a). Although the loop occurred somewhat to the northeast of the observed loop, the WRF run with the most vertical levels (36) seems to have simulated the loop rather well. The errors in the simulated position of the center of Parma were generally less than 200 km throughout each of the simulations, with the highest vertical resolution simulation (36 levels) producing track errors consistently less than 175 km and averaging no more than about 100 km (Fig. 5b). As the number of vertical levels increased, the position errors generally decreased. Wind speeds were in fairly good agreement with each other during the course of the simulation, although wind speeds were generally too low during the early part of the simulation and consistently too high during the latter part (Fig. 5c). Unsurprisingly, the simulation with the most vertical levels (36) generated the highest wind speeds. Minimum sea-level pressures are in general agreement regarding the trend, although the simulation with the lowest number of vertical levels (20) had phase differences (up to about 24 hours) compared to the other two simulations (Fig. 5d).

3.5 *One-way vs. two-way nesting*

Two simulations were performed to compare the effects of one-way nesting versus two-way nesting. In one-way nesting, there is no information exchange between the inner grid (3 km grid spacing) solution and the outer grid (12 km grid spacing) solution, other than the outer grid providing the lateral boundary conditions for the inner grid. For two-way nesting, however, there is further information exchange; in this type of nesting, the inner grid solution replaces the outer grid solution for outer grid points that lie inside the inner domain (Skamarock et al., 2008)[2].

Results from these two simulations are summarized in Fig. 6. The simulated tracks from the two simulations were in fairly good agreement with each other, although the width of the loop in the simulated tracks is too wide (Fig. 6a). The loop for the two-way nest, however, appears to be centered quite well when compared to the observed track. The errors in the simulated position of the center of Parma were generally less than 175 km throughout both of the simulations, with the two-way nesting simulation producing track errors consistently less than 125 km and averaging no more than about 75 km (Fig. 6b). Wind speeds generally were too low during the early part of the simulation and too high during the latter part of the simulation, although the two-way nesting simulation produced more accurate wind speeds over a large portion of the simulation (Fig. 6c). Differences in wind speeds between the two simulations were as high as 20 m/s. Significant differences in the minimum sea-level pressures are apparent, as well (Fig. 6d). Minimum pressures from the two-way nesting simulation are much higher—by about 25 mb—than those from the one-way nest. Based on the observed wind speeds (Fig. 6c), it is likely that the time series of minimum surface pressure from the two-way nesting simulation is the more accurate of the two.

3.6 *"Hurricane applications"*

The WRF model allows for a multitude of combinations of physics options (e.g.,

[2] When 2-way nesting is used, WRF allows for smoothing of the outer grid (via parameter *smooth_option*). For this simulation, this smoothing option was disabled.

microphysics, cumulus, PBL, radiation), as well as many other options regarding, for example, initialization, tunable parameters, diffusion, damping, and advection. Some options are believed to provide better solutions, depending on the phenomena to be simulated (e.g., deep, moist convection; land and sea breezes; wildfires; flooding events; regional climate). The WRF User's Guide (see References for web address) provides some sample options that are believed to be beneficial for hurricane/typhoon applications. The "hurricane applications" options that are different from the current operational WRF configuration are as follows:

Variable	Operational Value	"Hurricane" Value
mp_physics	5	8
sf_surface_physics	2	1
ra_sw_physics	1	2
e_vert	28	36
p_top_requested	5000	2000
omlcall	0	1

Results from the two simulations are summarized in Fig. 7. The simulated tracks were in fairly good agreement with each other, although the width of the loops was too wide, especially the "hurricane applications" track (Fig. 7a). The position errors, also, were in rather good agreement during the first half of the simulation (Fig. 7b). After that, the simulation from the current operational configuration performed better. Wind speeds, too, were in general agreement throughout the length of the simulation (Fig. 7c). Wind speeds for both simulations generally were too low during the early part of the simulation and too high during the latter part. Minimum sea-level pressures were similar, with only a few millibars at most separating the two simulations (Fig. 7d).

3.7 *Tropical cyclone (TC) bogusing*

From previous sections, we repeatedly saw that the wind speeds were excessively low during the initial portion of the simulation, due in part to the coarseness of the GFS analysis used to initialize the model. Within the WRF system is the capability for artificially increasing the strength of low pressure systems. This "bogusing" capability was used to intensify the model's representation of Parma at the initial time of the simulation (00 UTC 1 October 2009). At this initial time, we required that the typhoon had a maximum wind speed of nearly 50 m/s at a radius of 90 km from the center of the typhoon.

Results of this "bogusing" simulation compared to the simulation resulting from the operational configuration are summarized in Fig. 8. The simulated tracks were in reasonable agreement during the early part of the simulation (Fig. 8a). After that, however, there was significant deviation, especially the overly-large width of the loop in the track of the simulation that used bogusing. Oddly enough, however, after the initial one-third of the simulation was completed, the position error of the "bogusing" simulation was smaller than that associated with the operational configuration (Fig. 8b). This apparently is due to the "bogusing" simulation better matching the typhoon's location at the apex of the loop and better matching its location as Parma moved back southeastward and eventually westward across the island. In accord with the forced bogusing, the wind speeds from the "bogusing" simulation were in agreement with the observations during most of the early part of the simulation (Fig. 8c), whereas the wind speeds from the operational configuration were much below those observed. After the first one-third of the simulation or so, the wind speeds from the two simulations were in rather good agreement with each other, but the speeds were much higher than those observed. As expected, the "bogusing" simulation produced much lower initial minimum sea-level pressures than those associated with the operational configuration (Fig. 8d). After about 48 hours, however, the minimum pressures were in general agreement, with only a few millibars separating the two simulations.

4. Summary and Conclusions

In this study, we have examined the effects of several different WRF model configurations on the simulation of Typhoon Parma, which struck the northern Philippines in October 2009. In particular, we have examined the sensitivity of the simulated track, maximum 10 meter wind speed, and minimum sea-level pressure to—among other things—changes in selected physics options, the number of vertical levels, nesting options, and "bogusing" options. Below we summarize some of the most important findings from our study. Perhaps most important is that we advise against generalizing the results from this single case study to a broader array of applications. There is, of course, no guarantee that a similar sensitivity study on another event, even a typhoon, would lead to the same conclusions. With that caveat in mind, we found that:

- Differences in the model track were more sensitive to changes in the convective scheme than to changes in the microphysics or PBL schemes. Specifically, only the Kain-Fritsch convective scheme produced a track that impacted the northern Philippines during its northwestward journey across the Philippine Sea. All other convective schemes produced tracks well to the northeast of the observed track.

- Differences in the maximum 10 meter wind speed were quite sensitive to both the microphysics and convective schemes and much less sensitive to the choice of PBL schemes.

- The simulation associated with the most number of vertical levels (36) produced the best typhoon track when compared to observations. It is not obvious, however, that this simulation produced the best wind speeds.

- Two-way nesting provided superior results on the outer grid to the current operational WRF configuration that used one-way nesting. [Comparisons on the inner (3 km) grid, as well, indicated that the two-way nesting generally provided superior results to the one-way nesting (not shown).]

- The simulation tailored for hurricane applications provided no better results than those provided by the current operational WRF configuration.

- The “bogusing” capability within the WRF system provides the ability for better initializing intense typhoons such as Parma. Although we were indeed able to use this capability for better capturing the wind speeds during the early phases of the simulation, this capability provided little long-term improvement in the simulation, other than perhaps a slightly improved track.

5. References

http://www.mmm.ucar.edu/wrf/users/docs/user_guide_V3/users_guide_chap5.htm

Skamarock, W.C. and Coauthors, 2008: A description of the Advanced Research WRF Version 3. NCAR Technical Note, NCAR/TN-475+STR.

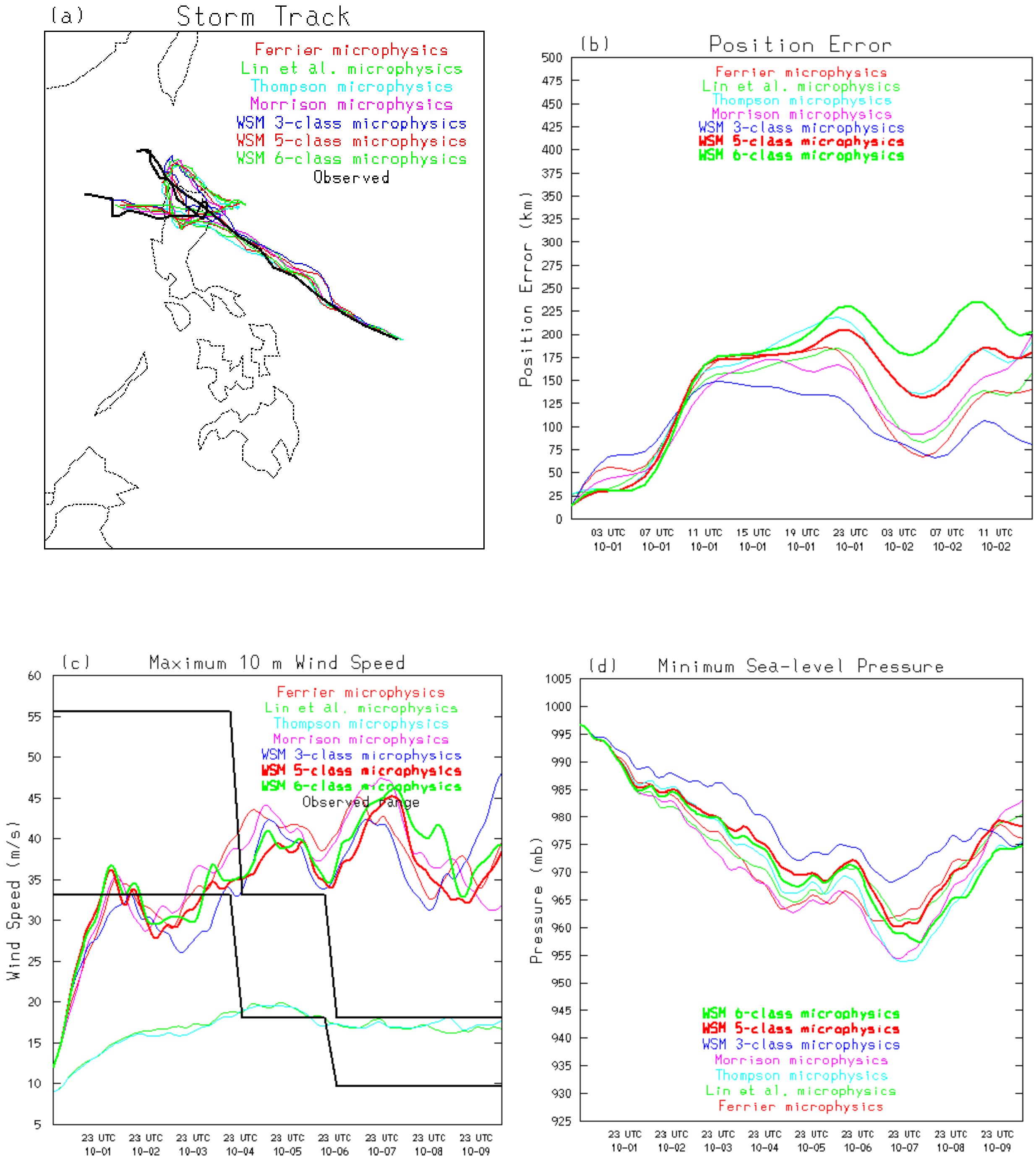

Fig. 2. Variations in the performance of the microphysics schemes for: a) storm track, b) position error (km), c) maximum 10 meter wind speed (m/s), and d) minimum sea-level pressure (mb). In a), the thick black line represents the observed track of Parma. In c), the black lines represent the bounds of the observed storm category. The thin red curves represent the microphysics scheme used by the current operation WRF configuration. Values are for the outer grid.

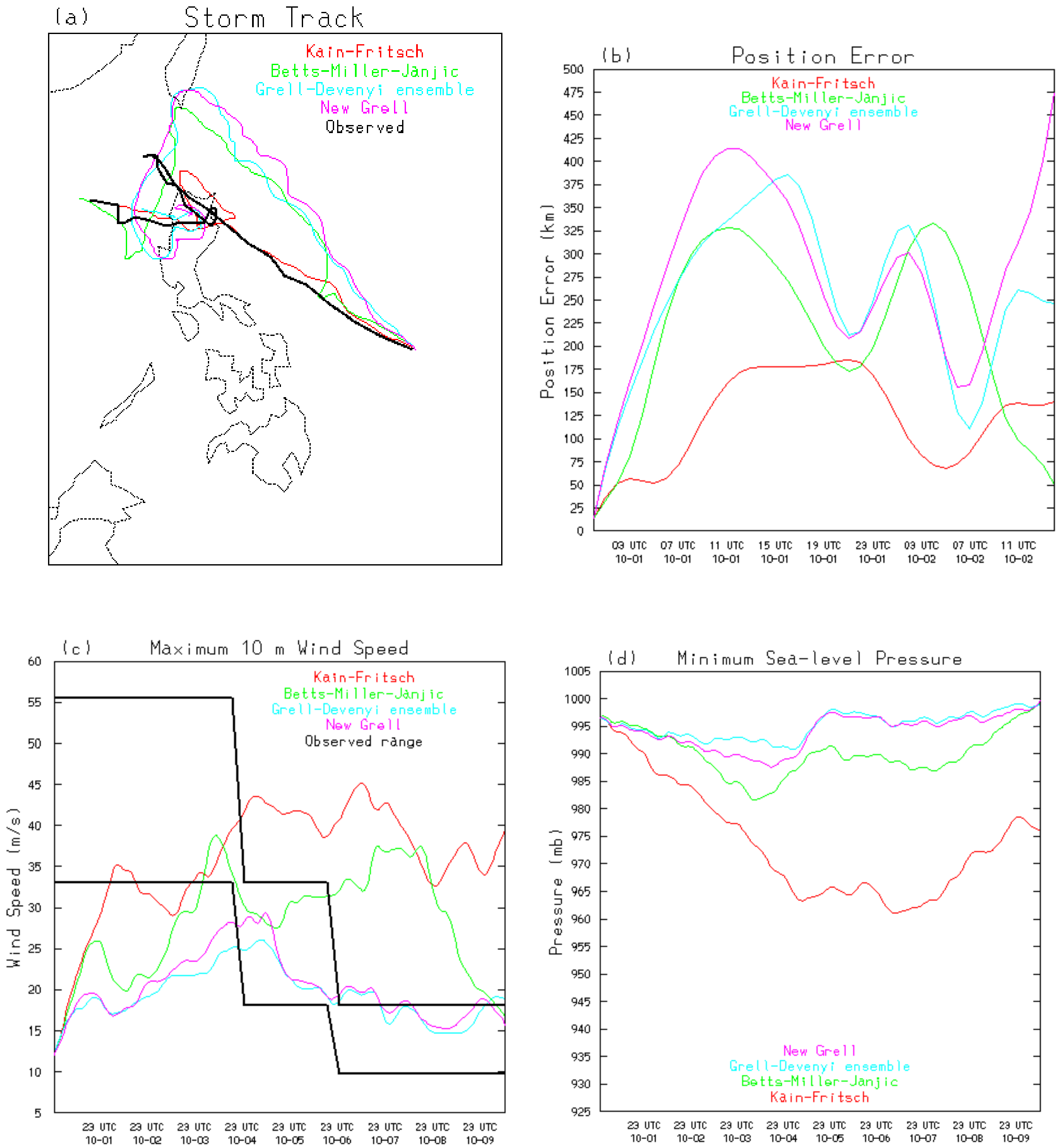

Fig. 3. Same as Fig. 2, except for the convective schemes. The thin red curves represent the convective scheme used by the current operation WRF configuration.

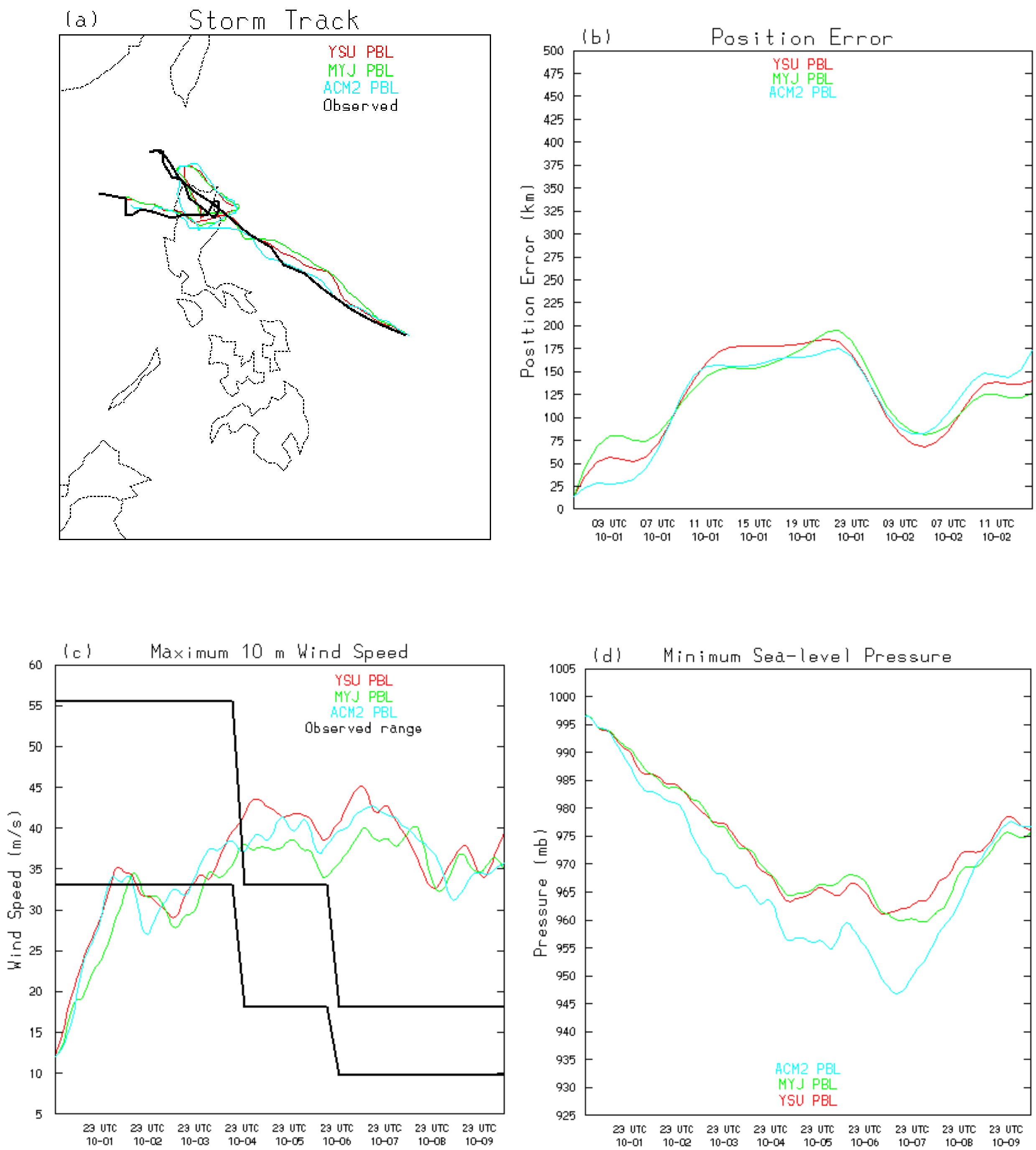

Fig. 4. Same as Fig. 2, except for the PBL schemes. The thin red curves represent the PBL scheme used by the current operation WRF configuration.

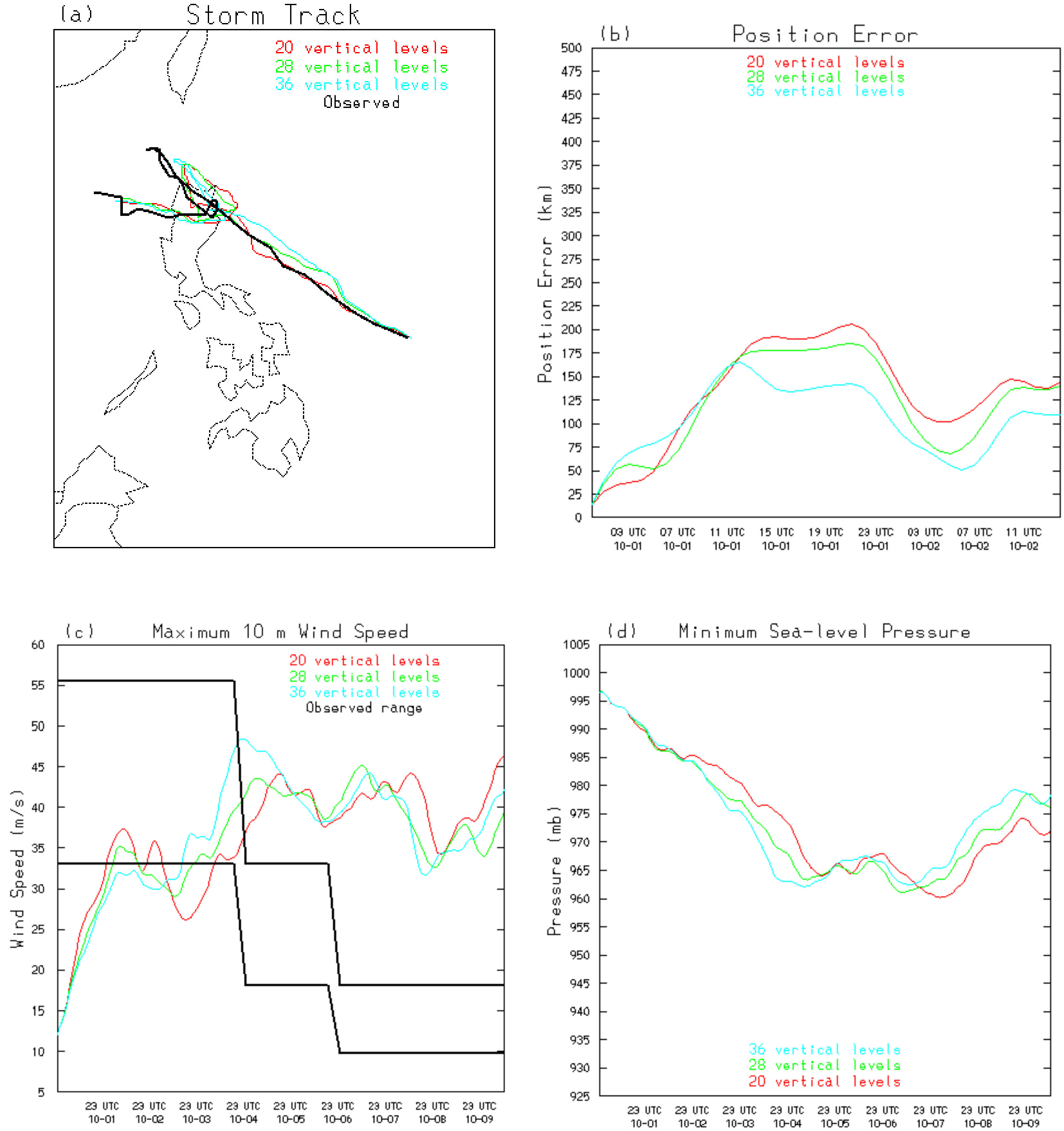

Fig. 5. Same as Fig. 2, except for the number of vertical levels. The green curves represent the current operational WRF configuration.

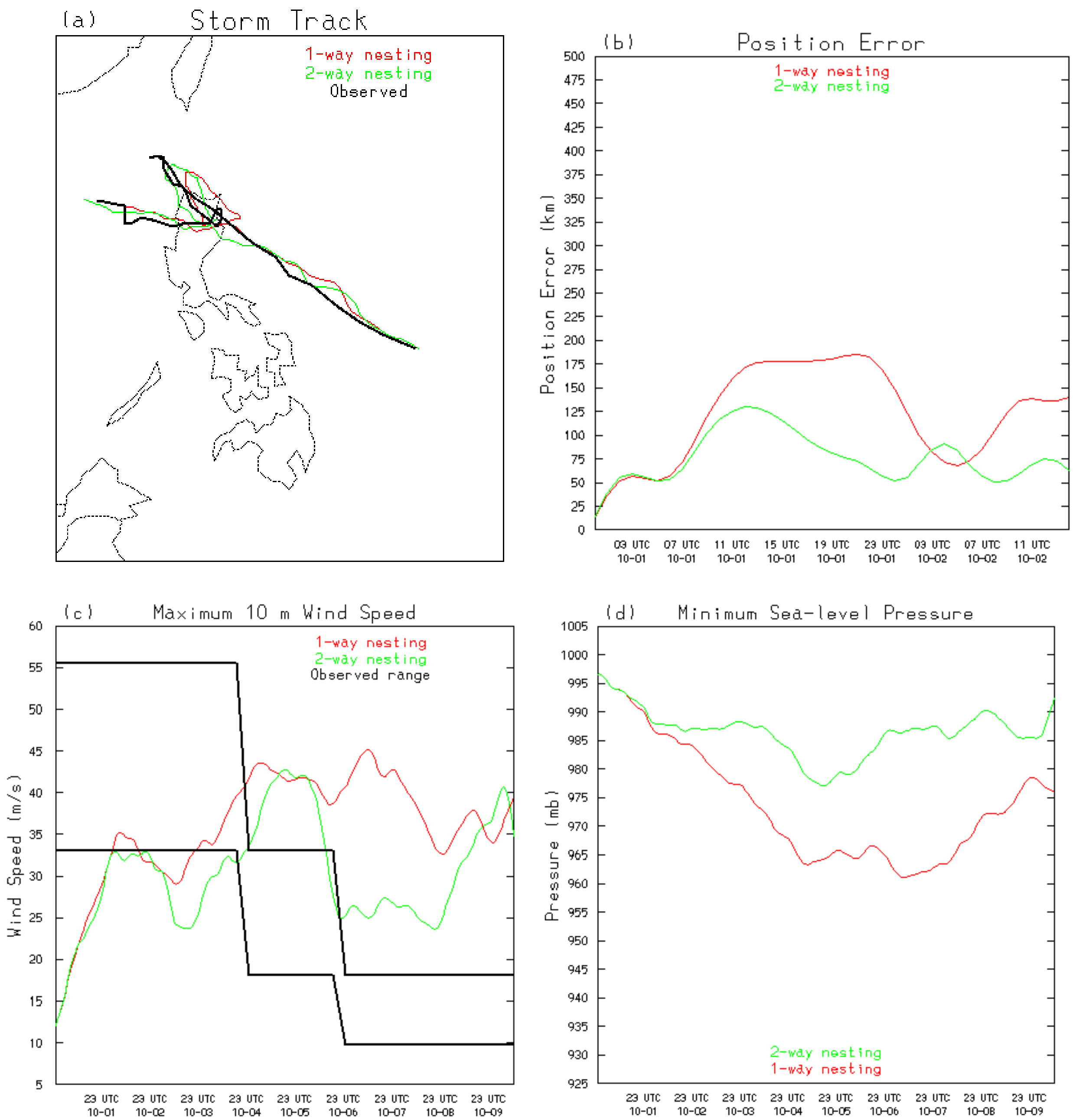

Fig. 6. Same as Fig. 2, except for nesting options (one-way and two-way). The red curves represent the current operational WRF configuration.

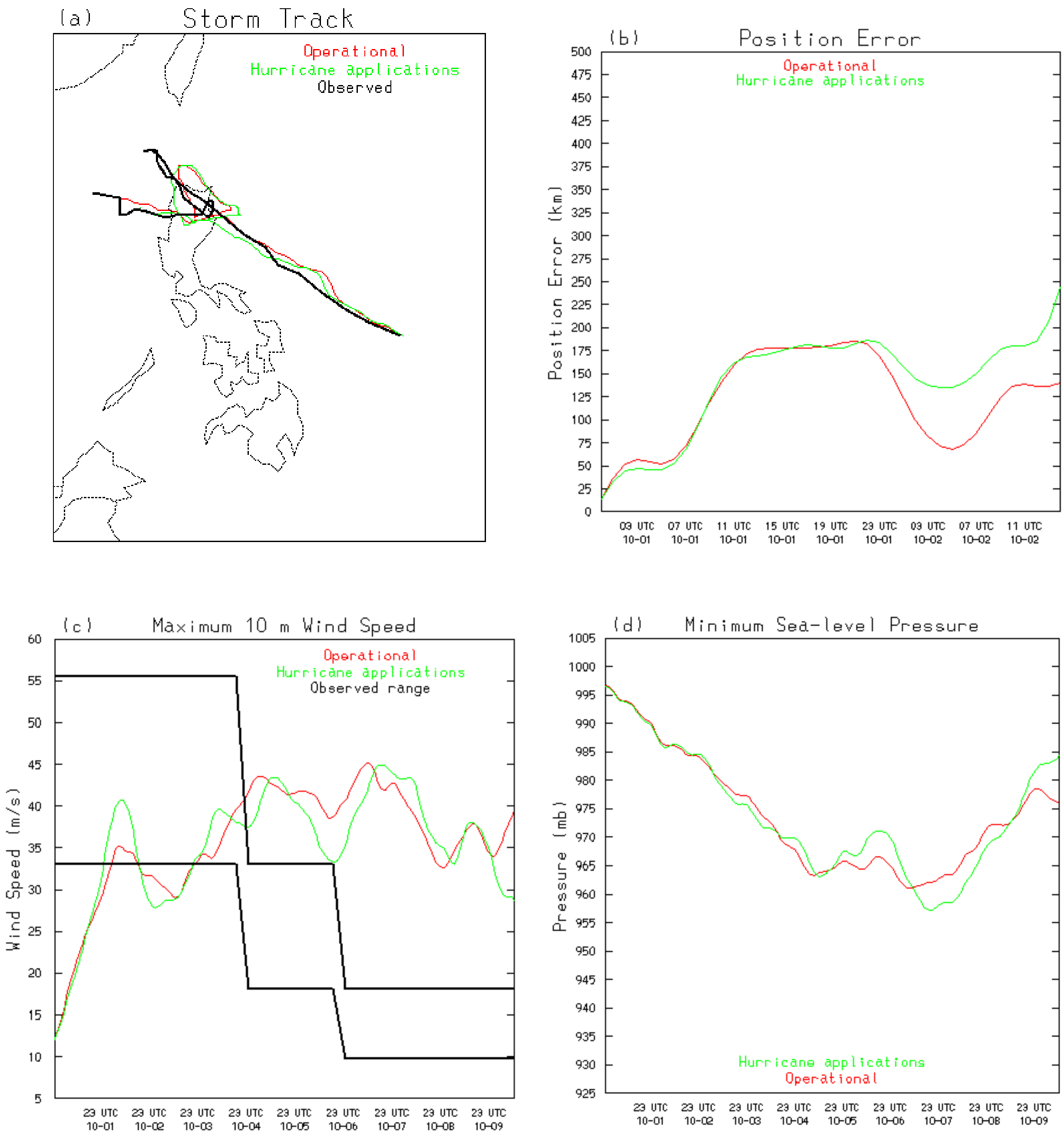

Fig. 7. Same as Fig. 2, except for the “hurricane applications” WRF configuration options. The red curves represent simulations from the current operational WRF configuration.

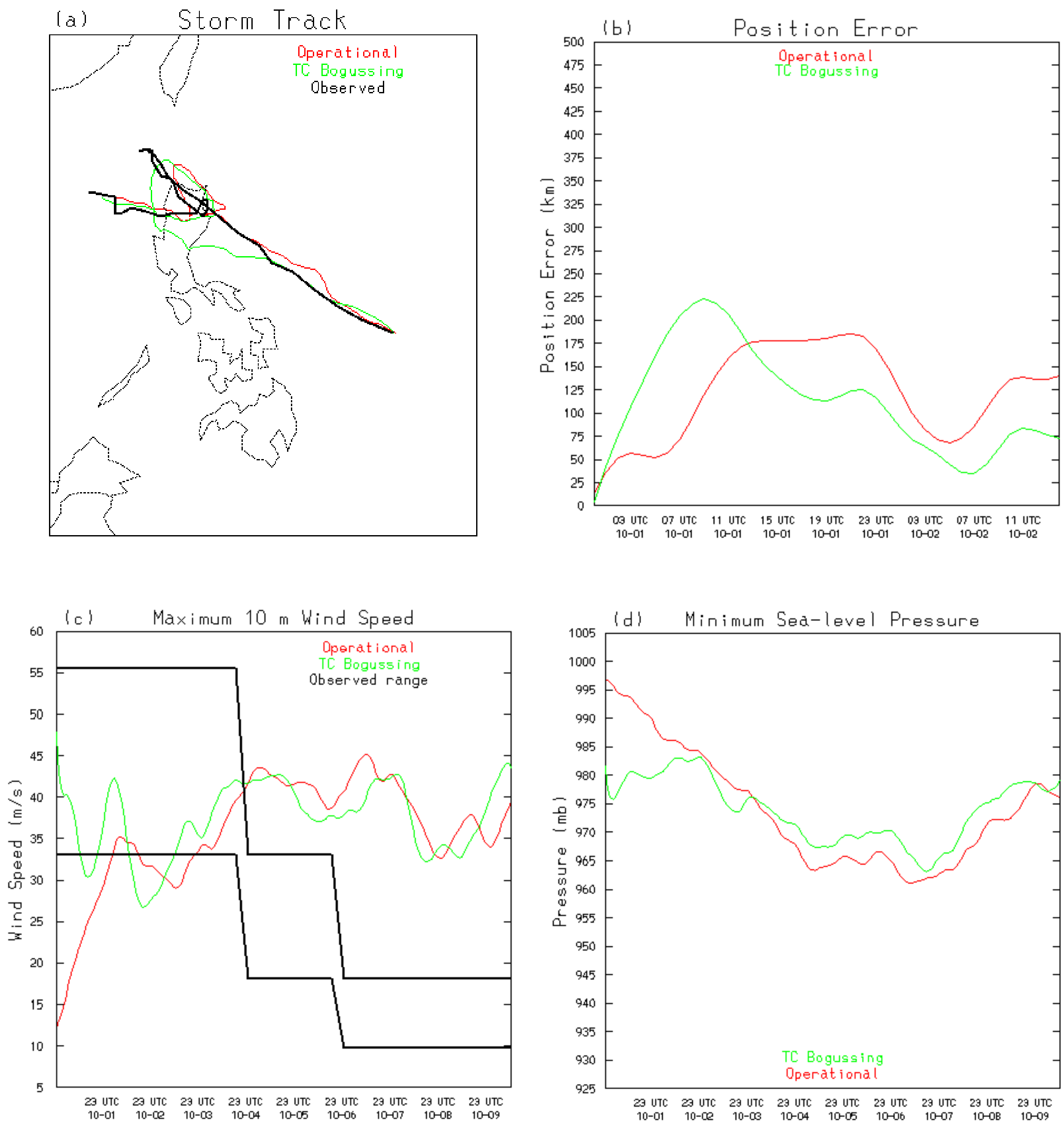

Fig. 8. Same as Fig. 2, except for bogusing. The red curves represent simulations from the current operational WRF configuration.