Improvements to a Tropical Cyclone Initialization Scheme and Impacts on Forecasts

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ABSTRACT

This study makes improvements to the tropical cyclone (TC) initialization method introduced by Nguyen and Chen (i.e., the NC2011 scheme). The authors found that prescribing sea level pressure associated with the initial vortex using a modified Fujita formula has very little impact on the vortex structure and intensity during a series of 1-h model integration and relocation. On the other hand, inserting an artificial warm core makes the vortex spin up much faster. When a warm core is inserted during the initial spinup process, the computational time required for model initialization is reduced by 1/2–1/3. Because prescribed sea level pressure is not required to spin up the vortex, information on vortex size, such as radius of maximum wind, is no longer needed. The performance of the improved NC2011 scheme with an initial prescribed warm core during the initial spinup process is tested for typhoons that made landfall over southern China or Vietnam in 2006. Before landfall, these storms were over the open ocean where conventional data were sparse, without special observations. Two sets of model runs, with (NC2011-CTRL) and without (CTRL) vortex initialization, are performed for comparison. The initial and time-dependent boundary conditions are from the NCEP Final Analyses (FNL). There are twelve 48-h simulations in each run set. Results show that the vortex initialization improves TC track and intensity simulations.

1. Introduction

Tropical cyclone (TC) initialization in numerical models is a crucial factor affecting TC track and intensity forecasts. Because TCs develop and spend most of their lifetime over the open ocean before making landfall, high-resolution observational data depicting detailed TC structure in the core area are frequently lacking. Usually, a bogus TC vortex is used to improve the TC structure in the model initial conditions. The bogus vortex can be constructed with empirical functions of pressure and/or winds (Fujita 1952; Holland 1980; Davidson and Weber 2000; Davis and Low-Nam 2001; Kwon and Cheong 2010) or by model integration (Kurihara et al. 1993; Liu et al. 1997). Data assimilation of both observed and vortex


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data (http://www.usno.navy.mil/JTWC). We investigate the Joint Typhoon Warning Center (JTWC) best track calculations of track, intensity, radar reflectivity patterns, and TC vortex leads to significant improvement in the simulations considered, using NC2011 to construct the initial vortex initialization scheme and sensitivity tests on cases considered, using NC2011 to construct the initial TC vortex leads to significant improvement in the simulations of track, intensity, radar reflectivity patterns, and TC circulations. Nguyen and Chen (2011) also showed that for Typhoon Morakot (2009), using the NC2011 initialization scheme results in better prediction of rainfall distribution before and after landfall because the scheme is able to depict better storm structure.

In this study, the impacts of prescribed SLP and prescribed warm core structure on spinning up a TC vortex in the NC2011 scheme are further investigated. One of the main challenges in TC research is forecasting the intensity change (Kucas 2010) and improving typhoon intensity at the model initial time in high-resolution models can help intensity forecast. In this work, this problem is investigated for typhoons that occurred in a relatively data-sparse region to determine the extent to which large-scale settings affect the TC spinup process and subsequent model simulations. Nguyen and Chen (2011) focused on typhoons that occurred over the Taiwan area where the observational network is dense with supplementary dropsonde observations over the adjacent oceans (Wu et al. 2005).

The case used in this study is Chanchu (2006), which formed as a tropical depression on 9 May 2006 around 8.3°N, 133.4°E. It made landfall over the Philippines on late 11 May 2006 and weakened. However, after crossing the Philippines, it intensified as a super typhoon in a data-sparse region between Vietnam and the Philippines. It made landfall again over the southern China coast on 18 May 2008. At 0000 UTC 15 May 2006, Typhoon Chanchu (2006) had a minimum SLP (Pmin) of ~916 hPa and a maximum wind speed (Vmax) of ~64 m s\(^{-1}\) based on the Joint Typhoon Warning Center (JTWC) best track data (http://www.usno.navy.mil/JTWC). We investigate the TC vortex associated with Typhoon Chanchu (2006) initialized at 0000 UTC 15 May. In addition, three more landfalling typhoons (Durian, Prapiroon, and Xangsane) occurred in the same region during 2006. These storms are used to assess the impact of the new TC initialization technique on the intensity and track simulations. Data and model descriptions are discussed in section 2. A brief description of the NC2011 scheme and sensitivity tests on factors affecting the TC initialization process are discussed in section 3. Some preliminary results on verifications of TC intensity and track simulations with the improved NC2011 scheme for four landfalling typhoons in 2006 are discussed in section 4. A summary and discussion are given in section 5.

### 2. Data and model descriptions

This research uses version 3.1 of the ARW Model, which is a nonhydrostatic, three-dimensional primitive equation model. Two nested domains with horizontal grids of 18 km (287 \(\times\) 226) and 6 km (379 \(\times\) 316), respectively, and 38 vertical levels from the surface to the 50-hPa level are employed in the model with two-way nesting. The full sigma levels are as follows: 1.00, 0.97, 0.95, 0.92, 0.89, 0.86, 0.84, 0.81, 0.78, 0.76; 0.73, 0.70, 0.68, 0.65, 0.62, 0.59, 0.57, 0.54, 0.51, 0.49, 0.46, 0.43, 0.41, 0.38, 0.35, 0.32, 0.30, 0.27, 0.24, 0.22, 0.19, 0.16, 0.14, 0.11, 0.08, 0.05, 0.03, and 0.00. The model configurations include the following: the WRF single-moment 6-class microphysics scheme (WSM6; Hong et al. 2004; Hong and Lim 2006), the Grell–Devenyi (Grell and Devenyi 2002) for domain 1 only, and a Rapid Radiative Transfer Model scheme (Mlawer et al. 1997) for long-wave radiation, the Dudhia scheme (Dudhia, 1989) for shortwave radiation, the Monin–Obukhov similarity scheme (Monin and Obukhov 1954) for surface layer physics, and the Yonsei University scheme (Noh et al. 2003) for planetary boundary layer physics. The precipitation schemes used are the same as Wu et al. (2012). The initial and lateral boundary conditions are from the National Centers for Environmental Prediction (NCEP) Final Analyses (FNLS) with a 1° horizontal resolution. Two separate simulations with and without (CTRL) the NC2011 scheme are performed for comparison.
3. Factors affecting the spinup of a TC vortex in the NC2011 scheme

a. Review of the NC2011 scheme

In the NC2011 scheme, model cycle runs were used to construct a TC vortex with the environment conditions almost unchanged. In each 1-h model integration, the initial SLP distributions associated with the TC vortex within $R < 400$ km were constructed by a modified Fujita (1952) formula using the observed minimum SLP ($P_{\text{min}}$) and storm size ($R_{\text{max}}$) from the best track data. The model is then integrated for a period of an hour. During the model integration within a 1-h cycle run, the TC vortex is free to develop under the given large-scale conditions from the global data. At the end of the current 1-h cycle run, the TC structure is separated from the large-scale environment using a modification to Kurihara et al. (1993). The TC vortex structure at the end of the current 1-h cycle run is then relocated to the observed location of the actual TC and used as the initial vortex for the next 1-h cycle run with the large-scale environment provided by global analysis at the model initial time. The above cycle run is repeated until the minimum SLP and the maximum wind speed of the integrated vortex are close to the observed values. Normally, the required number of cycles is about 80. The first important assumption used in the NC2011 initialization method is that within each 1-h cycle run the TC may move; however, it is still embedded in almost the same environment without many changes. The second assumption is that the TC structure is mainly controlled by the environmental conditions in which it is embedded. To satisfy the first assumption, it is desirable for the duration of each cycle run to be relatively short (<3 h) to ensure that the environment in which it is embedded does not change significantly.

In the rest of this section, sensitivity tests (Tables 1 and 2) are performed for Typhoon Chanchu (2006) and initialized at 0000 UTC 15 May 2006 to investigate the physical processes affecting the spinning up of an intense TC in the NC2011 scheme. At this time, the global analysis from NCEP FNL with a 1° horizontal resolution significantly underestimates the TC intensity because of the coarse resolution and lack of in situ data in the storm core region.

b. Impact of prescribed SLP on the spinup process

The first three sensitivity tests (Table 1) are designed to determine the need to prescribe SLP in the NC2011 scheme. In the NSLP run, SLP is not prescribed during the cycle runs. In the WSLP run, the SLP is prescribed by a modified Fujita (1952) formula using the observed minimum SLP ($P_{\text{min}}$) and storm size ($R_{\text{max}}$) from the best track data. The model is then integrated for a period of an hour. During the model integration within a 1-h cycle run, the TC vortex is free to develop under the given large-scale conditions from the global data. At the end of the 1-h model integration of each cycle, the TC structure is separated from the large-scale environment using a modification to Kurihara et al. (1993). The TC vortex structure at the end of the current 1-h cycle run is then relocated to the observed location of the actual TC and used as the initial vortex for the next 1-h cycle run with the large-scale environment provided by global analysis at the model initial time. The above cycle run is repeated until the minimum SLP and the maximum wind speed of the integrated vortex are close to the observed values. Normally, the required number of cycles is about 80. The first important assumption used in the NC2011 initialization method is that within each 1-h cycle run the TC may move; however, it is still embedded in almost the same environment without many changes. The second assumption is that the TC structure is mainly controlled by the environmental conditions in which it is embedded. To satisfy the first assumption, it is desirable for the duration of each cycle run to be relatively short (<3 h) to ensure that the environment in which it is embedded does not change significantly.

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### Table 3. The name, number of run cases, initial time, minimum central SLP, and maximum temperature anomalies (K) for the four TCs in 2006.

<table>
<thead>
<tr>
<th>Name</th>
<th>Initial time</th>
<th>$P_{\text{min}}$ (hPa)</th>
<th>$dT$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chanchu</td>
<td>0000 UTC 14 May</td>
<td>960</td>
<td>4</td>
</tr>
<tr>
<td>Chanchu</td>
<td>1200 UTC 14 May</td>
<td>940</td>
<td>6</td>
</tr>
<tr>
<td>Chanchu</td>
<td>0000 UTC 15 May</td>
<td>930</td>
<td>7</td>
</tr>
<tr>
<td>Chanchu</td>
<td>1200 UTC 15 May</td>
<td>930</td>
<td>7</td>
</tr>
<tr>
<td>Chanchu</td>
<td>0000 UTC 16 May</td>
<td>930</td>
<td>7</td>
</tr>
<tr>
<td>Durian</td>
<td>0000 UTC 2 Dec</td>
<td>965</td>
<td>4</td>
</tr>
<tr>
<td>Durian</td>
<td>1200 UTC 2 Dec</td>
<td>965</td>
<td>4</td>
</tr>
<tr>
<td>Durian</td>
<td>0000 UTC 3 Dec</td>
<td>955</td>
<td>5</td>
</tr>
<tr>
<td>Prapiroon</td>
<td>0000 UTC 2 Aug</td>
<td>980</td>
<td>3</td>
</tr>
<tr>
<td>Prapiroon</td>
<td>1200 UTC 2 Aug</td>
<td>970</td>
<td>3</td>
</tr>
<tr>
<td>Xangsane</td>
<td>0000 UTC 29 Sep</td>
<td>960</td>
<td>4</td>
</tr>
<tr>
<td>Xangsane</td>
<td>1200 UTC 29 Sep</td>
<td>955</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 1. The changes in (a) maximum wind speed (m s$^{-1}$) and (b) minimum SLP (hPa) with number of cycle runs for NSLP (blue), WSLP (red), and LSLP (green) sensitivity test runs.

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Figure 1 shows that during the spinup cycles, there are no significant differences in $V_{\text{max}}$ (Fig. 1a) and $P_{\text{min}}$ (Fig. 1b) among the NSLP (pink), WSLP (blue), and LSLP (green) runs. All three runs show that $P_{\text{min}}$ ($V_{\text{max}}$) significantly decreases (increases) during the first 40 cycle runs. Both $P_{\text{min}}$ and $V_{\text{max}}$ are close to best track values at about cycle 70. From cycle 70 to 90, both the $P_{\text{min}}$ and $V_{\text{max}}$ of the three runs do not change significantly. It is very striking that the prescribed SLP associated with the TC does not affect the spinup process in the NC2011 scheme. In addition, even without prescribing the horizontal distribution of SLP the storm is able to reach the observed intensity during the spinup process. These results attest to the fact that the storm environment has a significant impact on the observed typhoon intensity. Because prescribed sea level pressure is not required to spin up the vortex, the information on vortex size, such as $R_{\text{max}}$, is no longer needed. Thus, the storm size and structure will be mainly determined by the given large-scale conditions and the model employed.

c. A sensitivity test with an initial warm core

Because observational studies have shown that the maximum temperature anomaly within the eyewall of hurricanes occurs in the upper levels (e.g., Hawkins and Rubsam 1968), model sensitivity tests with a prescribed warm core using NC2011 (WRF-GD) (Table 2) are performed. The warm core test run is configured the same as the NSLP run except with a prescribed symmetric warm core with a maximum $(dT)_{\text{max}}$ at the 250-hPa level. The magnitude of the maximum temperature anomaly is dependent on the best track minimum surface pressure ($P_{\text{min}}$) using a linear relationship for typhoons over the northwestern Pacific suggested by Velden et al. (1991) \[ (dT)_{\text{max}} = (1013. - P_{\text{min}} - 2)/11.8 \]. The warm core has a radius of 60 km with a Gaussian weighting function.
Kidder et al. 2000; Kwon and Cheong 2010) in both the horizontal and vertical direction. The maximum temperature anomalies \([dT]_{\text{max}}\) for different typhoon intensities are shown in Table 3. The warm core is inserted into the initial temperature fields during the first ten 1-h cycles. The vertical cross sections of the inserted warm core and the development of the warm core during the cycle run are shown in Fig. 2. With the prescribed warm core, the Pmin associated with the TC vortex drops quickly toward the best track data. Because the warm core structure is prescribed as an external forcing, the Vmax also adjusts rapidly toward the best track value (Fig. 3, red). Once the prescribed warm core is removed after cycle 10, the TC vortex starts to adjust to the given large-scale environment in the following cycling runs. In the WRF-GD run, the vortex can reach the best track Pmin and Vmax after about 40 cycles as compared to about 70 cycles in the original NC2011 scheme (Fig. 1, red).

In most cases, the TC warm cores are not well resolved by global analysis in the initial conditions. Three-dimensional structures of TC warm cores can be constructed from satellite observations with an Advanced Microwave Sounding Unit (Kidder et al. 2000). It is apparent that 3D data assimilation of temperature data from satellite data or inserting a warm core structure constructed by satellite observations will reduce the number of cycles in the initialization of TC vortex using the NC2011 method.

d. Sensitivity tests of different precipitation schemes with an initial warm core

Because latent heat release is essential for the spin up of the TC vortex, model sensitivity tests are performed with three different combinations of cumulus parameterization schemes and microphysics schemes (Table 2). The microphysics and cumulus schemes are well tested by NCEP and recent publications related to TC simulations. Specifically, theEta microphysics (Rogers et al. 2001) and Betts–Miller–Janjić cumulus parameterization (Betts and Miller 1993; Janjić 1994) schemes are used by NCEP and Nguyen and Chen (2011). The combination of Lin’s microphysics (Lin et al. 1983) and Kain–Fritsch’s cumulus parameterization schemes (Kain and Fritsch 1993; Kain 2004) are used by Zhang et al. (2012). For all the schemes tested, a warm core structure is inserted during the first ten 1-h cycles. The inserted warm core helps the rapid spinup of the TC vortex regardless of the precipitation schemes employed (Fig. 3). From cycle 11, no prescribed warm core is inserted, which allows the TC structure to adjust to the given large-scale environmental conditions. The adjustment process initially reduces the intensity of the spinup vortex for the first ten 1-h cycles or so (Fig. 3) as the TC warm core structure adjusts to environmental conditions. After that, the spinup process of the TC vortex continues. There is about 10-hPa difference in Pmin and 5 m s\(^{-1}\) difference in Vmax between the different schemes. In this case, the combination of Bells–Miller–Janjić cumulus parameterization and Eta microphysics tends to underestimate the storm intensity as compared with the best track data. Nevertheless, it is apparent that inserting an artificial warm core during the first ten 1-h cycles or so in the modified NC2011 scheme greatly reduces the number of cycles and computational resources required to spin up the TC vortex for all four schemes (Fig. 3) tested.

4. Verifications of TC track and intensity simulations

Chen et al. (2014) initialized 18 TCs that occurred during 2003–13 over the western Pacific using WRF-GD precipitation schemes with the modified NC2011 method (NC2011-CTRL) (e.g., with a warm core and without prescribed SLP as described in section 3d). They demonstrate that the NC2011-CTRL TC initialization scheme is capable of reproducing the observed TC structure as compared with satellite microwave
observations, including asymmetric spiral rainbands and eyewall structure (single vs double), with an intensity very close to the best track data. The mean absolute error (MAE) in Vmax and Pmin are 3.3 m s$^{-1}$ and 2.6 hPa, respectively. Furthermore, the storm size in the model initial conditions also compares favorably with satellite observations. In this section, the NC2011-CTRL scheme is used to simulate Chanchu and three other typhoons (Table 3) in the same region in 2006 that made landfall over southern China or Vietnam. The model results are used to verify the performance of the NC2011-CTRL runs, in terms of TC intensity and track simulations. These four storms are all 2006 typhoons that crossed the Philippines and made landfall either over southern China or Vietnam. Two types of initial conditions, one with the NC2011-CTRL TC initialization method and the other from the global analysis (CTRL), are used to initialize the ARW model every 12 h after the TC crosses the

FIG. 4. Best track (circle, black) and 48-h simulated tracks (triangle, red) for five 48-h runs for Chanchu initialized every 12 h from 0000 UTC 14 May to 0000 UTC 16 May 2006 for (a) the CTRL and (b) NC2011-CTRL runs. The TC tracks are marked every 6 h.
Philippines and reaches 117°E about 36 h prior to landfall over Vietnam or China. For each type of model initialization, a total of twelve 48-h simulations were performed. The mean error statistics of track, maximum wind speed, and minimum SLP are computed for comparison and verifications. The model initial time for these runs is shown in Table 3.


Chanchu was a supertyphoon over the northwest Pacific in 2006. The typhoon affected the Philippines, Vietnam, China, Taiwan, and Japan. There were a total of almost 300 casualties, with losses totaling more than $1 billion U.S. dollars (USD). For Chanchu, five 48-h runs, initialized every 12 h from 0000 UTC 14 May 2006 are performed for each type of model initialization scheme (Table 3).

For the case of Chanchu (2006), both the CTRL (Fig. 4a) and the NC2011-CTRL (Fig. 4b) runs capture the almost 90° directional change from westward to northward in late 14 May 2006. Both runs show simulated track bias to the left of the best track. For intensity simulations, because the TC vortex in CTRL is much weaker than observed, Vmax (Pmin) in the CTRL run increases (decreases) rapidly within the 48-h simulated period (Fig. 5, green). For five CTRL runs in the Chanchu case, after 48 h of simulation, the simulated intensity is still weaker than observed (Fig. 5, green). For the NC2011-CTRL runs, both Vmax and Pmin (Fig. 5, red) are close to best track values at the model initial time without

![Image](image-url)
significant adjustments in Vmax and Pmin during the NC2011-CTRL simulations (Fig. 5, green). The NC2011-CTRL runs tend to underestimate Vmax and have a slightly lower Pmin as compared with the best track data (Fig. 5, red).


Durian is a rare supertyphoon that formed in December 2006 over the northwest Pacific and affected Vietnam and the Philippines. Durian formed as a tropical depression on 25 November 2006 at about 9.6°N, 147.2°E. It became a tropical storm on 26 November 2006 and a supertyphoon on 29 November, about 24 h before it made landfall over the Philippines. Typhoon Durian maintained its strong intensity for almost five days. It eventually moved to the southern coast of Vietnam, weakened, and finally disappeared on late 5 December. Durian caused severe damage in the Philippines and Vietnam. According to a report from ReliefWeb (http://www.reliefweb.int), the damage to the Philippines and Vietnam caused by Supertyphoon Durian was more than $10 billion USD with more than 1000 casualties. For Durian, three 48-h runs initialized every 12 h at 0000 UTC 2 December, 1200 UTC 2 December, and 0000 UTC 3 December 2006 are performed for each type of model initialization scheme (Table 3).

For track simulations, both the CTRL and NC2011-CTRL runs capture the southwestward movement of Durian (Fig. 6). For the intensity simulations, the CTRL runs simulate neither Vmax larger than 38 m s\(^{-1}\) nor Pmin
less than 990 hPa (Fig. 7, green). The NC2011-CTRL runs (Fig. 7, red) show much improvement in Vmax and Pmin simulations in comparison with the CTRL runs, but the simulated intensity is weaker than in the best track data.


Prapiroon developed as a tropical depression on 29 July 2006 at about 13.5°N, 129.2°E, east of the Philippines. It made its first landfall over the Philippines on 31 July 2006. After it crossed the Philippines, it intensified with maximum wind speeds of \( \sim 18 \text{ m s}^{-1} \) early on 1 August 2006. Prapiroon reached its peak intensity early on 3 August 2006 with maximum wind speed of \( \sim 33.5 \text{ m s}^{-1} \) about 6 h before it made landfall over China around 1200 UTC 3 August 2006. The typhoon weakened on 4 August and disappeared on early 5 August 2006. Although Typhoon Prapiroon was relatively weak, with Vmax not exceeding 35 \( \text{ m s}^{-1} \), the total reported damage was more than $1 billion (USD) with a total of more than 100 casualties in China and the Philippines. For Prapiroon, two 48-h runs initialized at 0000 and 1200 UTC 2 August 2006 are performed for each type of model initialization schemes (Table 3).

For track simulation, the NC2011-CTRL runs significantly improve the track simulation during the early hours of simulations as compared with the CTRL runs (Fig. 8). Both the CTRL and NC2011-CTRL runs tend to simulate track to the left of the best track. For the intensity simulations, the CTRL runs simulate a weak TC vortex with no significant changes in Vmax and Pmin within the 48-h simulations (Fig. 9, green). The NCB runs slightly overestimate vortex intensity (Fig. 9, red). The overestimation may be related to the simulated track being closer to the open ocean than the best track data. This results in a decrease in the frictional effect of landmasses and more fluxes from the ocean.
Typhoon Xangsane (2006)

Typhoon Xangsane formed on 25 September 2006 as a tropical depression centered at 11.8°N, 129.1°E. Xangsane reached its peak intensity, with a maximum wind speed of ~44 m s⁻¹ and a minimum SLP ~ 940 hPa, just before it made first landfall over the Philippines on 27 September. After landfall, Xangsane weakened with maximum wind speeds of ~31 m s⁻¹ early on 28 September. It then reintensified, reaching a maximum wind speed of ~41 m s⁻¹ on 30 September 2006, about a day before it made landfall over Vietnam.

**FIG. 8.** Best track (black) and 48-h simulated tracks (red) for two 48-h runs for Prapiroon initialized at 0000 and 1200 UTC 2 Aug 2006 for (a) the CTRL and (b) NC2011-CTRL runs. The TC tracks are marked every 6 h.
on 1 October 2006. Typhoon Xangsane caused almost 300 casualties and damages totaling about $700 million (USD) in the Philippines and Vietnam. For Typhoon Xangsane, two 48-h runs, initialized at 0000 and 1200 UTC 29 September 2006 are performed for each type of model initialization schemes (Table 3).

Figure 10 shows that NC2011-CTRL runs have significant improvement in track simulations especially at early hours of simulations. The observed landfall point is $15.9^\circ$N. The simulated landfall location in the NC2011-CTRL runs is $15.5^\circ$N, which is better than in the CTRL run ($15^\circ$N). Compared to the CTRL simulation, the NC2011-CTRL runs have better simulations for both Vmax (Fig. 11a) and Pmin (Fig. 11b). At 0000 UTC 30 September, Xangsane reached its second peak intensity. Errors for CTRL runs at that time are $60 \text{ hPa}$ and $35 \text{ m s}^{-1}$ for Pmin and Vmax (Fig. 11, green), respectively. In comparison, the simulated errors in Vmax and Pmin in the NC2011-CTRL runs are about $15 \text{ hPa}$ and $10 \text{ m s}^{-1}$, respectively (Fig. 11, red).

e. Mean error statistics for all four typhoons

The mean error statistics of the four typhoons are computed from all 12 runs to investigate the performance of the NC2011-CTRL runs in TC intensity and track simulations. The mean track errors in the NC2011-CTRL runs (Fig. 12a, red) are slightly smaller than those of the CTRL runs (Fig. 12a, green) for all simulation periods. The NC2011-CTRL runs show significant improvement in intensity simulations. The mean absolute errors of Vmax in the NC2011-CTRL runs (Fig. 12b, red) are always smaller than in the CTRL runs (Fig. 12b, green) for
all simulated periods. For the simulated period up to 24 h, the errors in the NC2011-CTRL runs are about 6 m s\(^{-1}\) (Fig. 12b, red), which is significantly less than the results for the CTRL runs (larger than 20 m s\(^{-1}\)) (Fig. 12b, green) for the same period. For mean absolute errors of Pmin, the NC2011-CTRL runs (Fig. 12c, red) are reduced by more than 60% when compared with the errors in the CTRL runs (Fig. 12c, green) for simulated periods up to 24 h (Fig. 12c). For simulations from 30 to 48 h, the Pmin errors in the NC2011-CTRL runs (Fig. 12c, red) are smaller than those in the CTRL runs (Fig. 12c, green). The exception is at 48 h where the Pmin errors in the NC2011-CTRL runs are comparable to those in CTRL runs (Fig. 12c). Some of those runs occur after the storms made landfall at 48 h of simulation. More cases with storms at various stages of their life cycles are needed to refine the model.

Model parameterization schemes introduce uncertainty in TC forecasting (Bao et al. 2012); therefore, we also investigated the effects of different precipitation schemes on typhoon track and intensity forecasts initialized by the modified NC2011 scheme. First we performed an additional set of runs for these four storms using the same Grell–Devenyi cumulus parameterization scheme for the 18-km domain only but with the Eta microphysics option (Eta-GD). Though,
cumulus parameterization is not needed for high-resolution grids, our 6-km grid may not be adequate to resolve the convective process within clouds. In addition, the vertical motions on the 6-km grid may not be large enough to lift an air parcel to reach saturation in a relatively short time during the initial stage of model simulations. With cumulus parameterization, subgrid-scale precipitation is allowed to occur on the grid points of the 6-km domain. We perform model runs with the same combination of cumulus parameterization and precipitation scheme (Eta-GD) but with the Grell–Devenyi cumulus parameterization scheme for both the 18- and 6-km (Eta-GDb) in the last phase of model configuration.

For the model runs using Eta microphysics (Eta-GD), the storm intensity is slightly weaker than that in WSM6 (NC2011-CTRL) (Figs. 12b,c). However, the track simulations are slightly better (Fig. 12a). When the cumulus parameterization scheme is used for both domains with Eta-microphysics (Eta-GDb), the simulated intensity is slightly weaker than the other two sets of runs without cumulus parameterization for the 6-km domain (NC2011-CTRL and Eta-GD). Nevertheless, the simulated track for Eta-GDb is slightly better compared to the other two sets of runs without cumulus parameterization for the 6-km domain (Fig. 12c). For all three sets of model runs, it is apparent that in addition to better initial TC structure and intensity (Chen et al. 2014), our initialization scheme will lead to better TC simulations as compared with the CTRL runs.

The composite error statistics from all three sets of runs (Fig. 13) show improvements for both the track and intensity simulations over the CTRL runs, especially the intensity simulations within the first 24–48 h before making the landfall. In addition to uncertainties in the
precipitation processes used in the models, there are uncertainties in the estimation of storm intensity over the open ocean where convection data are sparse. It appears that a small ensemble of high-resolution models initialized by the modified NC2011 scheme will improve both the track and intensity simulations over the ocean before TC landfall.

5. Summary and discussion

In this study, we made improvements to the typhoon initialization scheme developed by Nguyen and Chen (2011). We also test the performance of the new initialization scheme using the WRF Model for four typhoons that made landfall over southern China or Vietnam in 2006. Sensitivity tests show that the prescribed SLP has very little impact on the spinup process of the typhoon vortex. For an intense supertyphoon with Pmin as low as 916 hPa, the scheme can spin up the TC vortex close to the best track data without prescribing SLP. These results attest to the importance of the storm environment on the TC intensity. Because the prescribed SLP is not needed, there is no need to specify the radius of the maximum wind in the original scheme developed by NC2011. Thus, the size and storm structure are determined mainly by the given large-scale conditions and the model employed. Our results show that a prescribed warm core for the first 10 cycles or so significantly reduces the number of cycles needed for the TC vortex to spin up to the best track intensity.

The error statistics for these four landfalling typhoons in 2006, using the modified NC2011 scheme (NC2011-CTRL), are compiled and compared with those from the CTRL runs. A total of thirty-six 48-h simulations are performed for both sets of runs. Over the open ocean, typhoon intensity is usually estimated by satellite observations with some uncertainties. Despite these uncertainties, the modified NC2011 scheme shows remarkable skill in improving tropical cyclone simulations, especially intensity, in this data-sparse region without using in situ data, prescribed SLP, or the radius of maximum wind to initialize the model. The key element for success of the NC2011 scheme is simply that the initial TC vortex is well adapted to the model employed with a TC intensity close to the best track data at the very beginning of the model integration. For all the cases considered, including those simulated by Nguyen and Chen (2011) [Morakot (2009), Jangmi (2008), and Kalmaegi (2008)], the NC2011 scheme’s simulations of intensity and track are superior to the CTRL runs in which the initial vortex in the model needs to adjust to environmental conditions during the first 24–36 h of model simulations. We also show that with uncertainties in the precipitation physics used in the models and uncertainties in the estimation of storm intensity in the open ocean where conventional data are sparse, a small ensemble using high-resolution models initialized by the modified NC2011 scheme will improve both the track and intensity simulations over the ocean before TC making landfall.

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