Typhoon Relocation in CWB WRF

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1. Introduction

The community Weather Research and Forecasting (WRF) modeling system is a mesoscale forecast and data assimilation system that is designed to advance the atmospheric research and operational prediction. It has been used in atmospheric researches including mesoscale convective system, tropical cyclone (TC), and large eddy studies. The WRF has also been used by several numerical weather prediction (NWP) centers in their daily operations to provide guidance for forecasters, e.g., National Centers for Environmental Predication (NCEP), Air Force Weather Agency (AFWA), and Korea Meteorological Administration (KMA). At Central Weather Bureau (CWB), the WRF model is in a process of checking out for operation.

Typhoon initialization remains as a challenge for numerical model predictions of typhoons. This paper presents a method of improving the typhoon initialization, and hence typhoon forecast for the Advanced Research WRF Model (ARW; Skamarock et al. 2005). In this study, we use the 3.0.1 version of WRF-ARW with 45km resolution covering a 221x127 grid domain.

In recent years, typhoon (or tropical cyclone) relocation techniques have been successful implemented in the Global Forecast System (GFS) at NCEP (Liu et al. 2000) and the Nonhydrostatic Forecast System (NFS) at CWB (Liou 2004). The typhoon relocation technique is based on the method developed by Kurihara et al. (1995) that separates the typhoon vortex from the first guess field. In order to avoid the false spin-up problem of the vortex resulting from inconsistence between the model dynamics and physics, the initial typhoon vortex of the GFS is obtained from the model predicted vortex but relocated to its observed position. As a result, the average of the typhoon track forecasts in 1999 was substantially improved in both the NCEP global spectral model GFS and the GFDL model. The improvement is 31% for the GFS and 25% for the GFDL. In addition, the typhoon relocation technique is also implemented in the Global Ensemble Forecast System (GEFS) and significantly reduces the mean track errors of the GEFS forecast. For the NFS at CWB, in addition to the relocation technique to improve the first guesses, the NFS three dimensional variational analysis uses 41 bogus data generated around an observed typhoon to help defining the typhoon structure in the initial conditions (Liou 2002). With the typhoon relocation method, large errors in the first guess fields due to the position error are eliminated and the analyzed typhoon circulation is much reasonable without twisted centers. In considering the efficiency in the initialization of the vortex specification and the dynamic consistence with the forecast model, we apply the typhoon relocation technique based on Liou (2004) to initialize typhoons for the WRF model. Without the relocation, typhoons are not properly initialized yet in the WRF as we will see from the typhoon Jangmi track and structure forecasts by the WRF.

2. Methodology

The typhoon relocation procedure is applied to fix typhoon position errors in the guess fields for WRF incremental update cycles after the WPS (WRF Preprocessing System) module. The modified first guesses, observation and bogus data are then assimilated into the model initial conditions by the WRF-3DVAR. The first step of the typhoon relocation procedure is to separate the typhoon vortex from the environmental flow in the first guess fields. The separation procedure is similar to that described in Kurihara et al. (1995), except we use the vorticity maximum at η =0.85 to define typhoon centers of the first guess and Barnes (1994) analysis to obtain the non-typhoon perturbation inside the typhoon circulation domain. In this scheme, the computation steps are as the following:

1) Applying a low-pass filter to all analysis variables including zonal and meridional components of wind, potential temperature, relative humidity and surface pressure to filter out disturbances shorter than 1200 km wavelength for basic fields; and then calculating perturbation fields as the residuals of the basic fields from the total fields.

2) Determining the extent of the typhoon circulation by first interpolating the perturbation wind at η =0.85 to the typhoon centered polar coordinates in 24 directions, computing azimuthally averaged tangential wind profile at the 24 directions, and then determining the typhoon edge by searching outward to reach a radius where the tangential wind profile satisfies one of the two conditions: $v < 6$ m s^{-1} and $\partial v/\partial r < 4\times10^{-6}$ s^{-1}, or $v < 3$ m s^{-1} until the search hits the limit set for 800 km.

3) Obtaining non-typhoon perturbations inside the typhoon circulation domain by 2-pass Barnes analysis (Barnes 1994) using the perturbations at the typhoon edge as observational data of the non-typhoon perturbations, and then computing the typhoon vortex circulation as the residual of the non-typhoon perturbations from the total perturbations inside the typhoon domain.

The typhoon vortex separated by the above steps is then relocated to its observed location to form the modified first guess fields for the WRF 3DVAR analysis. In the WRF model, the vertical coordinate is defined as $\eta = \left(P_{dh} - P_{dht}\right)/\mu_d$, where μ_d represents the mass of the dry air in the column and P_{dh} and P_{dht} represent the hystrostatic pressure of the dry atmosphere and the hystrostatic pressure at the top of the dry atmosphere, respectively. The geopotential height (ϕ) is derived from the diagnostic equation for dry inverse density (α_d) as

$$\partial_\eta \phi = -\alpha_d \mu_d$$

With the definition, μ_d could be computed from the surface pressure which is calculated from the above steps. The typhoon relocation procedure is performed only when the first guess typhoon center is more than 1 grid distance away from its observed location, the typhoon center is at least 300 km away from the lateral boundary, and there are no grids with terrain height higher than 10 m within 200 km from the typhoon center.

It is noted that there are often more than one typhoon in the WRF model domain. The above relocation procedure is applied individually to each and maximum to 4 typhoons inside the model domain. In the following paper, the typhoon relocation procedure is tested to investigate its impact on the WRF typhoon forecasts for Typhoon Jangmi that CWB issued typhoon warnings in 2008.

3. Results

Typhoon Jangmi formed northwest of Guan on 24 September. As it moved northwest persistently in the first four days, its intensity increased gradually (Fig. 1). Subsequently, Jangmi made landfall at I-Lan in the northeastern Taiwan at 0740 UTC 28 September, and left Taiwan near Tao-Yuan at 2020UTC on the same day. It weakened considerably while approaching and crossing the northern of Taiwan.

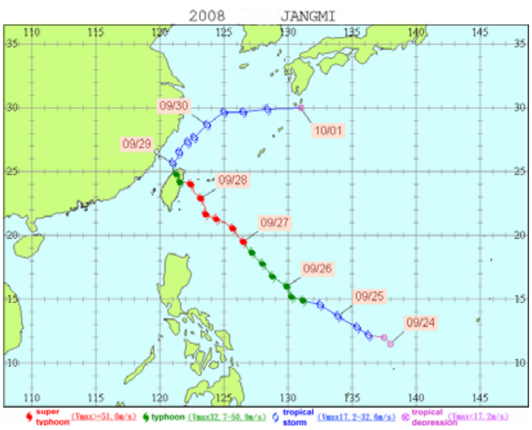

Fig. 1 Tracks of Typhoon Jangmi from best tracks of CWB. The symbol indicates the best track for every 6h and the label represents the date at 0000UTC.

After passing Taiwan, Jangmi turned toward the north-northeast and gradually dissipated over ocean two days later. In this study, the typhoon relocation procedure will be examined from 2412UTC to 2806UTC before the landfall at Taiwan.

The typhoon relocation procedure decomposes the atmosphere flow around the typhoon Jangmi into typhoon circulation flow and environment flow, while the environmental flow consists of a basic flow and non-typhoon perturbations. Figure 2 shows that the total atmosphere flow (Fig. 2a) at η =0.49 and the decomposed environmental flow (Fig. 2b), non-typhoon perturbations (Fig. 2c), and typhoon circulation (fig.2d) at 1200 UTC 26 September. The relocated first guess is obtained by relocating the typhoon circulation to the observed typhoon position and then adding it to the environmental flow. It is interesting to see that the environmental flow around the typhoon area is southeasterly which is aligned with the typhoon northwestern movement at this time. Meanwhile, the asymmetric structure associated with the total flow is similar to the typhoon circulation (fig.2d) at the vicinity of the typhoon.

Figure 3 shows the perturbation dry air mass in column (MU) before (red) and after (black) typhoon relocation procedure for the input of the WRF 3DVAR. It is shown that the first guess typhoon was relocated to the north where the typhoon center was observed (shown by the typhoon symbol) at 1200UTC 26 September. Similar to the MU field, the wind field distribution at η =0.85 shows the northward displacement of the typhoon circulation only to the observed typhoon position by the typhoon relocation procedure without generating neither discontinuity nor sharp gradient (Fig. 4). Two numerical experiments with and without using the typhoon relocation procedure were conducted to investigate the effects on the simulated typhoon tracks and structures. Both of numerical experiments have its own 6-h data assimilation cycles starting from 0000UTC 24 September with analysis first guesses from 6-h forecasts of the previous runs. Sixteen 72-h forecast runs were integrated by each experiment for the period from 1200UTC 24 September to 0600UTC 28 September. With the typhoon relocation procedure, the simulated tracks did not scatter much and they moved closely to the observed typhoon positions in the initial time (Fig. 5a). On the contrary, the simulated tracks without typhoon relocation procedure displayed much larger and scattered difference with the best track of the typhoon (Fig. 5b). Due to the effective typhoon relocation procedure, the initial position of typhoon centers were in more agreement with the observed typhoon centers than those without the procedure. In particular, the results of the track errors showed that the typhoon relocation procedure effectively improved the typhoon track forecast by more than 50% in the first 12 hours, especially at the initial time for higher than 75% difference (Fig. 6). The least improvement of the track forecast by the relocation was 30.7% at the 24-h forecast. With the increase of the integration time after 24 hours, the difference of simulated track errors were gradually increased in the relocation experiment. All of the 72-h forecasts exhibited better results by using the typhoon relocation procedure. The average track errors of WRF 72-h simulations with and without the typhoon relocation procedure are 172 km and 315 km, respectively, for about 48% improvement with the relocation procedure.

The comparison of the analyzed sea level pressure indicated that the typhoon circulation without the relocation procedure was displayed with the twisted distribution that was resulted from the different typhoon position between the first guess and bogus data constructed according to the observed typhoon position (Fig. 7a). With the typhoon relocation procedure (Fig. 7b), the much reasonable typhoon circulation was analyzed with a more symmetric and stronger typhoon center better agreed with the observational data. It is noted that the twisted typhoon circulation might be adjusted to be consistent with the dynamics and physics of the model at the early integration period, which is coincided with the large track errors within the 12 hours in Fig.6. In addition, the typhoon relocation procedure also has impacts on the typhoon vertical structure. Figure 8 shows an east-west vertical cross section of potential temperature and relative humidity fields, cutting across the typhoon center. The potential temperature field shows the presence of trough around typhoon center associated with the stronger typhoon structure in the experiment with the relocation. Meanwhile, the relative humidity exhibits the well-developed structure both on the horizontal and vertical that is close to 100% within the typhoon circulation. Overall, based on the typhoon Jangmi case, the impacts of the typhoon relocation procedure are significant not only on the typhoon track forecast but also on the dynamic and thermodynamic vortex structure.

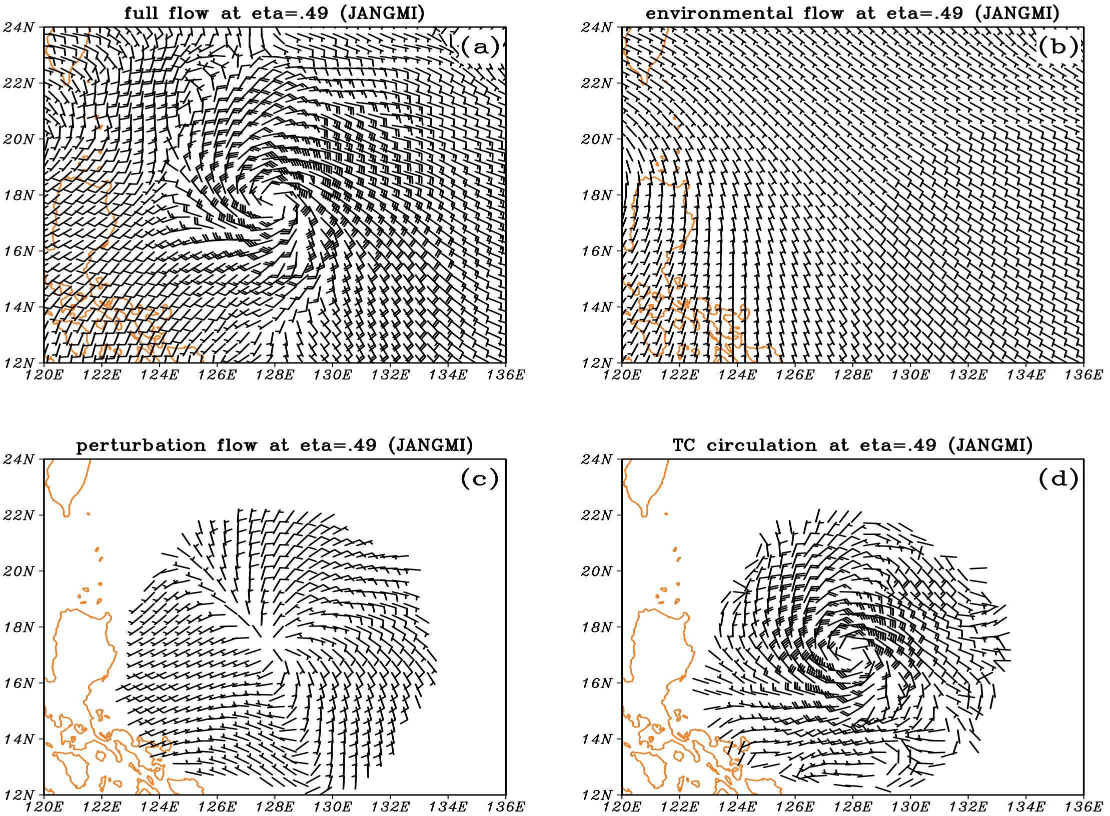

Fig. 2 The total atmosphere flow (Fig. 2a) decomposed into environmental flow (Fig. 2b), non-typhoon circulation (Fig. 2c), and typhoon circulation (fig.2d) with typhoon relocation procedure at 1200 UTC 26 September.

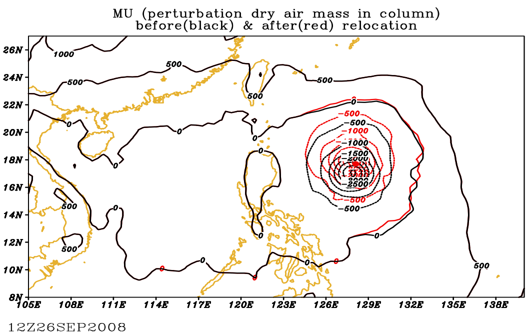

Fig. 3 The perturbation dry air mass in column (MU) from WRF 3DVAR input before (red) and after (black) relocation procedure.

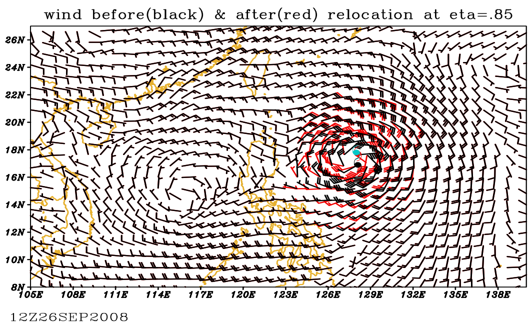

Fig. 4 Similar with Fig.3 except for the wind field distribution and the blue, red, black typhoon symbols represent typhoon center of observation, with and without typhoon relocation procedure, respectively.

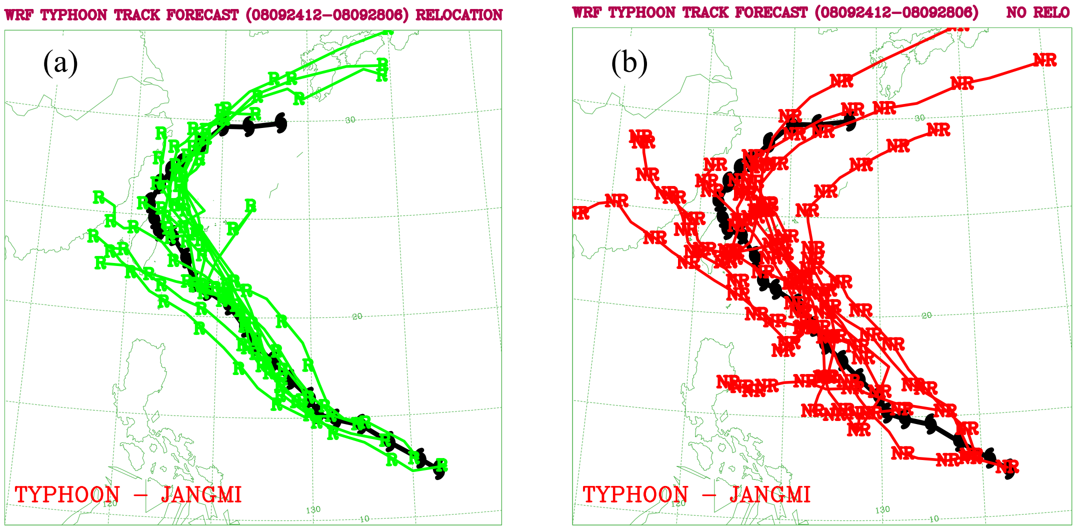

Fig. 5 Tracks of Typhoon Jangmi from best tracks of CWB (black) and with (a) and without (b) typhoon relocation procedure from 1200UTC 24 to 0600UTC 28 September. The typhoon symbol indicates the tracks for every 6 h.

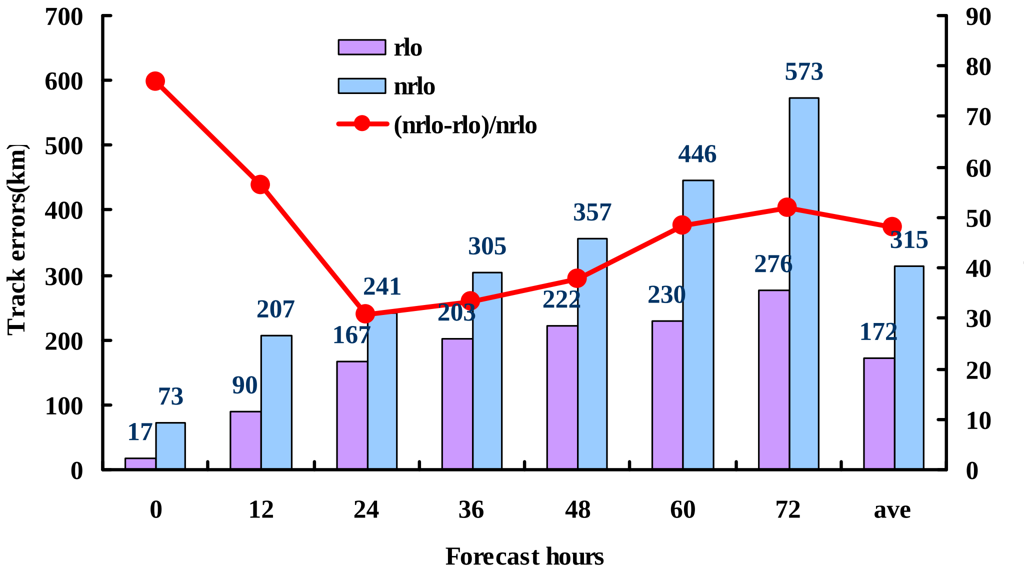

Fig. 6 The simulated typhoon track errors and the percentage differences of the track errors with (rlo) and without (nrlo) typhoon relocation procedure.

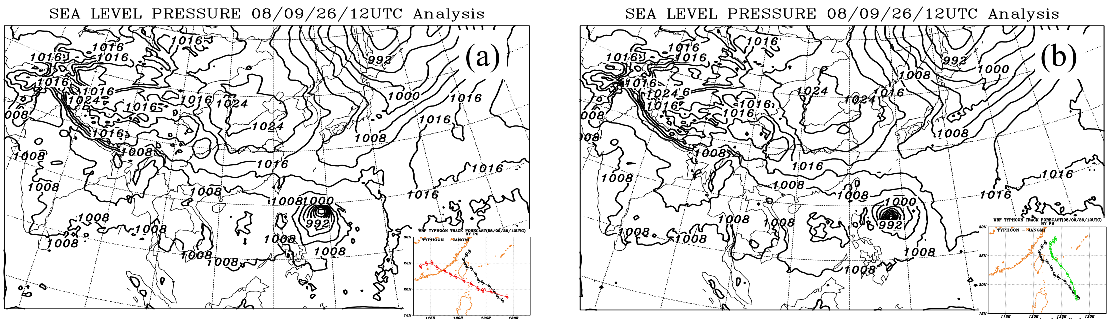

Fig. 7 The analysis fields of Sea Level Pressure without (a) and with (b) typhoon relocation procedure at 1200UTC 26 September. Tracks of Typhoon Jangmi from best tracks of CWB (black) and from the model 72 hours forecast at the same time (red and green for without and with typhoon relocation procedure, respectively) are also shown in the attached chart.

4. Summary

There are two components in this study, one is the introduction of the typhoon relocation procedure and the other is the application to typhoon Jangmi. Jangmi made landfall at northeastern Taiwan on 28 September and was one of the super typhoons that CWB issued typhoon warnings in 2008. With the typhoon relocation method, the atmosphere flow of the first guess is decomposed into basic flow, non-typhoon perturbations, and typhoon circulation. The typhoon circulation then can be either removed from the first guess or relocated to its observed position. Moreover, in the comparison of the difference from the WRF 3DVAR input with and without typhoon relocation procedure, the variables were relocated only around the region of the typhoon circulation and the typhoon center was close to the observed position.

As the typhoon relocation effectively removes the typhoon position error in the analysis, the simulated typhoon tracks are considerably improve in all of the forecast hours. In particular, it reduces the adjustment for the inconsistence with the model dynamics and physics in the earlier integration periods. Further investigation on the dynamic and thermodynamic structures of the typhoon circulation shows that the structure associated with the typhoon relocation procedure was symmetric and stronger resulted from the consistence with the observed typhoon position in the process of data assimilation with the bogus data. As the horizontal structure, the thermodynamic vertical structure is better analyzed with the relocation procedure. Therefore, with the typhoon relocation, large errors in the first guess fields due to the position error are eliminated and the analyzed typhoon circulation is much reasonable without twisted centers.

Acknowledgements

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REFERENCES

Barnes S. L., 1994: Application of the Barnes objective analysis scheme. Part I: Effects of undersampling, wave position and station randomness. *J. Atmos. Oceanic Tech.*, **11**, 1433-1448.

Kurihara, Y., M. A. Bender, R. E. Tuleya, and R. J. Ross, 1995: Improvements in the GFDL hurricane prediction system. *Mon. Wea. Rev.*, **123**, 2791–2801.

Liou, C.-S., 2002: High-resolution numerical modeling on tropical cyclone structure and track. *Weather and Climate Modeling*, Ed. S.V. Singh, Swati Basu and T.N. Krishnamurti, p198-208.

——, 2004: Improving forecast of rainfall and strong wind associated with typhoons approaching Taiwan. *CWB Report NO.CWB93-3M-01*, 2-24.

Liu, Q., T. Marchok, H. Pan, M. Bender, and S. Lord, 2000: Improvements in Hurricane Initialization and Forecasting at NCEP with Global and Regional (GFDL) Models, *NOAA Technical Procedures Bulletin* 472.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2005: A description of the Advanced Research WRF version 2. NCAR Tech. Note TN-468 STR, 88 pp.

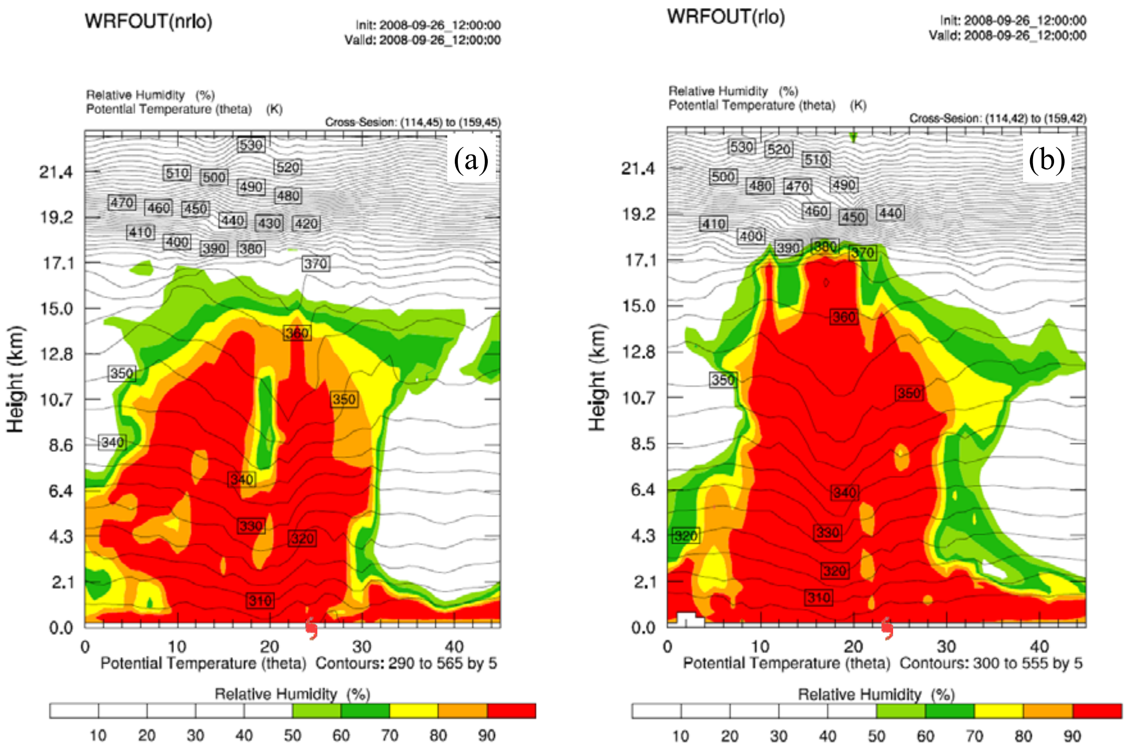

Fig. 8 Zonal cross section of potential temperature (with contour interval of 5K) and relative humidity (shaded for every 10%) cutting through typhoon center without (a) and with (b) typhoon relocation procedure.