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THE IMPACT OF CUMULUS PARAMETERIZATIONS AND MICROPHYSICS SCHEMES UNDER DIFFERENT COMBINATIONS ON TYPHOON TRACK PREDICTION

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Abstract: This study examines the effects of cumulus parameterizations and microphysics schemes on the track forecast of typhoon Nabi using the Weather Research Forecast model. The study found that the effects of cumulus parameterizations on typhoon track forecast were comparatively strong and the typhoon track forecast of Kain-Fritsch (KF) was superior to that of Betts-Miller (BM). When KF was selected, the simulated results would be improved if microphysics schemes were selected than otherwise. The results from Ferrier, WSM6, and Lin were very close to those in the best track. KF performed well with the simulations of the western extension and eastern contraction changes of a North Pacific high as well as the distribution and strength of the typhoon wind field.

Key words: cumulus parameterizations, microphysics schemes, typhoon track prediction

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1 INTRODUCTION

Track forecast is an important element of typhoon forecast and an accurate knowledge of the factors that influence typhoon movement and the actions of these factors has practical significance in the improvement of typhoon track forecast. Determining typhoon movement—subject to many factors, is very complex. For example, pressure gradient force, Coriolis force, typhoon internal force, the interaction between typhoon and environmental fields, frictional force, and temperature fields all influence typhoon's motion. Many studies have been conducted on typhoon motion[1-2]. Yuan et al.[3] claimed that the typhoon moves toward warmer sea water surfaces. He[4] indicated that asymmetrical non-isolation accelerates, decelerates, or switches typhoons. However, the above studies are merely the results of theorizing and numerical simulation, and physical process, interrelated with the actions of many factors, remained insufficiently understood. Xu et al.[5] performed diagnosis and analysis of the westward movement of typhoon Winna at landfall using U.S. National Centers for Environmental Predition (NCEP)/National Center for Atmospheric Research (NCAR) data and other observations. Zhang[6] experimented on the abnormal movement of typhoon Maggi through numerical simulation. Zhong[7] decided on a method of synthetic analysis, and comparatively analyzed, among the typhoons that hit the southeastern coast of China, changes in the environmental fields of typhoons that stayed for a short period over land and those of typhoons that stayed for a long period over land. Yuan[8] developed a method for creating many initial fields using early data from different types of numerical simulations.

Another sensitive issue in typhoon numerical forecast is cumulus parameterization. Cumulus parameterization is the most important adiabatic heating physical process in numerical simulation. This

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study mainly considers the cumulus parameterization that occurs under the compulsion and restriction of a large-scale environment. To reiterate, cumulus parameterization exerts considerable influence on large-scale motion through sensible heat, latent heat, and momentum transport. In particular, it plays a decisive role in the vertical structure of the temperature and humidity of the atmosphere. Many numerical simulation tests found that the simulation effects vary greatly depending on cumulus parameterizations. Through experiments[9-11], Chen[12] found that the improvement of the model's physical process is more effective with typhoon track and intensity forecast.

Thus, a comparative analysis on the abilities for typhoon track forecast, simulated with various cumulus parameterizations and microphysics schemes within mesoscale models, is significant in the typhoon forecasts with mesoscale numerical models that include typhoon track, intensity, and precipitation. This study designed ten experiments with different combinations of cumulus parameterizations and microphysics schemes in WRF to test the path forecast of typhoon Nabi and examined the effects of WRF's cumulus parameterizations and microphysics schemes on typhoon forecast by comparatively analyzing the effects of typhoon track forecast in each of the experiments.

2 CASE DESCRIPTION AND CONTROL EXPERIMENT

2.1 *Case description*

Typhoon Nabi formed 1 200 km northeast of Guam at 1200 UTC (Coordinated Universal Time) 29 August 2005 with the location of its center at 15°N, 152.2°E over the sea, and moved west at 17 km/h with a maximum wind velocity of 21 m/s. The typhoon rapidly increased in intensity when passing through an area with a sea surface temperature of 29°C or higher. At 0600 UTC 31 August, it was 470 km (see Table 1 for specific latitude and longitude) north of Guam, with a central atmospheric pressure of 945 hPa and a maximum wind velocity of 43 m/s, and moved in a west-northwest direction at 28 km/h. At 12 UTC 2 September, the typhoon intensified further with a central atmospheric pressure of 925 hPa and a maximum wind velocity of 49 m/s and moved northwest at 17 km/h. At 1200 UTC 4 September, its velocity slowed to 11 km/h and at 1200 UTC 5 September, the typhoon maintained its intensity, but changed its direction to north. The typhoon hit Kagoshima, Japan, at 0100 UTC 6 September with a central atmospheric pressure of 950 hPa and a maximum wind velocity of 39 m/s, after which it continued to move north and accelerated further. At 1200 UTC, the central atmospheric pressure reached 970 hPa, with a maximum wind velocity of 33 m/s, and the typhoon moved north-northeast at 21 km/h. At 0000 UTC 7 September, it weakened into a tropical storm, with a central atmospheric pressure of 980 hPa and a maximum wind velocity of 28 m/s. At 0600 UTC 8 September, it weakened into a tropical depression. On the east and south coasts of Korea, which were affected by the typhoon, the instantaneous wind velocity was recorded at 20 m/s and the rainfall was 100–600 mm. In Kyushu, Japan, the daily precipitation exceeded 1 300 mm.

Table 1. Description of Typhoon Nabi

Time		Typhoon center	Central pressure (hPa)	Maximum wind speed (m/s)	Movement velocity (km/h)	Movement direction
August	1200 UTC 29	15.0°N, 152.2°E	994	21	17	West
	0600 UTC 31	16.4°N, 144.9°E	945	43	28	West-northwest
September	1200 UTC 2	20.1°N, 136.1°E	925	49	17	West-North
	0000 UTC 4	24.8°N, 132.2°E	940	43	17	West-northwest
	0000 UTC 6	31.4°N, 130.0°E	950	39	22	North
	1200 UTC 6	34.1°N, 130.9°E	970	33	21	North-northeast
	0000 UTC 7	37.8°N, 134.1°E	980	28	50	East-North

2.2 *Experiment design*

This study selected various combinations of cumulus parameterizations and microphysics schemes in WRF for experiments. The experiments used AVN data (6-h time interval) provided by NCEP/NCAR as the initial values of forecast variables. To examine how the effects of different combinations have on the typhoon track forecast, each combination group was compared. The model is 30 km in horizontal resolution, has 28 vertical layers (50 hPa in the peak layer of the model), and runs 120 s for integration. Other physical processes were identical. The forecast time was set to 48 h starting at 0000 UTC 5 September 2005. Table 2 shows the data of the experiments.

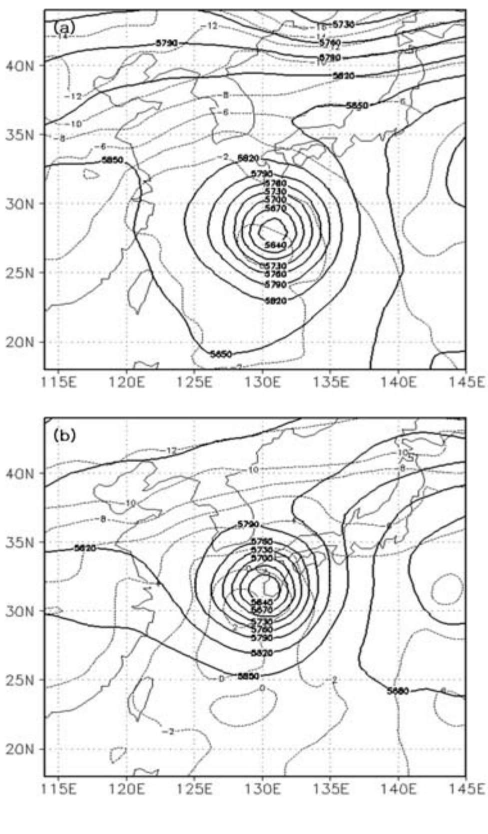
Table 2. Summary of the experiments

Names for experiments	Cumulus parameterizations	Microphysics schemes	Names for experiments	Cumulus parameterizations	Microphysics schemes
KF-Non (Exp.1)	Kain-Fritsch(KF)	None used	BM-Non(Exp. 6)	Betts-Miller (BM)	None used
KF-K(Exp. 2)	Same as above	Kessler	BM-K(Exp. 7)	Same as above	Kessler
KF-F(Exp. 3)	Same as above	Ferrier	BM-F(Exp. 8)	Same as above	Ferrier
KF-W(Exp. 4)	Same as above	WSM 6-class	BM-W(Exp. 9)	Same as above	WSM6-class
KF-L(Exp. 5)	Same as above	Lin	BM-L(Exp. 10)	Same as above	Lin

3 RESULTS

3.1 *Initial conditions of 500-hPa geopotential height*

Figure 1 shows 500-hPa geopotential heights of the NCEP/NCAR reanalysis at 24-h intervals, from 0000 UTC on 5 September to 0000 UTC on 7 September 2005. At 0000 UTC on 5 September, the outer line of the North Pacific High (NPH) was 5850 geopotential meter (gpm), with only weak short wave troughs forming in the East Sea of Korea (also known as the Sea of Japan—the editor), and no clear atmospheric pressure fields formed around the typhoon to influence its movement. At this time, the typhoon slowed to a mere 10 km/h. At 0000 UTC on 6 September, the outer line of the NPH contracted to the east and to the south, extended toward the west and touched the south of China. The typhoon moved northeast at a higher velocity, while the intensity of the typhoon center gradually decreased and the central force increased by 60 gpm.



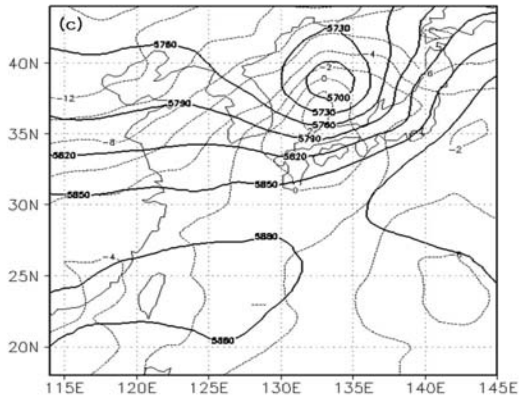


Fig. 1. 500-hPa geopotential height (a) at 0000 UTC September 5th; (b) at 0000 UTC September 6th;(c) at 0000 UTC September 7th

3.2 *Impacts of cumulus parameterizations and microphysics schemes on typhoon track prediction*

Figure 2 shows the best track of the typhoon of RSMC (Regional Specialized Meteorological Center) and the typhoon track forecast obtained from numerical simulation from 0000 UTC on 5 September to 0000 UTC on 7 September (at 6-h intervals). As shown in this figure, the northward movement and direction changes of the typhoon were similar even though the results of each experiment differed slightly from the best track in the latter part. In the simulation results of every experiment, the typhoon track leaned more toward the west than the best track, and the most prominent errors appeared after 24 h of the forecast time. Furthermore, cumulus parameterizations had a greater influence on typhoon track forecast than microphysics schemes did, and in cumulus parameterizations, the KF-simulated typhoon track was closer to the best track than BM was.

The selection of KF had a more pronounced influence on the typhoon track forecast depending on the selection of microphysics schemes. Ferrier, WSM6, and Lin (KF-F, KF-W, KF-L) had the closest simulation of the best track, and the simulation results of KF-L and KF-W were almost identical. When microphysics schemes were not selected, the simulations deviated the most to the west and the south, leading to the greatest error. At 48 h from the forecast time, the simulated moving velocities of the typhoon in KF-F, KF-W and KF-L were all faster than the best track, but those in the other experiments were slower than the best track. Thus, the typhoon track simulation results of KF-F, KF-W, and KF-L were relatively good, while the simulation results with no microphysics schemes selected (KF-Non) were the worst.

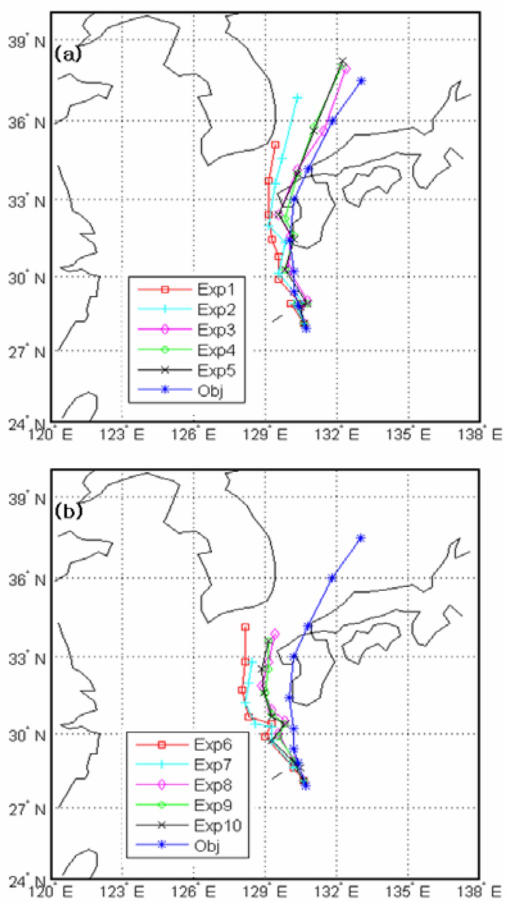


Fig. 2. RSMC best track and the simulated typhoon tracks from experiments (a) KF; (b) BM

When BM was selected, the experiment where microphysics schemes were not selected (BM-Non) simulated a typhoon track which deviated to the west the most, while the selection of Kessler (BM-K) yielded the greatest deviation to the south. The simulation results of BM-L and BM-W showed little difference, but were better than BM-Non or BM-K. The best simulation results were obtained from BM-F. The typhoon movement velocity simulated in every experiment was slower than the best track.

Table 3 shows the center locations of the typhoon simulated and the distance errors in each experiment compared to the best track. As shown in this table, typhoon track forecast error increased over time in experiments other than KF-L, KF-W, and KF-F. The error was the smallest in KF-F, and the average distance error was 49 km. In the case of BM-K, however, the simulation error increased the most over time and the average distance error was 274 km, which was approximately six times as high as that of KF-F. As the error data in the table indicate, KF-x showed smaller errors than BM-x in most cases. In particular, the error of KF-x at 12 h after the integration time was much smaller than that of BM-x. The error of BM-x was 2 to 4 times greater than that of KF-x, but the average error of KF-Non, which did not select BM, was 79 km smaller than that of BM-Non, the smallest error difference compared to other experiments which selected BM.

The above analysis found that in general, the selection of cumulus parameterizations for typhoons had a strong influence on the simulation results, but the selection of microphysics schemes did not. In cumulus parameterizations, KF led to better forecast simulation results for the typhoon path than BM on the whole.

Table 3. Track errors (km) of the experiments relative to the best track

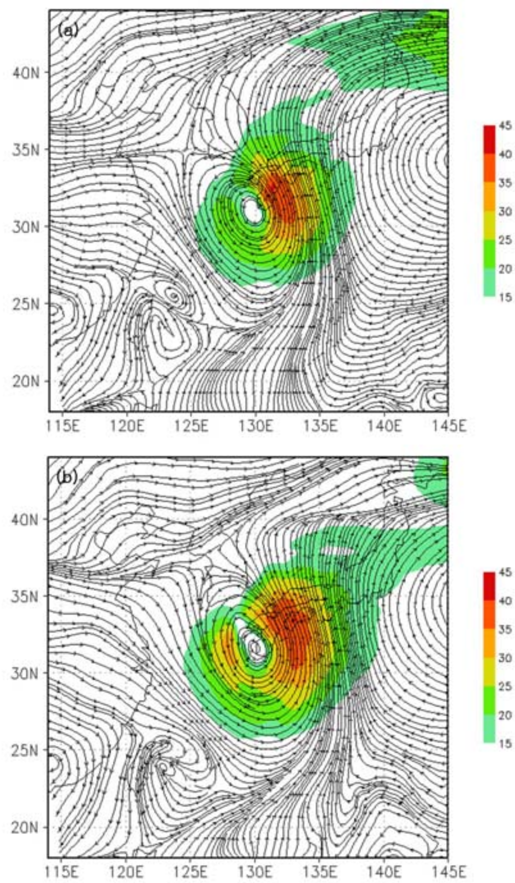
Forecast time/ h	KF-Non (Exp. 1)	BM-Non (Exp. 6)	KF-K (Exp. 2)	BM-K (Exp. 7)	KF-F (Exp. 3)	BM-F (Exp. 8)	KF-W (Exp. 4)	BM-W (Exp. 9)	KF-L (Exp. 5)	BM-L (Exp. 10)
0	22	22	22	22	22	22	22	22	22	22
6	37	27	22	20	11	22	12	22	11	22
12	64	85	72	85	74	55	83	72	83	91
18	83	138	73	116	28	77	43	83	43	116
24	84	138	22	150	24	99	33	114	25	114
30	197	331	160	338	97	250	90	264	97	278
36	268	406	165	438	50	334	53	348	53	357
42	382	529	281	583	56	456	88	480	93	499
48	474	644	300	718	84	559	106	601	115	601
Mean	179	258	124	274	49	208	59	223	60	233

3.3 *Impacts of cumulus parameterizations and microphysics schemes on 500-hPa height field prediction*

The NPH and typhoon movement are closely related. It is generally known that changes in the 500-hPa height field of the typhoon center in a certain range of the north-northeast directions have a strong influence on typhoon track forecast. Zhu[18] claimed that the key to typhoon track forecast lies in the activity of the NPH, the location of the western ridge, and intensity change of NPH. As can be seen from Table 3, typhoon track forecast error was the greatest in KF-Non and the smallest in the case of KF-F.

Changes in the 500-hPa height field for the typhoon track simulation results between KF-Non and BM-Non, and also between KF-L and BM-L, are explained below.

Figure 3 shows the 24-h forecasts of the streamlines and wind fields of 500-hPa obtained from simulations. The ridges of the NPH lie in the northeast-southwest direction, with dense streamlines east of the typhoon and the NPH in the KF-Non (Exp. 1) and KF-L (Exp. 5) and high wind velocity, more or less corresponding to actual conditions (Fig. 3e). On the other hand, the streamlines of BM-Non (Exp. 6) and BM-L (Exp. 10) have wider gaps, and the wind velocity is lower. KF-L has a divergence field in the middle region of Korea, which is similar to the reanalysis data (Fig. 3e), unlike other experiments, which placed it instead in the western sea of Korea (also known as the Yellow Sea—the editor). Due to the influence of the southwesterly of the NPH, the maximum wind velocity is to the east of the typhoon. The wind velocity simulated by KF-L was the strongest, and the range of the strong wind was wide as well. The simulations of KF-L for wind velocity distribution and the NPH are biased toward the northward movement of the typhoon. Furthermore, KF simulated relatively well the intensity and distribution of the wind field around the typhoon, and the simulation results of KF-L showed the closest similarity to those of the NCEP/NCAR reanalysis data.



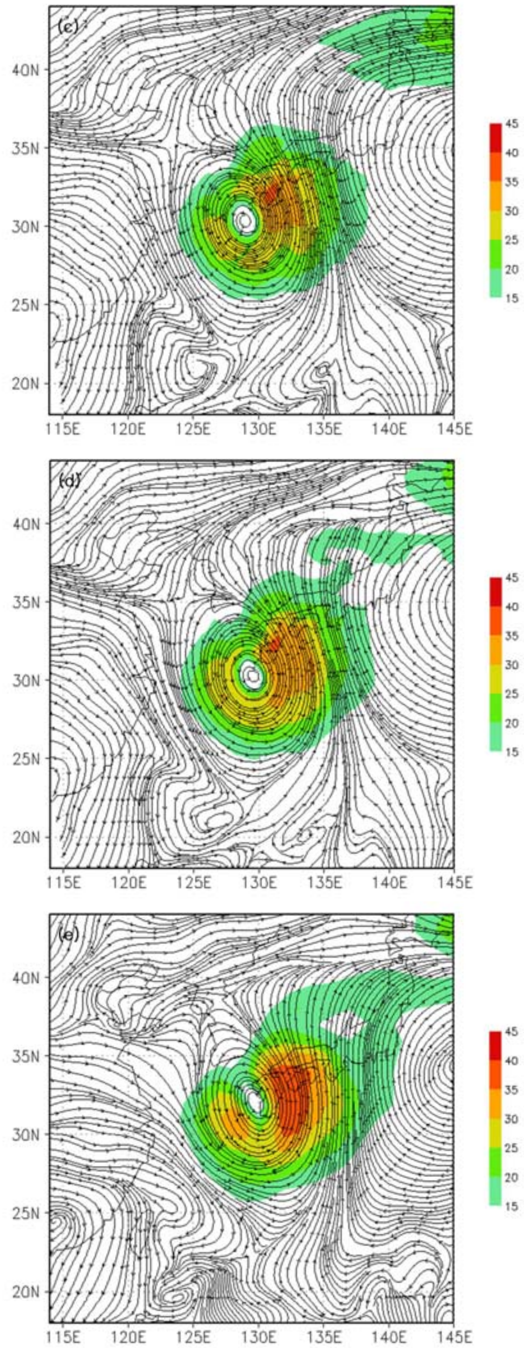
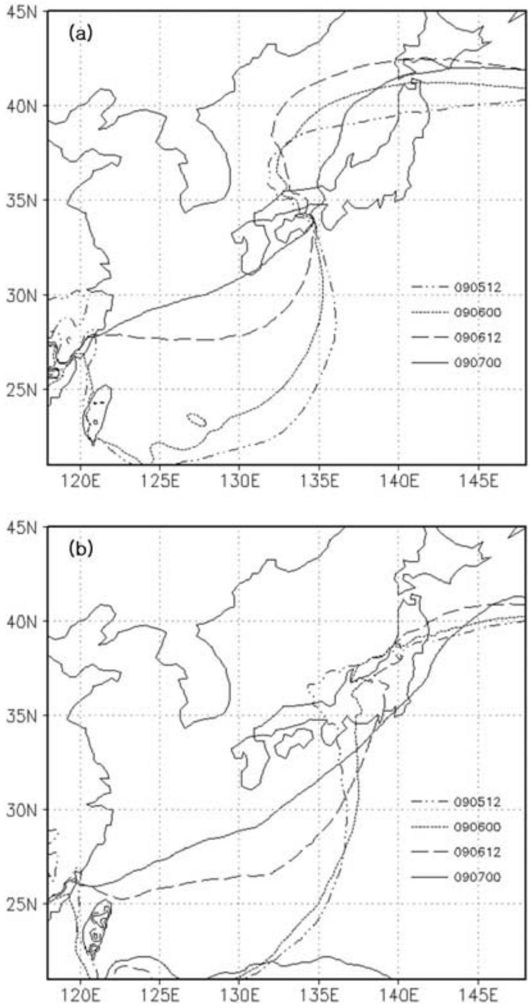


Fig. 3. 500-hPa wind field at 0000 UTC September 5th; (a) KF-Non; (b) KF-L; (c) BM-Non;(d) BM-L; (e) NCEP/NCAR

In order to better describe the effect of the NPH on typhoon movement, we examined the variation of the 5880-gpm line of 500 hPa. As shown in Fig. 4, all experiments simulated the eastern contraction of the NPH to the north of the typhoon and the western extension of the NPH to the south of the typhoon, albeit to varying degrees. KF-L (Exp. 5) simulated the greatest eastern contraction of the NPH to the north of the typhoon and the western extension of the NPH to the south of the typhoon, which is biased toward the northward movement of the typhoon. This was also similar to that of the NCEP/NCAR reanalysis data. In the reanalysis data of September 7th, the NPH to the south of the typhoon was separated but the movement of the NPH was similar to actual conditions (figure omitted). The simulations of KF-Non (Exp. 1) and BM-Non (Exp. 6) did not differ in the degree of eastern contraction of the NPH to the north of the typhoon, but differed in the degree of the western extension of the NPH to the south of the typhoon. KF-Non had a greater western extension of the NPH than BM-Non, and showed a greater bias for the northward movement of the typhoon as well. However, the eastern contraction of the NPH to the north of the typhoon was relatively small, which appears to have slowed the movement velocity of the typhoon. The simulations of KF-L (Exp. 5) and BM-L (Exp. 10) showed no significant difference in the eastern contraction of the NPH to the north of the typhoon, and almost none in the western extension of the NPH to the south of the typhoon. Based on the above findings, KF was shown to simulate the movement of the NPH relatively well (Fig. 4).



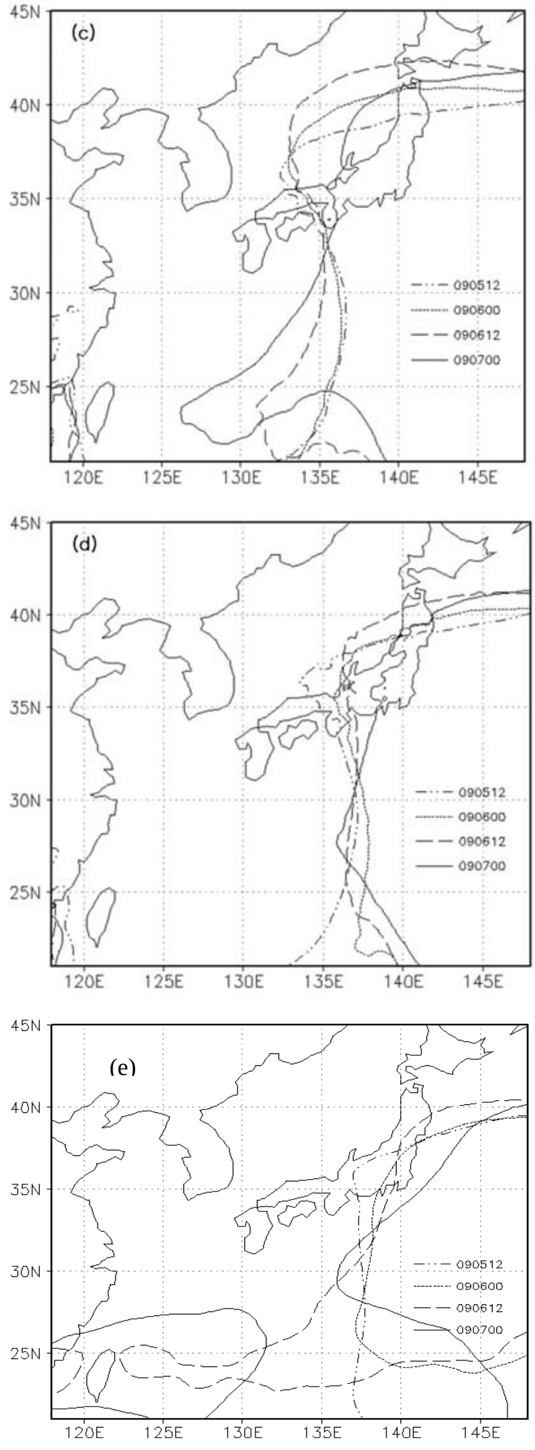


Fig. 4. Variation of 5880 gpm at 0000 UTC September 5th; (a) KF-Non; (b) KF-L; (c) BM-Non;(d) BM-L; (e) NCEP/NCAR

4 FINDINGS AND DISCUSSION

The impact of cumulus parameterizations and microphysics schemes under various combinations on the track forecast of typhoons has been simulated and studied with the WRF model. It is found that:

(1) Cumulus parameterizations had a strong influence on the typhoon track forecast, and of the two parameterization schemes, KF simulated better

than BM did.

(2) When KF was used, the selection of microphysics schemes is necessary in order to yield comparatively good simulation results. In particular, the simulation results from Ferrier, WSM6, and Lin were very similar to the actual track conditions.

(3) When BM was used, the simulation results of each of the experiments showed almost no difference and the typhoon motion velocity was slower than that of the best track in general.

(4) KF simulated the movement of the NPH, the wind distribution, and intensity of the surrounding field of the typhoon relatively well. This movement of the surrounding field appears to influence directly the typhoon track forecast.

The findings from this study may be limited since the study was based on the results of one numerical simulation. Because typhoon track forecast, typhoon central intensity, and precipitation vary in different weather systems, more reliable results may be obtained by continuing to experiment with a wider range of cases.

REFERENCES:

[1] MA Su-hong, WANG Jian-jie, WAN Feng. The effects of bogus typhoon and the observation data in the ocean on T213l31's ability of tc track prediction [J]. J. Trop. Meteor., 2007, 23(2): 141-145.

[2] YU Zhen-shou, HAO Zeng-zhou, XIE Hai-hua, et al. A numerical study of the effect of Taiwan Island Terrain on Typhoon Haitang (0505) Track [J] J. Trop. Meteor., 2007, 23(6): 575-580.

[3] YUAN Jin-nan, XIAO Wei-sheng. The Influence of SST variation on typhoon track [J]. Guangdong Meteor., 2002, (3): 1-2.

[4] HE Hai-yan, YANG Ping-zhang. A study on typhoon movement I. The effect of diabatic heating and horizontal temperature distribution [J] J. Trop. Meteor., 1995, 11(1): 2-9.

[5] XU Ai-hua, YE Cheng-zhi, OUYANG Li-cheng etc. The diagnostic analysis of the track and precipitation of typhoon "Rananim" after landfall [J]. J. Trop. Meteor., 2006, 22(3): 229-236.

[6] ZHANG Zhong-feng, LAU Kai-hon, TUO Rui-fang. Factors affecting the track of typhoon Maggie [J] J. Trop. Meteor., 2006, 22(1): 55-59.

[7] ZHONG Yuan, YU Hui, WANG Dong-fa. Effect of environmental field on tropical cyclone track after landfall from East China Sea [J]. J. Trop. Meteor., 2006, 22(4): 313-320.

[8] YUAN Jin-nan, WAN Qi-lin, HUANG Yan-yan, et al. The experiments of ensemble prediction of the track of tropical cyclone in South China Sea [J] J. Trop. Meteor., 2006, 22(2): 105-112.

[9] DENG Song, JU Jian-hua, LU Jun-mei. Study on mesoscale model cumulus parameterization scheme over low latitude plateau [J]. Plateau Meteor., 2002, 21(4): 414-420.

[10] WANG Jian-jie, HU Xin, GUO Xiao-rong. Comparison experiments on cumulus parameterization schemes of the MM5 [J]. Quart. J. Appl. Meteor., 2001, 12(1): 41-53.

[11] WANG Chen-xi, Comparison experiments on the effects of different cumulus parameterization scheme in MM5 on precipitation prediction [J]. Sci. Meteor. Sinica, 2004, 24(2): 168-176.

[12] CHEN De-hui, WANG Shi-wen, WANG Hou-jun. Performance of parameterization of sub-scale physical processes in numerical model and its effects on typhoon track forecastings [J]. Quart. J. Appl. Meteor., 1996, 7(1): 1-8.

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