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ENSEMBLE PREDICTION EXPERIMENTS OF TRACKS OF TROPICAL CYCLONES BY USING MULTIPLE CUMULUS PARAMETERIZATION SCHEMES

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Abstract: Ensemble prediction experiments of the tracks of eight tropical cyclones occurring between 2004 - 2006 over the western Pacific have been performed by using MM5 with five cumulus parameterization schemes. The results show that the predictions of the tracks of the tropical cyclones are sensitive to the selection of cumulus parameterization schemes. Each scheme has its own advantage and disadvantage, and the predications without cumulus parameterization schemes are not the worst, sometimes even better than the others. And all of the three ensemble methods improve the predictions of the tracks significantly, among which the ensemble method without parameterization schemes, the Grell, Betts-Miller and Kain-Fritsch schemes are the best.

Key words: ensemble prediction; cumulus parameterization; numerical experiment

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1 INTRODUCTION

In China, the research on ensemble forecast of tropical cyclone tracks is still in the preliminary stage and the theory of initial tropical disturbance has a long way to go before maturity so that there has not been a single method for the formation of initialization of ensemble forecast [1]. Due to the key role and effect of tropical adiabatic processes in the model initial disturbance [2], ECMWF introduced them into an adjoint model, accounting for humidity and derived initial singular vectors for the tropics. The model was used to conduct ensemble forecast experiments with the track and intensity of two west Pacific typhoons to produce "positive" effect [3 - 4]. It is then known that the term of adiabatic heating is also an important factor that needs to be taken into account in the study on a number of factors useful for the prediction of tropical cyclone tracks. In weak ambient fields, the asymmetric structure inside the tropical cyclone has significant effect on its motion. As shown in a numerical study [5], the tropical cyclone tends to move towards its inner zone of instability and the stronger the convection, the more powerful the force; the asymmetric structure tends to cause the tropical cyclone to make loops, turns or deviations from the direction of the ambient steering airflow. Under such circumstances, the quality of parameterization schemes plays an important role, because they immediately affect the thermal and dynamic structures in the interior of the tropical cyclone and in turn the prediction of moving track.

2 MODEL, DATA AND THE SELECTION OF CUMULUS PARAMETERIZATION SCHEMES

The experiment uses the non-hydrostatic, mesoscale model MM5v3 of PSU/NCAR, USA. It has a horizontal resolution of 45 km and is divided into 30 vertical layers. For the cumulus parameterization of the model, schemes of cumulus-free approach, Kuo's, Grell's, Betts-Miller (BM)'s and Kain-Fritsch (KF)'s are used. Consistent schemes are used for other parameterization while the MRF scheme is used for the boundary layer. Cases selected are the eight tropical

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cyclones in 2004 – 2006 (Tab.1). The initial forecast time is 36 – 48 h before landfall. Cases of 2004 are from AVN and those of 2005 and 2006 are from GFS. The resolution is 1°×1° for all data.

Tab.1 The eight cases of tropical cyclones for 2004 – 2006

Serial No.	Names (Codes)	Forecast starting time/UTC
1	Mindule (0407)	2004070100
2	Yagi(0414)	2004081100
3	Aere(0418)	2004082300
4	Haitang (0505)	2005071712
5	Matsa (0509)	2005080400
6	Talim (0513)	2005082900
7	Khanun (0515)	2005090912
8	Damrey (0601)	2006051600

3 EXPERIMENTS OF ENSEMBLE FORECAST

The eight tropical cyclone cases are studied for their 72-h track forecast with the five schemes of cumulus parameterization. It is found that the track forecast is sensitive to the choice of cumulus parameterization schemes and especially so for the time around landfall when the forecast tracks all show considerable amount of divergence (figure omitted). As shown in a study of the vertical thermodynamic structure of the tropical cyclone, the schemes of cumulus parameterization have much greater effect on the prediction of temperature and humidity structure and vertical velocity than on the 500-hPa geopotential field and the difference in the vertical thermal and dynamic structures will gradually increase with model integration and eventually lead to the difference in the tracks predicted.

To further verify the results of individual schemes on the track forecast, this work studies the mean error of 24-h, 48-h and 72-h track forecast and compares them with each forecast of the ensemble members using the following three ensemble schemes (Tabs.2 – 4). (1) The ensemble includes the cumulus-free scheme, Grell, BM and KF; (2) the ensemble includes Grell, BM and KF; (3) the ensemble includes all five members. The results show that the 48 – 72 h track forecasts are significantly divergent, showing the sensitivity of the former to the choice of cumulus parameterization schemes; The tracks are relatively concentrated when three ensemble schemes are used and some of the case tracks are very close to the observation. Tabs.2 – 4 give the quantitative results of track forecasts by individual ensemble member and the three ensemble schemes. In general, Kuo's scheme has larger error than all the other schemes and Grell, BM and KF schemes are close to each other. It is noteworthy that the track forecast with the cumulus-free scheme performs quite well and even better than all the other schemes for the 72-h track forecast. Track forecast is improved significantly with the use of the ensemble schemes. Both the 48-h and 72-h track forecasts are slightly better with Scheme (1) and (3) than with Scheme (2), which is due to the exclusion of the cumulus-free parameterization scheme. It shows that this scheme is favorable for the forecasts of the two valid periods, at least with the existing model resolution. The relatively poor performance of Scheme (3) shows that it may have be related with the inclusion of Kuo's scheme, which does not have the same good performance as the others. The errors for the 24-h and 48-h track forecast have reduced by 30 – 50 km as compared with each of the individual ensemble members while those for the 72-h track forecast have improved less. It can be shown from Tab.2 that the errors mainly contribute from the forecasts of two cases of tropical cyclones, Mindule (No.0407) and Khanum (No.0515). It is interesting to note that Kuo's scheme performs the best in their track forecast, much better than the other schemes. It also shows that the cumulus parameterization schemes are supplementary in advantages and disadvantages and ensemble schemes will improve track forecast to some degree.

For analyses of other aspects, refer to the Chinese edition of the journal.

4 CONCLUSIONS

(1) The forecasts of tropical cyclone tracks are sensitive to the choice of cumulus parameterization schemes, because the difference in the description of convection activity will lead to that in the thermal and dynamic fields predicted and then to that in the (diverging) tracks predicted of tropical cyclones. The cumulus parameterization schemes are supplementary in advantages and disadvantages. Though having the largest error in the forecast of overall track, Kuo's scheme is the best for some tropical cyclones. The choice of cumulus-free scheme performs quite well and is much better than the other schemes as far as the 72-h track forecast is concerned, making it an important reference in forecasting the track of tropical cyclones.

(2) As shown in the results of the three ensemble schemes for track prediction, ensemble forecast is able to reduce the effect of systematic error of the model and the errors of track forecast, being better than the forecast of any single ensemble members. The results of the three ensemble schemes are close to each other and the result of the four schemes combined is the best and has the least mean track errors.

Although unavoidable, the model systematic error can be reduced to some extent if ensemble forecast is used that involves multiple parameterization schemes. Differences among various cases have made it difficult to formulate ensemble schemes and the selection of ensemble members and the determination of the methods for ensemble analysis need to be based on intensive investigation and extensive experiments, which will be the focus in future study.

Tab.2 72-h track forecast errors (unit: km)

TC codes	None	Kuo	Grell	BM	KF	Scheme 1	Scheme 2	Scheme 3
0407	426.04	271.89	402.96	425.03	524.28	437.00	444.90	402.83
0414	117.47	305.46	166.07	97.23	169.06	117.53	126.21	153.15
0418	116.82	172.36	123.96	110.74	193.33	68.53	90.28	70.64
0505	139.33	382.94	63.91	246.58	201.58	120.71	146.44	165.41
0509	195.29	75.31	297.67	158.63	173.29	189.90	191.54	145.74
0513	114.57	454.43	109.37	273.59	184.46	136.88	186.15	197.19
0515	420.17	349.54	442.59	568.84	249.92	388.15	396.42	372.19
0601	298.53	151.32	297.39	199.25	297.20	257.46	244.36	234.91
mean	228.52	270.40	237.99	259.98	249.14	214.52	228.28	217.75

Tab.3 48-h track forecast errors (unit: km)

TC codes	None	Kuo	Grell	BM	KF	Scheme 1	Scheme 2	Scheme 3
0407	154.21	157.28	138.86	146.02	173.16	92.55	91.71	89.14
0414	180.78	166.33	202.12	106.24	141.81	127.25	124.03	122.58
0418	176.72	169.55	183.06	44.73	132.73	46.56	69.90	57.05
0505	107.61	212.01	89.02	154.58	153.66	114.32	121.24	124.88
0509	53.84	46.15	105.46	78.99	59.81	57.91	64.93	46.76
0513	79.28	263.00	90.64	176.99	148.48	95.71	124.67	124.38
0515	185.59	166.99	218.70	319.95	134.20	190.05	200.06	180.54
0601	141.24	63.23	161.52	103.92	135.72	101.65	99.08	90.02
mean	134.90	155.56	148.67	141.42	134.94	103.25	111.95	104.41

Tab.4 24-h track forecast errors (unit: km)

TC codes	None	Kuo	Grell	BM	KF	Scheme 1	Scheme 2	Scheme 3
0407	184.64	271.09	178.81	199.60	188.90	136.58	137.79	149.27
0414	177.66	166.61	159.66	155.12	136.27	99.24	100.44	98.63
0418	149.74	163.74	129.51	131.31	141.64	92.58	91.04	97.76
0505	77.43	108.51	81.02	85.13	90.09	75.81	77.00	79.36
0509	111.80	52.69	84.40	37.60	64.29	51.20	45.20	46.15
0513	84.33	104.33	61.15	98.98	90.46	40.43	49.53	49.02
0515	122.29	64.17	124.96	99.60	79.08	79.00	72.15	70.72
0601	55.83	52.20	50.03	27.71	58.16	39.67	36.61	36.04
mean	120.46	122.91	108.69	104.38	106.11	76.81	76.22	78.36

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