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VERIFICATION OF TROPICAL CYCLONE RAINFALL PREDICTIONS FROM CMA AND JMA GLOBAL MODELS

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Abstract: The number of tropical cyclone (TC) genesis over the South China Sea and the Northwest Pacific Ocean in 2009 is significantly less than the average (27.4). However, the number of landfall TC over mainland China and its associated rainfall is more than the average. This paper focuses on the performance of numerical weather prediction (NWP) of landfall TC precipitation over China in 2009. The China Meteorological Administration (CMA) and Japan Meteorological Agency (JMA) models are compared. Although the schemes of physical processes, the data assimilation system and the dynamic frame are entirely different for the two models, the results of forecast verification are similar to each other for TC rainfall and track except for TC Goni. In this paper, a day with daily rainfall amount greater than 50 mm was selected as a storm rain day when there was a TC affecting the mainland. There are 32 storm rain days related to the landing of typhoons and tropical depressions. The rainfall forecast verification methods of National Meteorological Centre (NMC) of CMA are selected to verify the models' rainfall forecast. Observational precipitation analyses related to TCs in 2009 indicate a U-shape spatial distribution in China. It is found that the rain belt forecasted by the two models within 60 hours shows good agreement with observations, both in the location and the maximum rainfall center. Beyond 3 days, the forecasted rainfall belt shifts northward on average, and the rainfall amount of the model forecasts becomes under-predicted. The rainfall intensity of CMA model forecast is more reasonable than that of JMA model. For heavy rain, the JMA model made more missing forecasts. The TC rainfall is verified in Guangdong, Guangxi, Fujian and Hainan where rainfall amount related to TCs is relatively larger than in other regions. The results indicate that the model forecast for Guangdong and Guangxi is more skillful than that for Hainan. The rainfall forecast for Hainan remains difficult for the models because of insufficient observation data and special tropical ocean climate.

Key words: tropical cyclone; rainfall; model; verification

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1 INTRODUCTION

The numbers of tropical cyclone (TC) in 2009 were significantly less in comparison to the climatology over the South China Sea and the West Pacific. However, the year saw more TCs landing in China and the annually first TC landed in China earlier than the average. Further, heavy rainfall zones were located along the southeast coast of China in 2009. As the TC structure usually changes evidently during landing, TC-induced rainfall becomes more difficult to forecast during this period. In Taiwan Island, Typhoon Morakot caused unprecedented disastrous flooding for the past 50 years with at least 491 dead and several hundreds missing. The distributions of rainfall were complicated.

There are detailed analyses and summaries of typhoon track and intensity predicted by numerical models and forecasters in Typhoon and Marine Weather Forecasting Center of National Meteorological Centre (NMC), Shanghai Typhoon Institute and Guangzhou Institute of Tropical and Marine Meteorology, and some case studies have been carried out on severe TC rainfall[1-4], and investigations on the impact of typhoon precipitation on climate change are shown in Wang et al.[5] , Chen et al.[6] , Li and Gao[7] , and Li et al.[8]. However, except for the study of Huang et al.[9] for the evaluation of GRAPES-TCM rainfall forecast for 4 of China's landing tropical cyclones in 2006 (and just for 1 day), there are almost no investigation into annual rainfall forecast related to TCs over the whole China for longer duration. Up to now, a little verification has been performed for rainfall prediction from numerical

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forecasts of landfall TCs in the world. Tuleya et al.[10] verified GFDL and simple statistical model rainfall forecasts for 25 U.S. landing tropical storms during 1997–2002. Three methods are presented to verify the landing TCs. However, TC rainfall cases are extreme and root mean square error (RMSE) looks bigger than in usual rainfall cases. As a result, this study selected two other methods to verify the TC rainfall.

2 MODEL DESCRIPTION AND VERIFICATION METHODS

A hydrostatic model, TL639L60, has been developed at China Meteorological Administration (CMA). It was put into official operation on 9 March, 2009. It runs with a horizontal resolution of 639 waves (30 km) and 60 vertical levels (up to 0.1 hPa), with a time step of 600 s. 10-day forecast is made twice a day, at 0000 and 1200 Coordinated Universal Time (UTC) respectively. Its physical processes include long-wave radiation[11], short-wave radiation [12]), sub-grid orographic gravity wave drag parameterization, Mass Flux Scheme for Cumulus Parameterization[13]) , turbulence diffusion, cloud and large-scale precipitation parameterization schemes, and soil and surface process schemes, among others.

The Japan Meteorological Agency (JMA) model, T959, upgraded the resolution of the Global Spectral Model (GSM) from TL319L40 to TL959L60 on 21 November, 2007. The major changes are as follows: (1) an increase in the resolution from TL319L40 to TL959L60 with the topmost level raised from 0.4 hPa to 0.1 hPa, (2) an increase in the resolution of the inner model of the four-dimensional variational (4D-Var) data assimilation system from T106L40 to T159L60, (3) use of new data from high resolution analysis of sea surface temperature and sea ice concentration as ocean surface boundary conditions, (4) use of surface snow depth data from the domestic dense observational network in global snow depth analysis, (5) upgrade of the numerical integration scheme from a three-time-level leap-frog scheme to a two-time-level scheme, (6) introduction of a new convective triggering scheme proposed by Xie and Zhang[14] into the deep convection parameterization, and (7) introduction of a new two-dimensional aerosol climatology derived from satellite observations for radiation calculation.

Table 1 gives the two models about TC track forecast mean errors in 2009. The track errors are close to each other within 72 h, and most of landing TC track forecast is similar to each other except for TC Goni. The TC rainfall forecast is further verified in this study.

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Table 1. Mean errors of TC track forecast from CMA and JMA models.

	24 h	48 h	72 h	96 h	120 h
CMA T639 (km)	126	220	326	415	588
JMA T959 (km)	124	220	316		

An NMC data set, which includes the TCs which occurred in Northwest Pacific and the South China Sea and 24-h accumulated precipitation (from 0000 UTC to 0000 UTC) from 2510 observation stations in mainland China in 2009, is used in this study. It is observed that the TC landfall of interest started with a typhoon on June 22, and ended with a tropical depression on October 23, 2009. During the TC season from June to October in 2009, 9 tropical storms and 2 tropical depressions that caused heavy rainfall were observed. In order to understand the performance of the numerical weather prediction (NWP) models, a TC torrential rain day is defined to take place when a dominant tropical weather system occurs with at least one observation of more than 50 mm of precipitation in 24-h accumulation. In total, 32 TC torrential rain days have been identified during the TC season. We calculated the observed mean rainfall distribution for those 32 TC torrential rain days and compared them to those predicted for the same 32 TC torrential rain days by CMA' T639 model and JMA's T959 model. The forecasts were statistically verified and compared with the forecasts made by forecasters [15]. In order to give more details of TC rainfall process forecast in the different provinces which were more significantly affected by the TC landfalls, the evolution of the rain process was evaluated. The results showed that the TC rainfall forecasts in Guangdong are better than those in Hainan and other provinces.

3 RAINFALL PREDICTIONS FROM THE MODELS

Figure 1 illustrates the observed mean rainfall distribution for the 32 TC torrential rain days in 2009. The distribution of the TC rainfall was mainly along the southeast coast of China. Strong rain zones cover Leizhou Peninsula of Guangdong province and the north of Hainan province. The most remarkable annual rainfall is found in Hainan in those 32 TC torrential rain days. Except for the southern area, the daily rainfall rate exceeds 20 mm, and the annual amount of precipitation is over 600 mm. In addition, the TC rainfall spatial distribution is in a U shape: less rainfall is observed in the central part of mainland

China. The observed rainfall in the southeast coast and eastern part of southwest of China is much larger than in other regions. In most parts of Hubei, Hunan and Jiangxi provinces, the rainfall is less remarkable. This distribution is due to the northeast wind at 110°E, leading to less rainfall when the TCs landed in the southeast coastal regions. Why there is more rainfall in the southwest needs further investigation.

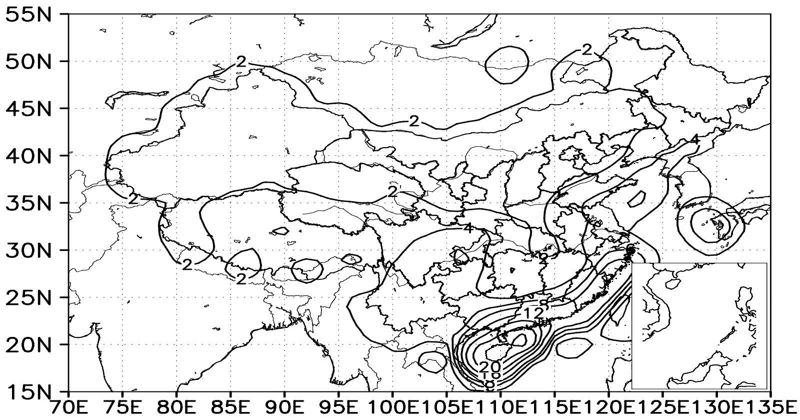
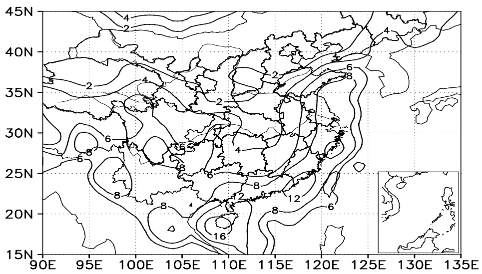


Figure 1. Daily average of observed rainfall (mm/d) for the 32 TC torrential rain days in 2009.

Figures 2 and 3 depict the mean rainfall prediction of CMA's T639 and JMA's T959, respectively. The predicted rain zones are similar to the observation for all 36- to 108-h forecasts. The 60-h forecast is in better agreement with observations both in distributions and locations of the heaviest rainfall. Two models underestimate the intensity of typhoon rainfall in comparison to the observation, and the rainfall intensity of the T639 model is better than that of the T959 model.

The U-shape distribution of the 84-h rainfall forecasts can still be easily identified for both the T639 and T959 models, but with over-estimations in the east, south and west parts of mainland China. For the 108-h forecasts, the rainfall amount decreases in general with a relatively indistinct pattern of U-shaped spatial distribution of the rainfall. After 132 h, the rainfall forecast belts are not clearly consistent with the observation.



(a)

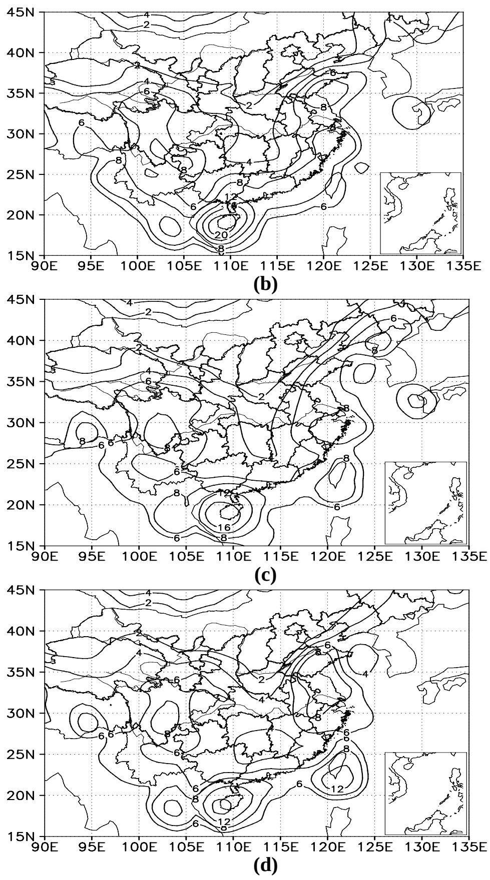


Figure 2. The same as Figure 1 but for the forecast of CMA's T639 model (a: 36 h; b: 60 h; c: 84 h; d: 108 h).

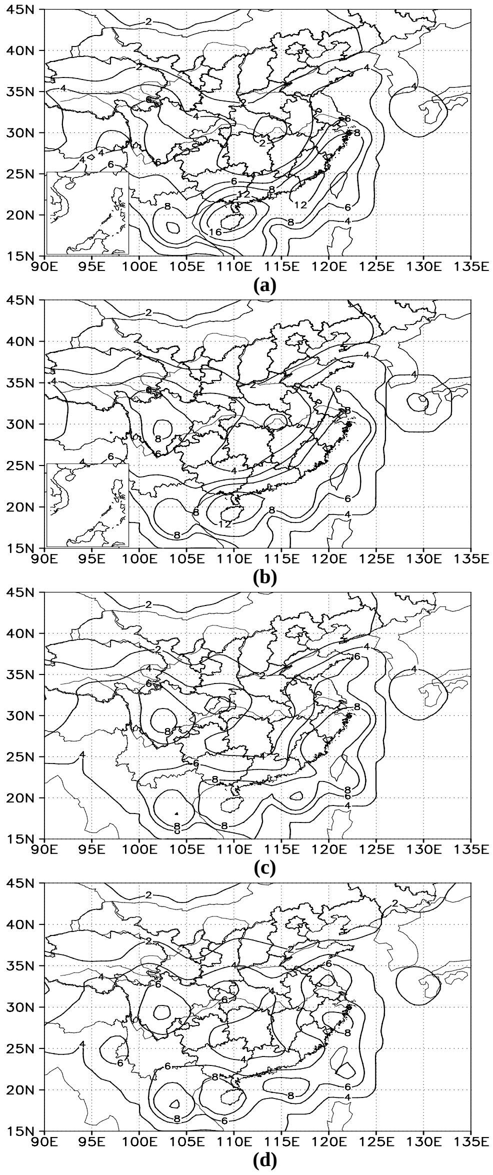


Figure 3. The same as Figure 1 but for the forecast of JMA's T959 model (a: 36 h; b: 60 h; c: 84 h; d: 108 h).

The distribution for June, July, August, September and October monthly mean TC rainfall is different from the observed annual mean rain because of TC landing position and time differences (Figure 4). The rain amount is larger in August, September and October than in the other two months. The monthly rain forecasts of the two models exhibit agreement.

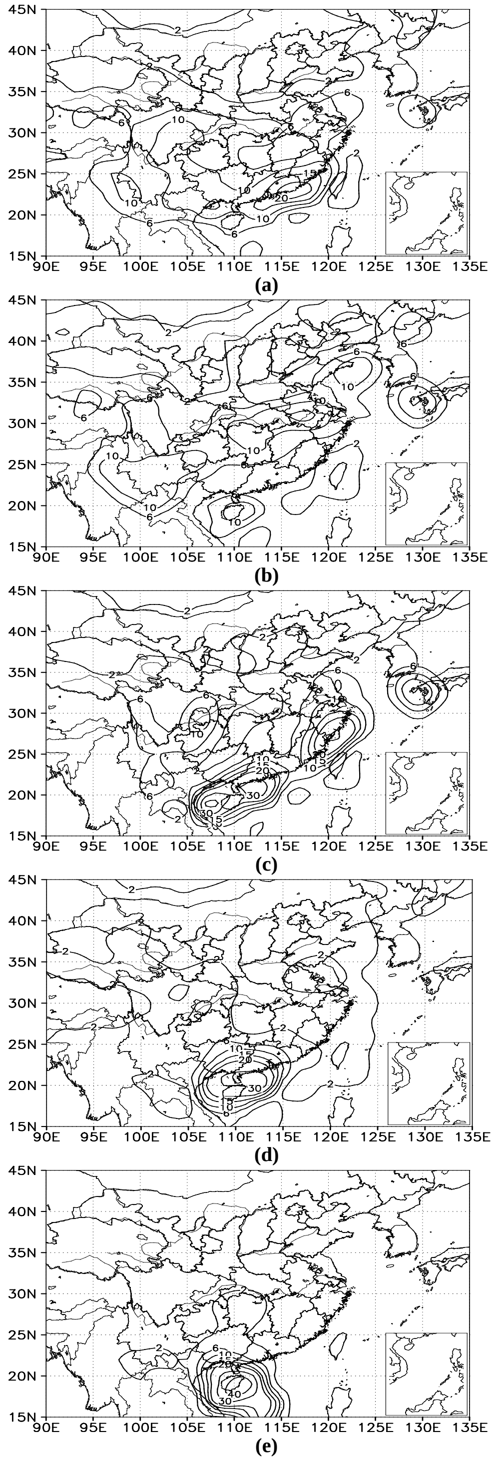


Figure 4. Daily averaged rainfall observation (mm/d) for landing TCs in June (a), July (b), August (c), September (d) and October (e), 2009.

4 VERIFICATION OF RAINFALL FORECASTS

The statistical scores, TS (Threat Score) and Bias, are used for the verification of precipitation forecasts by CMA's T639, JMA's T959 and the forecasters of NMC. The verification results are listed in Table 2. It shows that TS of forecasters is generally higher than those of NWP models, except for the threshold above 10 mm/d of the 24-h forecasts. This means that the forecasters can well "ingest" all the most recently available information of predictions and observations, and give better forecasts than the models. However, the bias made by forecasters is also higher than those by both NWP models for higher thresholds of 10–50 mm/d for 24–108 h forecasts. Beyond 120 h, the bias of T639 is the highest. However, the TS of the CMA T639 is higher than those of the JMA T959 for nearly all the valid time of the 50 mm threshold except for the 36-h forecast. In other words, the CMA T639 is superior to the JMA T959 for the TC storm rain in 2009.

Table 2. Verification results of rainfall forecasts by forecasters of NMC, CMA T639 and JMA T959 models over mainland China for the 32 typhoon torrential rain days.

		TS						Bias					
		24/36h	48/60h	72/84h	96/108h	120/132h	144/156h	24/36h	48/60h	72/84h	96/108h	120/132h	144/156h
≧0.1mm	F	0.616	0.572	0.552	0.532	0.496	0.464	1.111	1.123	1.072	1.09	1.062	1.015
	JMA	0.555	0.542	0.521	0.495	0.472	0.456	1.684	1.714	1.701	1.737	1.625	1.59
	CMA	0.561	0.532	0.499	0.484	0.467	0.451	1.477	1.475	1.46	1.49	1.503	1.57
≧10mm	F	0.294	0.264	0.227	0.203	0.181	0.152	1.663	1.565	1.677	1.655	1.788	1.813
	JMA	0.303	0.257	0.213	0.163	0.148	0.138	1.017	1.069	0.977	1.021	1.003	1.198
	CMA	0.278	0.205	0.165	0.139	0.119	0.097	1.377	1.393	1.556	1.629	2.079	2.339
≧25mm	F	0.271	0.233	0.193	0.153	0.108	0.078	1.533	1.543	1.35	1.321	1.543	1.417
	JMA	0.218	0.19	0.153	0.078	0.057	0.058	0.591	0.677	0.61	0.523	0.518	0.612
	CMA	0.196	0.161	0.131	0.109	0.071	0.049	0.931	0.91	0.949	1.061	1.387	1.612
≧50mm	F	0.223	0.168	0.129	0.085	0.067	0.044	1.688	1.534	1.491	1.193	1.471	0.997
	JMA	0.164	0.101	0.072	0.017	0.021	0.03	0.448	0.41	0.511	0.335	0.196	0.227
	CMA	0.116	0.11	0.087	0.047	0.038	0.012	0.822	0.867	0.816	0.922	1.016	1.259
≧100mm	F	0.097	0.078	0.037	0.031	0.029	0.016	1.846	1.365	1.086	1.005	0.659	0.927
	JMA	0.051	0.02	0.021	0	0.011	0	0.277	0.213	0.347	0.146	0.166	0.36
	CMA	0.065	0.027	0.039	0.013	0.018	0.002	0.827	1.052	1.3	1.252	1.173	1.446

It is noted that for the cases of Goni and Morakot in which the TC tracks were complicated, the NWP models gave better prediction than the forecasters.

Because the TC landfall mainly affected Hainan, Guangdong, Guangxi and Fujian in 2009, TC rainfall verifications are specifically conducted in this paper for them. The results show that the evolution of rainfall is not well predicted more than 3 days ahead. From the daily mean precipitation rate of typhoon rainfall over Hainan province where TC affected most frequently in 2009, it shows that the forecasts of the JMA's T959 model are slightly more skilful than those of the CMA's T639 model. For rates more than 20 mm/d, however, it underestimates the rainfall. Moreover, the forecast maxima of most TC cases appear ahead of or behind observations, with the case of TC 0917—Parma being the exception, in which the forecast of 50 mm torrential rain is accurate in occurrence time. The TC rainfall amount of the T639 60-h forecast is close to the observation, particularly for the torrential rains of more than 50 mm with Goni, Mujigae and a tropical depression in October. In addition, the date on which TC 0917 gets extreme is consistent with that of the T639 forecast, but the amount is less than the observation.

The TC precipitation forecast is better for Guangdong than for Hainan. The changing tendency of rainfall of the two models is inconsistent with the rainfall observation, and the intensity is close to the observation, particularly for the 36-h and 60-h forecasts.

Moreover, in Guangxi the change of TC rainfall tendency is inconsistent with that of the observation. Meanwhile the 36-h forecasts for Molave and Koppu are quite accurate, and the tendency and intensity are close to the observation, while the rainfall forecast of typhoon Morakot in Fujian by the T639 model is better than that of the JMA model in short range.

5 SUMMARY

The verification results show the rainfall belts of 60-h forecasts of both models (T639 and JMA's T959) are corresponding closely to the observations. The location of rain belts and maximum rainfall center are also in good agreement with the observations. But the rain belts of 3-day forecasts are shifted to the north of the observation, and the models underestimate the amounts as compared to the observation.

The statistical verification shows that the model of CMA made better rain forecast of heavy rain than the JMA model, though the latter made better rain forecast of medium rainfall than the former. The verification of rainfall forecasts have been conducted in detail for the southern and south-eastern coastal regions of China, such as Guangdong, Guangxi, Fujian and Hainan where TC affected more frequently than in other regions of China. The verification results show that the predictions of NWP models are more skillful in rainfall forecasts for Guangdong and Guangxi than for Hainan. It is known that Hainan is an island surrounded by sea and observations are not enough for data analysis. In addition, Hainan is located in the tropical zone and the synoptic systems change sharply. The JMA and CMA models are hydrostatic. They are not adequate to describe the tropical convection. In order to improve the rain forecast for Hainan, satellite and radar data must be used in the global model. Moreover, schemes for convection parameterization need to be modified to better describe the evolution of tropical synoptic systems.

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