IMPROVEMENT OF QUANTITATIVE PRECIPITATION FORECAST IN HUAIHE BASIN BASED ON DOWNSCALING BY WRF MODEL

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ABSTRACT

In this study, an attempt was made to improve QPF (Quantitative Precipitation Forecast) skill in Huaihe Basin based on Numerical Weather Predictionto increase the accuracy and resolution of flood forecasting as well as prolong the lead time for flood fighting preparedness. In order to achieve the target, JMA (Japan Meteorological Agency) and ECMWF (European Centre for Medium-Range Weather Forecast)data were utilized.The Weather Research and Forecasting (WRF) model was employed for dynamical downscaling. Downscaling corrected the locations of the misplaced ECMWF forecasts and the underestimated rainfall amount derived from JMA. Downscaled forecasts predicted more accurate amount of rainfall in the right location 3 days ahead of the rainfall occurrence. Meanwhile, the resolution of precipitation forecast became 5 times and 19 times higher in the outer and inner frame respectively. Finally, flood peak can be predicted 5 days in advance.

Keywords: Quantitative, Precipitation, Forecast, downscaling, parameterization

INTRODUCTION

HuaiheRiver which is located in the eastern part of China (112°E -121°E, 31°N -36°N) is considered as one of the seven largest rivers in China with a catchment area of approximately 270,000 km^2 (Figure 1).This basin suffers from flood frequently. As a result,the improvement of flood forecast skill is urgently demanded. Numerical Weather Prediction (NWP) as the most essential method has been a strong support for the predicted precipitation forecast period of hydrological model. However, the NWP has low resolution and doesn’t focus on the meso-scale weather system. As a result, downscaling is carried out with the help of WRF model to produce more accurate QPF with longer lead time and higher resolution. This research focus on a heavy rainfall case which occurred on July 8^{th} during flood 2007. The heavy rainstorm (daily precipitation ≥100 mm) appeared in the 26 stations along Huaihe River, among them Anhui Yingshang County and Fengtai County reach 221.5 mm and 219.4 mm respectively. Due to this rainfall process, the discharge of Wangjiaba climbed to the peak value (4600 m^3/s) and water level reached 29.59 m, exceeding highest safety stage on July 11^{th}.

METHODOLOGY

First of all, NWP data (JMA, ECMWF) were used as input to WRF model for downscaling. The Weather Research and Forecasting (WRF) Model is a next-generation meso-scale numerical weather prediction system designed to serve both atmospheric research and operational forecasting needs.

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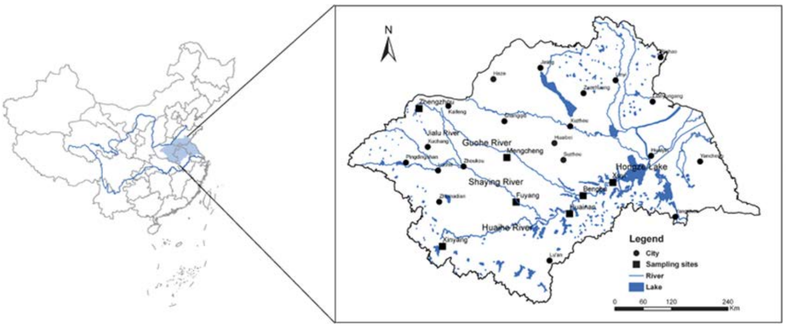

Figure 1 Geographic location of HRB

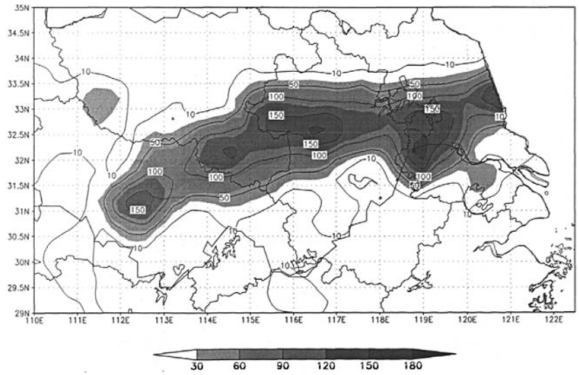

Figure 2 Accumulated precipitation distributionon July 8th

The design of WRF model about parameters and domain are shown in Table 1. During downscaling, 11 combinations of physical parameterization were selected for inter-comparison to customize WRF model.The 11 sets include 2 land-surface schemes(thermal diffusion scheme, unified Noah scheme), 4 cumulus convection parameterization schemes(Kain-Fritsch scheme,Betts-Miller-Janjic scheme, Grell-Devenyi ensemble scheme, New Grell 3D scheme) and 7 microphysical schemes(Kessler scheme, Lin et al., scheme,WSM 3-class simple ice scheme, WSM 5-class scheme, Ferrier microphysics, WSM 6-class graupel scheme, Thompson graupel scheme). After forecast skill of each set of physical parameterization schemes were evaluated by objective and quantified metrics, such as threat score, regional average precipitation, and absolute error, the optimal scheme was selected. Next, it was applied to ECMWF and JMA forecast with different initial time and compared with the original version to check the improvement of predictability. Lastly, the application of downscaling based on the parameterization were evaluated and the importance of application for flood mitigation was analyzed.

Table 1The overview of the WRF model configuration used in the present study.

Model configuration	**Model specifications**	
	Outer frame	Inner frame
Horizontal grid spacing	20Km	5Km
Number of horizontal grid points	80*70	157*117
Centre of domain	33.206°N, 116.104°E	
Horizontal grid system	Arakawa C-grid	
Integration time step	60s	
Number of vertical levels	28	
Top of model	50hPa	
Initial conditions	ECMWF	
Lateral boundary conditions	ECMWF	
Shortwave radiation	Dudhia (1989)	
Longwave radiation	RRTM	
Surface layer	Monin-Obukhov scheme	
Planetary boundary layer	Mellor-Yamada-Janjic (Eta) TKE scheme	

DATA

The THORPEX Interactive Grand Global Ensemble (TIGGE) provides operational global ensembleforecast data quasi-operationally (2 days delay). ECMWF and JMA precipitation forecast data which have the horizontal resolution of 0.5*0.5 spacing grid were downloaded from TIGGE portal. The longest forecast time of ECMWF is 360 hours (15 days) with 6 hours interval, and JMA is 264 hours (9 days) with the same time interval. 9 parameters were selected for the downscaling in the surface layer. In the pressure level, 5 meteorological elements (geopotential height, specific humidity, temperature, U velocity, V velocity) in 9 levels (1000 hPa, 925 hPa, 850 hPa, 700 hPa, 500 hPa, 300 hPa, 250 hPa, 200 hPa, 50 hPa) were collected. All of the data are written in Grib2 format.The Grid Analysis and Display System (GrADS) is an interactive desktop tool that is used for easy access, manipulation, and visualization of earth science data (from GrADS homepage)

RESULTS AND DISCUSSION

1. Customization Result by Inter-comparison of Physical Parameterization Schemes

Customization of WRF model was done by following the procedures: First of all, I used “Kain-Fritsch scheme” as cumulus convection scheme and “WSM 5-class” as microphysical scheme. Next, comparison was made between "thermal diffusion scheme" and "Noah schemes" to select the optimal land-surface scheme. After two runs, I used the selected land-surface scheme and fixed microphysical scheme (WSM 5-class) to search the suitable cumulus convection scheme among "Kain-Fritsch scheme" "Betts-Miller-Janjic scheme", "Grell-Devenyi ensemble scheme" and "New Grell 3D scheme". Afterward, land-surface scheme and cumulus convection scheme have been selected, comparisons among"Kessler", "Lin", "WSM 3-class", "WSM 5-class", "Ferrier", "WSM 6-class" and "Thompson" was conducted to fulfill purpose of selection. At last, an optimal combination of parameterization schemesthat is the configuration of Noah scheme, WSM 6-class scheme and Betts-Miller-Janjic scheme (set 10)was selected,.

Quantification was conducted with the help of different statistical metrics including threat score (Figure 3) and regional average rainfall (Figure 4).In outer frame, comparing the best scheme with the WRF default schemes (set 1), the threat score of light rain increased from 0.23 to 0.55 while the TS of rainstorm increased from 0.04 to 0.13. On the other hand, the best scheme decreased the absolute bias of regional average rainfallfrom -21 mm to -3 mm. Thus, parameterization played an important role on the improvement of precipitation forecast skill.

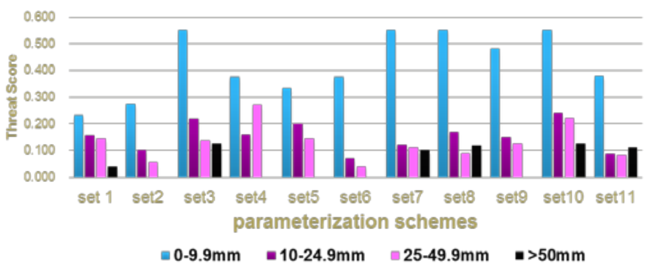

Figure 3 The threat scores of different parameterization schemes in outer frame

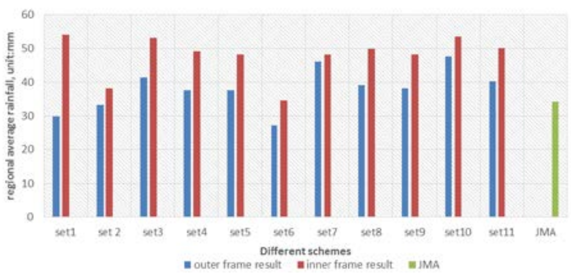

Figure 4 The regional average rainfall generated from different parameterization scheme and original JMA forecast

2. Improvement of QPF by Downscaling ECMWF Forecasts

Downscaling was performed using the optimal parameterization scheme with different lead time. The simulated precipitation predictions was initialized from July 1 to July 7, 2007. Through the analysis, it was found out that if the downscaling wasn't carried out, no heavy rainfall could have been predicted in Huaihe Basin. Thus, the precipitation forecast in ECMWF original forecasts can't be helpful for flood control. After the downscaling, a heavy rainfall belt is predicted 6 days earlier and the maximum precipitation is over 200 mm which matched the actual condition. Even the location of rain band is north, when the lead time becomes shorter, the predicted precipitation area become closer to observed precipitation. After downscaling, the QPF captured the horizontal scale and intensity of weather system to some extent which can give a good clue to the forecasters.

3. Improvement of QPF by Downscaling JMA Forecasts

A subjective comparison was done between the QPF from original JMA forecasts and its downscaling.Before downscaling, a rain belt was predicted in the correct location by JMA. However, the intensity was greatly underestimated. The maximum rainfall was predicted to be only 80 mm in the forecast by JMA initialized on July 5^{th}(Figure 5). It is difficult to be taken note by flood fighters and decision makers. According to this QPF, the early warning alarm may not have been issued. However,the downscaling forecast with the initial time on July 5^{th}(Figure 6) predicted the location of heavy rain band and rainfall center as well as rainfall intensity much better than the previous forecast. More details about heavy rainfall centers are shown in Figure 6. As we knew, there are five storm centers in observed precipitation distribution. Four of them which lie in (112.5°E,31.2°N), (114.6°E,32.3°N),(116.5°E,32.5°N),(119°E,32.5°N) respectively are predicted in a proper location close to observed rainfall centers. In addition, the mainstream of Huaihe River is predicted to receive more than 60 mm precipitation which is similar to the rain gauge data. In the aspect of maximum rainfall, it is predicted to be 160 mm with 20 km resolution and 200 mm with 5 km resolution. The observation shows that 12 stations have accumulated precipitation of over 150 mm. The daily precipitation in Fengtai county and Yingshang county in Anhui Province reach 219.4 mm and 221.5 mm respectively. So the intensity also agreed with the observed rainfall very well.

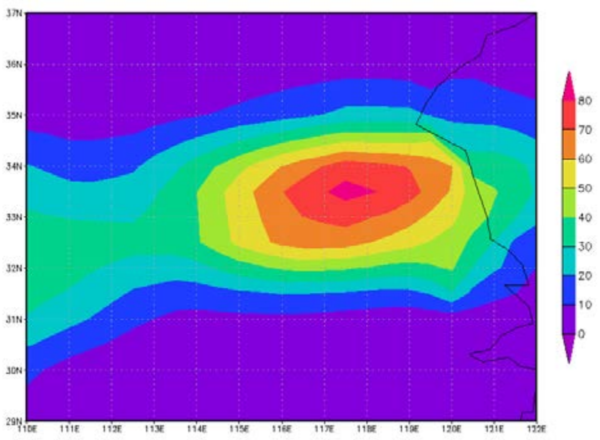

Figure 5 Prediction of accumulated rainfall by JMA original dataset initialized onJuly 5^{th}

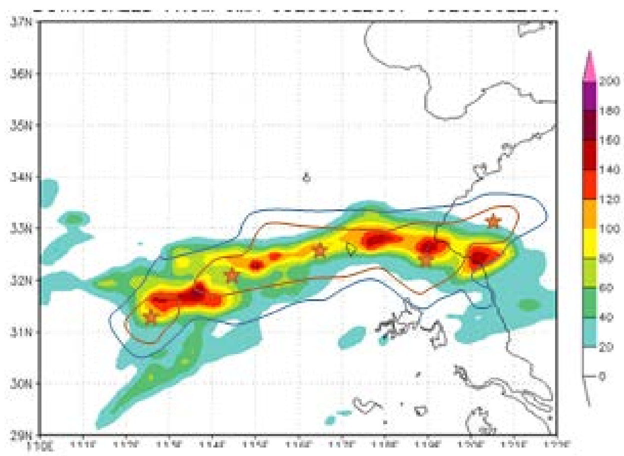

Figure 6 Downscaled precipitation forecast of JMA initialized on July 5^{th}

4. Evaluation of Downscaled Forecasts

When we evaluate the simulation result of WRF model with the initial time on July 5th, several statistical metrics are commonly used [e.g., Yu et al., 2006; Han et al., 2008], such as correlation coefficient (corr) and root mean-square error (RMSE). All the formulas of these metrics can be found in Seigneur et al. [2000].

① Correlation Coefficient

There is a higher correlation between forecasting and observation with the correlation coefficient of 0.664. According to correlation coefficient significant checking table, under α=0.01 significance level, the correlation coefficientpassed the significance test. It is concluded that there is a significant correlation between downscaled forecast and observed rainfall.In addition, we selected the correlation coefficient of precipitation forecast whose lead time is 24h from JMA and CMA for comparison. The correlation coefficients are 0.4-0.6 in JMA and 0.2-0.5 in CMA. So the correlation coefficient (0.664) of QPF downscaled by JMA is higher than both JMA and CMA. The improvement was made by downscaling.

②Threat Score

On July 5th, very high scores of light rain (0.84) and rainstorm (0.67) are displayed. Comparisons were done between the best annual threat scores of precipitation forecasting in Anhui Meteorological Observatory and downscaled JMA forecasts with similar lead time. In 2011, the threat score of light rain (0-9.9 mm), moderate rain (10.0-24.9 mm), heavy rain (25-49.9 mm) and rainstorm (>50 mm) in AMO with the lead time of 3 days are 0.39, 0.17, 0.10 and 0.09 respectively. On the other hand, downscaled forecasts with the same lead time which have the TS of 0.84, 0.17, 0.20 and 0.67 sequentially show significant improvement of predictability.

5. The Application of improved QPF in Flood Disaster Mitigation

Hydrograph of Huaibin hydrologic station (Figure 7) illustrates that about 2 days after the heavy rainfall event on July 8thwhich was predicted 3 days before, the flood peak appeared.Thus, the first floodgate can be predicted 5 days in advance. On the other hand, another flood peak occurred 3 days after the third rainfall process. The third rainfall event was predicted 8 days before.

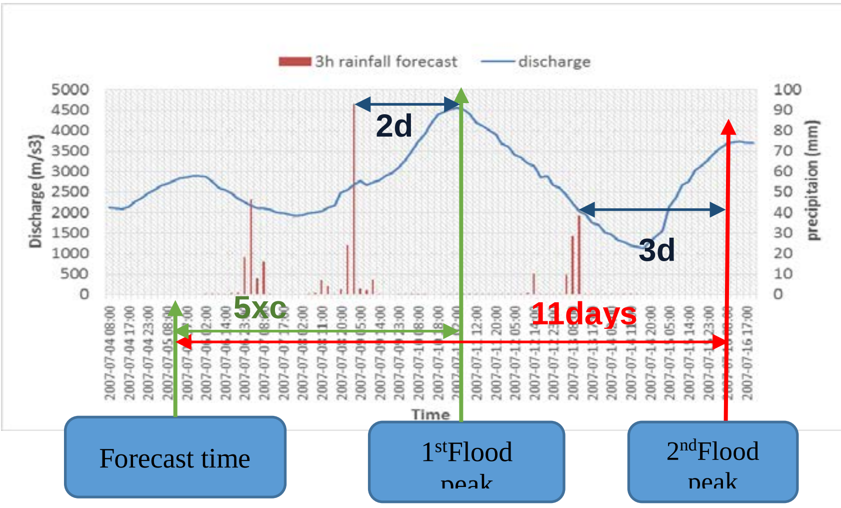

Figure 7 The observed discharge and predicted rainfall initialized on July 5th

Therefore, the second flood peak can be forecasted 11 days in advance.That means, after the decision makers receive the forecast information produced by downscaled JMA forecasts on July 5th, they will have more than 5 days to take action in advance to minimize the losses caused by the coming flood. So the QPF products which obtained from our study are quite useful for flood disaster mitigation.

CONCLUSIONS

(1) Before downscaling, inter-comparison of physical parameterization schemes is proved to be necessary to customize WRF model. The suitable cumulus convection scheme, land-surface scheme and microphysical scheme can simulate precipitation system better. It was proven that the best scheme has more predictability than the default scheme.

(2). Resolution is increased by downscaling. After downscaling, the resolution of QPF become 5 times higher in the outer frame and 19 times higher in the inner frame.

(3) Through subjective evaluation, improvements are made by downscaling both in the aspect of intensity and vastness. Both downscaled JMA outputs and ECMWF outputs indicate a large scale heavy rainfall event during July 8thand July 9th.

(4) Through objective evaluation, it was proven that downscaling can obtain QPF with more accuracy. The performances of downscaled JMA forecast were evaluated by threat score and correlation coefficient. The results show that after downscaling, the threat scores of heavy rainfall is 58% higher than the prediction level of AMO. The correlation coefficient of downscaled version is higher than that of JMA and CMA and has significant relation with the observed rainfall.

(5) The improved QPF with longer lead time creates more time for flood fighting preparation. Decision makers have more than 5 days in advance to take action before flood peak occur if they refer to the QPF products obtained from our study.As a result it plays an important role on flood mitigation.

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