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Calculating the fine spatial distribution of the daily precipitation in the Heihe River Basin by using WRF model output result with DEM method

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ABSTRACT

Because that the terrain is complex and the station is scarce in the Heihe River Basin, understanding the fine spatial distribution and the amount changes of precipitation become a difficult problem. This paper focuses the influence of the atmospheric variability in the earth-atmosphere system on the precipitation to solve the above problem. Firstly, The paper designed a 16-member sensitivity test by a cross pairing of different parameterization schemes of land surface process, planetary boundary layer and microphysics. Based on which, we simulated two representative precipitation events in the Heihe river basin, and verified the simulation effect with the daily precipitation data observed by 12 meteorological stations in this area. The sensitivity tests showed that the WRF model have a good performance to the topographic effect of precipitation process. Secondly, using the best combination of parameterization schemes, we get the data of the daily precipitation and make the precipitation as a function of latitude, longitude, slope. Combined the model output with DEM analysis of the daily precipitation, We present a method to calculate the grid distribution of precipitation(100m×100m) and the corresponding results, by "dynamical - Statistics" downscaling methods. This paper gives a different approaches and has a reference value to the research of the fine spatial distribution in the Heihe River Basin.

Key words: Heihe River Basin, precipitation, downscaling methods, fine spatial distribution

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INTRODUCTION

The Heihe River Basin is a typical inland river basin in the arid and semi-arid areas of northwest China. The precipitation here is more concentrated in the southern Qilian Mountains with gradual reduction from south to north as the terrain changes[1,2]. Precipitation is the most important source of the surface water resource in the Heihe river basin, which has great significance for regional ecological security and sustainable development of the socioeconomic system. At present, the fine distribution of precipitation is basic input for eco-hydrological process studies, and also is a premise for accurate calculation of total precipitation[3]. The Heihe river basin locates in the transitional zone of the westerly and the southwest monsoon and also in the northeast of the Qinghai Tibet plateau. For this reason, the study of precipitation has become a difficult problem. In this paper, we studied the fine distribution of precipitation in this area for above demand.

The downscaling method is based on the large-scale climate change as the background of regional climate change. Such theory is to transform low-resolution information into regional-scale surface climate. Studies have shown that using global climate model (GCM) to simulate large-scale climate information is credible, serving as a very important premise for downscaling[4,5]. WRF model as a mesoscale numerical simulation system provides extraordinary result. But since the model provides a multitude of physics parameterization schemes, such as microphysics schemes, cumulus convection schemes, the selection of an appropriate parameterization scheme is particularly important. To this end, national and international scholars have done a lot of researches[6,7].The correspondence of each physical parameter in the simulation to the spatial location is the key to the precipitation simulation. Many scholars noted that parameterization scheme has a strong regional[8,9]. So different regions, exactly what sort of schemes will be better still need further study.

At the same time, the daily precipitation had significant correlation with altitude, latitude and slope, and the relationship model was established between the precipitation and geographical and topographic parameters[10]. Fitting analysis showed that the regression equations of the daily precipitation was through the 0.001 credibility test. On the basis of the previous findings, the paper simulated the two precipitation processes in the Heihe river basin with several better physics parameterization schemes commonly used in order to select the parameterization schemes suitable for the precipitation simulation. Based on the relation model of precipitation and geographical and topographic parameters, using the high-resolution DEM data, the fine spatial distribution(100m×100m) of the daily precipitation was obtained in the Heihe river basin. The results indicated that the fine distribution of precipitation can show more details about the topographic and topographic which were better than the analysis results only by using meteorological stations measured data.

MODEL AND SIMULATIONS

The comparison precipitation data used in the paper came from the observation of daily precipitation by 12 ground meteorological stations in the Heihe River Basin (1 Shandan, 2 Minle, 3 Qilian, 4 Yeniugou, 5 Tuole, 6 Sunan, 7 Zhangye, 8 Linze, 9 Gaotai, 10 Jiuquan, 11 Jinta, and 12 Dingxin) from 2008 to 2009. The data was from the Environmental and Ecological Science Data Center for West China.

Through statistical analysis of the daily precipitation data in the Heihe river basin, two representative precipitation processes were selected (respectively, test 1: July 9-11, 2008; test 2: July 15-17, 2009). The daily precipitation of two processes observed by the 12 meteorological stations was shown in Fig.1. The accumulated precipitation of the 12 stations for each test was 164.6 mm and 74.4 mm respectively.

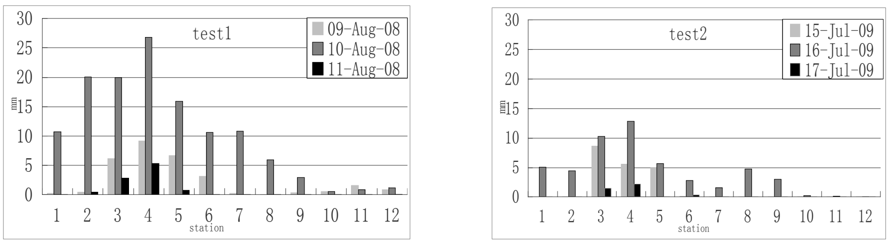

Fig.1: Observed daily precipitation of two events

Regarding verifying and processing the model result, the simulated value of the simulation grid point nearest to the latitude and longitude of the stations was analyzed comparing with the observed value. And the proximity between the simulated result and measured result of each member was analyzed by using the following statistical methods. The root-mean-square error was used to measure the deviation between the observations and true value, which was very sensitive to the extra large or very small data (Equation 2). The correlation coefficient reflects the relevance of the two sets of data. The greater the absolute value of the correlation coefficient, the stronger the relevance. The correlation coefficient closer to 1 or -1 represents a stronger relevance, while to 0 for weaker relevance (Equation 3).

$$Bias = \frac{1}{N}\sum_{i=1}^{n}(M_i - O_i) \tag{1}$$

$$E = \sqrt{\frac{1}{N}\sum_{i=1}^{n}[(M_i - M) - (O_i - O)]^2} \tag{2}$$

$$R = \frac{\sum_{i=1}^{n}(M_i - M)(O_i - O)}{\sqrt{\sum_{i=1}^{n}(M_i - M)^2}\sqrt{\sum_{i=1}^{n}(O_i - O)^2}} \tag{3}$$

Where, n is number of stations within the region; M is the simulated value; O is the measured value. The correlation coefficient between the simulated value and observed value was calculated by using Pearson linearly dependent coefficient.

The paper verified several physics parameterization schemes with better simulation effect in WRF 3.1 version by referenced to the previous research findings. In order to further understand and know their performance, characteristic and sensitivity to the precipitation simulation, providing some reference for rational selection and use of physics parameterization schemes in the model.

The selection of physics parameterization schemes was shown in the table 1. The microphysics schemes including four kinds: Ferrier, WSM3, WSM5 and Lin; the land surface process schemes including two kinds: NOAH and RUC. The surface layer determines the friction velocity and exchange coefficient of the surface heat and moisture flux, which is closely related to planetary boundary layer. The planetary boundary and surface layer parameterization schemes included two kinds: MYJ/Eta and YSU/MM5. The remaining parameterization schemes were set to: the BMJ cumulus convection parameterization schemes; the RRTM long wave and the Dudhia short wave radiation schemes respectively; the USGS topographic data.

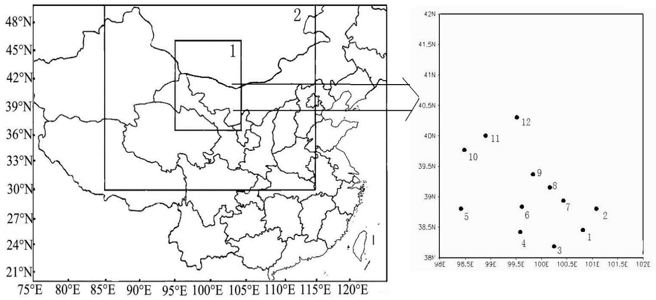

Fig.2:Location and distribution of 12 stations in the area simulated by model

The simulation adopted double nested grid in the area of in the Heihe River Basin (Fig. 2) with the grid center of (100°E, 40°N) and the outer simulation range of (85°E ~ 115°E, 30°N ~ 50°N), resolution of 15km, a total of 175x148 grid points; the inner simulation range of (95°E ~ 105°E, 36°N ~ 44°N), resolution of 5km, a total of 223x178 grid points and 27 layers in vertical direction. In the simulation, the NCEP global reanalysis data was used as a background field with a resolution of 1°×1° and time interval of 6h.

Table.1: Ensemble design of physics schemes

Ens.id	PBL	MP	LS
1	MYJ/Eta	Ferrier	RUC
2	MYJ/Eta	Ferrier	NOAH
3	MYJ/Eta	Lin	RUC
4	MYJ/Eta	Lin	NOAH
5	MYJ/Eta	WSM3	RUC
6	MYJ/Eta	WSM3	NOAH
7	MYJ/Eta	WSM5	RUC
8	MYJ/Eta	WSM5	NOAH
9	YSU/MM5	Ferrier	RUC
10	YSU/MM5	Ferrier	NOAH
11	YSU/MM5	Lin	RUC
12	YSU/MM5	Lin	NOAH
13	YSU/MM5	WSM3	RUC
14	YSU/MM5	WSM3	NOAH
15	YSU/MM5	WSM5	RUC
16	YSU/MM5	WSM5	NOAH

ANALYSIS OF THE SIMULATION RESULTS

Fig.3 showed the bias comparative analysis of simulated and observed precipitation for each member in the two tests. All the bias calculations were performed with the mean error of accumulated precipitation of the 12 stations. Each scheme simulated in test 1 had positive error, while other tests showed no consistency. To analyze test 1 first, we found the precipitation was more intensive compared with other processes. The error of members 4, 9, 10, 11 and 12 was positive and others were negative. The members with the greatest simulation error: 4 and 14 are both used with microphysics scheme WSM3, which was relatively simple for only considering three water substances: vapor, cloud water/ice and rainfall/snow, thus generating simulation of heavy precipitation. And the members with greatest positive error were these using the most complex microphysics parameterization scheme-Lin. The planetary boundary layer determined the flux of vertical sub-grid through eddy transmission. YSU is a non-local closure scheme while MYJ is local. For the plateau region, the geographic terrain condition is an important factor of precipitation. The simulation error of land surface process scheme Noah and RUC varied little, different from the foregoing situations. In test 2, members showed negative errors except members 2, 4, 10, and 12. We believed that the simulation level using the microphysics schemes Ferrier and Lin was generally larger. Ferrier was provided with two kinds of predictors in connection of water substances, one as mixing ration of water and vapor and the other as the total mixture of cloud water, rainfall, ice, sleet, snow, etc. And microphysics scheme Lin considered six water substances, i.e., cloud water, vapor, rainfall, cloud ice, snow and sleet. All of them were relatively complex microphysical processes, allowing more water vapor to be activated and form precipitation. Among members 1 to 16, the level of these using Noah land-surface process parameterization schemes were comparatively higher. Similar to test 1, the land-surface process scheme Noah proved better effect in the simulation of the regional precipitation value. These using boundary layer scheme MYJ showed larger simulation errors as the regional closure scheme MYJ brought more water vapor to lower atmosphere layer , thereby triggering the cumulus convection scheme. The error range of the rest members was also found to be roughly the same, representing little connection between simulation effect and precipitation level. As shown in the Taylor figure, the members in test 1 were more concentrated than test 2. This may be attributed to the temporal and spatial characteristics of precipitation in the Heihe River Basin, as the simulation effect of moderate precipitation level was better than that of the low level.

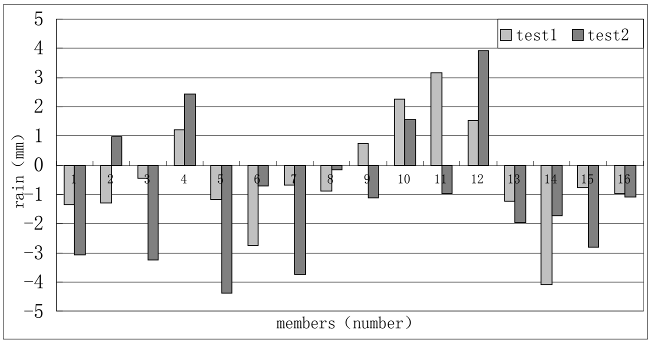

Fig.3:bias for each member of the four tests between WRF and observed

From the statistical analysis, we can see the simulation effect of different precipitation processes by the model is greatly different. Some events are provided with better overall simulation, while others present significantly declined correlation coefficients with the worst one as only 0.13 for using inappropriate physics parameterization scheme. Visibly, the selection of parameterization scheme is closely related to the simulation effect of models. In addition, these testing programs with high correlation coefficient were also found to be all adopted land-surface process scheme Noah and boundary layer scheme MYJ. Neither the correlation coefficient of precipitation simulated by testing program using boundary layer scheme YSU nor that of the observed precipitation was high. The sensitivity to precipitation simulation was further analyzed. From the point of polymerization condition between members, the sensitivity of land-surface schemes to precipitation simulation were the lowest, while that of the microphysics schemes were the highest.

In order to select the optimal scheme, we should sequence the simulation members by following certain methods. In this paper, we used correlation coefficient, root-mean-square error and mean absolute error. The correlation coefficient can reflect the ability of simulation of precipitation distribution to a certain extent, while root-mean-square error and mean absolute error can reflect the ability of simulation of precipitation level. We standardized and enabled the root-mean-square error and mean absolute error to fall into 0 to 1, a smaller value representing a better simulation. Also, we reversed the correlation coefficient to the interval of 0 to 1, closer to 0 representing a better simulation effect. Each member sorted by simulation effect was obtained by averaging the mean of the three variables in the two tests. We standardized each test first and then averaged each scheme in the two tests.

The top three were found to be members 6, 8 and 13 respectively(Tab.2). And members 6 and 8 used the same land-surface scheme Noah and boundary layer scheme MYJ. The simulation effect of the microphysics schemes WSM3 and WSM5 were found to be significantly better than Ferrier and Lin. We noted that the final ranking members all used the microphysics schemes Ferrier and Lin, and Lin is worse than Ferrier. In addition to the evaluation of simulated precipitation precipitation level simulation single station outside the rainfall distribution is also an important aspect. Next, we would further verify the simulation effect of two programs with high correlation coefficient for the distribution center. With the distribution of the observed precipitation comparison, the members 6 are better simulate the range of precipitation and precipitation centers position. But the simulated precipitation central location and magnitude is still slightly different. However, due to the scarcity of observation stations, the detailed distribution of precipitation center in mountains was unavailable to the disadvantage of model validation.

Table.2: Sequencing simulation members

Rank	Ens.id	Mean	PBL	MP	LS
1	**6**	0.463	MYJ/Eta	WSM3	NOAH
2	**8**	0.506	MYJ/Eta	WSM5	NOAH
3	**13**	0.516	YSU/MM5	WSM3	RUC
4	**7**	0.521	MYJ/Eta	WSM5	RUC
5	**5**	0.539	MYJ/Eta	WSM3	RUC
6	**4**	0.568	YSU/MM5	WSM3	NOAH
7	**5**	0.589	YSU/MM5	WSM5	RUC
8	**6**	0.590	YSU/MM5	WSM5	NOAH
9	**1**	0.590	MYJ/Eta	Ferrier	RUC
10	**2**	0.610	MYJ/Eta	Ferrier	NOAH
11	**9**	0.614	YSU/MM5	Ferrier	RUC
12	**11**	0.617	YSU/MM5	Lin	RUC
13	**4**	0.621	MYJ/Eta	Lin	NOAH
14	**3**	0.626	MYJ/Eta	Lin	RUC
15	**10**	0.706	YSU/MM5	Ferrier	NOAH
16	**12**	0.829	YSU/MM5	Lin	NOAH

THE FINE SPATIAL DISTRIBUTION

In the Heihe River Basin, there are few observation stations, making it quite difficult to launch fine distribution. WRF model can give a synoptic-scale distribution of daily precipitation but the regional precipitation effect is poor through interpolation of the direct output data. Based on the preceding precipitation sensitivity test, the paper gets the simulation result of daily precipitation (5km). With regard to weather-time scale, the relationship of daily precipitation with geographical terrain parameters is analyzed, based on which, the regression equation of the two factors is established by using multiple linear regression. The important impact of terrain on precipitation has been well known. The quantitative study of precipitation needs to quantify the affecting factors. The quantitative geographical terrain factors commonly used include longitude, latitude, altitude, slope gradient and direction. Where, the longitude and latitude may be considered as the characteristics of large scale while the altitude, slope gradient and direction represents local characteristics of smaller scale. Different terrain factors reflect terrain features from different aspects.

First extract and calculate 100 m×100 m lattice longitude, latitude, altitude, slope gradient and direction by use of the high-resolution DEM data in the Heihe River Basin, create the regression equation between model output precipitation and its corresponding geographical terrain factors through regression analysis, and then obtain the precipitation field of fine spatial distribution of 100 m×100 m and calculate the total precipitation in the basin on this basis.

The study area of fine distribution is limited to the Heihe River Basin. Extract the precipitation output result that locates inside Heihe River Basin by DEM, getting a total of 177 x 222 =39294 lattices for WRF output data. There are 5222 lattices inside the Heihe River Basin (with distribution shown below) after extraction. Selecting the day with maximum precipitation in the preceding process as the study case, the paper focuses on the relationship of daily precipitation with geographical terrain factors.

The correlation analysis of daily precipitation with each geographical terrain factor suggest that the altitude, latitude and slope gradient have significant linear correlation with daily precipitation. The latitude and altitude present the maximum correlation and the slope direction, the minimum correlation. For the latitude, the figure shows the distribution scatter diagram of latitude and daily precipitation. Comparing figure a and figure b, a clear demarcation is found around the latitude 39.9^o. I the mountains in the latitude below 39.9^o, the daily precipitation presents good negative correlation with the latitude, which is consistent with the previous conclusions. However, in the plain regions in the latitude above 39.9^o, there is no clear linear correlation. This is due to the smaller impact of terrain factors on regional precipitation. The mountains generate precipitation more significantly under the influence of terrain. This supports the previous studies, “the spatial variation of precipitation mainly is expressed as overall consistency, followed by the contrary of the south and north with the boundary around 39^{o}N”. For this reason, the following analysis is targeted at mountains in the latitude below 39.9^o. For the case precipitation on July 10, 2008, there are 1689 lattices with precipitation and latitude below 39.9^o (lattices with precipitation less than 0.1mm and these without precipitation are negligible together)

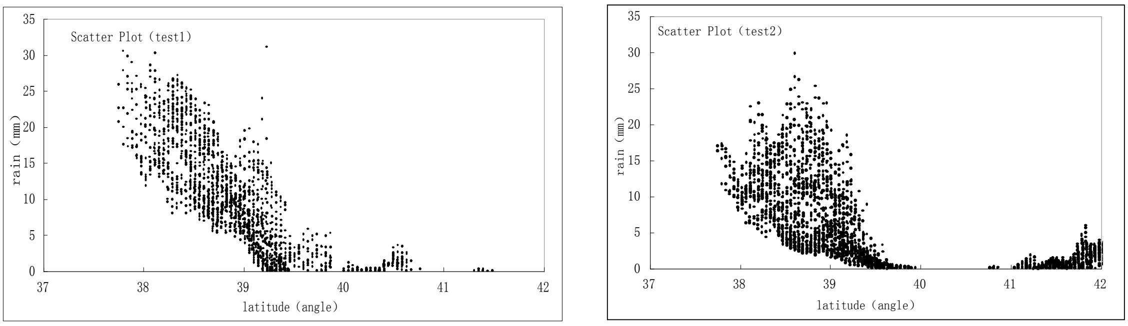

Fig.4: Scatter plot of latitude and daily precipitation (test 1: July 10, 2008; test 2: July 16,2009)

The figures below show the scatter diagram distribution of daily precipitation and latitude, altitude, and slop gradient respectively for the two cases. The daily precipitation is correlated with latitude, altitude, and slop gradient to some extent. The larger the slope gradient, the higher the altitude, the greater the precipitation is. However, the latitude is negatively correlated with precipitation with greater precipitation in high-latitude mountains. This conforms to the previous conclusion on the overall increase of precipitation from northwest to southwest in the Heihe River Basin.

The latitude has the most important effect with correlation coefficient of up to -0.79 and -0.62 respectively, followed by the altitude with correlation coefficient of 0.41 and 0.74, and then the slop gradient with correlation coefficient of 0.36 and 0.47, all of which pass the confidence level of 0.01. Instead, the longitude, slope direction and openness are insignificantly correlated with precipitation, probably because that their weak impact is unobservable under the stronger influence of altitude, latitude and slope gradient. Through further analysis of the correlation scatter diagram, the precipitation is found to change nonlinearly with altitude, which has better cubic polynomial fitting effect with a correlation coefficient of up to 0.98, significantly higher than the linear correlation coefficient. The slope gradient affects the local precipitation through working upon the vertical motion. Previous studies show that the terrain elevation speed increases with larger slope gradient below 45 degrees while decreases above 45 degrees. In the physical sense, using sin2θ to characterize the slope gradient parameter is more reasonable and more explicit, thus eventually selecting sin2θ to represent the impact of slope gradient.

Based on the preceding analysis, the relational model between annual average precipitation and geographical terrain parameters can be expressed as:

$$P = a_0 + a_1 h + a_2 \phi + a_3 \sin(2 \cdot \theta) \tag{4}$$

Where, P is the precipitation; h is the altitude; ϕ is the latitude; θ is the slope gradient; a_0 is the constant term; and $a_1 \cdots a_3$ are variable coefficients

For test 1, determine the parameters by using the least squares method. Calculate and get a_0= 461.3358,a_1= -11.6552,a_2= 4.53289e-5,a_3= 2.969944. The correlation coefficient of simulating precipitation and fitting precipitation is 0.807, indicating that the fitting equation is statistically credible. The fitting precipitation has the maximum of 24.365mm and the minimum of -2.67mm with a smaller average. (actual measurement of 0.1--31.2mm). It is the same case to test2, calculate and get a_0= 180.3276,a_1= - 4.69082,a_2= 0.003384,a_3= -0.48395. Comparing the daily precipitation of fitting with model output in the Heihe River Basin, the fitted value is found to have basically identical distribution characteristics with model output in most areas. In general, the daily precipitation result of midstream and upstream of the Heihe River Basin simulated by regression model is quite credible. (Figure not shown) According to (4), extend the fine distribution of daily precipitation to the midstream and upstream of the Heihe River Basin by use of 100 m × 100 m DEM data, with result shown in Figure 5. The deficiency is that the fitting in the central position of precipitation is slightly inaccurate.

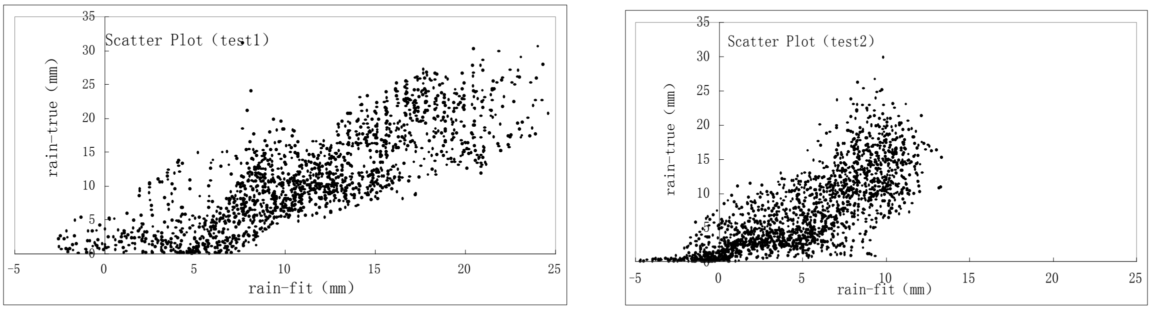

Fig.5:Scatter plot of the daily precipitation of the true and fit

Based on the fine spatial distribution of daily precipitation in the Heihe River Basin, the paper extend the high-resolution DEM data and obtain the 100 m × 100 m fine distribution of precipitation in midstream and upstream of the Heihe River Basin. The fine distribution of precipitation field shows more details about the terrain and topography, which is unrealizable by merely using the analysis result of meteorological station data Based on the spatial fine distribution of precipitation in the Heihe River Basin, calculate the total daily precipitation of 4.5 and 4.4 billion m3 in the midstream and upstream by considering the area as 30.8 thousand km2. In a process of a larger precipitation, the amount on the day with the maximum precipitation accounts for 3% of the annual precipitation.

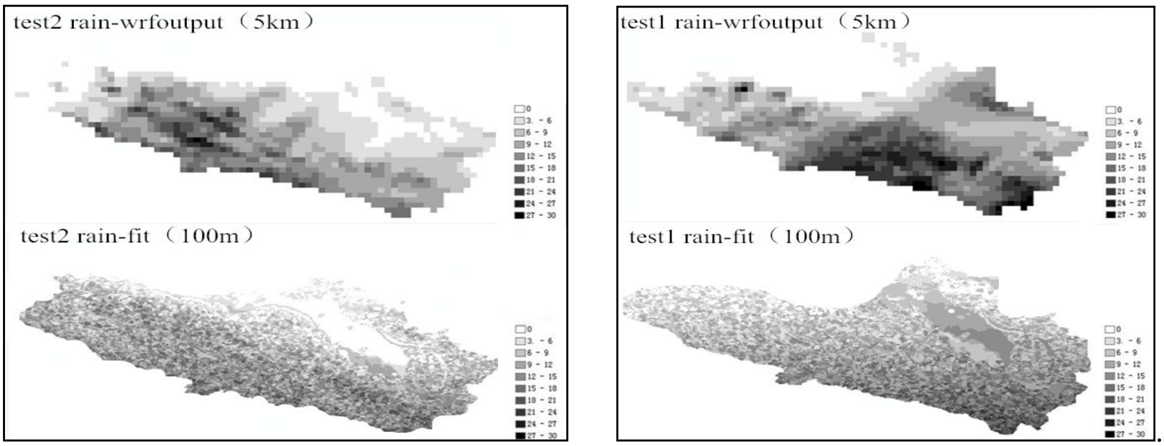

Fig.6:Scatter plot of the wrf output and fitting precipitation

CONCLUSION

In this paper, 16 groups of different physics scheme configuration were selected to simulate the two precipitation events in the Heihe River Basin using WRF model. In addition, the simulation effect was verified by the daily observation of precipitation. The result shows that the appropriate choice of physics schemes can simulate the distribution and magnitude of precipitation in the Heihe River Basin better.

The relationship of daily precipitation with geographical terrain factors are analyzed with the model output data, thereby establishing a fitting equation of precipitation that expand the precipitation resolution to the accuracy of 100m.

Using WRF model to simulate the precipitation in the Heihe River Basin, the results simulated by different schemes are significantly different with correlation coefficient from 0.99 to 0.13, thereby making the selection of schemes particularly important. Since the overall level of precipitation in the Heihe River Basin is low, the moderate level has better simulation results.

From the correlation analysis, the members 6 was found to be provided with better simulation effect in the two processes, both of which adopts land-surface scheme Noah and boundary layer scheme MYJ. While the schemes using microphysics scheme Lin generally produce poor simulation effect, because simulating vertical stratification instability and rising velocity greater ,which is suggested to be not used in simulating the precipitation in the area.

The relationship of the model output daily precipitation with geographical terrain factors has been analyzed. The analysis shows that the daily precipitation in the Heihe River Basin is significantly correlated with the altitude, longitude and slope gradient of the observation stations. Based on the analysis, the relational model between precipitation and geographical terrain factors has been established. The regression analysis shows that the regression equation of daily precipitation and geographical terrain factors pass confidence level of 0.001. The fitted value has basically identical distribution characteristics with model output in most areas. Although the fitted value is smaller, the overall fitting effect is still great.

The primary objective of this work is to provide reference for the precipitation simulation in the Heihe River area. Moreover, the simulation is also of great potential application for the research of "dynamical - Statistics" downscaling methods. But we should note that since the observation stations are scarce in this area, some other data observed by researches without assessment are not applicable yet. There are still some difficulties in obtaining the actual distribution of precipitation in the area to the disadvantage of the model validation. This is the inadequacy of the work, and based on which, the further work is to simulate more cases of precipitation.

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