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The analysis of replacing high-resolution terrain data forforecasting solar radiation in Wuhan, China

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Abstract: This experiment uses the data from European Center for Medium-Term Weather Forcast and the mesoscale numerical model WRF to predict the total solar radiation in Wuhan in January, April, July and October 2018. During the experiment, the Aster global digital elevation model data was used as high-precision topographic data to replace, and two sets of data which are forecasted by WRF were compared with the observation data of Wuhan station. The experiment results show that the four-month forecast has a good correspondence with the observation station data, and which has passed the 0.01 significance test. Meanwhile, the simulation results in January were poor, and the simulation results in July and October were the best. After the improvement of replacing high-precision terrain data, the MAE and RMSE for 4 months have been reduced by 10-20W/m2, and both MAE and RRMSE have also been reduced by 5%-10%.

1. Introduction

Insufficient reserves and poor structure are the main problems for Chinese three major energy sources . In recent decades, the economy has developed rapidly and energy demand has been excessive. As of the end of 2018, Chinexe coal reserves accounted for only 13.2% of the global coal reserves, while oil and natural gas reserves accounted for only 1.5% and 3.1% of the global coal reserves. Converting all three types of fossil energy into standard oil, the total energy reserves are 780.99 billion tons of standard oil, accounting for 8.3% of the world's total reserves. Due to the excessive shortage of resources, it is imperative to use solar energy as an energy supply.

using solar energy can be a solution to the problem of resource shortage. However, there are many difficulties in the use of solar energy. Such as, the distribution of solar energy is too scattered, the photoelectric conversion efficiency is too low, and the regular maintenance of each system leads to high cost of solar energy. Therefore, accurate prediction of solar radiation is particularly important[1,2]. In recent decades, the pace of solar radiation forecasting has never been interrupted, and there are also many excellent forecasting models, WRF is one of them.

The Weather Research and Forecast (WRF) model[3] is a mesoscale numerical weather forecast system designed for atmospheric research and numerical weather forecasting. The model is suitable for a wide range of meteorological applications ranging from tens of meters to thousands of kilometers, and a variety of atmospheric process options are provided for simulation.

Minghuan Wang[4] et al use WRF to simulate the daily total solar radiation in January, April, August and October 2009. Compared with the data from Wuhan station, the simulation results have a good corresponding relationship with the measured values, the correlation coefficient is above 0.8, and the significance experiment with the confidence level of 0.01 has passed.

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Based on the hourly output results of WRF, Yongqing Bai[5] et al designed an hourly total solar radiation model output statistical forecast process. Using the Wuhan station data as observational data, the results show that the monthly forecast is relatively ideal, and the radiation is improved by about 50% compared to the direct forecast of the model.

In this study, high-precision terrain data is used to replace the terrain data of WRF. A simulation was conducted for Wuhan in the January, April, July and October 2018. The purpose of this research is to replace high-precision terrain data and obtain more accurate total solar radiation data.

2. Data and Methods

In this study, the 6-hour 1°×1° European Center for Medium-Term Weather Forecast (ecmwf) is used as the driving data for the initial and boundary fields. Aster global digital elevation model data[6] is replaced in WRF as improved high-precision terrain data. The solar radiation data of Wuhan station is used as observation data and compared with the data output by WRF.

The simulation uses the Lambert projection. The total duration is 4 months, which are January, April, July and October of UTC. The simulation area uses a single-item nested domain model, where nested domain 1 is composed of grids of 89×82 with a

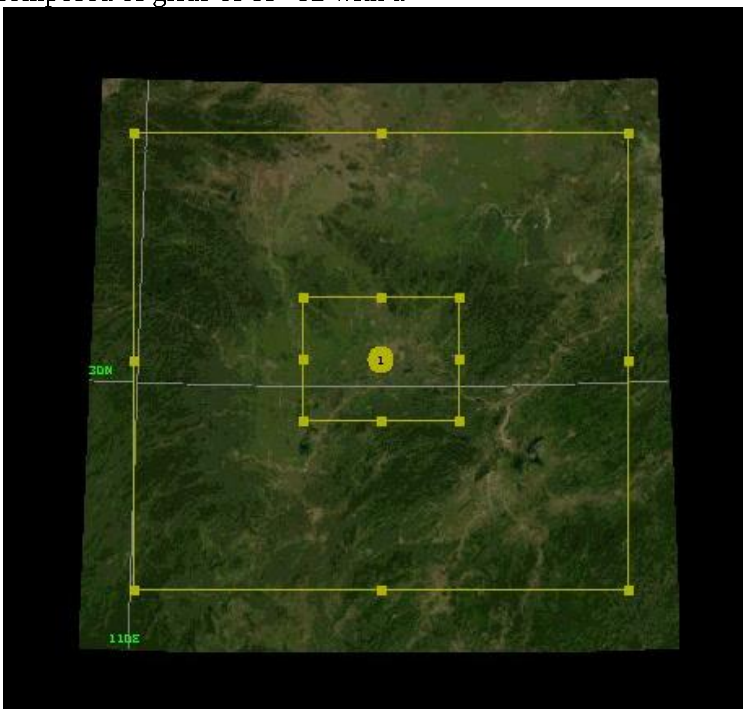

Figure1.The view of nested domain

resolution of 9000m,nested domain 2 is located at latitude and longitude and is composed of grids of 85×67 with a resolution of 3000m (figure1).The Center latitude and longitude is 30.36°N114.03°E.

Thompson aerosol-aware is used in Microphysic, which can specify aerosol parameters in the initial field and boundary field[7]. Longwave Radiation and Shortwave Radiation use RRTM and Dudhia schemes respectively[8,9]. Land Surface uses Noah land surface, which includes four layers of soil temperature and humidity. The remaining options are shown in Table 1.

Table1.Choice of schemes in the model

Physics Options	Domain1	Domain2
Microphysics	Thompson aerosol-aware	Thompson aerosol-aware

Longwave Radiation	RRTM	RRTM
Shortwave Radiation	Dudhia scheme	Dudhia scheme
Surface Layer	MM5	MM5
Land Surface	Noah Land Surface	Noah Land Surface
Planetary Boundary layer	Yonsei University scheme	Yonsei University scheme
Cumulus Parameterization	Betts-Miller-Janjic scheme	Betts-Miller-Janjic scheme

In order to evaluate the results of comparing the WRF output and the improvement WRF output with the observation data of Wuhan station, MAE and RMSE[10] are introduced for judgment. Meanwhile MAPE and RRMSE are the standard of error percentage.

$$MAE = \frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \left| \mathrm{pre_i} - \mathrm{obs_i} \right| \tag{1}$$

$$RMSE = \sqrt{\frac{1}{\mathrm{n}} \cdot \sum_{\mathrm{i}=1}^{\mathrm{n}} \left(\mathrm{pre_i} - \mathrm{obs_i} \right)^2} \tag{2}$$

$$MAPE = \frac{\frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \left| pre_i - obs_i \right|}{\frac{1}{n} \sum_{i=1}^{n} \mathrm{obs}_i} \times 100\% \tag{3}$$

$$RRMSE = \frac{\sqrt{\frac{1}{\mathrm{n}} \sum_{i=1}^{n} \left(pre_i - obs_i \right)^2}}{\frac{1}{n} \sum_{i=1}^{n} obs_i} \times 100\% \tag{4}$$

Where i represents the number of time node, n represents the total time node number, pre represents the total solar radiation of prediction output in WRFd02, and obs represents the total solar radiation of observation data obtained from Wuhan Station.

3. Result and Comments

Figures 2 and 3 respectively show the comparison of the solar radiation data output by WRF in each month and the solar radiation data output by WRF after improving the terrain data with the observation data from Wuhan Station. It can be seen from the figure that the forecast curves simulated by these two schemes basically overlap with the observation station data, and both have good simulation results. The total solar radiation forecasted by the model is more consistent with the observed data for trend. But, there is a certain deviation in the numerical range, and the range of deviation in different months are different. Among them, the days of existing deviation is most in January, and the numerical agreement between July and October is relatively good.

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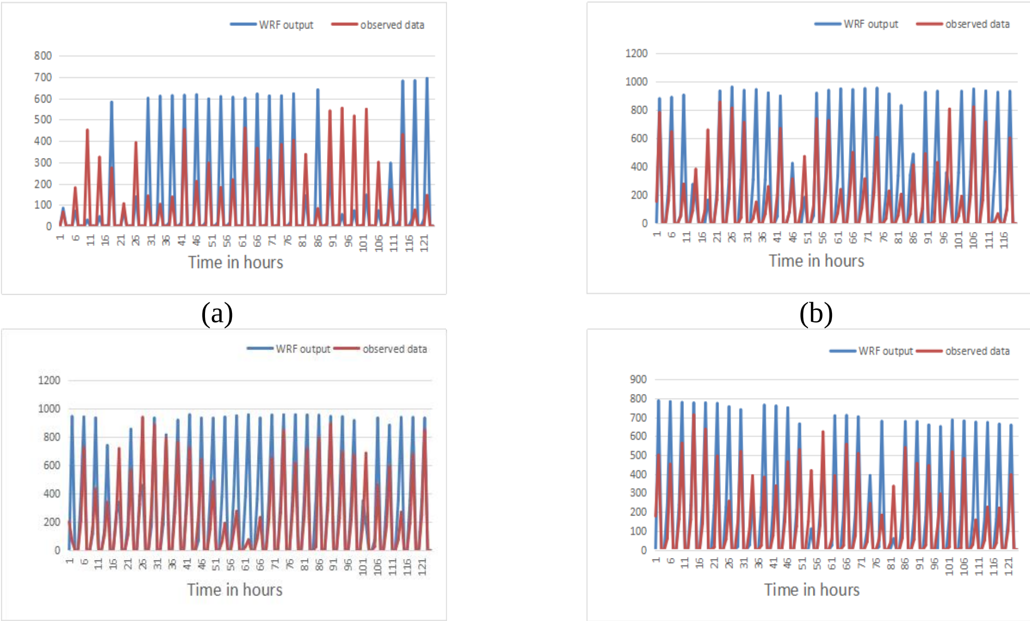


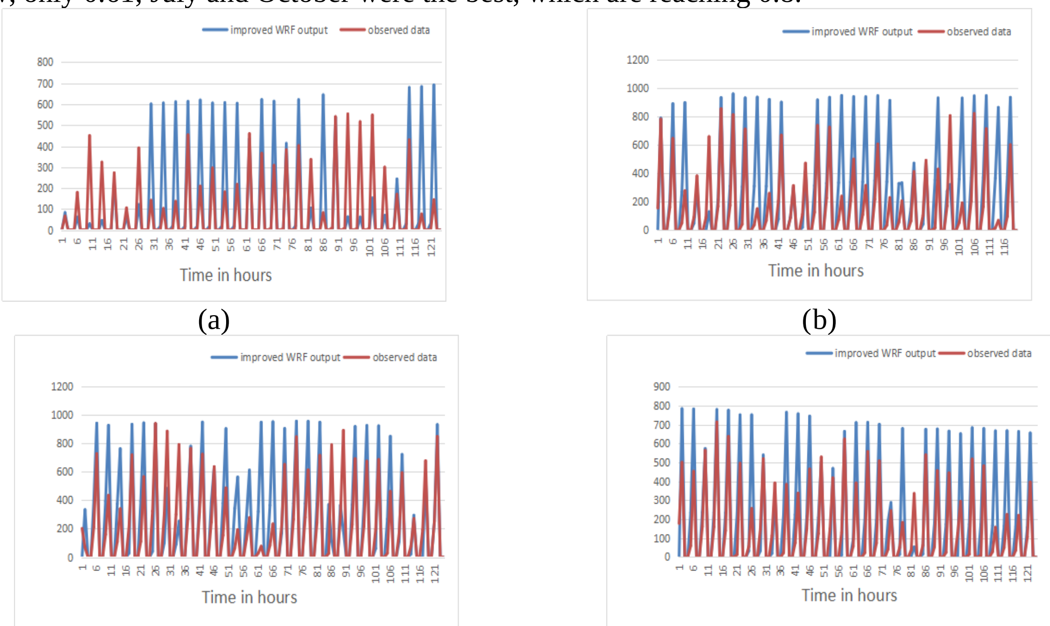
(a) (b)

(c) (d)

Figure2.The camparision of WRF output and observed data
(a)January (b)April (c)July (d)October

It can be seen that the WRF simulation results are better in July and October when there are more sunny days, while in January, where there is more rain and snow, the error in the predicted results is larger.

The correlation coefficients between the WRF output and the improved WRF output with the observation station data in the months are 0.61, 0.78, 0.80, 0.88 and 0.61, 0.79, 0.82, 0.89 respectively, and both have passed the significance test of 0.01. Among them, the correlation coefficient in January was low, only 0.61; July and October were the best, which are reaching 0.8.



(a) (b)

(c) (d)

Figure3.The camparision of imroved WRF output and observed data
(a)January (b)April (c)July (d)October

It can be seen from Tables 2, 3, 4 and 5, the MAE in January reached 81.42W/m2, the RMSE reached 176.05W/m2, and the MAPE and RRMSE are 109% and 236%. Compared with April, July and October, MAPE is 10%~50% higher; RRMSE is 70% to 110% higher. It can be seen that the forecast of the WRF model in January is not very good, but the forecasts of MAPE and RRMSE in April, July and October have shrunk to within 100% and 170W/m2. After changing the high-precision terrain data, the four-month error has been significantly decreased. MAE and RMSE are basically reduced by 10 to 20W/m2, and MAPE and RRMSE are reduced by 5% to 10%.

Table2.The MAE, RMSE, MAPE and RRMSE of WRF model and improved WRF model in January

	WRF model	improved WRF model
MAE(W/m^2)	81.42	74.84
RMSE(W/m^2)	176.05	171.12
MAPE(%)	109	100
RRMSE(%)	236	229

Table3.The MAE, RMSE, MAPE and RRMSE of WRF model and improved WRF model in April

	WRF model	improved WRF model
MAE(W/m^2)	141.6	129.57
RMSE(W/m^2)	251.27	237.1
MAPE(%)	92	84
RRMSE(%)	163	153

Table4.The MAE, RMSE, MAPE and RRMSE of WRF model and improved WRF model in July

	WRF model	improved WRF model
MAE(W/m^2)	130.63	121.74
RMSE(W/m^2)	234.92	213.64
MAPE(%)	67	62
RRMSE(%)	120	109

Table5.The MAE, RMSE, MAPE and RRMSE of WRF model and improved WRF model in October

	WRF model	improved WRF model
MAE(W/m^2)	97.16	87.31
RMSE(W/m^2)	161.91	153.77
MAPE(%)	77	69
RRMSE(%)	128	121

4. Conclusions

In this study, using ECMWF data as the initial field and boundary field, a comparative experiment with improving high-precision topographic data was conducted in Wuhan in January, April, July and October by WRF model. The results of this experiment show that the WRF model has a good foundation for the prediction of total solar radiation. The comparison between the forecasting of all months and the observation station data has passed the significance test of 0.01.Menwhile, the error in January was most,the error began to decrease in April, and the simulation results in July and October were the best. January belongs to winter, rain and snow have a greater impact on the forecast of WRF model. There are more sunny days in July and October, the results of WRF forecast are generally better than other months. After improving the high-precision terrain data, the forecast errors of total solar radiation in these months have all been reduced by a certain extent, indicating that terrain data is one of the key factors affecting the forecast of total solar radiation.

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