

# The Afforestation Effect on Regional Climate: Take Xuzhou Region as an Example

Y. R. Yang<sup>1</sup>  · J. Y. Zhuang<sup>2</sup> · Z. X. Zhang<sup>1</sup>

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**Abstract** Forest coverage has been increasing in the Xuzhou region, Jiangsu Province, China, since the 1960s, increasing from about 1–31.8% in 2013, or expanding by more than 30 times in the past 50 years. Normalized Differential Vegetation Index data which represents ‘the degree of green’ in 1998–2008 also showed an obvious increasing trend in the Xuzhou region. Even though the climate is affected by a population increase and urbanization, the effects of forest vegetation on the regional climate are still very significant in the Xuzhou area. Using statistical analysis, remote sensing and numerical simulation, the main effects of climate on vegetation are as follows. (1) Reduced range of annual temperatures and increased warming rate. Based on meteorological observation data, the mean high temperature showed a declining trend over the 50 year study period, while the mean lowest temperature did increase, and the annual mean temperature range declined from 24.3 °C in the 1960s to 22.0 °C in the 2000s. For the four seasons, the minimum winter temperature increased moderately and the maximum temperature decreased significantly. Simulation results from Regional Climate Model, version 3 (RegCM3) also suggested that with the increase of forest coverage the warming rate

decreased over this entire region. (2) Increasing humidity. Based on single point meteorological observations, the mean water vapor pressure rose from 13.4 hPa in the 1960s to 14.2 hPa in the 2000s; the rising trend in winter was the most significant. In addition, results from the RegCM3 model showed coincident conclusions. In the entire Xuzhou region, the water vapor mixing ratio rose from 9.75 kg/kg in the 1960s to 10.35 kg/kg in the 1990s. Furthermore, the relative humidity was 80.5% in the 1980s, and 81.3% in the 1990s, suggesting an increasing trend for atmospheric humidity exists under the warming conditions. (3) Significantly reduced wind speed at and near the earth’s surface. Based on observations, wind speed decreased from 10.99 m/s in the 1960s to 7.59 m/s in the 2000s; in addition, wintertime wind speeds decreased significantly. Data from the RegCM3 model clearly show wind speed at the surface fell from 4.72 m/s in the 1960s to 1.4 m/s in the 1980s, to 1.2 m/s in the 1990s, then to 0.6 m/s in the 2000s in the entire Xuzhou region. (4) Reduced duration of surface sunshine. Weather station data showed that the monthly mean sunshine hours were 198.4 h in the 1960s, but only 165.5 h in the 2000s.

**Keywords** Forest coverage · Regional climate · Simulation

✉ Y. R. Yang  
yangyanrong@njfu.edu.cn

J. Y. Zhuang  
893701387@qq.com

Z. X. Zhang  
njzhangz@gmail.com

<sup>1</sup> College of Biology and Environment, Nanjing Forestry University, L.P. Road 159, Nanjing 210037, Jiangsu, China

<sup>2</sup> College of Forestry, Nanjing Forestry University, L.P. Road 159, Nanjing 210037, Jiangsu, China

## 1 Introduction

The study of the relationship between vegetation and climate change has become an important topic that lies at the core of research related to global change. People desperately want to know how their local conditions will change in the future, rather than how global temperature will climb [1]. Therefore, most current research has focused on how

climate change will affect the terrestrial ecosystem; however, few studies have addressed the influence of forest ecosystems on regional climate. Researchers have investigated that terrestrial vegetation provided the ecological service of carbon storage, with forests accounting for 90% of this carbon storage capacity [2]. In theory, increasing forest coverage can affect regional climate change by increasing the capacity of this carbon pool and also by providing increased surface roughness. The carbon pool provided by photosynthesis tends to offset greenhouse gas emissions, while changed forests structures such as increased surface roughness reduce surface wind speeds directly. Meanwhile, forest transpiration can result in increased humidity, and research has suggested that the evapo-transpiration of forests and woodland were stronger than other land types [3]. The forest canopy intercepts solar radiation and reduces reflectivity. Of the energy absorbed by forests, 70% is used in the latent heat of evaporation, creating an effect of slowing cooling or heating the forest microclimatic. In addition, a forest can also decrease in-forest soil evaporation, decrease runoff volume, prevent soil erosion and help retain soil water. Based on all of these findings, forests are very important and irreplaceable in a period of slowing changing regional climate. Research has shown that the development of forest structure would lead to an increase in the forest carbon reserve [4]; under the newly observed climate conditions, such as a 1.5 °C increase in temperature and a 10–20% decrease in precipitation, changes will occur in the native forest species present, in forest structure and in ground water storage [5]; all of these will affect regional climate while a reduction in forest area would tend to result in increased climatic warming [6]; to increase forest coverage, i.e., afforestation, not only affects the carbon and water cycles, it also influences biodiversity and reshapes the regional ecological system [7]. Therefore, studying forest coverage is a very important part of research related to regional climate change.

What is the specific influence of a forest on regional climate? A previous study suggested that forest growth and expansion may result in less rapid climatic warming but the mechanism involved in this process is not yet known and will require further study [8]. In this context, it will be very difficult to know how to document the effects of anthropogenic activities and try to analyze the role of forests. For example, attempts to understand how a forest affects regional precipitation will have to consider both the type of precipitation and related weather phenomena. The role on air temperature change also needs to be considered as part of the energy balance of earth's surface along with the changing amounts of carbon dioxide and airborne pollutant particles in this region. Therefore, the effects of a forest on regional climate

depend strongly on the specific location of a particular forest; for example, the effects of a forest on regional temperature may result in either warming or cooling; or perhaps both effects will be weak [9]; no definite conclusions can presently be drawn.

Afforestation has conspicuously increased in China in recent years; the rate of forest coverage increased from 12% in the 1970s to 21.63% in 2014, an increase of 80%; the resulting effects on climate should be carefully considered. Some Chinese research has suggested that using afforestation blindly, especially when it involves the cultivation of non-native tree species, has resulted in unexpected and undesirable changes to the corresponding ecosystem and environment [10], for example, under the condition of climatic drying and warming, desertification in some areas had not been offset by an increase in the available forest resources [11]. Although a forest may store carbon, this role will be poor when the forests are immature or young growth, mature forest plays the strongest role in carbon storage. And simply planting various trees without selecting appropriate species for various types of habitat, and without protecting seedlings from harsh conditions, does not work. Therefore, in China land managers should protect original forestland while returning farmland to forest simultaneously, instead of only blindly attempting to increase the spatial extent of forest areas [12]. On the other hand, some research has provided definite and positive conclusions related to afforestation. For example, in China's "Three North" (northwest-north-northeast China) shelterbelts networks, Wang employed a meso-scale numerical model to investigate regional climate and found that the presence of forestland resulted in decreased wind speeds and increased humidity, while at the same time patterns of air temperature and precipitation had changed [13].

The present research area encompassed Xuzhou, Jiangsu Province, in eastern China. Previous research on the effects of the temperate forests of eastern China on climate have produced inclusive results [14]; that is, reforestation may create forests that absorb some carbon, but compared to tropical and boreal forests, the albedo and evapo-transpiration of these forests is smaller. However, the effects in the Xuzhou area are a special case. Since the founding of modern China in 1949, the people of Xuzhou have been actively engaged in returning farmland to forestland and in afforestation. After half a century of hard work, immature forest has gradually matured; the previously saline-alkali soil in this region has been managed effectively and the regional climate has obviously improved. The present study combined the analysis of climatic data, remote sensing data and regional climate simulation to investigate how forests regulate and affect the regional climate in the Xuzhou area.

## 2 Condition of Xuzhou Region

The Xuzhou region, located in the north of Jiangsu Province, China, lies between 33°43′–34°58′N, 116°–118°40′E. The region spans about 210 km from west–east and about 140 km from north–south, while covering about 11,200 km<sup>2</sup>. A plain landscape covers most of the area which also features a warm temperate semi-humid monsoon climate. The ancient bed of the Yellow River traverses the city of Xuzhou and has burst out of its banks flooding the surround farmland many times in the past. Prior to the 1960s, this region had been covered by typical ‘saline-alkali land’ and a ‘wind–sand nest’ (an area wind erosion with blowing sand) created an extremely unwelcoming climate. Traditional land management and rapidly growing population over a very long period time had resulted in extensive forest removal. Forest coverage was about less than 1% in the 1950s. Soil erosion and a sharply deteriorated environment were common at that time, leading to extremely poor grain output and economic development in Xuzhou city. Based on China’s early history, the afforestation movement has long been advocated, after the 1980s, people actively and extensively restored the landscape of Xuzhou’s barren hills. This environmental rectification, renewed landscape scale ecological functioning, and increased forest coverage rate all combined to result in a thorough restoration of the predominately saline-alkali land. This resulted in restoration of the previously heavily impacted environment and a clearly improving regional climate. The reasons for these improvements lie in many factors, but for Xuzhou area, the most prominent feature was the increased forest coverage which gradually changed into the largest in Jiangsu province, for example, in 2014, forest coverage in Xuzhou area was 31.8%, far

more than that of Jiangsu province average (20.64%) and the national average (21.62%).

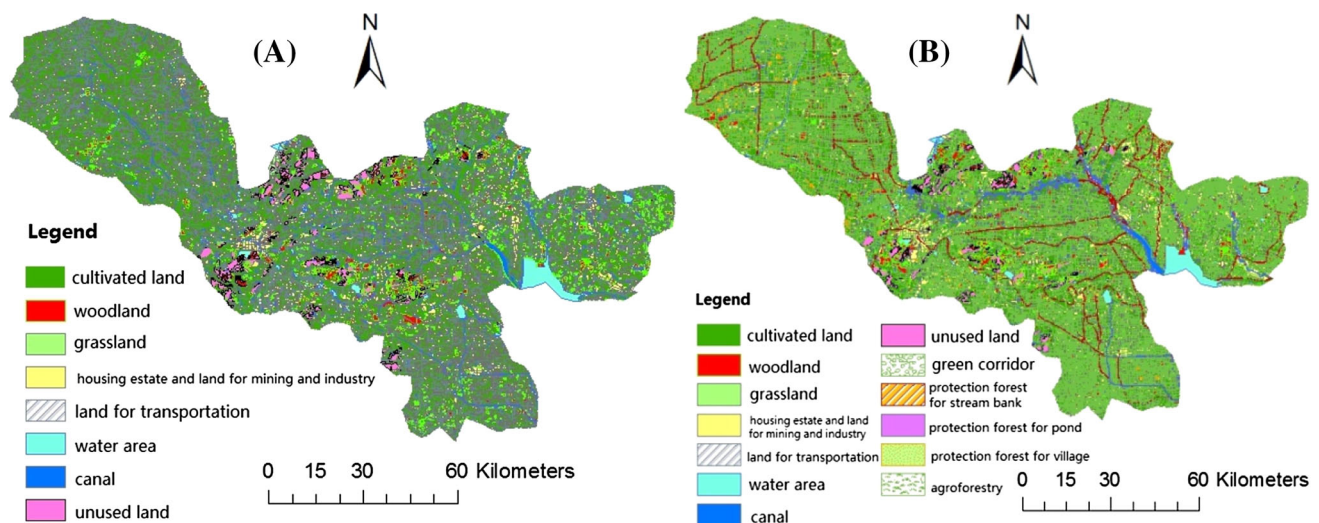
Figure 1 shows land use conditions in 1987 and 2006. Using LANDSAT enhanced thematic mapper remotely sensed images, we used ArcGIS9.3 software and visual interpretation to define seven types of land use and employed 1:50,000 scale topographic maps. When considering that the area of woodland sharply increased since the 1980s, five new woodland types were added into the figure for 2006 (see Fig. 1b), such as green corridors, protective forests, etc.

Comparing 1987 and 2006 (Fig. 1a, b) the largest area of change is farmland, followed by forestland; these two land types accounted for more than 60% of the study area. The main changes were a rapid decline of cultivated land and rapid expansion of forestland. The ratio of forest area increased from about 6.2% in 1987 to 22.96% in 2006, an increase of 16.76%. The farmland coverage decreased by 14.6% (Table 1).

## 3 Data and Methods

Observations of conventional meteorological site in Xuzhou provided historical climate data, including the highest and lowest air temperature, humidity, wind speed, sunshine duration, etc. This data was harvested from China’s meteorological data sharing service system (<http://cdc.cma.gov.cn/home.do>), monthly time resolution was used.

The remote sensing data used here was mainly harvested from the Chinese data subset of long term series of NDVI (Normalized Differential Vegetation Index) SPOT4/Vegetation\_NDVI with a spatial resolution of 1 km and a temporal resolution of 10-days. Based on the corrections of



**Fig. 1** The land use types of the Xuzhou study area in 1987 (a) and 2006 (b)

**Table 1** Change of land use types in the Xuzhou region (unit of area: km<sup>2</sup>)

	Cultivated land	Woodland	Grassland	Residential area	Transportation land	Open water	Wasteland
Area in 1987	645,925.7	69,411.1	2059.9	240,436.9	64,988.7	55,501.7	38,470.5
Ratio in 1987	57.8%	6.2%	0.2%	21.5%	5.8%	5.0%	3.4%
Area in 2006	482,402.7	256,424.7	927.7	227,925.0	65,500.2	56,707.2	26,908.6
Ratio in 2006	43.2%	23.0%	0.1%	20.4%	5.9%	5.1%	2.2%

atmosphere, radiation, and geometry, as well as the transformation of geographic coordinates, the NDVI data was processed by the maximum value composite (MVC) method [15] and was changed into a monthly resolution by the ENVI4.0 software image processing program.

Inadequate meteorological observations needed to be dealt with because only meteorological sites have observational data while other places do not. To deal with this situation a regional climate model was used in this paper, it's a very popular method to study regional climate change [16, 17], in this paper Regional Climate Model (RegCM, Version 3, i.e., RegCM3) was employed, because it by many Chinese meteorology bureaus for climate simulation and forecasting, especially in east China [18]. Model input data were from the National Centers for Environmental Prediction (NCEP) Final operational global analysis data on  $1.0^\circ \times 1.0^\circ$  grids (<http://www.ncep.noaa.gov/>), and the surface elevation data from global digital elevation model with a horizontal grid spacing of 30 arc seconds (GTOPO30) and global land cover characterization (GLCC). The simulation had  $60 \times 60$  grid points with a horizontal resolution of 30 km; the spatial span for the experiment was located in the center of Xuzhou ( $34.26^\circ\text{N}$ ,  $117.19^\circ\text{E}$ ). Through simulation we obtained extrapolated regional climate data from 1960 to 2010 for the entire study area, including humidity, wind, temperature, precipitation, etc.

## 4 Results and Analysis

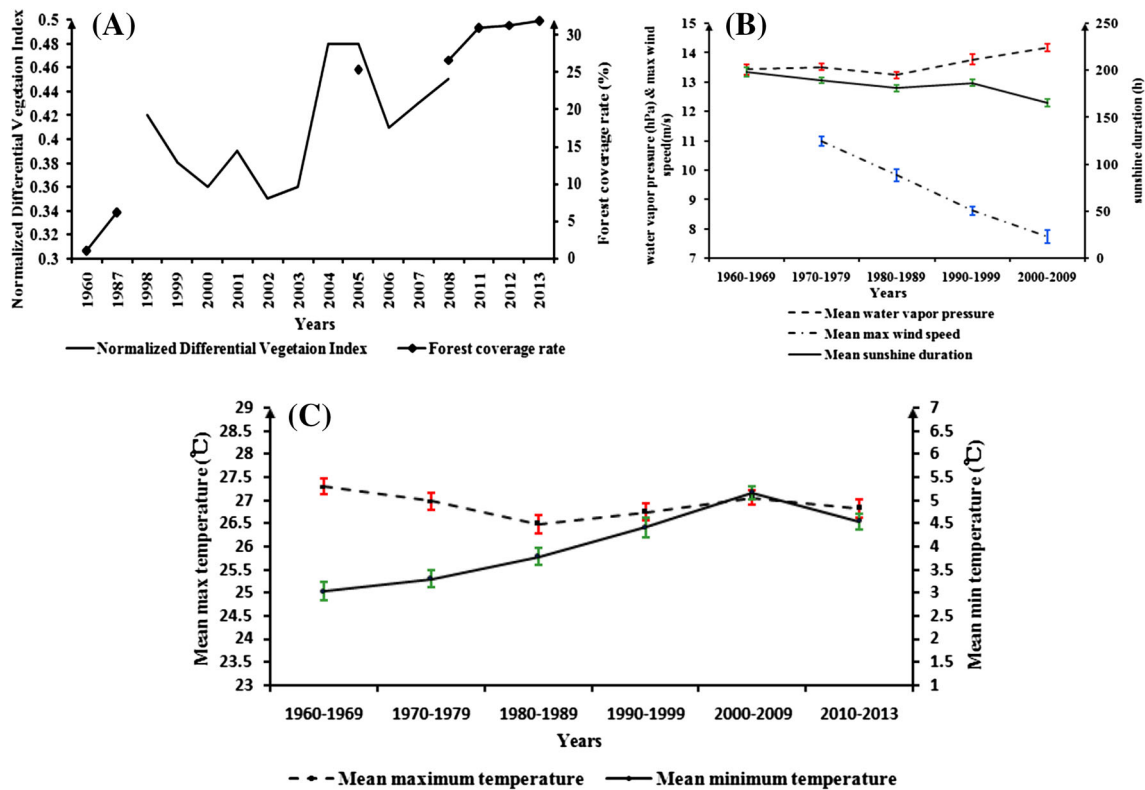
### 4.1 Observations Results

Figure 2 shows the percentage of forest coverage, mean NDVI, mean annual maximum and minimum temperatures, mean maximum wind speed, mean vapor pressure and mean sunshine duration over the analyzed time period in the Xuzhou region.

Figure 2 shows that forest coverage increased from about 1% in the 1960s to 31.8% in 2013; the correlation coefficient  $R$  reaches to 0.99. The character  $R$  means the correlation between the values showed in Fig. 2 and the years, the same below. Here the NDVI value that represents the degree of green at the surface also shows an

increasing trend with  $R$  equal to 0.52 (Fig. 2a), reflecting the fact that forest vegetation coverage increased rapidly in recent decades. Figure 2b, c give climatic change under these conditions. We can see that in about the last 50 years, beginning from the 1960s, the annual mean sunshine duration and annual mean maximum wind speed decrease deeply (Fig. 2b). Correspondingly, the mean annual water vapor pressure tended to increase ( $R = 0.76$ ). Among them, the most typical is the maximum annual wind speed; even the correlation coefficient  $R$  in the most recent years is 0.999, being very close to 1, showing obvious linear downward trend. The values in the 1970s, 1980s, and 1990s are 10.99, 9.83, and 8.62 m/s, respectively; this even declines to 7.74 m/s during the period from 2000 to 2010, then continues to fall to 7.59 m/s in the following 3 years; this value declined by 45% over the 43 years study period. The  $R$  of the mean annual sunshine is 0.89, being slightly less than that of the maximum wind speed. In contrast to the sunshine duration and wind speed, the value of the annual water vapor increased from 13.4 hPa in the 1960s to 14.2 hPa in the 2000s. For air temperature (Fig. 2c), the mean annual maximum and minimum values were analyzed during the period from 1960 to 2013, showing that the mean annual maximum temperature tended to decline while the minimum increased. From the value of trend, the latter ( $R = 0.91$ ) is larger than the former ( $R = 0.36$ ), which indicating that annual temperature range decreases step by step in about 50 years, from  $24.3^\circ\text{C}$  the 1960s to  $22.0^\circ\text{C}$  in the 2000s, declining by  $2.3^\circ\text{C}$ .

All of the values suggested that the increasing coverage of forest vegetation had a positive effect on the regional climate and helped to mitigate climate change. The increase in canopy density caused by afforestation allowed a reduction in the duration of sunshine reaching the earth's surface. Plant transpiration and the consequent evapotranspiration resulted in increased humidity in the region, so the water vapor pressure rose. At the same time, increased forest coverage resulted in increased landscape surface roughness reducing the wind speed at the surface effectively. In addition, an important effect of forest vegetation on climatic adjustment was to reduce the annual temperature range (Fig. 1c). All of these phenomena interacted, resulting in comprehensive changes with decreased surface wind speed, increased humidity, and



**Fig. 2** Meteorological elements and forest vegetation in Xuzhou. **a** forest coverage rate (unit: %) and Normalized Differential Vegetation Index (NDVI); **b** mean water vapor pressure (unit: hPa), mean maximum wind speed (unit: m/s), mean sunshine duration (unit: h); **c** mean maximum and minimum temperatures (unit: °C). Error

bars based on standard deviation (SD) are given, as indicated by color short vertical lines, every specific value of SD shows in attached Table 2, similarly hereinafter (color figure online)

decreases in the duration of sunshine and annual temperature range in the Xuzhou region during the last 50 years. When we compare the current conditions to the description for the Xuzhou region in the early years immediately after the founding of modern China in 1949 that was described as, “Sand blown by wild wind was flying as high as three feet, crops were buried by thick loess,” the current moderate and moist climate here makes the Xuzhou region a good place to live.

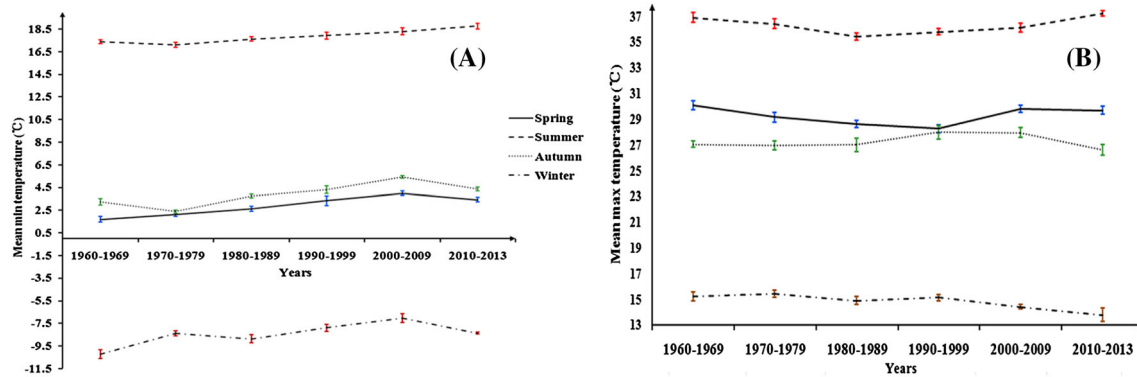
The effects of forest vegetation on climate mitigation were also reflected in the seasonal changes in meteorological elements (Fig. 3). With four seasons, the rising trend of the mean minimum temperature (see in Fig. 3a) could be ranked as: summer ( $R = 0.94$ ) > spring ( $R = 0.92$ ) > autumn ( $R = 0.78$ ) > winter ( $R = 0.72$ ). In addition, the change of the mean maximum temperature presents a weaker increase in autumn ( $R = 0.14$ ) and summer ( $R = 0.08$ ) and showed no change in spring. For winter, however, the maximum temperatures present an obvious downward trend (Fig. 3b,  $R = 0.88$ ).

From the point of the temperature change of the four seasons, the trends in the change of the mean minimum temperature were larger than that of the maximum;

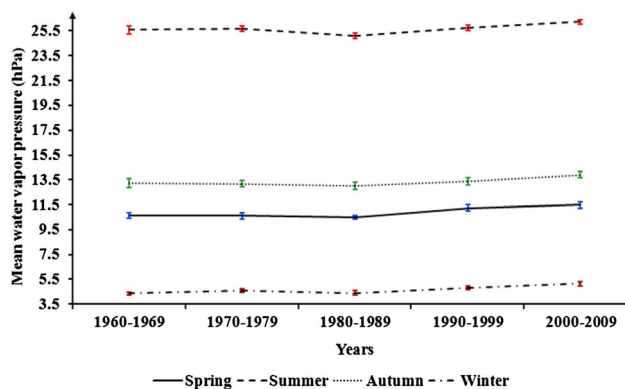
however, winter showed the slowest increase of temperatures. Even the highest temperature appeared to decrease over time, which led to the fact that winter should experience the smallest rate of increase across the seasons for temperature. Commonly, winter is a period with low crop yield. The contribution of surface vegetation to regional climate change mainly comes from evergreen forest vegetation in the area, such as *Sabina chinensis*, *Platycladus orientalis*, *Juniperus chinensis*, *Pinus thunbergii*, *Taxus chinensis* and *Cinnamomum camphora*, etc. All of these species are easy to find in the Xuzhou Mountain forests; this also fully illustrates the influence of afforestation on improving the regional climate.

Water vapor pressure tended to increase in all seasons without exception with an overall trend of winter ( $R = 0.87$ ) > spring ( $R = 0.85$ ) > autumn ( $R = 0.70$ ) > summer ( $R = 0.52$ ; Fig. 4). Figure 4 also shows a time inflection point, i.e., the 1980s; after the 1980s, the four growth ratios increase more remarkably than previously.

The actual water vapor pressure is a direct response to the content of water in the atmosphere; it mainly comes from evaporation of ground water and transpiration from plant leaves. The surface water content basically remained



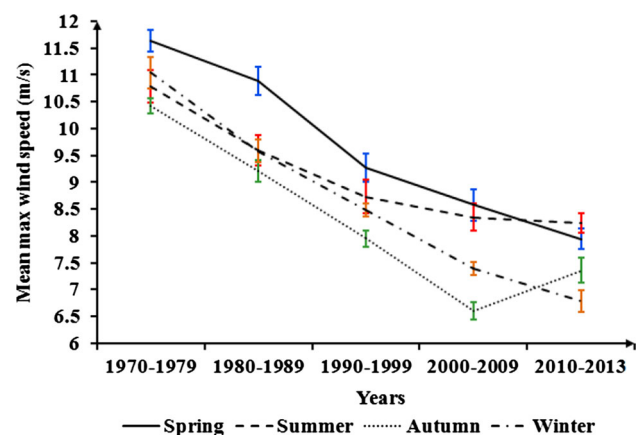
**Fig. 3** Mean minimum (a) and maximum (b) temperatures in different seasons (unit: °C)



**Fig. 4** Mean average water vapor pressure (unit: hPa)

unchanged in the Xuzhou area (Table 1). Usually, winter experiences the lowest evaporation and the lowest cropland coverage, therefore, winter should have the lowest water vapor pressure values and also lower water vapor pressure change rate; but the change rate showed quite the opposite. This was caused by the role of underlying vegetation, especially for green forest vegetation in winter as we mentioned above. Furthermore, in terms of the question about the transition time point (the 1980s), this transition is mainly related to process of growth of forests. The national and regional governments had promoted afforestation starting in the 1960s in the Xuzhou region. After about 20 years, the plantation forests had gradually matured in the 1980s, so effects on the increase of water vapor also changed little by little. As a result, Fig. 4 shows a rapid increase of water vapor after the 1980s, a trend that has continued up to the present day. Also at this time, change appeared in the annual vapor pressure (Fig. 2b) and the annual temperature range (Fig. 2c), probably for the same reason.

The mean maximum wind speed experienced a steep declining trend in that winter ( $R = 0.99$ ) > spring ( $R = 0.98$ ) > autumn ( $R = 0.94$ ) = summer ( $R = 0.94$ ); even though winter has the least amount of crop vegetation



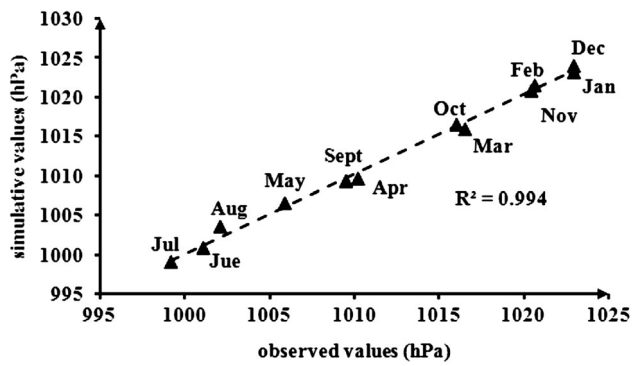
**Fig. 5** Mean average maximum wind speed (unit: m/s)

coverage its  $R$  is the largest (Fig. 5). Farmland area in the Xuzhou region decreased year after year (Table 1). Similarly, Fig. 5 further demonstrates why the mean maximum wind speed also decreased year after year; this occurred not because of the role of crops but because the growth of forests and their increased height increased the surface roughness.

An analysis of all the above observations shows that afforestation influences the changes regional climate in Xuzhou including an inhibition of warming, an increase in humidity and a reduction in wind speed and sunshine duration.

## 4.2 Simulation Results

The above analysis only employed in situ meteorological observations to study the influence of forest vegetation on regional climate. However, because of the temporal-spatial resolution limit, the results above may not thoroughly represent the full climate change in this region. Therefore, simulation was done by means of a regional climate model, RegCM3. And the simulated results need to verify their reliability; however, the detailed progress of verifying will

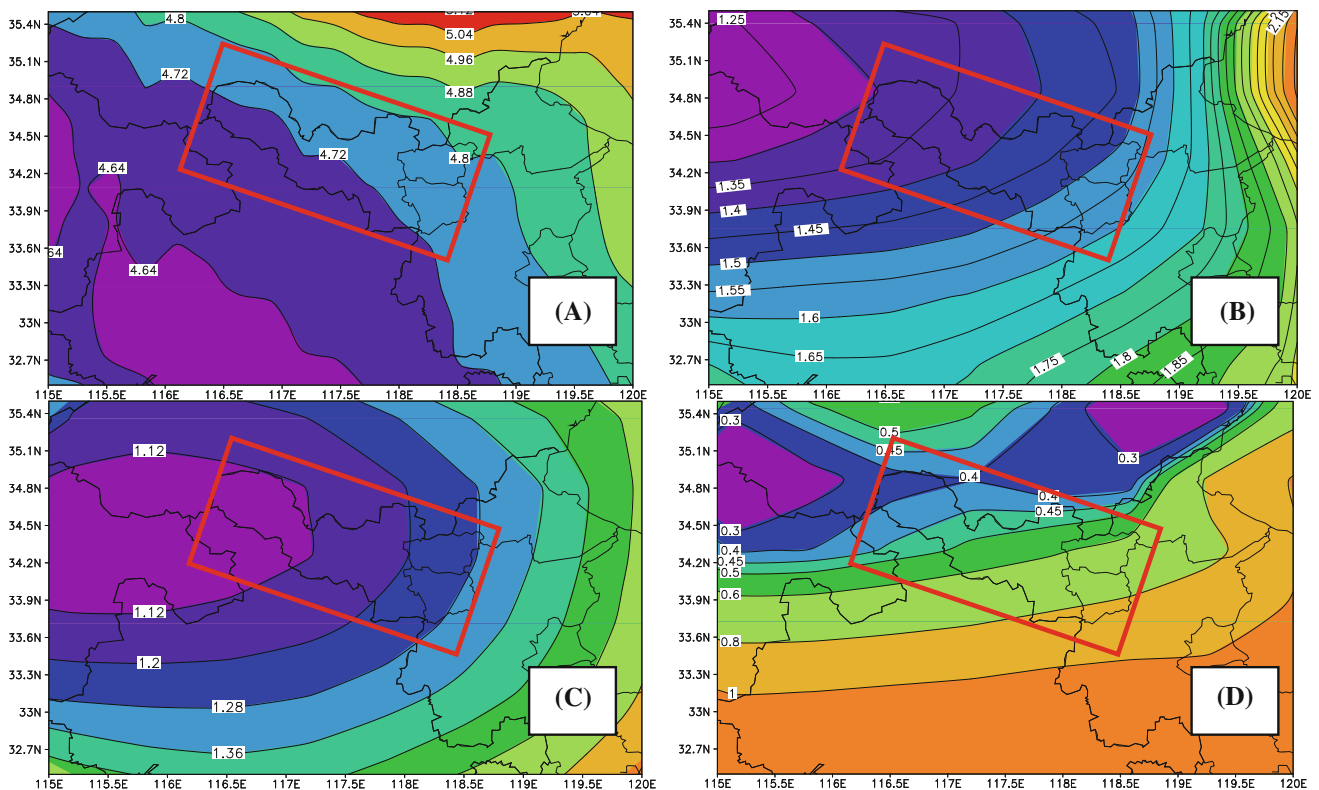


**Fig. 6** Observational and simulated monthly mean pressure over 30 years (unit: hPa)

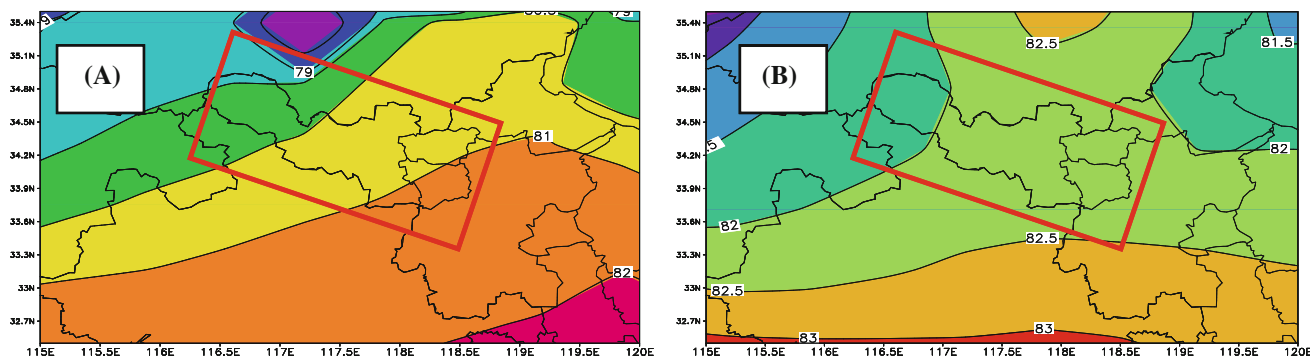
not be presented, because the simulation data are too extensive and the scale of the annual span is too large. Only a simple example was given here, such as monthly surface pressure (Fig. 6), using a consistent latitude and longitude followed with the Xuzhou observational site. Each pair of data was derived from observations and simulated values, for a total of 12 dataset pairs. In the same location (i.e., observational site point), each pair of data was in a comparison. The values in the scatter figure are monthly mean pressures during 1970–2000; each pair in the same month exhibited a good match, and the correlation coefficient  $R$  equals to 0.997, corresponding RMSE equal to 0.691.

Wind speed at ground level suggests that surface wind speeds decreased gradually over time in the Xuzhou region (marked as a box in Fig. 7). Wind speed fell from 4.75 m/s in the 1960s (Fig. 7a), to 1.42 m/s in the 1980s (Fig. 7b) and 1.18 and 0.59 m/s, respectively, in the 1990s (Fig. 7c) and 2000s (Fig. 7d). These simulated values are larger than that of observations shown in Figs. 2b and 5, possible reasons are: 1, observatory is located in the suburb of less high and complex surface features, and the simulated had to consider the whole surface roughness of Xuzhou region. 2, observations represent values at the height of 1.5 m above ground, which is national standard in China, while the simulated represents ground level, i.e., 0 m. 3, the observational wind speed is just a value of one point, while the values from simulation represent the whole Xuzhou region. So, strictly speaking, the two types of value cannot compare to each other directly, only we analyze their trend change.

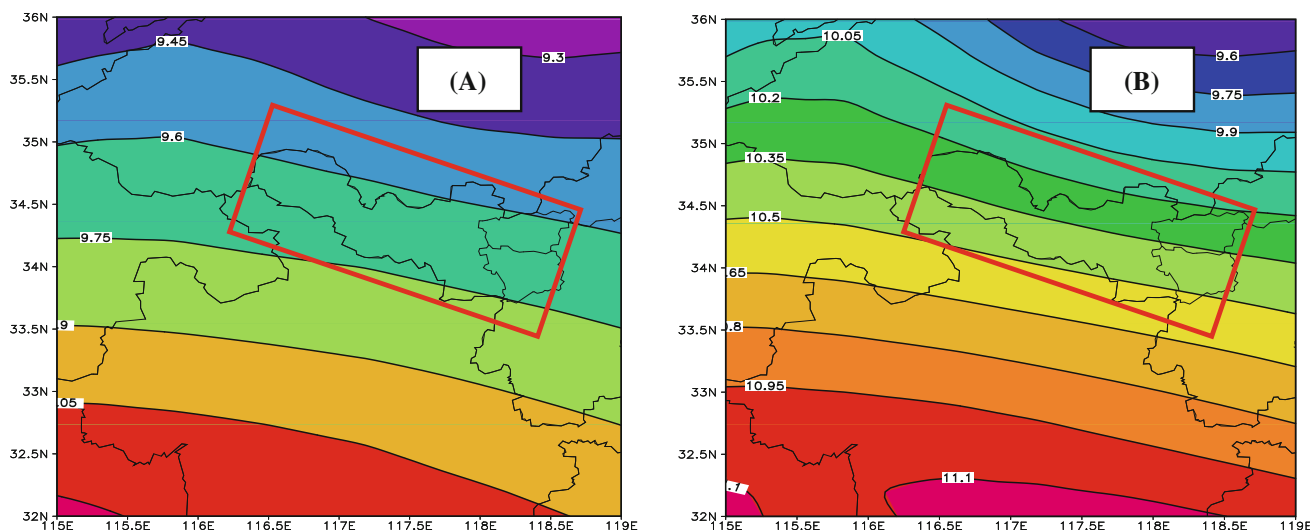
From simulation we can see that, in about 20 years, the ratio fell by 70.1% from the 1960s to the 1980s; it fell another 58.8% from the 1980s to the 2000s. In about 10 years, the decline ratio reached to 16.9% from the 1980s to the 1990s, and increased to 50% from the 1990s to the 2000s (Fig. 7). Specifically, the wind speed not only decreased, but the rate of decline increased after the 1980s. Therefore, we can see that the simulated trend matches the results of observational analysis very well; this shows that



**Fig. 7** Ground layer wind speed in the Xuzhou region (unit: m/s) a the 1960s, b the 1980s, c the 1990s, d the 2000s



**Fig. 8** Mean relative humidity in the 1980s (a) and the 1990s (b) (unit: %)



**Fig. 9** Mean water vapor mixing ratio at 2 m: a the 1960s, b the 1990s (unit: kg/kg)

the ground level wind speed is indeed declining from one single point to the entire area in the Xuzhou region. Do not take the effects of atmospheric circulation at higher altitudes into consideration, the decline is mainly caused by the increasing underlying surface roughness caused by the growth of forests; it is also may be caused by the increase in population density and urbanization. However, the contribution of forest cover in reducing wind speed should not be neglected [19].

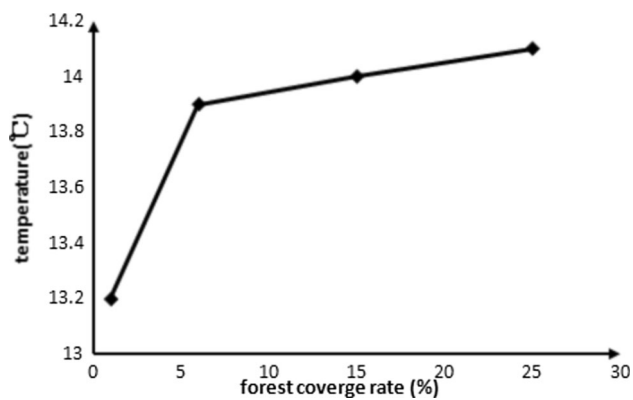
As for water vapor, the simulation results are just like the analysis results from single meteorological site observations, i.e., the content of water vapor is increasing persistently during tens of years in the Xuzhou region. Using the more conspicuous change in the 1980s and 1990s as examples, Fig. 8 shows the simulated results.

The mean relative humidity at ground level in the Xuzhou area was 80.6% in the 1980s (Fig. 8a), increasing to 82.2% in the 1990s (Fig. 8b), and increasing by 1.6%. Relative humidity is the ratio between actual water vapor pressure and saturation vapor pressure which is a monotone increasing function of temperature. Based on data

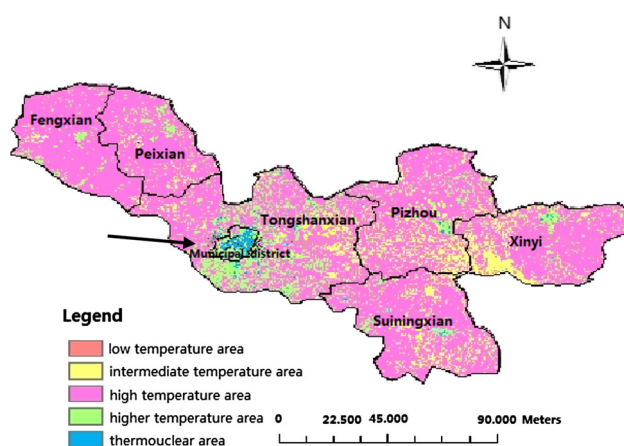
published by the China Meteorological Administration (<http://cdc.cma.gov.cn/home.do>), mean temperature in the 1980s and the 1990s was 14.32 and 14.80 °C in Xuzhou, respectively, increasing by 0.48 °C. Therefore, the corresponding saturation vapor pressure should rise from the 1980s to the 1990s, and then the resulting relative humidity should decrease for the same reason. However, the opposite situation occurred: relative humidity increased with increasing temperature and did not decline (Fig. 8). Therefore, we believe that water vapor pressure is certain to increase; this means the absolute water content in the Xuzhou region atmosphere should also increase. Another result also supports this conclusion: Fig. 9 shows the simulated mean water vapor mixing ratio at 2 m height; for example, the value was 9.68 kg/kg in the 1960s (Fig. 9a) and increased to 10.35 kg/kg in the 1990s (Fig. 9b). This increase in water vapor is closely associated with the improved transpiration caused by the increase in forest coverage, as mentioned above.

Figure 10 graphs the relationship between simulated mean temperature in the entire area and the forest coverage





**Fig. 10** The relationship between forest coverage (unit: %) and simulate mean temperature (unit: °C)



**Fig. 11** The retrieved value of temperature in summer, 2006, in the whole Xuzhou region

ratio in the 1960s, 1980s, 1990s, and 2000s, with the ordinate showing the simulated temperature and abscissa showing the forest coverage. A relatively obvious monotone increasing function relationship is shown in this figure. Specifically, the increase in forest coverage ratio and temperature is not directly showing a forest ‘cool’ or ‘warming’ effect on the climate. After anatomizing the data we can see the results: followed with the widespread increase in the forest coverage ratio, although temperature does not decrease, the value of warming decreases markedly. The warming reaches to 0.7 °C in the 20 years from the 1960s to the 1980s; however, in the same time period, i.e., from the 1980s to the 2000s the value is only 0.3 °C, an increased that is 0.4 °C smaller. So the obvious truth is: less forest coverage rate coupled with larger warming value, and vice versa. In addition, the warming is far less than the increase in forest coverage.

Figure 10 shows that the simulated mean value of temperature is slightly less than the published data by China Meteorological Administration in the analysis of Fig. 8, which mentioned above. For example, the simulated

value is 13.92 °C in the 1980s and 14.00 °C in the 1990s, being smaller than the published values of 0.4 and 0.8 °C respectively. The main cause for this increase is believed to be the urban heat island (UHI) effect which has been observed in many Chinese cities [20]. The population of Xuzhou only had far less than millions at the beginning of establishment of the new China in 1949, now this number has grown by the millions, nearing to ten million, and the change of population density and urbanization do contribute to the increase in the UHI effect. The UHI effect is impossible to ignore; meteorological observations taken at a single point located in the region have to be influenced by this effect. The arrow in Fig. 11 indicates the location of the meteorological station, i.e., the municipal district area, which is located on the edge of the high temperature core area, as we used Xuzhou region’s summer surface layer temperature as an example; so, the temperature values which was observed by local meteorological instruments might be higher, whether these data can represent the real condition of the entire Xuzhou region, we may be permitted to doubt this. Some data from other sources should be added, such as the simulated one in this paper. Furthermore, though the simulated data may not reveal the true situation; it really reflects the very possible mean value in the entire region, not only including the urban area but also covering the suburbs. This, to some extent, reduces the influence of the UHI effect, so the value is slightly lower than the observed value.

The large size of the study area made it difficult to choose LANDSAT enhanced thematic mapper remote sensing data for a single time period. Therefore, June was selected for Fengxian and Peixian counties and August for the other counties. The 6th band of LANDSAT contains the infrared wavelengths, which contain surface thermal radiation information, and finally allow acquisition of the surface layer temperature [18, 19]. Then, data were reclassified using ArcGIS9.3 software. To study the distribution of urban heat islands in the Xuzhou region, we classified the surface layer temperature into five grades: low temperature range (19.16–24.53 °C), intermediate temperature range (24.53–25.61 °C), high temperature range (25.61–27.13 °C), higher temperature range (27.13–28.36 °C) and high temperature core range (28.36–35.78 °C).

## 5 Conclusions and Discussion

The newest data shows that forests cover more than 32% of the Xuzhou region. At present, forests cover 21.6% of China as a whole account in for less than 3/4 of the world’s mean value. Most of Jiangsu Province is a flat plain area with only 14.8% forest cover. Therefore, the forest

**Table 2** Standard deviation values

	1960s	1970s	1980s	1990s	2000s	2010–2013
Annual mean water vapor pressure	0.17	0.12	0.12	0.18	0.13	0.19
Annual mean maximum wind speed	–	0.24	0.16	0.2	0.15	0.23
Annual mean sunshine duration	4.88	2.98	3.5	3.33	4.35	3.7
Annual mean maximum temperature	0.2	0.21	0.2	0.2	0.19	0.22
Annual mean minimum temperature	0.25	0.23	0.23	0.3	0.2	0.18
Mean minimum temperature of spring	0.25	0.12	0.22	0.4	0.2	0.2
Mean minimum temperature of summer	0.15	0.2	0.18	0.29	0.3	0.25
Mean minimum temperature of autumn	0.3	0.12	0.15	0.32	0.1	0.18
Mean minimum temperature of winter	0.4	0.23	0.38	0.3	0.38	0.08
Mean maximum temperature of spring	0.33	0.37	0.28	0.30	0.25	0.32
Mean maximum temperature of summer	0.30	0.30	0.22	0.2	0.31	0.15
Mean maximum temperature of autumn	0.20	0.31	0.32	0.33	0.28	0.31
Mean maximum temperature of winter	0.30	0.23	0.25	0.17	0.15	0.45
Mean water vapor pressure of spring	0.20	0.25	0.15	0.27	0.28	0.30
Mean water vapor pressure of summer	0.28	0.18	0.18	0.17	0.13	0.27
Mean water vapor pressure of autumn	0.30	0.20	0.21	0.23	0.16	0.21
Mean water vapor pressure of winter	0.13	0.11	0.14	0.10	0.14	0.20
Mean maximum wind speed of spring	–	0.2	0.26	0.26	0.25	0.2
Mean maximum wind speed of summer	–	0.3	0.28	0.29	0.25	0.18
Mean maximum wind speed of autumn	–	0.15	0.2	0.12	0.16	0.23
Mean maximum wind speed of winter	–	0.3	0.22	0.12	0.12	0.2

coverage and afforested condition of Xuzhou is the highest of any region within Jiangsu Province, is about 10% higher than the mean value for all of China and is about 17% higher for Jiangsu Province. This region has transitioned from the old saying that Xuzhou region has ‘Sand all over the sky’ at the beginning of the founding of China in 1949 to the ‘tree-lined’ conditions now. The change has been from ‘the earth scar’ to ‘the green engine of Jiangsu Province;’ the improvement and optimization of forest coverage and environment are obvious to all of us; afforestation must have made one of the greatest contributions.

Based on analysis in this paper, the Xuzhou regional climate change can be distinctly represented as follows: the wind speed at and near the surface has declined sharply of the past 40 or more years; water vapor pressure and atmospheric humidity increased and improved; sunshine duration decreased over time; the maximum temperature decreased while the minimum temperature increased during the same time periods, and the trend of the latter is larger than that of the former, meaning the annual temperature range decreases. In addition, we found that the annual rate of increase of forest coverage is much greater than rate of temperature increase; as forest cover has improved and increased, the rate of temperature increase has been decreasing. All of these also have obvious characteristics related to time and season; temporal

characteristics are expressed in the threshold of the 1980s. After this time period, the trend of meteorological elements changes is more clear; those changes also conform to the concept that a forest affects the regional climate and that effect is related to stand age [12], showing that mature forests have better adjust actions on regional climate. The seasonal characteristics of Xuzhou’s forest are embodied in the season of winter, do the forest in winter contribute to regional climate change by creating a rough surface and providing transpiration, leading to the largest wind speed declining trend and water vapor pressure increasing trend, as well as the lowest mean minimum temperature increasing trend, even presenting decline trend of maximum temperature, these features help us to realize the effects of forest on regional climate change.

For the regional climate, though the influence of the forest is not perfectly clear, and the data and methods used in this paper inevitably have some limitations, the analysis of the Xuzhou region still clearly indicates that increasing forest coverage results in improved regional climate and ecological optimized, based on single point observations and simulated data covering the entire region. Reports suggested that in the past Xuzhou was looked upon as a city of ecological devastation with serious pollution, but now Xuzhou have been reborn [21]. The city has had more than 300 days good air quality days for 5 years, annual precipitation amount of 1100 mm which is close to the

average for the cities of Yangtze River basin, exhibiting very good aquatic ecology which is rare among cities of northern China. Experts at the national climate center said restoration of the environment 'is equal to relocating the Xuzhou region toward the south by about eight hundred miles.'

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