Agroforest Syst
DOI 10.1007/s10457-016-9928-9

Effect of forest shelter-belt as a regional climate improver along the old course of the Yellow River, China

Jia-Yao Zhuang · Jin-Chi Zhang · Yangrong Yang · Bo Zhang · Juanjuan Li

Received: 24 January 2015 / Accepted: 17 March 2016

Abstract Up to now very few case studies have provided evidence of the effect of large regional increases in forest area on improving regional climate. This article is perhaps the first description of a unique positive case study of the increasing protection provided by reforestation in controlling a formerly disastrous climate, where gale days have decreased by 80 % per year, and maximum wind speeds of gales have decreased on average from 26 to 11 m/s, while overall average annual wind speed has decreased by 90 % near the ground surface when forest coverage has increased from 3 % in 1950s to 36.9 % in 2010s within 60 years, changing the long-term trend of sandstorms and desertification into a wetter climate where disastrous droughts are now rare despite a global megatrend of decreasing forest area and climate warming. The local climate has been improved by reducing the extreme highs in temperature, reducing the power and frequency of gales, and increasing the number of foggy days. Thus, we propose in arid and semi-arid regions, billions of trees may have a direct effect on improving regional climate, which is worth attention to more than just because of its function as a carbon sink.

J.-Y. Zhuang · J.-C. Zhang (✉) · Y. Yang
Lab of Water and Soil Conservation, Nanjing Forestry University, Nanjing 210037, China
e-mail: zhang8811@njfu.edu.cn

B. Zhang
University of Miami, Coral Gables, FL 33124-0421, USA

J. Li
The Walt Disney Research China, Shanghai 200021, China

Keywords Forest shelter belt · Regional climate change · Average annual wind speed · Number of foggy days

Introduction

Global warming is a reality, predicted based on sound evidence from many different research methods (McCright and Dunlap 2000), and the function of forests as carbon sinks that may slow down this trend is well recognized around the world. But a forest's hydrological function, that is, its effect on increasing or decreasing runoff of precipitation, is still in dispute. It has been controversial to plant trees in arid and half arid region due to evapotranspiration of trees being deemed water consuming rather than a means of water conservation (Jiangchu 2011; Robert et al. 2005; Bradford and Yun 2010). In some regions, forest has been removed for economic reasons, or forests have been planted for material production, followed by clear-cutting, including even the removal of litter, grass and shrub, without regard to the huge damage and economics loss from increased drought caused by forest loss and hence the loss of the forest's water and soil conservation function (Jane 2010; Daniel et al.

Published online: 14 June 2016

2010). Furthermore, the results of these actions may turn a forest's carbon sink function into carbon source (Oliver et al. 2009). Up to now, very few case studies from around the world have provided evidence of the effect of large regional increases in forest coverage on improving climate. Here we show a unique positive case of the increasing protective function provided by a forest on control of a disastrous climate over 50 years for the region along the old course of the Yellow River in northern Jiangsu province, China, which had experienced some devastating earlier climate changes.

Historically and present situation of study area

The old course of the Yellow River($E116°9'15''$-$E116°52'3''$, $N34°24'25'' - N34°59'27''$), the Dasha River in the Huanghuaihai Plain in north Jiangsu province, China, is a total of 54 km in length, which was a historically notorious alkaline landscape and sandstorm depression, where more than 50 % of the residents had to be beggars for half of each year before 1980s, because its climatic conditions were extremely severe. The total land area of basin is 152,000 ha, most of which underwent desertification, in fact amounting to 132,600 ha in the early 1950s. Since the area along the old course of the Yellow River was formed by the abundant sandy soil from Loess Plateau, soil desertification was very severe after it had dried. The old ballad "When no wind the height of sandy dust is 1 m, loess soil buries crops" is the true portrayal of that time (Photo 1a). The area of forest was just around 1900 ha at that time, and forest coverage was no more than 3 %. There were many natural disasters at that time, such as drought, waterlogging, low temperature, blasts of intense heat, tornados, and so on, which not only limited agricultural production, but also tremendously affected the sustainable development of the social economy.

Over the past several decades, the measures adopted by local government for sandstorm prevention and control were afforestation of the desert areas, as well as a shelter-belt forest network consisting of trees along the roads, ditches, ponds, and cultivated land ridges (Photo 1b). This was achieved by coupling tree plantations of millions of family around their self-managed (ownership) land with new techniques and ownership of planted trees, as well as subsidies for buying trees and digging planting holes. Figure 1 shows the outstanding progress of forest shelter-belt along the old course of the Yellow River, Jiangsu province, China, from 7 % in 1959, to 18.2 % in 1987 to 36.9 in 2010. At the present time, the formerly extremely severe climate along the old course of the Yellow River has been fundamentally changed. The improved quality of the regional environment is verified by the greatly increased productivity and welfare of the people. The saline alkali soil has been treated, along with poverty, transforming a beggar's hometown into a modern region, famous as a producer of food, fruits, vegetables and wood. However, in present-day China, due to higher profit from crops than from wood, as well as the negative effect of forest shelter-belt on crop yields within 1–2 times of tree height distance, farmers prefer not to replant shelter-belt forest along their land ridges and ditches after the clear-cutting of mature trees, so some forest shelter-belt has been turned into crop land again, meaning a decrease of the shelter-belt forest. If this continues, it may also mean a revival of sandstorm-stricken desertification. The research on the increase of regional forest coverage

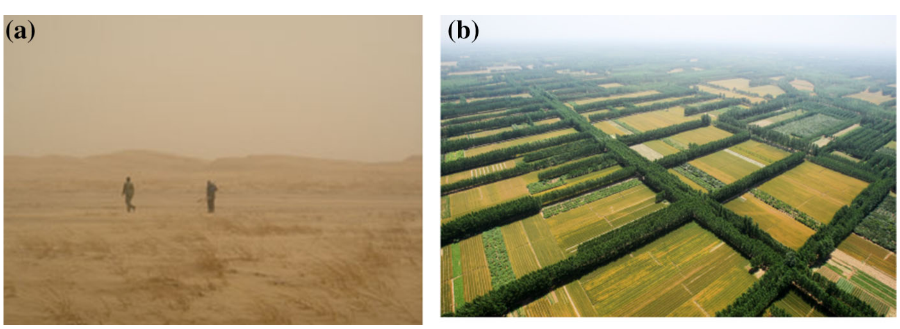

Photo 1 Contrast between historical and present scenery along the old course of the Yellow River, Jiangsu province, China **a** salinization land and sand-laden wind in the 1960s and **b** present forest shelter belt along the cultivated land ridges along the old course of the Yellow River, Jiangsu province, China

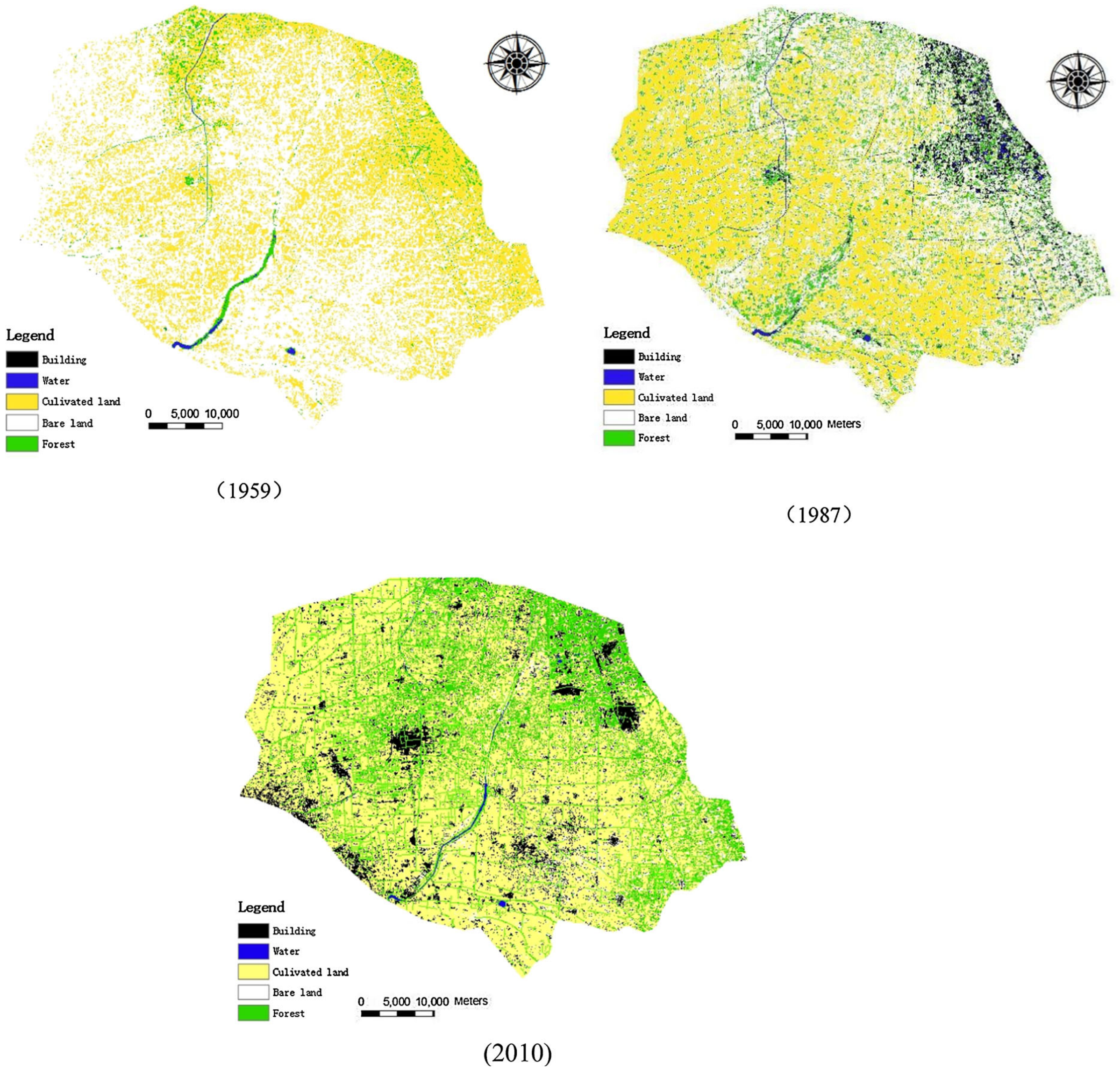

Fig. 1 Variation of forest belt along the old course of the Yellow River, Jiangsu province, China, from 1959 to 2010

and its relationship of regional climate change after 1950 not only can provide a theoretical foundation for development of forestry on the Chinese plain, but can also supply a wonderfully positive case study of favorable regional climate changes, despite the megatrend of a decrease of global forest area and global climate warming. It can have important instructive significance for the proper recognition of the value of forestry on the plain and the strategy of dealing with global climate change pursued by the Chinese government.

Methods

LU/LC derivation

The LULC (land use/land cover) maps of in two years were made using aerial photos in 1959, TM images in 1987, 2010 by combining visual interpretation and automatic classification method, which was collapsed into five LULC types: cultivated, forest, water, building, and bare land.

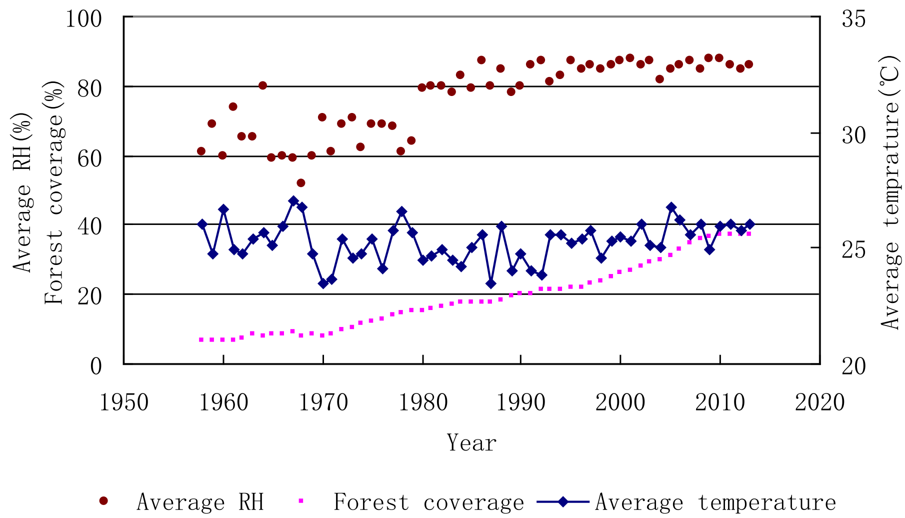

Fig. 2 Forestry coverage and average RH, average temperature in June from 1950s to 2010s

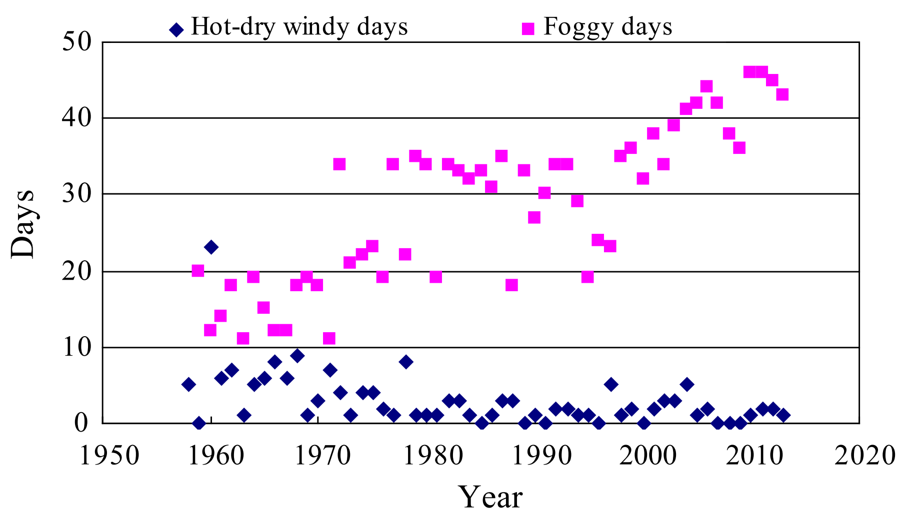

Fig. 3 Annual variation of both hot-dry windy days and foggy days in a year from 1958 to 2013

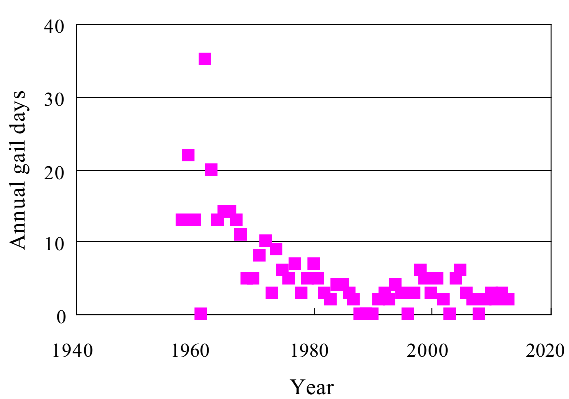

Fig. 4 Variation of annual gale days from 1958 to 2013

Variation of meteorological factors

Figures 2, 3, 4 and 6 were made using 66 years of meteorological data from the Fengxian prefecture Meteorological Bureau and 50 years of general survey materials of forest area from the Fengxian prefecture Bureau of Agriculture and Forestry,

Simulation of average annual wind speed

RegCM3 model was used with NCEP1° × 1°reanalyzed data with 30 × 30 km^2 resolution from 1960 to 2010. The simulated result was averaged every

10 years and compared with the observed averaged values of meteorological data from the Fengxian prefecture Meteorological Bureau.

Results and analysis

Increased average relative humidity

Using 66 years of meteorological data from the Fengxian prefecture Meteorological Bureau, Fig. 2 was made, which shows that forest coverage rose slowly from the end of the 1960s to the 1970s, during which time great efforts in reforestation were made and forest coverage increased from 11 % to 15 % correspondingly. Then from the 1970s to 1980s, when the young trees that were planted in the previous decade grew up to maturity, along with the continuing efforts of tree plantation, forest coverage increased rapidly from 13 to 16 % in the year 1980. From then on, it increased at a constant rate up to 36.9 % in 2013.

Correspondingly, ARH (average relative humidity) in June varied between 55 and 80 % during the years from 1958 to 1980, and from then on, during the past 30 years it has varied between 78 and 90 %, while average temperature in June stayed constant period. This meant a real increase of water vapor, on the one hand, perhaps, largely because of the increased evapotranspiration from trees and crops, and on the other hand, due to the greatly decreased frequency of gales and of the average annual wind speed (see below), the latter of which reduced the wind's effect in blowing water vapor away from the local area. Soil and air moisture are so important that the limited moisture supply in some regions has caused a recent decline in the global land evapotranspiration trend (Martin et al. 2010). It is suggested that, when forest coverage increased to 16 % in the plain, a great climatic change may occur, transitioning from dry weather to humid weather.

Decreased dry-hot windy days and increased foggy days

Dry-hot wind is also called, variously, fire wind, dry wind and hot wind, which is a disastrous sort of weather for agriculture, with high air temperature and low air humidity. During the period before reforestation, the dry-hot wind mostly occurred during early May to the middle of June in Fengxian prefecture, when the wheat is at the heading, flowering and filling time, with physiological evaporation increasing rapidly due to its close coupling with the physical environment of high temperature. Low air humidity caused by dry-hot wind, which facilitated evaporation, caused insufficient grain filling or even death of wheat. Figure 3 shows the variation of dry-hot wind days and foggy days over a 50 year period. Dry-hot wind days before 1960 varied from 1 to 22 days. They varied from 0 to 20 days between 1960 and 1970, 0–10 days between 1970 and 1980, 0–6 days between 1981 and 2005, and 0–3 days from 2006 to 2013. Foggy days varied from 10 to 20 days between 1958 and 1971, 18–35 days between 1972 and 2000, and 35–45 days between 2001 and 2013.

In related cases, in Xishuangbanna, Yunnan province, China, which experienced its longest and most severe drought in 2010, annual foggy days decreased from 180 days in the 1950s to 30 days in 2010s (Cheng and Xie 2008), while annual precipitation days decreased from 270 to 150, even though total precipitation decreased no more than 10 %, showing the strong relationship between drought and decrease of mist. It has been reported that deforestation at the foot of western Costa Rican mountains is causing a drying out of the traditional swirling summit mists. This is likely due to the fact that agriculture has eroded lowland forests and the fluffy cumulus clouds that feed the peaks' forests no longer form, due to insufficient water moisture from evaporation, which has the effect of lowering air temperature through evaporation. In the absence of the evaporation, air is warmer and has to be lifted higher before it cools into mist (Lawton et al. 2011). North China has suffered severe droughts since the 1960s (Shilong et al. 2010), during which both evaporation and precipitation decreased. The same phenomenon occurred along the old course of the Yellow River, where both evaporation and precipitation decreased by a quarter within 50 years. But over this period ARH, remained almost constant for all 12 months, except that in June ARH increased rapidly by 15 % from the 1980s–1990s and kept increasing slowly, showing a strong drought control function on regional climate. Increasing mist may signal proof of drought control, as well as providing beautiful scenery in the old Yellow River course (Photo 2).

Photo 2 A foggy day on the old course of Yellow River on March 26th, 2013

Decreased gale days and average annual wind speed in different times

Gales can blow water vapor off into the atmosphere while calm wind days facilitate the formation of mist. Increasing the number of foggy days requires both sufficient water vapor and cold enough air temperatures to condense water vapor into mist. With the construction of the forest and shelter belt forest network system, wind speed was decreased and gales that once blew off water vapor and caused sandstorms were controlled. Figure 4 shows the variation of annual gale days; that is, days in which the instantaneous wind speed was larger than or equal to 17 m/s, from 1958 to 2013. The number of gale days dropped year by year from 35 days/year in 1958 to 10 days/year in 1970, and remained under 10 days/year till 1980. From then on, it stayed within 5 days/year up to 2013.

One shelter forest belt may reduce wind speed by 25 %, the effective range of which may reach 5 times of the height of trees in the windward side of the forest belt, and 22 times of the height of trees in the leeward side of the forest belt. The shelter forest belt network has controlled gales with respect to both wind speed and duration. During 1958–1972, the annual average maximum wind speed was 26 m/s, and the number of gale days was 14d/a. But after the 1990s, the comprehensive protection forest system, which consisted of forest along the earthen ridges, roads, ditches, river banks and around ponds and villages, as well as agro-forestry and fruit garden trees, was established. During the period 1988–2013, the annual mean maximum wind speed decreased to 11.1 m/s, and only 2.1 days gale days occurred on average every year. The shelter forest greatly reduced the wind speed within the forest belts, and raised the soil moisture at the same time. The positive role of the forest belt is especially remarkable in the sandstorm-stricken areas and the saline-alkaline waterlogging depression, which had been the scene of serious natural disasters. The wind is frequently a predominant factor in the productivity of regional agriculture. Gales may erode the farmland's fertile surface soil, resulting in crop failures or poor harvests, and may bury the farmland, the water wells and the drainage ditches, causing severe harm. However, with the protection of shelter forest network, these negative effects are greatly reduced or even avoided. This was further confirmed by simulated results with the RegCM3 model, as shown in Fig. 5. The results show that in the 1960s, simulated average annual wind speed in the 1960s was 4.5 m/s, while in the 1980s, it decreased by 70 % to 1.45 m/s; in the 1990s, it decreased by 76 % to 1.1 m/s; and in the 2000s, it decreased further by 90 % to 0.45 m/s. This may be due to the great increase of shelter-belt forest planted in the 1990s, both in area and in forest stand volume, although these figures may also reflect a common function of increased forest together with decreasing average annual wind speed together in a much larger area than that along the old course of the Yellow River. This decreases was further confirmed by comparison the simulated result with the observed result in the Fengxian meteorological station. Figure 6 shows the simulated average annual wind speed near ground surface in four time periods, from the 1960s to the 2000s significantly correlated with the observed results at 1.5 m height, showing a linear regression, $y = 3.71x - 6.32$,with $R^2 = 0.99$.

In the eastern China, decreased wind speed may also be caused by an increase of both forest area and forest quality which means great increase of biomass of trees and shrubs under the canopy, which were formerly cut for cooking fuel 10 years ago by farmers and gradually saved by using cheap and convenient gas fuel. Decreased wind speed may mean low moving speed of air mass, causing extremely long and hot summer days such as in the year 2013 and long, cold and rainy days such as in the year 2014.

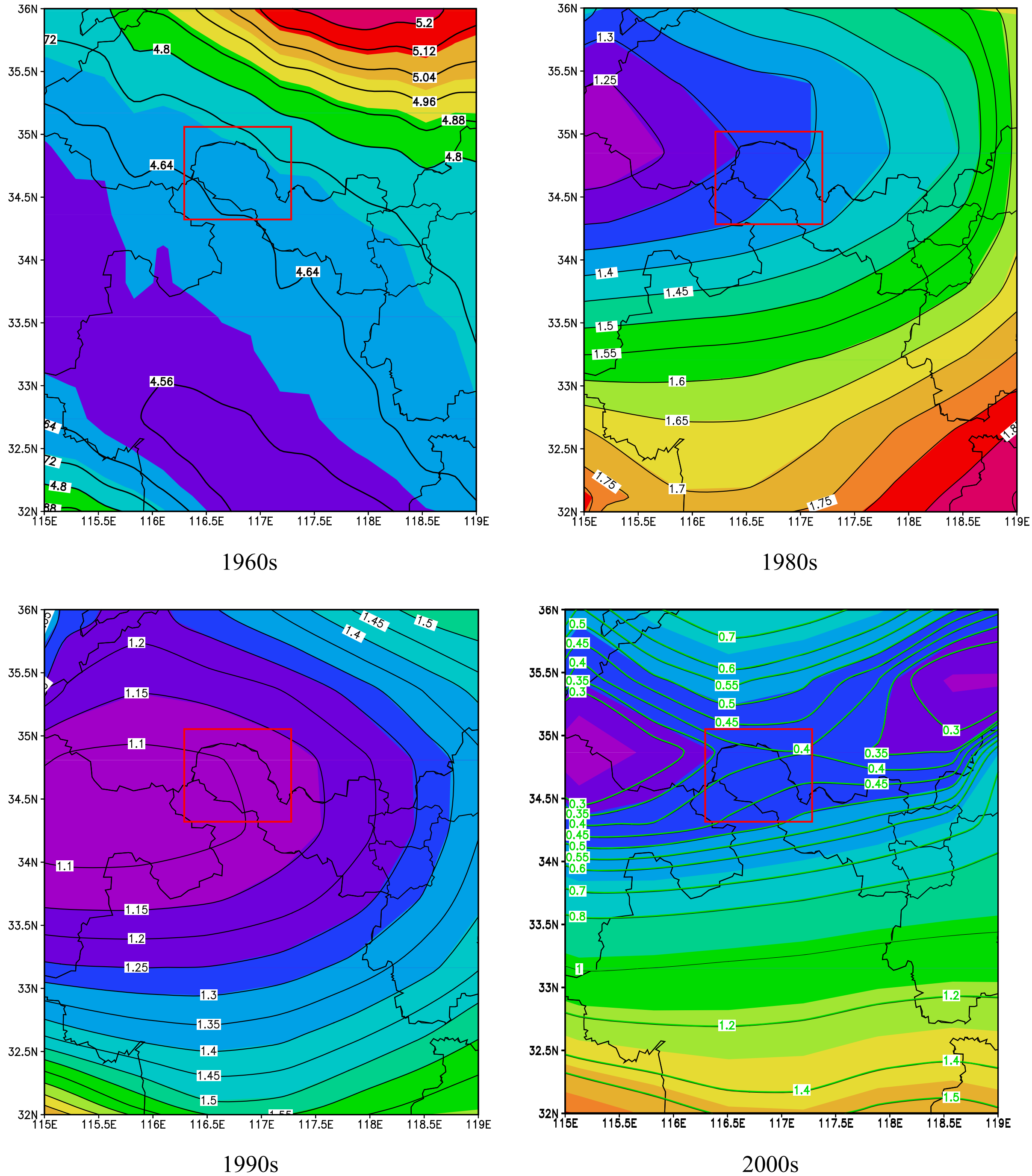

Fig. 5 Average annual wind speed in four times from the 1960s to 2000s. The area within the red square means the research area along the old course of the Yellow River

Variation of hot days

Even with the urban expansion that has occurred, which would be expected to have the effect of increasing temperatures, Fig. 3 shows that days with max air temperature >35° declined remarkably within 50 years. It varied between 0 and 28 days/year during 1958–1970, 0–20 days/year during 1971–1995, and

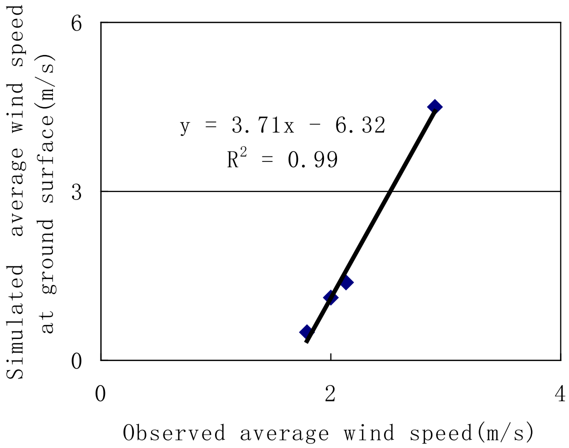

Fig. 6 Comparison of observed average annual wind speeds with simulated wind speeds at four times from the 1960s to the 2000s

stayed between 6 and 11 days/year during 1996–2013. In recent decades, the global climate has been experiencing remarkable changes, mainly being characterized by global warming, which has had an aggravating tendency. The smallest warming trend over the past five decades is found over southwest China and southeast China, with a trend of 0.15–0.19 °C per decade (Shilong et al. 2010). But there is a great difference in the speed of expansion of urban area in the two regions, due to rapid economic growth in southeast China. Urbanization has expanded 3–5 times within 50 years, and the meteorological stations in southeastern China that were once in the suburban areas are now included in the city or are very close to the city, while those in southwestern only once or twice showed a urban heat Island (UHI) effect. Because of the increase of forest cover rate, which has eliminated the UHI effect on the Fengxian meteorology station, which was once in the suburbs before 1990s, and is now at the edge of the city, the annual average temperature of the old Yellow River course in the northern region of Jiangsu province decreased by 0.63° during 1991–2006. This shows that the construction of the plain's farmland protection network of forest belts played an important role in regional modulation of global warming. When the UHI effect on temperature in taken into consideration, by subtracting it out of the regional temperature change, the smallest warming trend over the past five decades should be over the southeastern China, which experienced a great increase in forest plantation area, which in turn facilitates crop and other plant growth, finally contributing to the improvement of regional climate.

Conclusions

With constant application of reforestation for 50 years, the regional climate in the old course of Yellow River has improved greatly, from its former long term status as a region of sandstorms and desertification, into a region that can be considered as being intermediate between mesic and humid in weather, and with few natural disasters. Sandstorms, dry-hot wind and saline-alkali soil have been eliminated at the root source, along with poverty of the local population. Thus we proposed that, even though a single or several plots of trees might be net consumers of water in arid and half arid region, millions of trees may have a "mass effect function on improving regional climate."

The protection forest of the old course of the Yellow River in northern Jiangsu province, China, plays a positive role in the amelioration of extreme climate, reducing the extreme highs in temperature and moderating the extreme lows. The protection forest of the old course in North Jiangsu has improved the environment for living and the productivity of agriculture, having lessened the damage from arid wind to spring wheat and rape, having reduced the power of gales, having reduced the number of gale days, and having effectively controlled the formation of disastrous droughts in an environment with a drying trend. This provides a fine example and revelatory view for similar areas suffering from saline alkali soil and sandstorms, of how such natural disasters might be controlled. Both the local farmers and the Chinese government should reconsider the great eco-value of forest shelter-belt, try their best to maintain the continuity of the shelter-belt forest, rather than turning it into crop land.

Acknowledgments The National Natural Science Foundational of China (Grant No. 31170663) and Disney Research China financially supported parts of this study.

References

Bradford PW, Yun H (2010) Woody plant encroachment paradox: rivers rebound as degraded grasslands convert to woodlands. Geophys Res Lett J 37:1–5

Cheng JG, Xie MG (2008) The analysis of regional climate change features over Yunnan in recent 50 years. Prog Geog J 27(5):20–27

Daniel RC, Tapash D, David W et al (2010) Future dryness in the southwest US and the hydrology of the early 21st century drought. PNAS J 107(50):21271–21276

Jane Q (2010) China drought highlights future climate threats. Nat J 465:142–143

Jiangchu X (2011) China's new forests aren't as green as they seem. Nat J 477:371

Lawton RO, Nair US, Pielke RA et al (2011) Climatic impact of tropical lowland deforestation on nearby montane cloud forests. Sci J 294:584–587

Martin J, Markus R, Philippe C (2010) Recent decline in the global land evapotranspiration trend due to limited moisture supply. Nat J 467:951–954

McCright AM, Dunlap RE (2000) Challenging global warming as a social problem: an analysis of the conservative movement's counter-claims. Soc Probl J 47(4):499–522

Oliver LP, Luiz EOCA, Simon LL et al (2009) Drought sensitivity of the Amazon Rainforest. Sci J 323:1344

Robert BJ, Esteban GJ, Roni A et al (2005) Trading water for carbon with biological carbon sequestration. Sci J 310: 1944–1948

Shilong P, Philippe C, Yao H et al (2010) The impacts of climate change on water resources and agriculture in China. Nat J 467:43–51