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Effects of wind farms on near-surface wind speed

Zhang Xin[1], Yin Ruiping[1], XU Ronghui[2], Liu Jing[3], He Jingli[1], Liu Yanping[1] , Wu yongsheng[1] Sun Xu[3] and Wang Lixia[1]

[1] Institute of Water Conservancy Science, Ministry of Water Resources in Inner Mongolia, Hohhot 010020, P.R. China

[2] Forestry Monitoring and Planning Institute, in Inner Mongolia, Hohhot 010020, P.R. China

[3] College of Ecology and Environmental Science, Inner Mongolia Agricultural University, Hohhot 010019, P.R. China

E-mail: nmmkszx@163.com

Abstract. Large-scale development of wind farm has brought environmental benefits, at the same time, it will also affect local meteorological environment .We choose Zhurihe wind farm, which is located in Sonid Youqi of Inner Mongolia, as our study area. Our Observation instrument is HOBO automatic meteorological station. The observation points are set on upwind area, inner wind farm and downwind area, in order to parallelly observe wind speed of 0.5m，1.5m and 3.0m height. The results show that the wind farm consumes wind energy and reduces wind speed of inner wind farm and downwind area. The relationship of average wind speed in spring, summer and autumn is upwind area> downwind area > inner wind farm. Compared with upwind area, the decrease scope of average wind speed of inner wind farm and downwind area in spring is 5%-22%,summer is3%-25%,autumn is 5%-33%.The influence of wind farm on the near surface wind speed reduces with the increase of environment wind speed in the same season. The existence of the wind farm has no effect on the form of wind velocity profile, which are all the standard logarithmic curve. But the slope of wind velocity profile of inner wind farm and downwind area is decrease. That is to say the fluctuation trend of wind speed increasing with the increase of height is not significant. In addition, compared with upwind area, the existence of wind farm has increased the surface roughness of the area where the wind farm is located in.

1. Observation sites and observation method

1.1. Selection of observation area and observation point

In order to reduce the influence of terrain factors on wind speed observation, this study chooses ZhuRihe wind farm which is located in Inner Mongolia grassland and has a relatively flat terrain. The geographical coordinates of the central position of the study area is E 112°47′,N 42°31′.The region belongs to arid continental climate, the average temperature is 4.3℃, the maximum and minimum temperature is 38.7℃ and -38.8℃, respectively. Average annual precipitation and evaporation is 170-19mm and 2384mm. The study area prevails northwest wind throughout the year, the average wind speed is 5.5 m/s and maximum level can reach 10.Our study wind farm covers an area of 20 square kilometers with 6km north-south direction and east-west 4 kilometers. The wind farm consists of 33 turbines and each turbine is 65-m-tall with 50-m-long rotor blades.

In study area, we set four observation sites paralleling to the wind direction. In upwind area and downwind area we set up one observation point respectively and two points in wind farm area. The nature of the underlying surface of each observation point is similar. Main soil type is Sandy soil and the main vegetation type is *Stipa breviflora Griseb*. Specific layout of observation points is shown in figure 1.

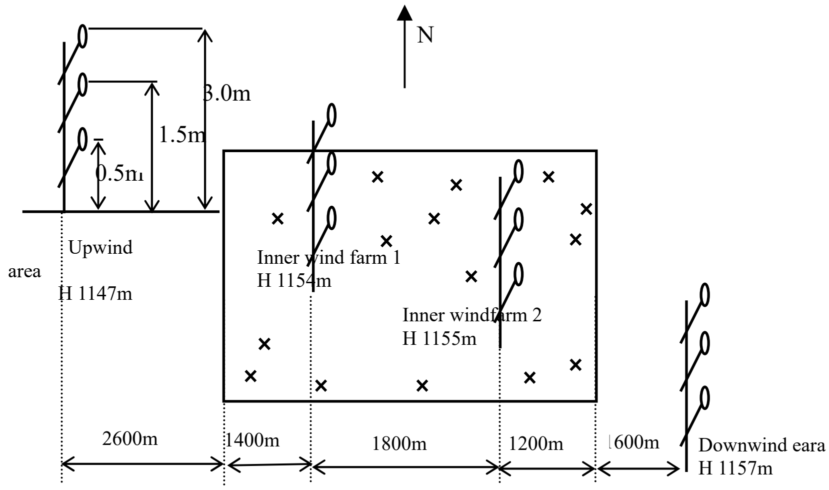

Fig.1 Observation point

1.2. Observation method
HOBO automatic weather stations are used in each observation point to synchronously observe wind speed value of 0.5 m, 1.5 m and 3.0 m height. Data sampling interval is set to 5 min with continuous 6h observation from 10:00-16:00.Spring observation time is March 24 - March 27, 2013 and early summer observation time is May 29- June 1,2013. Early autumn season of observation time is August 27-September 2, 2013 and the winter observation time is December 6- December 13, 2013.

1.3. The data processing
The experiment observation data were processed by Excel and SAS9.0 data processing software.

2. Results and analysis

2.1. The influence of wind farm with different seasons on wind speed

2.1.1. Average wind speed in the day
Average wind speed can show the overall rule of wind speed in the area, the average wind speed in daytime of different season is analyzed in this paper.

Figure 2 is the contrast of average wind speed at different height in three seasons. Wind speed change rules at different height are basically identical, which is upwind area>downwind area>inner wind farm. It can be seen from the figure 2, in 3.0 m height, the average wind speed of two locations of inner wind farm were 80% and 85% compared the upwind area ,respectively. Wind speed of two points inner wind farm velocity decreases obviously and the maximum decreases amplitude of 0.65 m/s. The downwind area average wind speed is 85% of upwind area. The regular average wind speed of 1.5 m height is similar to 3.0 m. The average wind speed of inner wind farm 1,inner wind farm 2 and downwind area decreased 23%,18% and 15%,compared with upside wind farm, respectively. At 1.5m height, the average wind speed of inner wind farm 1,inner wind farm 2 and downwind area decreased 25%,15% and 9% .

Observed from figure 3, we can see that compared with spring, the summer wind speed value is reduced. The average wind speed relations is similar to the spring, That is upwind area>downwind area>inner wind farm 2>inner wind farm 1. At 3.0 m height, the average wind speed of wind farm 1,wind farm 2 and downwind area decreases by 33%, 15.1% and 14.8%.,respectively, compared with upwind area. At 1.5m height and 0.5m height, the educed ratio is respectively 24.5%,19%,8.4% and 19.9%,5%,4.6%.Autumn also shows a similar regular that the average wind speed is upwind farm>downwind area>inner wind 2>inner wind farm 1.Thus, the wind speed of upwind area position three observation height was greater than the average wind speed of inner wind farm and downwind area, that is to say when the wind went through wind farm, wind motor consumes a certain wind power, which led to the loss of wind speed, and then the average wind speed reduced obviously.

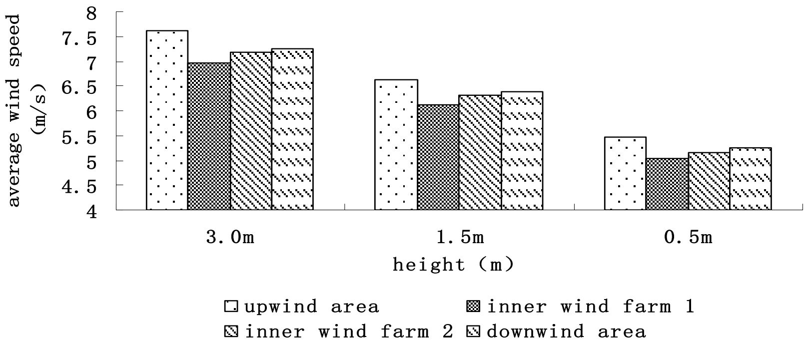

Fig.2 Comparison of the average wind speed in spring

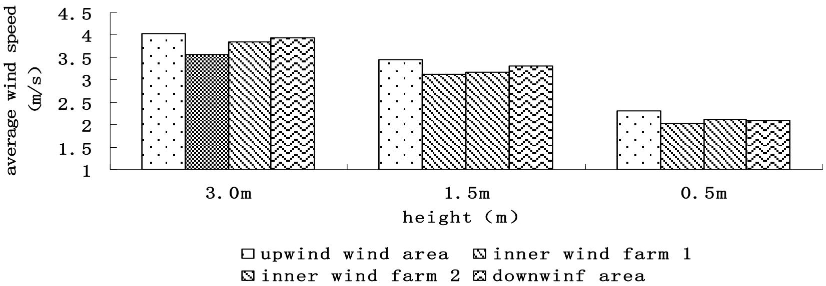

Fig.3 Comparison of the average wind speed in summer

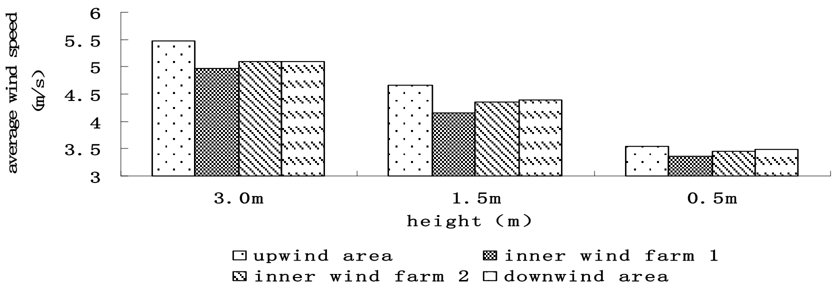

Fig.4 Comparison of the average wind speed in autumn

2.2. The influence of wind farms to the near-surface wind speed profile

Wind speed profile refers to the distribution of wind speed with height curve, it is one of the most important indicators reflect the features of near-surface airflow. Wind speed profile can show the changing rule of the variations in wind speed with height. Under normal circumstances, the surface layer of the wind speed increases with height [1-3]. Figure 5-7 is the wind speed profile chart of three seasons of each measuring point. By three figures, we can see that in the spring, summer and autumn, the average wind speed of upwind area, inner wind farm and down wind area is increased with the increase of height. The wind speed profile of each measuring points is the standard logarithmic curve and the equation of the correlation coefficient R2 was greater than 0.9, the fitting is very good. Thus it can be seen that the existence of the wind farm does not affect the near-surface velocity profile form.

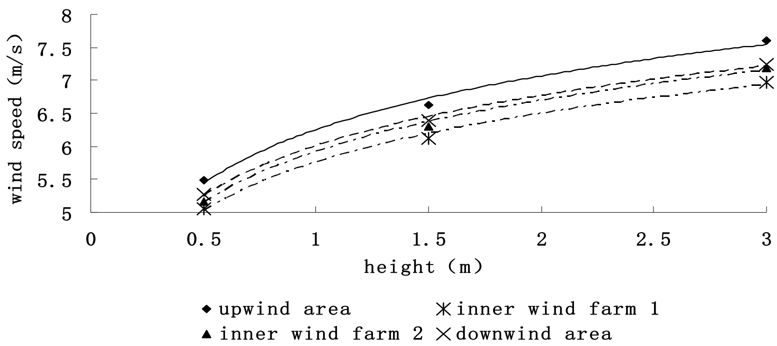

Fig.5 The wind velocity profile in spring

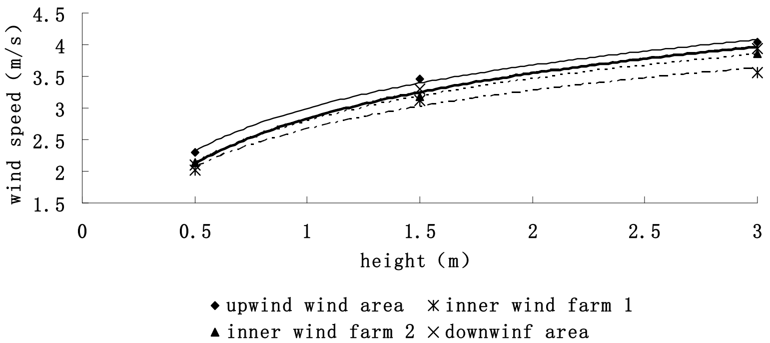

Fig.6 The wind velocity profile in summer

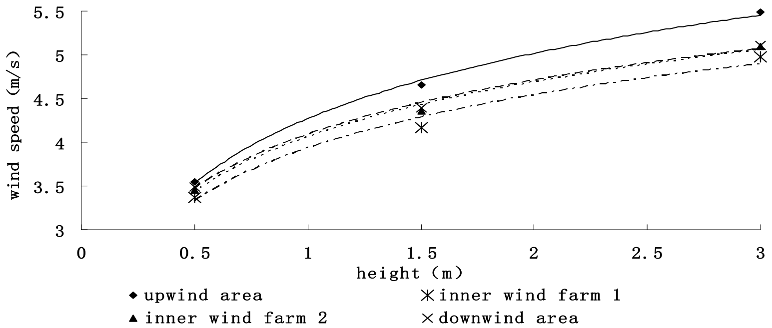

Fig.7 The wind velocity profile in autumn

Tab 1. The wind velocity profile regression model of each measuring point in spring

Saeson	Average Wind Speed	Observation Points	Regression Model
Spring	6.5m/s	Upwind Area	y = 1.0337Ln(x) + 5.0315
		Inner Wind Farm 1	y = 0.7883Ln(x) + 4.0688
		Inner Wind Farm 2	y = 0.8379Ln(x) + 4.5065
		Downwind Area	y = 0.917Ln(x) + 4.9166
Summer	2.5m/s	Upwind Area	y = 1.1753Ln(x) + 6.2541
		Inner Wind Farm 1	y = 1.0674Ln(x) + 5.7575
		Inner Wind Farm 2	y = 1.1001Ln(x) + 5.9162
		Downwind Area	y = 1.1219Ln(x) + 6.0032
Autumn	4m/s	Upwind Area	y =1.0321Ln(x) + 2.9983
		Inner Wind Farm 1	y = 0.8751Ln(x) + 2.6661
		Inner Wind Farm 2	y = 0.9599Ln(x) + 2.7923
		Downwind Area	y = 0.982Ln(x) + 2.8339

In spring, comparing the wind speed profile on the slope of inner wind farm, and upwind area can be seen, wind speed profile slope of inner wind farm 1 was the minimum, the value was 0.7883.It reduced 0.2454, vertical gradient wind speed change was relatively small. Reduction of downwind area was lightly smaller, the value was 0.12,compared with upwind area. In spring and summer, four observation points of wind velocity profile was still the standard logarithmic curve because underlying surface vegetation coverage in summer increased than spring, under the condition of the same wind speed, the wind speed profile equation slope was increased compared with spring. In summer, wind speed profile slope of inner wind farm 1 was still minimum, Its value is 1.0674, it reduced 0.197. The slope of inner wind farm 2 and downwind area increased gradually but were also less than the upwind area. Inner wind farm 2 reduced 0.0752 and downwind area reduced 0.0534.The wind speed profile of each measuring point in autumn also showed the same rule. Wind velocity profile slope of each measuring point was less than the upwind area, slope of inner wind farm 1 and inner wind farm 2 reduced 0.167 and 0.0822, respectively.

Speed profile slope of inner wind farm was less than upwind area. Compared with the wind speed of upwind area, the scope of the vertical wave amplitude of wind speed was smaller of inner wind farm within 0.5-3.0m. Within the scope of the height of 0.5-3.0m, the occurrence of wind speed with height obvious change trend was not significant. The slope wind speed profile of observation points increases with the increase of wind speed. Compared with upwind area, the decrease degree of the wind speed profile slope of inner wind farm and downwind area, decreased with the increase of wind speed.

2.3. Wind farm effects on the surface roughness

The surface roughness is the surface itself attribute, it is properties of a physical quantity used to measure roughness to air. It represents the height where wind speed became zero on the wind speed contour line in the near-surface region. When the fluid flows through the ground surface, the surface roughness difference has the significant influence on the fluid above [4].That is to say surface roughness can reflect the different underlying surface morphological structure on the influence of wind speed [5]. The surface of wind resistance increases with the increase of surface roughness, the wind weakening ability has been increased [6]. The surface roughness of computation formula is as follows:

$$LgZ_0 = {(Lg\mu_2 - ALg\mu_1)} / {1 - A}$$

Z_0-surface roughness,μ_1,μ_2-any two height of wind speed, A – the average value of wind speed ratio on two height. In this article,.μ_1 and μ_2 represented for wind speed value of 3.0 m and 0.5 m height,.

When calculating the surface roughness, based on different wind speed range of upwind area at 3.0 m height, selection wind speed value of at 0.5 m and 3.0 m height inside and outside of wind farm, calculate the surface roughness value inside and outside of the wind farm. Shown in table 2 to table 4:

Tab 2. The surface roughness of inside and outside wind farm in spring

Measuring point	Upwind area wind speed（m/s）						
	0-1	1-2	2-3	3-4	4-5	5-6	6-7
Upwind area	0.19	0.42	0.60	0.74	0.98	1.64	1.86
Inner wind farm 1	0.27	0.46	0.64	0.82	1.20	1.78	1.98
Inner wind farm 2	0.25	0.44	0.63	0.80	1.14	1.69	1.93
Downwind area	0.24	0.42	0.61	0.76	1.07	1.63	1.88
Measuring point	Upwind area wind speed（m/s）						
	8-9	9-10	10-11	11-12	12-13	13-14	14-15
Upwind area	2.65	2.75	3.01	3.48	3.76	4.05	4.27
Inner wind farm 1	2.73	2.87	3.15	3.65	3.90	4.18	4.36
Downwind area	2.67	2.80	3.10	3.60	3.84	3.94	4.31

Tab 3. The surface roughness of inside and outside wind farm in summer

Measuring point	Upwind area wind speed（m/s）				
	0-1	1-2	2-3	3-4	4-5
Upwind area	0.25	0.41	0.69	0.99	1.32
Inner wind farm 1	0.37	0.53	0.74	1.04	1.40
Inner wind farm 2	0.31	0.46	0.73	1.01	1.38
Downwind area	0.29	0.45	0.72	0.98	1.32
Measuring point	Upwind area wind speed（m/s）				
	6-7	7-8	8-9	9-10	10-11
Upwind area	2.15	2.35	2.65	2.89	3.20
Inner wind farm 1	2.37	2.50	2.75	3.00	3.27
Inner wind farm 2	2.20	2.45	2.73	2.93	3.11
Downwind area	2.19	2.41	2.71	2.90	3.23

Tab 4. The surface roughness of inside and outside wind farm in autumn

Measuring point	Upwind area wind speed（m/s）				
	0-1	1-2	2-3	3-4	4-5
Upwind area	0.34	0.43	0.75	1.07	1.31
Inner wind farm 1	0.36	0.57	0.82	1.24	1.48
Inner wind farm 2	0.34	0.55	0.81	1.11	1.45
Downwind area	0.36	0.58	0.81	1.13	1.43
Measuring point	Upwind area wind speed（m/s）				
	5-6	6-7	7-8	8-9	9-10
Upwind area	1.63	1.82	2.02	2.24	2.57
Inner wind farm 1	1.76	1.97	2.23	2.48	2.67
Inner wind farm 2	1.72	1.87	2.07	2.42	2.64
Downwind area	1.71	1.84	2.12	2.45	2.63

According to table 2-4, we can see that in different seasons and different wind speeds, the surface roughness inner wind farm was higher than upwind area, but the difference was not significant. Due to the summer vegetation coverage is better, under the condition of the same wind speed, surface roughness both inside and outside the wind farm were significantly higher than that in summer and autumn. In spring and autumn, the difference of surface roughness gestures of each measuring point was not obvious. The surface roughness of each observation point coincided with the changing of average wind speed change, showing the negative correlation relationship. The relationship of the surface roughness to each season was inner wind farm>down wind area>upwind area.

Compared with upwind area, the surface roughness of inner wind farm 1 in spring increased most in spring.Under the condition of wind speed less than 7 m/s, the surface roughness of inner wind farm increased 0.1cm,inner wind farm 2 increased 0.06cm, downwind area increased the minimum 0.03 cm, the proportion of increase was 11.2%,7% and 2.8% ,respectively. When the wind speed increases, the surface roughness of inner wind farm 1and inner wind farm 2 increased 2.6% and 1.2%, compared with upwind area. Wind speed in spring relatively reduced obviously than summer, the regularity of the surface roughness is still inner wind farm>down wind area>upwind area. Also when the wind speed is less than 7 m/s, the surface roughness of inner wind farm 1,inner wind farm 2 and downwind area increased 0.06cm,0.05cm and 0.02cm ,respectively, compared with upwind area. The increase proportion was 8.7%,4.7% and 2.1% . Wind speed was more than 7 m/s, the surface roughness of three measuring points increased 3.9%,1.4% and 1.2%.The surface roughness of each measuring point in autumn had similar rule, that was inner wind farm>down wind area>upwind area.

Thus it can be seen that in different seasons and different wind speed conditions,The surface roughness of both inside and outside of wind farm is increased due to the existence of wind farm. The influence of existence of wind farm to the surface roughness decreased with the increase of environmental wind speed. Resulting in under the condition of large wind speed, the weakening of the wind farm on wind speed was less than the impact of low wind speed conditions.

3. Discussion

The study of climate impact of wind farms abroad began in recent 10 years, main research reports focus on 80-300 -m height above the surface within the scope of wind effects on climate. Foreign existing research is given priority to with model simulation, in the related research, there are more reports on wind farm impact on underlying surface temperature, the research on the effects of wind speed is relatively small.

D.B.Barrie and D.B.Kirk-Davidoff[7], Marc Calaf[8] using the regional climate model simulated wind farm effects on climate, the results showed that wind farms disturbed atmospheric boundary layer to increase the surface turbulence changed terrestrial atmospheric water heat flux, which impacted on local climate. SW, Walko RL[10],DANIEL B. KIRK-DAVIDOFF[11],X.Li, S.Zhong and W.E. Heilman、Keith.ect [12] obtained the consistent conclusion through the model simulation. Daily average wind speed of 80m height significantly reduced and showed great seasonal variability. Sten T. Frandsen 's [13]studies have shown that the difference of wind speed at wind turbine height is obvious both upwind area and downwind area. When the wind went through wnd farm with speed of 8-9m/s.Compared with the original wind speed, the wind speed of downwind area from the wind farm edge 6 km ,8 km and 10km was 0.86,0.88 and 0.90. The influence of wind farm on wind speed at least reached beyond the downwind of 10 km. In Merete Bruun Christiansen,ect[14]study, Satellite synthetic aperture radar (SAR) was used to study the large offshore wind farm's influence on the wind climate of the area. The results showed that after the wind went through wind farms, the average wind speed decreased 8-9%.

The results based on the field observation were similar to the conclusion of model simulation, Establishment and operation of the wind farm will have a significant effect on the local near-surface climate. It mainly caused wind speed decreased significantly inner wind farm and downwind area. Analysis of the reason may be the wind turbines' operation consumes part of the wind energy, and one of the forms of wind energy consumed is the decrease of the wind speed. Moreover wind farms as attached on the surface of the earth buildings, The existence of wind farms changed the surface roughness of the original structure and increased near surface roughness. It also led the decrease of the wind speed near-surface.

4. Conclusion

(1) In different seasons, wind speed of inside and outside wind farm exist a certain differences. The average wind speed regulation of 0.5m,1.5m, and 3.0m height was upwind area>downwind area>inner wind farm. In different seasons, comparatively speaking, spring wind speed was larger. The influence of wind farm on wind speed was smaller than summer and autumn.Wind farms can reduce the wind speed of inner wind farm and downwind area, and reduce the overall wind speed. The influence degree of the wind farm to the instantaneous wind speed was reduced with the increase of environmental wind speed.

(2) Different seasons, the regional wind speed profile of slope of inner wind farm and down wind area decreased. Within the height of 0.5 m - 3.0 m , the scope of the vertical wave amplitude of wind speed inner wind farm was small. That is to say, within the scope of this height, obvious changes in

wind speed with height were not significant inner wind farm. The surface roughness of both inner wind farm and downwind area is increased by the existence of wind farms.

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