Research on Simulation Model of Wind Speed Change before and after Protection Forest Belt

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Abstract. Reducing wind speed is the main role of shelterbelt. To reveal wind speed change characteristics in the protected area, establish a simulation model of the average wind speed, height and average wind speed after the forest belt. Established three wind speed variation models respectively by the least squares method, ridge regression and elastic network method. Verified the wind speeds of the windward and leeward sides of eight different structural forests under wind speeds of 8,11 and 14 m·s^{-1} by wind tunnel experiments. Model evaluation indicators are the coefficient of determination (R^2) and root mean square error(RMSE).The results show that the R^2 of models all are higher than 0.9, and RMSE are 1.05492, 1.05490 and 1.05092 in turn. Comparing the modeling performance of three methods, the generalization ability of elastic network is better. The average of 0-5H wind speed before the forest belt and height can estimate the average wind speed after 0-10H the forest belt.

Introduction

The shelterbelt is a forest type based on the forest ecological service function[1]. The windbreak can effectively reduce the wind speed and form a protected area after the forest belt. Many domestic and foreign scholars have studied the wind speed distribution after windbreaks through field observation experiments, wind tunnel experiments or numerical simulation techniques[2].

Zhang et al. observed the wind speed of forest net under five different wind directions under two wind speeds in the field. The wind speed was analyzed by mathematical expectation method found that with the decrease of the angle between the wind direction and the main forest belt, the average wind speed showed an increasing trend, which provided a basis for the construction of farmland shelterbelt[3]. Niu et al. used the spatial multi-point observation method to observe the wind speed distribution in the field experiment. It was found that when the wind speed in the field was 3.84 m·s^{-1}, the wind speed of each heights in the leeward first decreased and then increased[4].

Rosenfeld et al. constructed a 3D cypress tree model by numerical simulation technology (CFD), and analyzed the windbreak layout of single row of infinite long cypress trees and two rows of infinite cypress trees. It is concluded that the wind speed of single row cypress canopy decreases near the edge of the forest edge; the wind speed of the stem near the ground increased. The wind speed of the two rows of cypress windbreaks was more obvious than that of the single row[5].

Takahash used wind tunnels to simulate wind speed the distribution solid barriers of three different widths and distributions and three different widths of porous windbreaks. It is found that the narrower single-row or multi-row solid barrier leeward wind speed decreases with increasing distance. The larger single-row solid barrier wind speed increases rapidly with distance, and the turbulent area is closer to the solid barriers than the former two, while the minimum wind speed which porous shelterbelt of the three different widths are different position , but after, the wind speed increases with the same proportion with the distance[6].

Cheng et al. measured the wind speed of eight different characteristics of single plant belts under three wind speed gradients by wind tunnel test, compared the wind speeds at different distances and heights after the forest belt, corrected the relaxation equation of individual plants airflow recovery

on the leeward side and establishing a linear function of minimum wind speed and forest belt structure after forest[7].

Lee et al. used the particle image velocimetry(PIV) technique to quantitatively measure the entire velocity field of the flow around the cedar tree placed in the wind tunnel test area, and compared the influence with or without leaves on the wind speed in the leeward, indicating that the leaves can reduce the porosity of the canopy to enhances the wind speed reduction effect in the leeward region[8].

Previous studies have analyzed the distribution trend of wind speed before and after windbreaks, and discussed the wind speed distribution of windbreaks under different forest belt structures. However, the simulation model for the relationship between the average wind speed on the windward surface and the height of the detection point and the average wind speed in the leeward has not been determined.

Based on the wind tunnel experimental observation, this study uses the least squares method, the ridge regression and the elastic network algorithm to establish the wind speed model to predict the shelterbelt wind speed in the leeward.

Data Acquisition

Experimental Equipment and Materials

The wind tunnel experiment was carried out in the wind tunnel experimental system of Beijing Forestry University that is the Key Laboratory of Soil and Water Conservation and Desertification Prevention and Control(refer with: Fig. 1).The trees employed are Larch with 8 kinds of different structures(refer with: Table 1).The windbreak forest used a soft simulated plant that is 10cm high. Its ratio to the natural plant is 1:100.
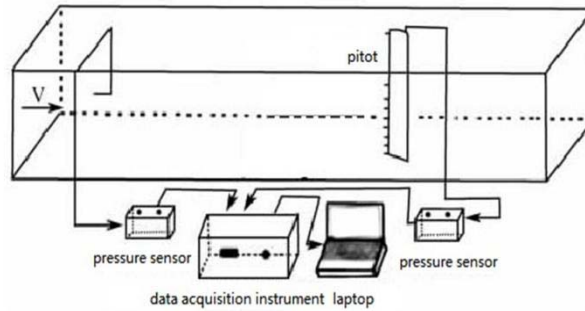

Figure 1. Wind tunnel experiment equipment

Table 1. Information of 8 kinds of different windbreak forest belt structure

Forest belt number	Rows	Tree number	Proportion of branches	Plant spacing [cm×cm]	Forest bandwidth [cm]	Density	Degree of opacity
1	2	30	0.167	4×4	8	6.250	0.3037
2	3	45	0.113	4×4	12	6.250	0.1764
3	4	58	0.102	4×4	15	6.444	0.1323
4	5	73	0.096	4×4	20	6.083	0.1296
5	3	32	0.148	6×6	16	3.333	0.4458
6	3	23	0.208	8×8	20	1.917	0.5106
7	3	45	0.159	4×6	16	4.688	0.3359
8	3	29	0.192	6×8	20	2.417	0.4315

Wind Speed Measurement

In wind tunnel experiment, set the free wind speed gradient to 8,11 and 14 m·s^{-1}. The plants of different types are respectively placed at the wind tunnel. For each case, the wind speed at 17

heights are measured (1cm, 2cm, 3cm, 4cm, 5cm, 6cm, 7cm, 8cm, 9cm, 10cm, 11cm, 12cm, 13cm, 14cm, 16cm, 18cm and 20cm).Meanwhile, we measure the average wind velocities for 17 locations along a center line perpendicular to the shelter belt locations with windward(0,1H,2H,3H,4H and 5H)and leeward(0,1H,2H,3H,4H,5H,6H,7H,8H,9H and 10H) ,where H is the average tree heights and is equivalent to 10m actually (refer with: Fig. 2)
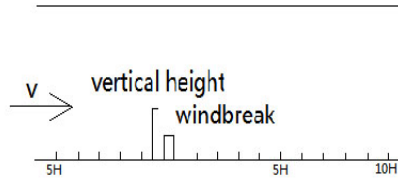

Figure 2. Position of measurement locations for shelter belt in wind tunnel

Model Establishment

In order to establish a wind speed relationship simulation model between average wind velocities after the forest belt, height and the average speed before the windbreak belt. First, we calculate the average wind speed of different heights before 0-5H in the shelter belt and after 0-10H in the forest belt. Second, check the speed data and analyze data correlation. Finally, the speed model is established by least squares linear regression, ridge regression and elastic network algorithm.

Data Outliers Check

Outliers are defined as individual values in the sample that deviate significantly from the rest of the observation. Box plots display discrete distribute of data and quickly identify outliers[9,10].Five values from a set of data are conventionally used; the upper(Q_u) and lower (Q_d) extremes, the upper(Q_1) and lower(Q_3) quartiles, and the median(Q_2).(refer with: Eq. 1, Eq. 2,Eq. 3) . A value greater than Q_u and less than Q_d is defined as an abnormal value.

$$Q_u = Q_1 + 1.5IQR \tag{1}$$

$$Q_d = Q_3 - 1.5IQR \tag{2}$$

$$IQR = Q_1 - Q_3 \tag{3}$$

In Eq. 1, Eq. 2, Eq. 3, IQR is the length of the box.

Because the abnormal value will affect the analysis of the data and the establishment of the model, the outliers of the wind speed sample data is judged by the box plot. By analyzing the figure 3(refer with: Fig. 3), there are no outliers in each set of data.
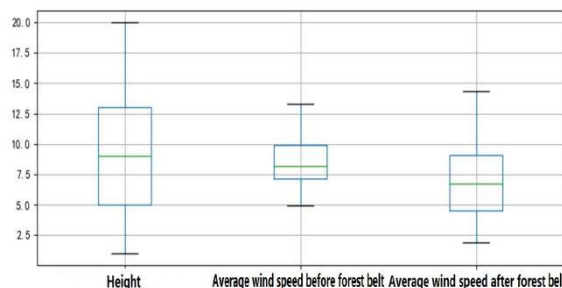

Figure 3. Box plot of data

Wind Speed Model Establishment

After the outliers are checked, we establish the wind speed model the average wind speed of 0-5H before windbreak and heights are defined as independent variables and the average wind speed of 0-10H after the belt is the dependent variable. We divided 272 test data into 218 training samples and 54 test samples. On the training samples, we obtain the correlation coefficient between each

independent variable and the dependent variable, analyze the necessity of establishing a model between the three variables, and use 3 kinds of multiple regression algorithms to establish the wind speed model.

Correlation Analysis

According to the correlation analysis between the independent variable and the dependent variable, the correlation coefficient between the height and the average wind speed of 0-10H after the forest belt is 0.8057, and the correlation coefficient between the average wind speed of 0-5H and the dependent variable before the forest belt is 0.8306. There is a strong correlation between the two influencing factors and the dependent variable, so it makes sense to establish a model between the three(refer with: Fig. 4).
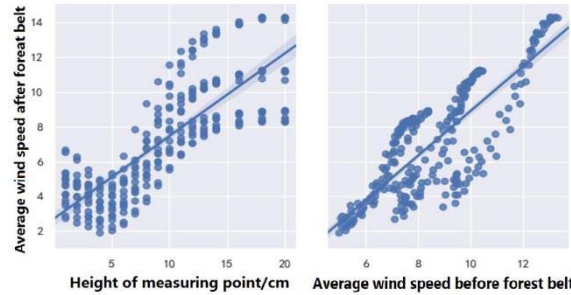

Figure 4. Correlation between two independent variables and dependent variables

Model Establishment

Simple linear regression is a statistical analysis method that can determine the quantitative relationship between two or more variables. When two or more variables are included in the regression analysis, the fitting relationship is no longer a "straight line" but a "face" or "hyper plane", so it is called multiple linear regression. Wind speed model was established for 218 training samples by three regression methods.

We set the average wind speed of 0-5H before the windbreak forest belt as the influence factor x_1, and the height is the influence factor x_2, then the average wind speed of 0-10H after the forest belt is the dependent variable $h_\theta(x^{(i)})$. The wind speed model format is Eq. 4.

$$h_\theta(x^{(i)})=\theta_0+\theta_1 x_1^{(i)}+\theta_2 x_2^{(i)} \tag{4}$$

In Eq. 4, $i = 1,2, ..., m$ represents number of samples, θ_0 is the equation intercept, and θ_1,θ_2 are the coefficients of the influence factors x_1,x_2, respectively.

Establishing a Wind Speed Model Based on Least Squares Linear Regression

The least squares method[11,12] constructs a loss function ($J(\theta)$) used as the constraint condition to mesure the error between the predicted value and the true value, and the loss function $J(\theta)$ is adjusted to minimize it so that we can obtain the optimal coefficient of the influence factor (refer with: Eq. 5).

$$J(\theta) = \frac{1}{2m}\sum_{i=1}^{m}(h_\theta(x^{(i)})-(y)^{(i)})^2 \tag{5}$$

In Eq. 5, m is number of samples, $h_\theta(x^{(i)})$ is the predicted value of the its sample, and $y^{(i)}$ is the true value of the its sample. The wind speed model is Eq. 6:

$$y = -3.51667 + 0.90426\ x_1 + 0.30931\ x_2 \qquad (R^2=0.90676) \tag{6}$$

Establishing a Wind Speed Model Based on Ridge Regression

Ridge regression[13,14] can solve the multicollinearity problem between independent variables. The least squares method is very sensitive to the noise in the input variable. The slight change of the

independent variable will cause a large change in the output result. The ridge regression can add the L2 paradigm to the loss function. To solve this problem, the loss function is as in Eq. 7.

$$J(\theta) = \frac{1}{2m}\sum_{i=1}^{m}(h_\theta(x^{(i)}) - y^{(i)})^2 + \lambda\sum_{j=1}^{n}\theta_j^2 \qquad (7)$$

In Eq. 7, λ is a regularization parameter, j = 1,2 is the number of impact factor (x_1,x_2), θ_j is the coefficient factor(θ_1,θ_2).

When λ = 0.1, the loss function value is the smallest, and the wind speed model(refer with: Eq. 8) established by the ridge regression algorithm:

$$y = -3.51582 + 0.90414\ x_1 + 0.30932\ x_2 \qquad (R^2=0.90676) \qquad (8)$$

Establishing a Wind Speed Model Based on Elastic Networks

Elastic Net[15,16] is a continuous iterative linear regression method using the L1 paradigm and the L2 paradigm as a priori regular terms. The l1_ratio parameter can be used to control the convex combination of L1 and L2, and l1_ratio is the elastic mesh mixing parameter. The loss function is of Eq. 9.

$$J(\theta) = \frac{1}{2m}\sum_{i=1}^{m}(h_\theta(x^{(i)}) - y^{(i)})^2 + \lambda_1\sum_{j=1}^{n}\theta_j^2 + \lambda_2\sum_{j=1}^{n}\|\theta_j\| \qquad (9)$$

In Eq. 9, λ_1 and λ_2 are regularization parameters.

When l1_ratio=0.7, λ_1 = 0.02801 and λ_2 = 0.13070, the loss function value is the smallest, and the wind speed model(refer with: Eq. 10) established by the elastic network:

$$y = -3.15764 + 0.85962\ x_1 + 0.31212\ x_2 \qquad (R^2 =0.90602) \qquad (10)$$

Wind Speed Model Test and Selection

In order to test the wind speed simulation model, this study used independent test samples to assess the model estimation ability. We use the training set, test set determination coefficient(R^2) and root mean square error (RMSE) as the evaluation indicators, and select the optimal wind speed model by comparing the evaluation indicators. We use 54 data to complete the test of the model.

Table 2. Comparison table of three kinds of multiple linear regression method

Method	Training set (R^2)	Test set (R^2)	RMSE
Least squares	0.90676	0.90059	1.05492
Ridge regression	0.90676	0.90060	1.05490
Elastic Net	0.90602	0.90135	1.05092

According to table 2(refer with: Table 2), it can be seen that the R^2 and RMSE of the three models are not significantly different, and the coefficient of determination is above 90%. The R^2 of the model established by using the elastic network is closer to the training set and the test set, and the RMSE is 1.05092. Therefore, the elastic network is used to construct the wind speed model(refer with: Fig. 5).
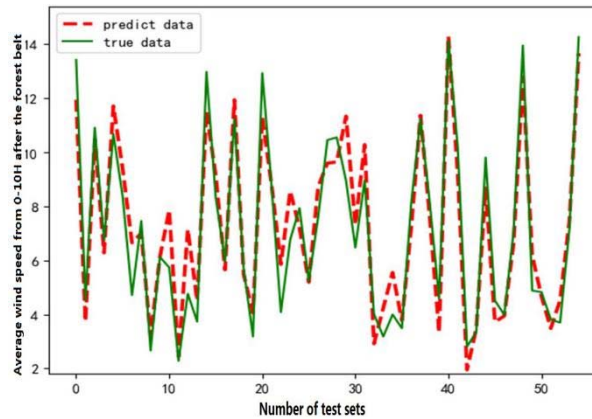
Figure 5. ElasticNet true and predicted values of test set samples

Conclusions

(1)The wind speed model can be established by least squares method, ridge regression and elastic network algorithm. At free wind speeds of 8, 11 and 14 m·s^{-1}, the average wind speed after 0-10H the forest belt can be estimated by the average wind speed of 0-5H before the forest belt and height. (2)The wind speed model established by the elastic network is better and the generalization ability is better.

Acknowledgement

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