

Research Article

Research on Wind Flow Control by Windbreak Fence for a Large Radio Telescope Site Based on Numerical Simulations

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The higher the pointing accuracy of the radio telescope, the more obvious the influence of wind disturbance on antenna performance. Taking the site of the 110 m aperture QiTai radio Telescope (QTT) as an example, the terrain and air flow characteristics of the site are studied. It is found that the wind direction with high incoming wind frequency and relatively high speed is mostly located in the mountain gap on the periphery of the antenna. If the wind resistance facilities are precisely arranged in the upstream tuyere, the wind speed in the antenna area can be effectively reduced. This study proposes a method to control the wind flow at a telescope site based on the precise arrangement of the windbreak fence. The windbreak fence simulation model is constructed using the theory of porous jump. The mean error of the simulation results is less than 14% compared to the wind tunnel measured data, indicating that the constructed windbreak fence model has high reliability. The computational domain model of the working conditions for the site is constructed. The extreme condition of the windbreak fence arrangement is considered, and the simulation results show that the wind speed in the antenna area can be reduced by more than 30% through the control of the windbreak fence. It verifies the feasibility of the method of controlling the wind flow by the windbreak fence for the site which provides a reference for the subsequent research on the precise arrangement of the windbreak fence.

1. Introduction

The larger the effective receiving area of the radio telescope antenna, the higher its sensitivity and resolution [1]. However, on the one hand, with the increase of antenna aperture, the wind area of the antenna reflector surface increases, which leads to the increase of wind load on the antenna; on the other hand, with the improvement of comprehensive performance of the antenna, the requirement of pointing accuracy also increased, so that the influence of site wind disturbance on pointing accuracy cannot be ignored. Therefore, the effect of wind disturbance on the efficiency and pointing accuracy of large antennas becomes more obvious and more difficult to solve. According to the 100 m aperture fully steerable radio telescope GBT (the Green Bank Telescope) report [2], the antenna pointing accuracy up to 1.5" at wind speeds below 2.5 m/s; when the wind speed is greater than 3 m/s, the pointing error caused by wind disturbance will affect the observation of greater than 40 GHz; when the wind speed is greater than 5 m/s, observations greater than 20 GHz will be limited; and when the wind speed continues to exceed 11 m/s, all the observations will stop.

Currently, antenna wind resistance methods mainly include the following methods: for small- and medium-sized radio telescopes with high pointing accuracy, a radome can be built outside the antenna to prevent wind disturbance, such as 13.7 m Delingha telescope in China [3] and 36 m Haystack telescope in the United States [4]. However, the radome will reflect and absorb radio signals, affecting the antenna performance. And, with the increase of antenna aperture, the engineering cost of radome increases geometrically. Therefore, radome is not suitable for the wind



FIGURE 1: QTT site. The red wireframe indicates the site area. "A" and "W" stand for the location of the antenna and the wind tower, respectively. The arrow points to the incoming wind in the gap of the mountain.

resistance of large aperture antennas. For large aperture antennas, mesh reflectors can be used to reduce wind load, such as the 64 m Parkes telescope in Australia [5]. However, because high-frequency waves will directly penetrate the mesh surface, the design of the mesh reflector is not suitable for high-frequency antennas. Facing the urgent needs of wind resistance for large aperture and high frequency antennas, many scholars try to reduce the influence of wind disturbance on electrical performance of antennas by controlling compensation. NASA (National Aeronautics and Space Administration) designed the LQG (Linear Quadratic Gaussian) controller for the 70 m antenna, and the simulation results show that this method can effectively reduce the rotational axis error caused by wind disturbance [6]. Gawronski and Souccar [7] discussed the effect of PID (Proportional Integral Derivative) control, LQG control, and $H\infty$ control for suppressing wind disturbance. $H\infty$ control has the best performance, but its practical use is limited by antenna hardware performance. Ukita et al. [8] applied a fixed compensation method to reduce the telescope beam pointing error caused by steady-state wind disturbance for the 10 m Atacama Cosmology Telescope (ACT) in Chile. However, the previous methods of control compensation are still passive, and it is difficult to fast control the time-varying wind disturbance. Therefore, the problem of wind disturbance that affects the performance of large radio telescopes needs further study.

By studying the terrain for the site of some large radio telescopes, it is found that most of these sites are located in valleys or basins. The GBT site, for example, is located in a valley 800 m above sea level at 38.4° north latitude, surrounded by mountains 1,400 m above sea level [9]; the 100 m Effelsberg Radio Telescope is located about 40 km southwest of Bonn in a valley surrounded by mountains [10]; and the 110 m aperture fully steerable radio telescope QTT, which is under construction in Qitai County, Xinjiang, China, is located in a basin surrounded by mountains with an elevation of 1760 m [11]. The height of the mountain around the site ranges from 1860 to 2250 m. Such terrain can not only effectively shield electromagnetic interference but also block wind disturbances. However, the natural mountain barrier does not completely block the inflow of wind. There will still be some directions of the incoming wind blowing to the antenna area, and the direction of the incoming wind is mostly concentrated at the mountain gap. The QTT site incoming wind statistics are taken as an example, as shown in Figure 1; the wind from the mountain gap accounts for more than 55% of all incoming winds. And, the wind direction with relatively high speed is mainly located in the mountain gap. Based on the previous findings, antenna wind resistance research can be carried out from the perspective of improving the wind environment at the site.

The windbreak fence is often used in port material yard [12], highway bridge [13], Gobi Desert [14] etc. It has a certain porosity, which can have a certain blocking effect on the wind, to change the direction of the wind and consume wind energy, so that the wind speed behind the fence is attenuated [15]. Research on the theory of wind and dust suppression by the windbreak fence was carried out earlier in the United States, the United Kingdom, and New Zealand [16–18]. After 1990, China gradually carried out application research in the windbreak fence project for the coal storage yard of Qinhuangdao Harbor [19], coal open yard of Jingtang Harbor [20], and the Taiyuan Coal Gasification Company [21]. The sheltering effect of the windbreak fence is affected by its porosity, surface shape, height,



FIGURE 2: The framework chart of the article.

distance from the target area, etc. [22]. Fang et al. [23] studied the optimal porosity for wind barrier design based on numerical simulations, and the result showed that a porosity of 0.35 is optimal and a porosity of 0.3~0.4 can provide the longest sheltering distance. Yu et al. [24] studied the influence of porosity and height of fences on blocking effect based on the wind tunnel experiment. Sand fences with porosity of 0.36 had the highest blocking efficiency (reducing wind speed by 70%) and the longest blocking distance (9 times the distance of the fence height) among fences with porosities of 0.75, 0.63, 0.56, and 0.36, and the higher the fence, the better blocking effect. Wang et al. [25] studied the sheltering effect of punching plate and wire mesh fences with the same porosity, and the results showed that punching plate fences reduced wind speed more than wire mesh fences. At present, the resisting wind effect of fences is studied based on numerical simulation and it is low cost and fast. Meanwhile, the reliability of the fence model in numerical simulation can be ensured by verified with measured data in wind tunnel [26, 27].

According to previous studies, wind flow control by a windbreak fence can improve the wind environment at the site to some extent. But the application of windbreak fence in astronomy is different from other fields. In the working conditions of the mineral storage yard, the windbreak fence can be very close to the target area and completely shield the target area in terms of height, thus greatly reducing wind speed and dust emission [12]. However, for the telescope site, the windbreak fence cannot block the view of the antenna, which means that the fence must be a certain distance from the antenna position, so the shielding effect will be weakened to some extent. But the wind speed of the site is relatively small. The direction of the incoming wind and the location of the tuyere are relatively clear [28]. So, there is no need to completely cover the antenna area with the windbreak fence. In order to reduce the influence of wind disturbance on the electrical performance of the antenna, a method to control wind flow at the site is proposed based on the precise arrangement of the windbreak fence through the analysis of the terrain and wind characteristics of the site. The wind speed in the antenna area is expected to be reduced by accurately arranging the windbreak fence so as to increase the effective observation time of the radio telescope. The framework chart of the article is shown in Figure 2.

2. Construction and Verification of the Windbreak Fence Model

2.1. Theory of Numerical Simulation. At present, there are three numerical simulation methods based on computational fluid dynamics (CFD) theory: direct numerical simulation (DNS), large eddy simulation (LES), and Reynoldsaveraged Navier-Stokes (RANS). The DNS method does not do any approximation or simplification of the Navier-Stokes equation (N-S equation). However, the required grid accuracy and computing power are so high that it cannot be used for engineering calculations except with supercomputers. The LES method uses filter function to separate largeand small-scale vortices. Large-scale vortices are directly calculated by the unsteady N-S equation, and small-scale vortices are calculated by the turbulence model. It solves the problem of a large amount of grid and computation to a certain extent, but it still requires high computer performance. The RANS method performs time homogenization on turbulent characteristic quantities in the N-S equation and divides instantaneous variables into average variables and pulsation variables. It reduces the number of calculations, and the turbulence model is used to guarantee the accuracy of the simulation, which meets the requirements of engineering calculations. In this paper, the RANS method is used. Several turbulence models have been developed for this method. Among them, the standard k- ε model was proposed by Launder and Spalding in 1972 [29]. It is widely used in industrial applications because its computational convergence and accuracy meet the needs of engineering calculations. Subsequently, the RNG k- ε model [30] and the realizable $k - \varepsilon$ model [31] were developed. The realizable k- ε model is relatively new, which not only has higher accuracy but is also more consistent with the actual physical situation of the flow. Santiago et al. [32] used the standard k- ε model, the RNG k- ε model, and the realizable k- ε model to simulate the wind flow behind the fence and compared with the result of the wind tunnel experiment, while the root mean square (RMS) of the realizable k- ε model was relatively smaller. Bourdin and Wilson [33] simulated the air flow around the windbreak fence to study the applicability of fluid dynamics to windbreak aerodynamics, and the simulation result of the realizable k- ε model was consistent with the observation result. In this paper, the realizable k- ε model is used for numerical simulation. The air flow follows three laws of conservation of mass, conservation of momentum, and conservation of energy. The numerical simulation method is established based on the basic governing equations. The energy equation is not used because the local thermal effect has little effect on the numerical simulation of this study condition. The basic



FIGURE 3: Overall schematic diagram of the numerical simulation.

governing equations for CFD numerical simulation are as follows:

$$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \overrightarrow{v}) = 0, \tag{1}$$
$$\frac{\partial}{\partial t} (\rho \overrightarrow{v}) + \nabla \bullet (\rho \overrightarrow{v} \overrightarrow{v}) = -\nabla p + \nabla \bullet (\tau) + \rho \overrightarrow{g} + S,$$

where ρ is the air density, *t* is time, $\overrightarrow{\nu}$ is the wind velocity vector, *p* is the static pressure, τ is the stress tensor, $\rho \overrightarrow{g}$ is the gravitational body, and *S* is the momentum source term.

The finite-volume method (FVM) is used to discretize the governing equations. The second order upwind is used to spatially discretize the characteristic quantities of momentum, turbulent kinetic energy, and turbulent



FIGURE 4: Computational domain of simulation.

dissipation rate. The SIMPLEC (semi-implicit method for pressure-linked equations consistent) algorithm is used to solve the discrete equation system. The solution is considered to have convergent when the iterative dimensionless residuals of all characteristic quantities are reduced to less than 10^{-5} and the velocity of the flow field near the monitoring point no longer changes significantly. The overall schematic diagram of the numerical simulation is shown in Figure 3.

2.2. Construction of the Computational Domain of the Windbreak Fence Simulation Model. In order to verify the reliability of the windbreak fence model in the simulation, the experimental data of the windbreak fence in the wind tunnel are cited for verification. This article uses the wind speed reduction data of the windbreak fence conducted by Wang Zetao at the Wind Tunnel Laboratory, Dalian University of Technology [34]. The butterfly-type windbreak fence is 0.5 m in height, 0.0016 m in thickness, and 0.40 and 0.33 in porosity, respectively. The simulation computational domain for the windbreak fence is shown in Figure 4. The computational domain area is 5 m * 25 m. The inlet boundary type is "velocity-inlet," the outlet boundary type is "outflow," the top boundary type is "symmetry," and the bottom boundary type is "wall." The windbreak fence is placed 5 m from the entrance.

2.3. The Model Construction and Parameter Setting of the Windbreak Fence. In the wind flow simulation, the windbreak fence can be simplified to a porous medium and the porous jump model can be used. The essence of the porous jump model is to add a momentum source term to the momentum equation to simulate the obstruction of wind flow by porous materials. The momentum source term consists of the viscous resistance term and the inertia loss term. The formula is as follows:

$$S = -\left(\frac{\mu}{\alpha}\overrightarrow{\nu} + C_2\frac{1}{2}\rho|\overrightarrow{\nu}|\overrightarrow{\nu}\right),\tag{2}$$

where μ is the fluid viscosity, α is the permeability coefficient, ν is the fluid velocity, and C_2 is the pressure-jump coefficient.

The parameter α and C_2 of porous jump model are set according to the property of the windbreak fence. The model parameter α and C_2 can be obtained by physical experiments. For example, the resistance coefficient a_1 and a_2 are calculated by using the relationship between pressure drop Δp and velocity v before and after the fence. The fitting formula is as follows:



FIGURE 5: Grid division of computational domain.

$$\Delta p = a_1 \overrightarrow{v} + a_2 \overrightarrow{v}^2. \tag{3}$$

The source term of the momentum equation is the pressure drop per unit length, namely,

$$\frac{\Delta p}{\Delta n} = -S,\tag{4}$$

where Δn is the thickness of porous medium.

In the absence of measured data, the C_2 can be obtained according to the equation of Smith et al. [35, 36]:

$$C_{2} = \frac{1}{C^{2}} \frac{\left(A_{p}/A_{f}\right)^{2} - 1}{\Delta n},$$
(5)

where A_p is the area of the plate, A_f is total area of the holes, and *C* is a coefficient that has been tabulated for various Reynolds number ranges and for the ratio of hole diameter to plate thickness.

According to the measured data in the wind tunnel [15], it is known that the permeability of the windbreak fence is about the magnitude of 10^{-5} . In the simulation, the influence of changing permeability parameters on the simulation result is very small, so the viscous resistance term is not paid much attention to the simulation process.

2.4. Grid Division. A structured grid is used for the grid division in paper. The grid is encrypted around the windbreak fence and in the terrain area, and the density of the grid can be appropriately reduced away from the area of concern. The meshing of the computational domain (Figure 4) is shown in Figure 5. A uniform distribution of the grid below the height of the fence along the y-axis is presented, with a grid size of 0.025 m. The grid length above the height of the fence is increased by the "geometric law" method with a growth factor of 1.033. The maximum grid length is 0.087 m. Along the x-axis, the grid from the inlet to the fence is reduced by the "geometric law" method with a reduction factor of 0.992. The size of the grid around the fence is 0.01 m. The grid from fence to outlet is growth with a growth factor of 1.007. The maximum grid length is 0.143 m. The number of grids is below 38,000.

2.5. Boundary Conditions of the Atmospheric Boundary Layer. In the atmospheric boundary layer, the law of variation of the wind speed with height is called the mean wind speed gradient, which is usually described by a mathematical formula of the power or logarithmic law. In this paper, the power law profile formula is adopted for the wind speed condition at the inlet:

TABLE 1: The mean error of the results between the simulation and the wind tunnel experiment.

	NS40-0.5 H	NS40-0.8 H	NS33-0.5 H	NS33-0.8 H
Mean error (%)	3.7	7.5	6.1	13.5

$$V(z) = V_0 \left(\frac{z}{z_0}\right)^{\beta},\tag{6}$$

the terrain of the site belongs to class B; roughness of the index β takes 0.15; z is the altitude, set z_0 as 10 m and V_0 as 15 m/s.

V

The empirical formula of the turbulence intensity is based on Type II of the Architectural Institute of Japan (AIJ):

$$I_{(z)} = \begin{cases} 0.23, & z \le 5, \\ 0.1 \left(\frac{z}{z_g}\right)^{-0.2}, & 5 < z < z_g, \end{cases}$$
(7)

where z_a is 350 m.

The turbulent kinetic energy k and the turbulent dissipation rate ε are set according to the following formulas:

$$k = \frac{3}{2} (V_{(z)} I_{(z)})^{2},$$

$$\varepsilon = \frac{k^{(3/2)}}{l},$$
(8)

where *l* is the turbulence length scale, $l = (0.07L/C_{\mu}^{(3/4)})$; *L* taken as the top height of the computational domain; $C_{\mu} = 0.09$.

2.6. Verification of Numerical Simulation Results for the Windbreak Fence. The numerical simulation without and with fences is carried out, respectively. The porosity of the fence is 0.4 and 0.33. Taking fence height H as the basic length unit, the wind speed data at y = 0.5 H, 0.8 H; x = 1 H, 2 H, 3 H, ..., 19 H, 20 H (downstream of the fence) are extracted, respectively. The formula to calculate the coefficient of reducing wind speed is as follows:

$$\lambda = \frac{V_e - V_n}{V_e},\tag{9}$$

where λ is the coefficient of reducing wind speed, V_e is the wind speed without fence, and V_n is the wind speed with fences.

The results comparing simulation and wind tunnel experiment are shown in Figure 6. As can be seen from the figure, the coefficient of reducing wind speed in wind tunnel experiment increases first and then decreases with the distance after the fence, and the simulation result fully conforms to this trend. The mean error of the results between the simulation and the wind tunnel experiment is shown in Table 1. In results with a height of 0.5 H, the mean error of both is relatively small. In the wind tunnel



FIGURE 6: Comparison of the results between simulation and wind tunnel experiment. (a) The height of 0.5 H. (b) The height of 0.8 H. "WT" is the wind tunnel experiment. "NS" is the numerical simulation. "40" and "33" are porosities. The "0.5 H" and "0.8 H" are different heights.

experiment, the curves of the two porosities are intertwined after a distance of 7 H; in the simulation, the difference value, which is the coefficient of reducing wind speed with two fences, decreases with the increase of the distance after the fence, but two curves do not intersect. This is due to the inherent turbulence effect of wind. There will be a certain degree of volatility, although incoming wind conditions are to some extent artificially controllable in the wind tunnel experiment. The numerical simulation is a more ideal experiment, and the results are smoother. The average error of this study is at the minimum of 3.7% and at the maximum of 13.5%. Therefore, the windbreak fence model is reliable.

3. Simulation for Wind Flow Control at the Site

3.1. The Top Height of the Computational Domain. The determination of the boundary of the computational domain is very important for the wind flow simulation, especially the influence of the top height of the computational domain on the simulation result. If the top boundary is set too low, it will compress the bottom flow field and affect the accuracy of the flow field structure. Considering the terrain of the site, the top height of the computational domain is constructed as 1200, 2000, and 3000 m, respectively. The length of the computational domain is set to 6000 m. The windbreak fence is 120 m high and is located 1200 m from the entrance. The computational domain is similar to Figure 4. The simulation result is shown in Figure 7.

As can be seen in Figure 7, the simulation result of multiple computational domain models with different top heights set based on real working conditions of the site are completely consistent with the simulation result of Section 2.6, which fully demonstrates that the windbreak fence model constructed in this study is robust enough. The coefficient of reducing wind speed of fences changes almost the same with the distance after the fence for different top heights of the computational domain, and there is a slight difference between the values. It indicates that the setting of the top height above 1200 m can guarantee the full development of the bottom flow field. Therefore, the top height of



FIGURE 7: Influence of the top height on reducing wind speed. "NS40-0.5 H" and "NS33-0.5 H" are the simulation results of Section 2.6. "NS" is numerical simulation. "40" and "33" are porosities. "0.5 H" is the height. "1200," "2000," and "3000" are the top heights of the computational domain.

the computational domain is set as 1200 m in the simulation of the actual working conditions for the site.

3.2. Construction of the Model and Simulation for the Slope Terrain of the Site. Along the north-south direction of the antenna position (the blue dotted line in Figure 1), the 2-dimensional topographic data of the site area are extracted, as shown in Figure 8. Point 0 of the horizontal coordinate is the antenna position; the vertical coordinate indicates the relative altitude. In the figure, both the north and south ends are at the bottom of the canyon. In terms of terrain, the topography of the site is high in the south and low in the north.

The more realistic the terrain model is constructed, the more it can fully reflect the influence of the terrain on the wind flow. However, small bumps and depressions in the ground will also be retained in the model. These structures have a weak effect on the wind flow but are extremely detrimental to grid division, consuming a large amount of



working time and computational resources. Therefore, it is essential to determine the effect of local microtopography on wind flow to optimize the terrain model. The simplified terrain model (named the S model) and the real terrain model (named the R model) are constructed by analyzing the terrain of the site, as shown in Figure 9. In the computational domain model, the upstream and downstream terrains of the slope are replaced by straight lines. The slope terrain in the S model is replaced by the oblique line. And, the slope factor is obtained by fitting the actual terrain data. The slope terrain in the R model is constructed from actual terrain data.

The grid length in the terrain area is set to 3 m, and the grid outside the terrain area is increased by the "geometric law" method with a growth factor of 1.005. The maximum grid length is 7.735 m and the number of grids is less than 380,000. The fence with 0.33 porosity and no fence is set in computational domain models of the site, and then the wind flow simulation is performed separately. The simulation results are shown in Figure 10. The antenna position is 6.7 H behind the fence. The changing trend of the curve that is the coefficient of reducing wind speed in S and R models is completely the same with two heights relative to the ground. Due to the fluctuation of the actual ground, there is a slight difference between the reducing coefficients of two terrain models.

The simulation results of the S and R models are extracted separately to make diagrams of the wind speed distribution, as shown in Figure 11. In the condition without windbreak fence, as in Figure 11(a), the wind speed gradient is evenly distributed due to the flat ground; as in Figure 11(b), there are sporadic disturbances in the wind speed gradient distribution near the ground due to the slight fluctuation of the real ground, but the flow field structure is the same as in Figure 11(a). In the condition with the windbreak fence, the wind speed distributions in Figures 11(c) and 11(d) are almost the same. This is because the fence is also one of the obstacles on the ground, and the height of the fence is much higher than the height difference of the ground fluctuation. Therefore, the influence of the small ground undulation on the wind flow is no longer obvious. Through the analysis of Figures 10 and 11, it is concluded that the construction of the terrain model can properly smooth the local microstructure on the basis of retaining the original terrain contour, which can not only save the workload and computing resources but also not affect the simulation accuracy.



FIGURE 9: Computational domain models of the site terrain.



FIGURE 10: The reducing coefficient of the terrain of the site. "NS40-0.5 H" and "NS33-0.5 H" are the simulation results of Section 2.6. "S" is the simplified terrain model and "R" is the real terrain model. "33" is porosity. "0.5 H" and "0.8 H" are different heights relative to the ground. The antenna position is 6.7 H behind the fence.

3.3. Analysis and Discussion of the Simulation Results at the Site. The frequency of incoming winds from the south and north (N and S directions in Figure 1) is also very high. Along the north-south direction, the terrain is high in the south and low in the north. Wind from north, the windbreak fence is arranged in low terrain, and the sheltering effect of the fence will be weakened. Furthermore, the location of the fence is in the wind mouth of the river valley, which is the most extreme working condition of the wind fence to control the wind flow. Based on the terrain data in the interval of $x = -1350 \sim 600$ m in Figure 8, the computational domain model of the extreme condition of the site is constructed and the simulation of the wind field is performed.

The simulation results are shown in Figure 12, from which it can be seen that the reducing wind coefficient of the fence increases first and then decreases in the



FIGURE 11: The distribution of wind speed: (a) simplified terrain without fence, (b) real terrain without fence, (c) simplified terrain with fence, and (d) real terrain with fence.

working conditions of the site terrain. Due to the impact of the slope terrain, the reducing wind coefficient of the fence that is placed at the bottom of the slope is smaller than that placed on the flat ground. And, as the distance behind the fence increases, the sheltering effect decreases faster. The distribution of wind speed with and without



FIGURE 12: The reducing coefficient of the extreme condition of the site. "NS40-0.5 H" and "NS33-0.5 H" are the simulation results of Section 2.6. "A" is the actual terrain model. "33" is porosity. "0.5 H" and "0.8 H" are different heights relative to the ground. The antenna position is 6.7 H behind the fence.



FIGURE 13: The distribution of the wind speed of the actual terrain. (a) In the condition without fence. (b) In the condition with fence.

fence working conditions is shown in Figure 13. It can be seen from the figure that the area of low wind speed downstream is significantly larger in the condition without the windbreak fence (Figure 11(b) compared to Figure 13(a)) due to the shading of the hill at x = 1000 m position; while the area of low wind speed downstream of the windbreak fence is significantly smaller in the condition with the windbreak fence (Figure 11(d) compared to Figure 13(b)). In terms of wind shielding efficiency, the coefficient of reducing wind speed at the antenna position (antenna position at x = 2200 m) is reduced by 5%.

In general, because the windbreak fence is far from the antenna position, the windbreak fence has a relatively weak sheltering ability to the antenna position, and the optimal sheltering position is $x = 1600 \sim 2000$ m, as shown in Figure 13(b). The analysis concluded that slope terrain will weaken the sheltering effect of the windbreak fence at the bottom of the slope. However, based on the current assumption of the height and location of the windbreak fence, the coefficient of reducing wind speed at the antenna area can still reach more than 30% after control of the windbreak fence, that is, the wind coming from 5 m/s can be effectively reduced to within 3.5 m/s. This shows that wind flow can be controlled even if the windbreak fence is placed at the bottom of the slope. As can be seen in Figure 1, the mountain to the north of the antenna is relatively high. Within the lowest pitch angle of view, it is possible to try to place the windbreak fence closer to the antenna position, while reducing the height of the windbreak fence to achieve the optimal shielding effect of the antenna area.

4. Conclusions

The larger the aperture and the higher the observation frequency, the more affected the observation efficiency of the radio telescope is by wind disturbance of the site. In this paper, we summarize the terrain characteristic of some large radio telescope sites. And, the QTT site is taken as the research object. Through the analysis of terrain characteristics and incoming wind characteristics, it is found that the direction of incoming wind with a high frequency and relatively high speed is located mainly in the mountain gap outside the antenna. Therefore, a method for controlling the wind flow of the site is proposed by windbreak fences.

The windbreak fence simulation model is constructed based on the theory of porous jumps. The mean error between the simulation result and the measured wind tunnel data is less than 14%. And, it has a strong reliability in the simulation for working conditions at the site. The influence of the top height of the computational domain on the simulation results is considered. Based on analysis of the simulation results with the top height of 1200, 2000, and 3000 m, the top height with 1200 m can meet the requirements. In addition, the simplified terrain model and the real terrain model of the site are constructed, respectively. The reducing wind coefficient of the windbreak fence is almost the same in two terrain models, and there is a slight difference between the values. Therefore, when constructing the terrain model, the microtopographic structure with small influence on wind flow can be smoothed appropriately.

Based on the current assumption of the height and location of the windbreak fence, even if the windbreak fence is placed at the bottom of the slope, after control of the windbreak fence, the wind speed at antenna position can still be weakened by more than 30%. This shows that the windbreak fence can play a role in optimizing the wind environment at the telescope site. This study verifies the feasibility of the method for the windbreak fence controlling the wind flow of the site and also provides a method reference for the subsequent design of more accurate windbreak fence arrangement schemes. In the next phase, we will conduct a more detailed study of the windbreak fence in the 3D model. For example, the influence of parameters such as the width of the fence in the horizontal wind direction, the width of the fence in the downwind direction, the different wind angle, and the different angles of wind attack on the downstream wind blocking effect.

Data Availability

The experimental data of the wind tunnel are from a master dissertation (sources cited in the article). Other data supporting the findings of this study are available from the corresponding author (xuqian@xao.ac.cn) upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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