Nonlinear Dynamics and Applications. Vol. 13 (2006) 146 - 153

Assessment of wind potential inhomogeneity in the surface layer of atmosphere

A.G. Lukashevich, A.G. Trifonov,* and A.A. Mikhalycheva
Joint Institute of Power and Nuclear Research - Sosny,
National Academy of Sciences of Belarus
99 Acad. Krasina Str., 220109 Minsk, Belarus

A.A. Andrijievskij
Belarussian State Technological University
Sverdlova Str., Minsk, Belarus

Application of real-time near-range atmospheric model for description of flow over surface with mixed roughness is presented. Max and min wind velocity deviations as function of wind wheel axle height are discussed. The results of calculation and experiment show, that the wind velocity deviation grows with increase of the average wind velocity and the roughness of terrain.

PACS numbers: 92.60.hk, 47.27.E-
Keywords: wind velocity, velocity deviations, turbulence structure, near-range atmospheric model, atmospheric surface-layer turbulence

1. Introduction

It is well known that the wind velocity measured at the same position under seemingly identical large-scale conditions changes from one instant to the next. It seems that the velocity takes random values which changes rapidly in time. Fluctuating motions of this kind are said to be turbulent. The average properties of the motion are modeled by a very simple parameterization (or approximation to the equations of motion).

Turbulence structure over flat homogeneous terrain is relatively well known. Real terrain modifies this turbulence in several different ways: compression or stretching of mean over hills, which in turn will distort the turbulence; gradual changes in turbulence level due to changing surface.

The real-time near-range atmospheric model chain includes the spectral code, which was originally developed by Rise for modeling the mean wind fields over hilly, but otherwise homogeneous, terrain.

2. Compression or stretching of mean over hills

The drawing next illustrates qualitatively how the turbulence spectra are distorted over a ridge. The method is based on a model of the spectral tensor for atmospheric surface-layer turbulence at high wind speeds and can simulate two- or three-dimensional fields of one, two or three components of the wind velocity fluctuations. The colored curves are spectra as functions

*E-mail: tral@sosny.bas-net.by

of wave number k (which is proportional to frequency). The red curve is u, the green - v, and the blue - w components wind velocity.

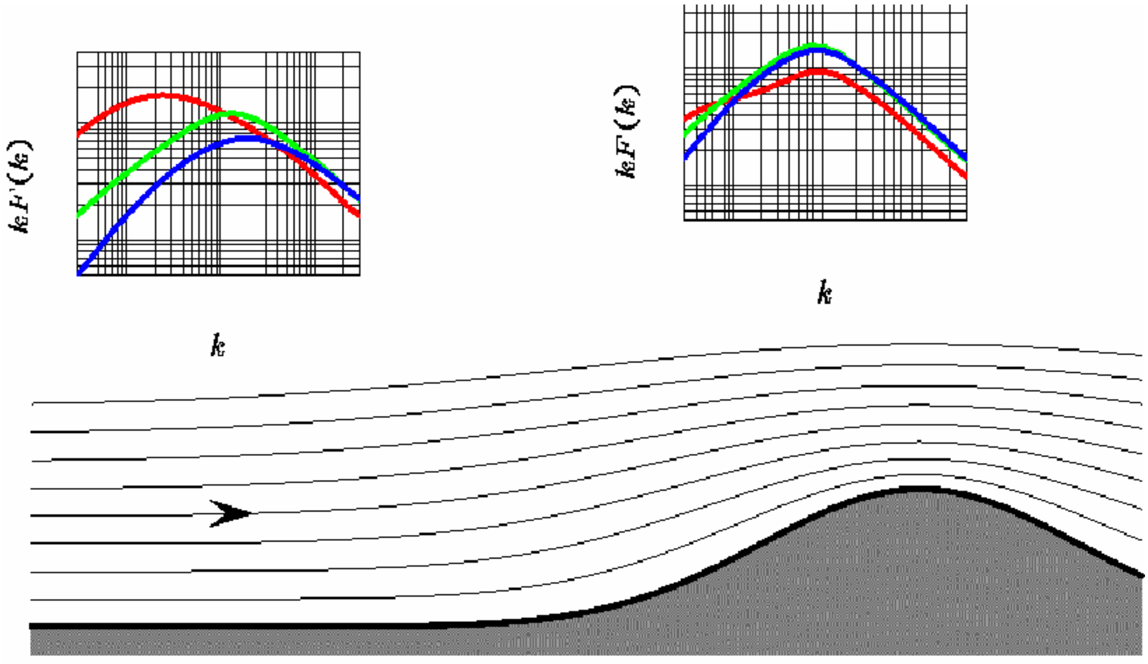

FIG. 1: Turbulence spectra over a ridge.

3. Specifying terrain roughness

There are two different ways of describing the roughness characteristics of the terrain surrounding a site: in the form of a digital map of roughness-change lines, i.e. lines separating areas of equal roughness (length); in the form of a site-specific roughness description, also referred to as a roughness rose.

In the first case, roughness rose is calculated from the roughness map, in the second case the rose is specified by the user directly. The roughness map offers the greatest flexibility, because the site can be chosen at random within the area covered by the map. The roughness rose, on the other hand, generally offers higher accuracy in the roughness description of single sites. The roughness of a particular surface area is determined by the size and distribution of the roughness elements it contains; for land surfaces these are typically vegetation, built-up areas and the soil surface.

The different terrains have been divided into four types, each characterized by its roughness elements. Each terrain type may be referred to as a roughness class. A description and illustration of four such roughness classes is given in the Fig 2 - 5, which furthermore give the relation between roughness length and roughness class, the former being the commonly used length scale to characterize the roughness of a terrain. In Fig 2 it is shown example of terrain corresponding to roughness class 0: water areas. This class comprises the sea, fjords, and lakes. The roughness length is z_0 = 0,0002m.

The example of terrain corresponding to roughness class 1: open areas with few windbreaks is shown in Fig 3.The terrain appears to be very open and is flat or gently undulating. Single farms and stands of trees and bushes can be found. The roughness length is z_0 = 0,0003m.

The example of terrain corresponding to roughness class 2: farm land with wind-breaks, the mean separation of which exceeds 1000 m, and some scattered built-up areas is shown in

Fig 4. The terrain is characterized by large open areas between the many windbreaks, giving the landscape an open appearance. The terrain may be flat or undulating. There are many trees and buildings. The roughness length is $z_0 = 0{,}10$m.

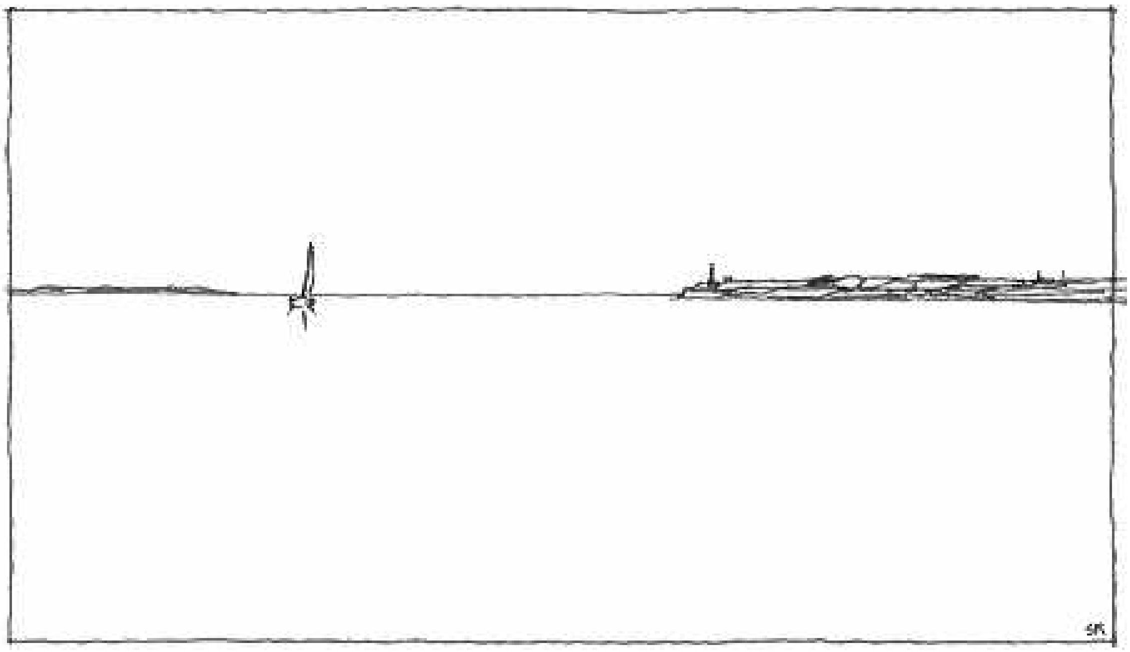

FIG. 2: Example of terrain corresponding to roughness class 0.

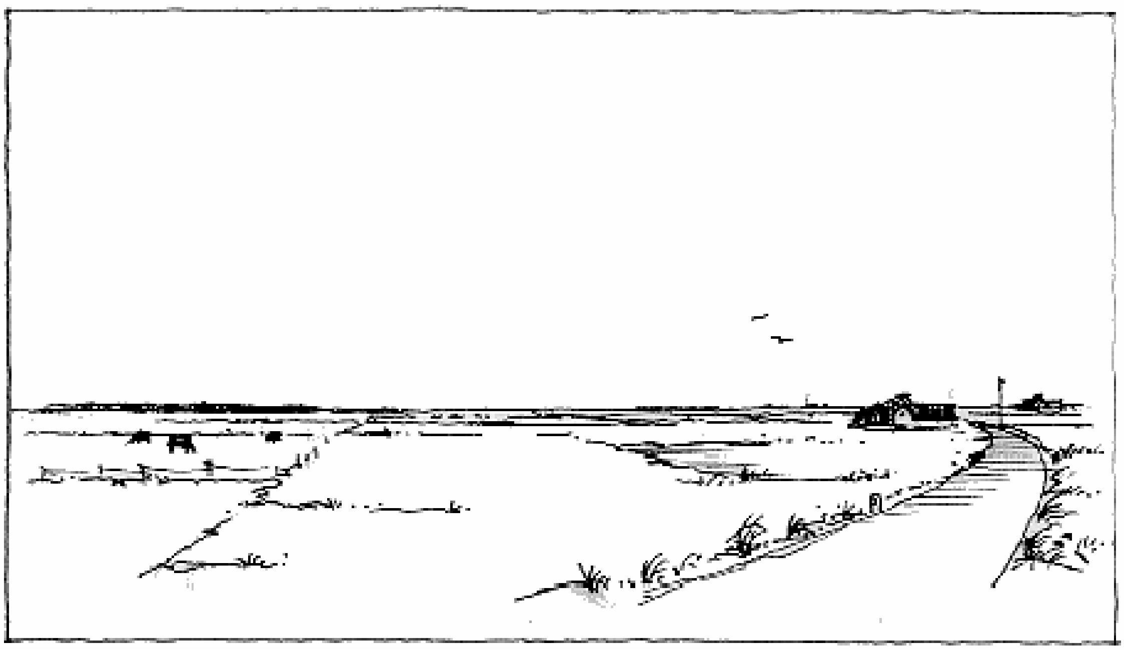

FIG. 3: Example of terrain corresponding to roughness class 1.

The example of terrain corresponding to roughness class 3: urban districts, forests, and farm land with many windbreaks is shown in Fig 5. The farm land is characterized by the many closely spaced windbreaks, the average separation being a few hundred metres. Forest and urban areas also belong to this class. The roughness length is $z_0 = 0{,}40$m.

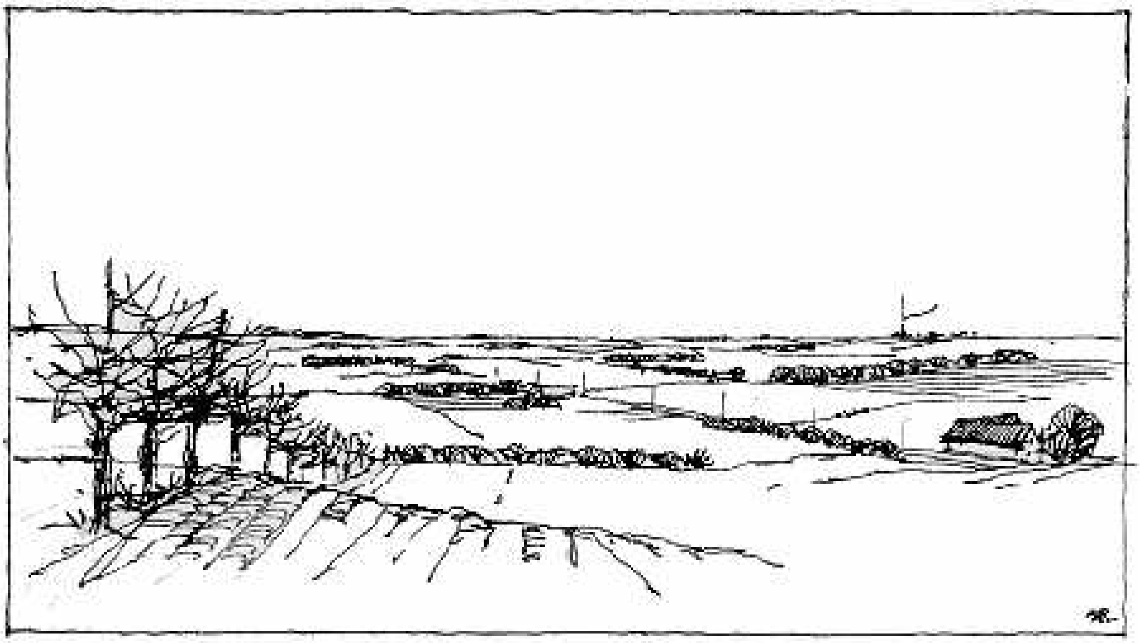

FIG. 4: Example of terrain corresponding to roughness class 2.

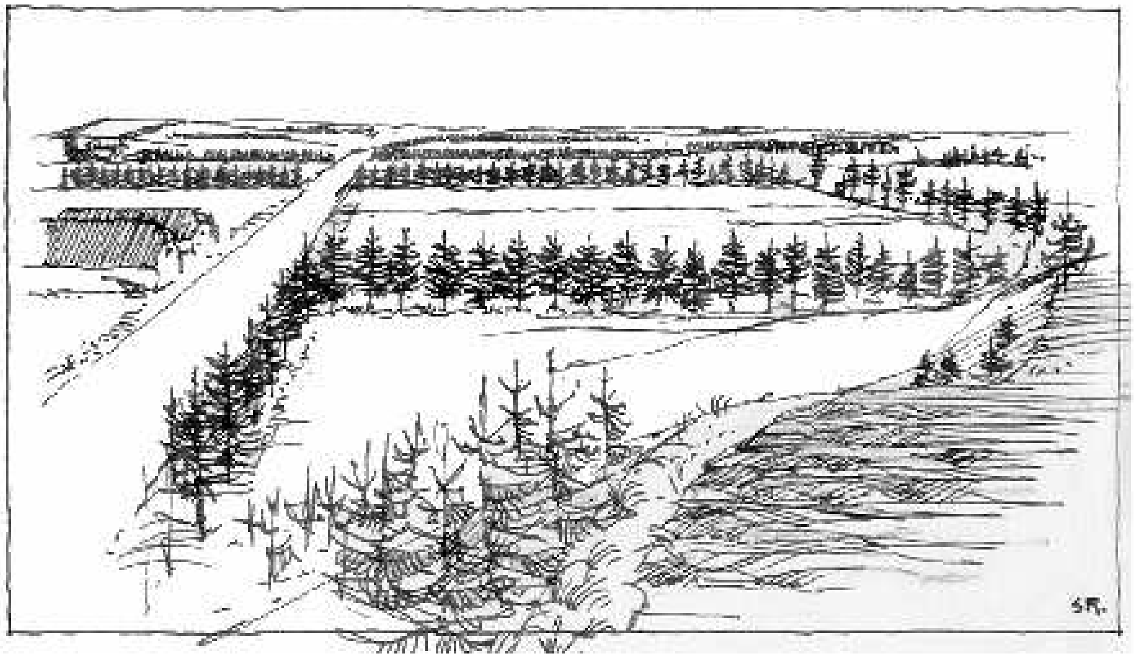

FIG. 5: Example of terrain corresponding to roughness class 3.

The roughness of a terrain is commonly parameterized by a length scale called the roughness length, z_0. Formally, z_0 is the height where the mean wind speed becomes zero, if the wind profile has a logarithmic variation with height. This usually occurs during moderate and strong wind conditions. A simple empirical relation between the roughness elements and the roughness length has been given by Lettau (1969). A roughness element is characterized by its height h and the cross-section facing the wind S. Further, for a number of roughness elements distributed evenly over an area, the density can be described by the average horizontal area, A_H, available to each element. Then

$$z_0 = \frac{0,5(h * S)}{A_H}$$

This relation gives reasonable estimates of z_0 when A_H is much larger than S. It tends to overestimate z_0 when A_H is of the order of S; this is because, when the roughness elements are close together, the flow is 'lifted' over them. Then only a fraction of S and h contributes to the roughness. Furthermore, the lifting of the flow requires measuring the height above ground from somewhere between the top of the roughness elements and half the height of the elements. This height is referred to as a displacement length. The displacement length must often be taken into account on sites with forests, cities, and tall vegetation. Finally, the equation assumes that the porosity is approximately zero, i.e. the roughness elements are solid. For porous roughness elements, z_0 from the equation above must be reduced by a fraction equal to the porosity.

4. Results of applications of turbulent wind model with mixed surface roughness

The real-time near-range atmospheric model chain includes the spectral code, which was originally developed by Rise for modeling the mean wind fields over hilly, but otherwise homogeneous, terrain.

Time history of wind velocity in the surface layer of atmosphere is shown in Fig 6.

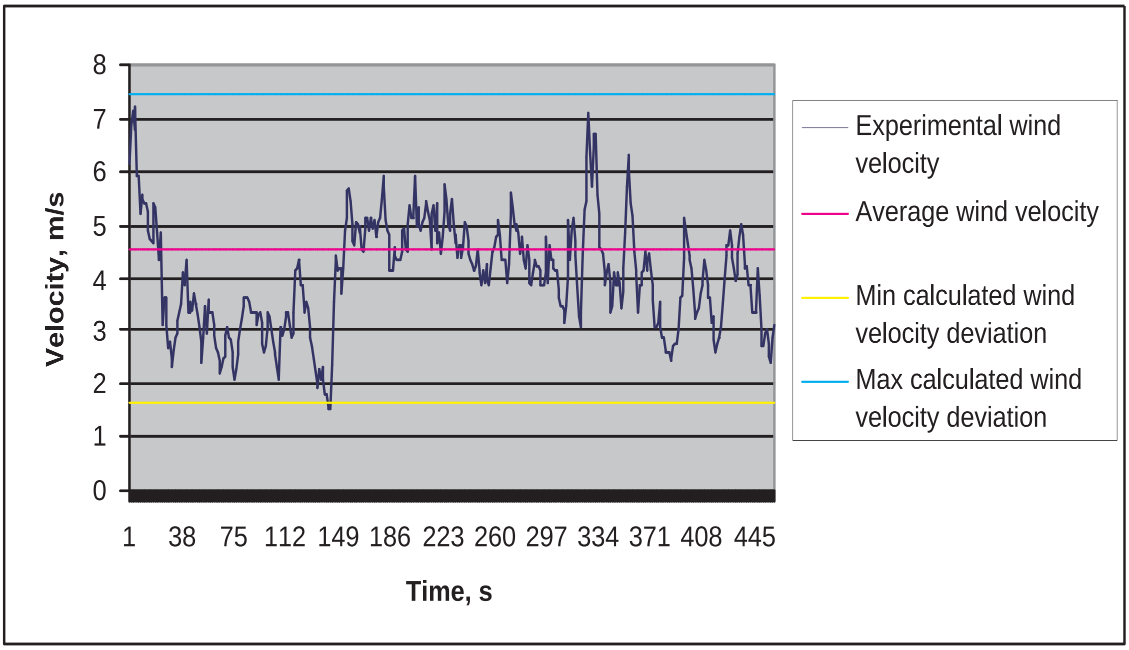

FIG. 6: The time history of wind velocity in the surface layer of atmosphere.

Yellow curve is *min* wind velocity deviation, blue curve is *max* wind velocity deviation, calculated by Mann turbulence model. Experimental data deviations are inside the range of predicted velocity deviations. The results of calculation of *max* and *min* wind velocity deviations vs height of wind wheel axle are shown in Fig 7 and Fig 8, average wind velocities are 6 m/s and 2 m/s accordingly. Yellow curves are *min* wind velocity deviations, blue curves are *max* wind velocity deviations, violet lines are average wind velocities.

Max and *min* wind velocity deviations vs height of wind wheel axle and roughness of a terrain , calculated by Mann turbulence model, are presented in In Fig 9 and Fig 10, average wind

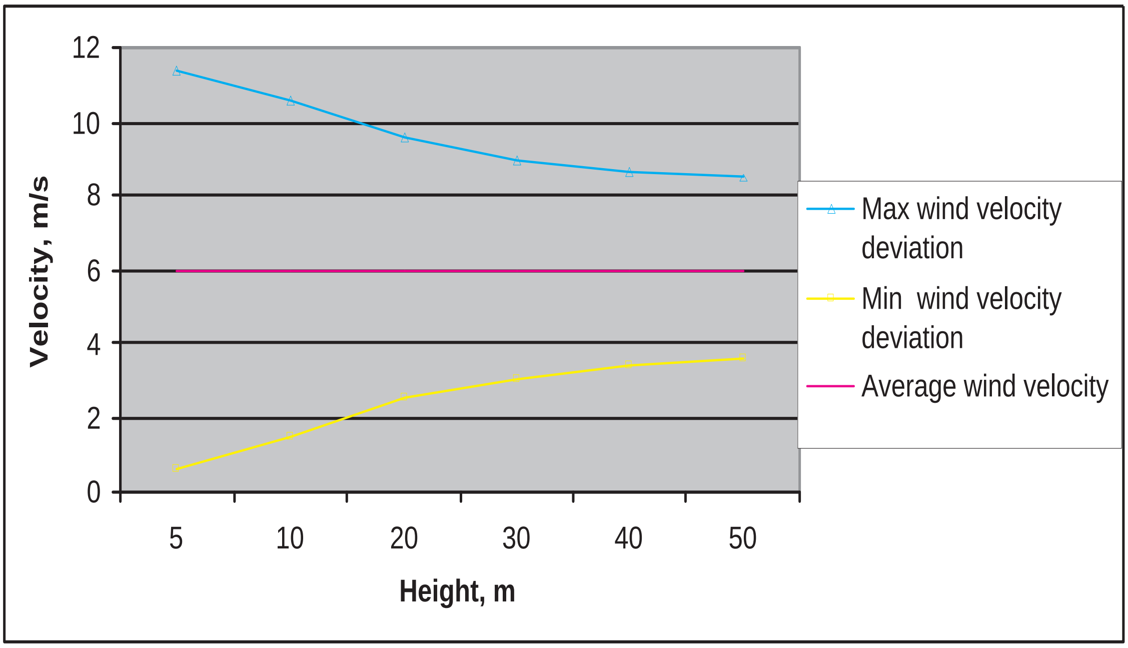

FIG. 7. Max and min wind velocity deviations vs height of wind wheel axle and roughness of a terrain (average wind velocities are 6 m/s).

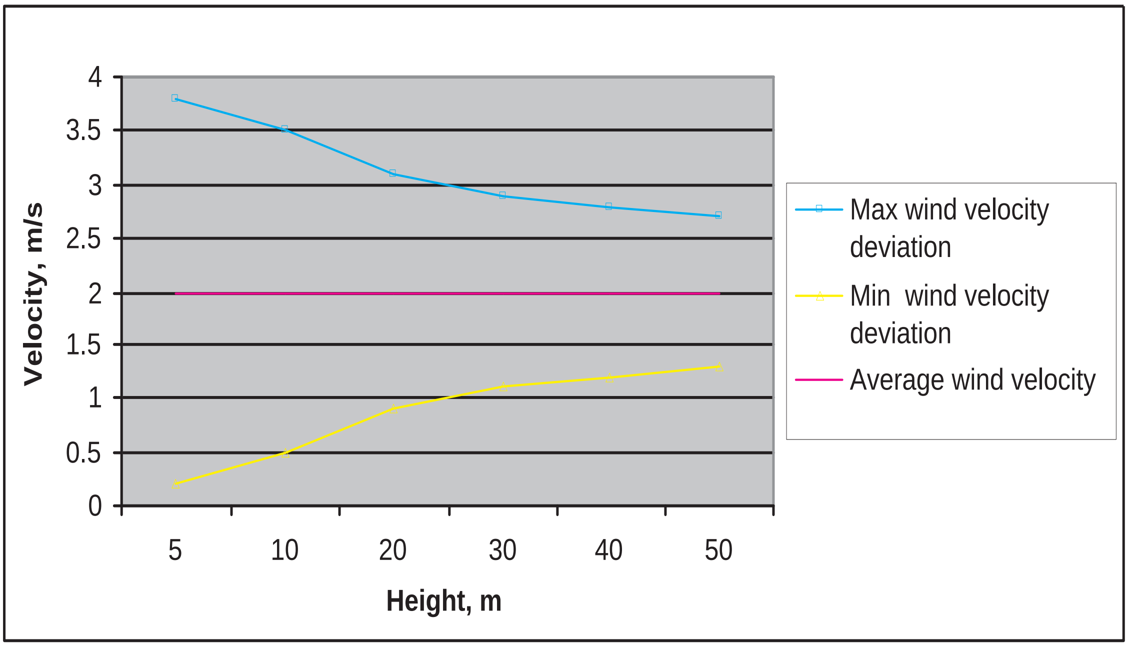

FIG. 8. Max and min wind velocity deviations vs height of wind wheel axle and roughness of a terrain (average wind velocities are 2 m/s).

velocities are 2 m/s and 6 m/s accordingly. Yellow curves are min wind velocity deviations at the roughness of terrain 0,1; 2,5; 7,5 accordingly. Blue curves are max wind velocity deviations at the roughness of terrain 0,1; 2,5; 7,5 accordingly. Violet lines are average wind velocities, 2 m/s and 6 m/s accordingly.

The results of calculation and experiment show, that the wind velocity deviation grows with increase of the average wind velocity and the roughness of terrain.

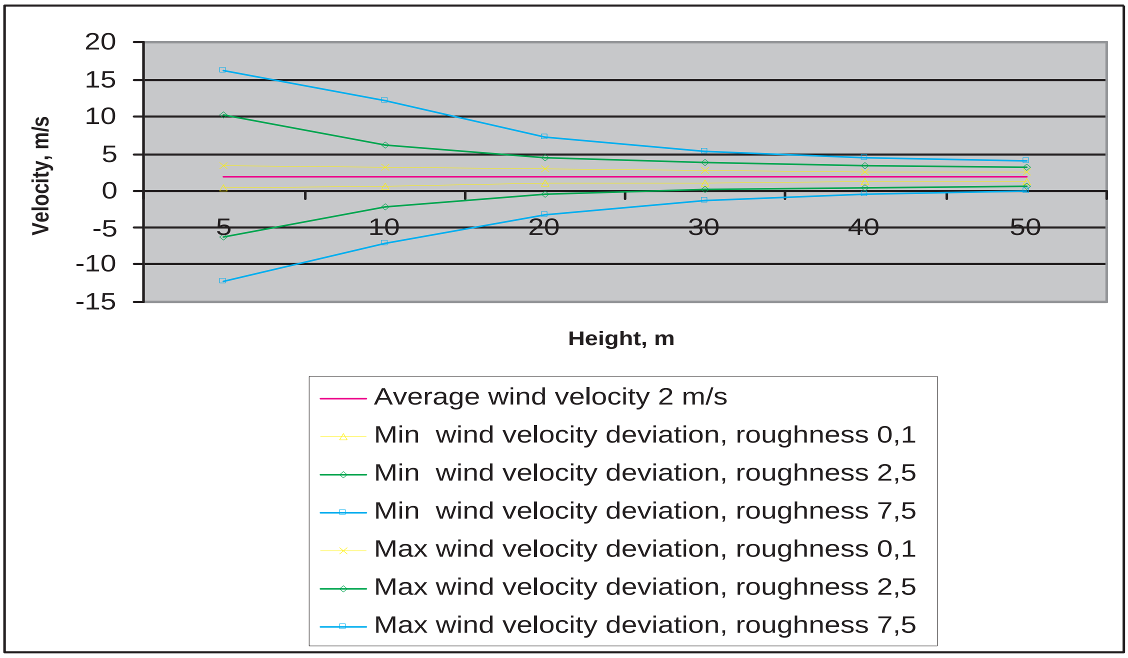

FIG. 9. Max and min wind velocity deviations vs height of wind wheel axle and roughness of a terrain , calculated by Mann turbulence model (average wind velocities are 2 m/s).

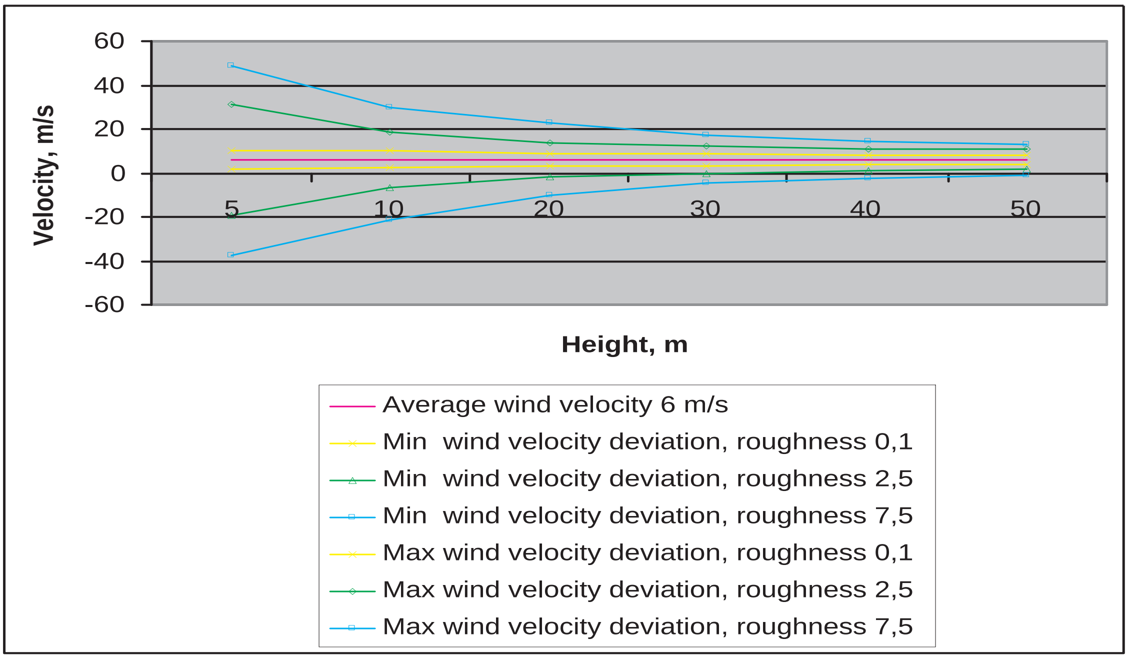

FIG. 10. Max and min wind velocity deviations vs height of wind wheel axle and roughness of a terrain , calculated by Mann turbulence model (average wind velocities are 6 m/s).

5. Conclusion

The real-time near-range atmospheric model chain includes the spectral code, which was originally developed by Rise for modeling the mean wind fields over hilly, but otherwise homogeneous, terrain. In this paper have been shown time history of wind velocity in the surface layer of atmosphere; the results of calculation of max and min wind velocity deviations vs height of wind wheel axle; max and min wind velocity deviations vs height of wind wheel axle and roughness of a terrain , calculated by Mann turbulence model.The results of calculation are in rather good accordance with the experimental data, and show, that the wind velocity deviation grows with increase of the average wind velocity and the roughness of terrain.

References

[1] A fast model for mean and turbulent wind characteristics over terrain with mixed surface roughness, Astrup P, Mikkelsen T and Jensen N O, Radiation Protection Dosimetry, 73: (1-4) 257–260, 1997,

[2] Wind field simulation, Mann J, Probabilistic Engineering Mechanics, 13: (4) 269-282 OCT 1998.

[3] Wind field simulation, Mann J, Probabilistic Engineering Mechanics, 13: (4) 269-282 OCT 1998. The spectral velocity tensor in moderately complex terrain, Mann J, Journal of Wind Engineering And Industrial Aerodynamics, 88: (2-3) 153-169 DEC 2000.

[4] Atmospheric Turbulence, Panofsky H.A. and Dutton J.A., 1984, John Wiley & Sons, New York.