PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Dynamics of turbulence kinetic energy from minisodar measurements

N. P. Krasnenko, L. G. Shamanaeva, O. F. Kapegesheva

N. P. Krasnenko, L. G. Shamanaeva, O. F. Kapegesheva, "Dynamics of turbulence kinetic energy from minisodar measurements," Proc. SPIE 10833, 24th International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, 108333Y (13 December 2018); doi: 10.1117/12.2503904

SPIE.

Event: XXIV International Symposium, Atmospheric and Ocean Optics, Atmospheric Physics, 2018, Tomsk, Russian Federation

Dynamics of turbulence kinetic energy from minisodar measurements

N.P. Krasnenko[a1,2], L.G. Shamanaeva[3,4], O.F. Kapegesheva[4]
[1]Institute of Monitoring of Climatic and Ecological Systems SB RAS; [2]Tomsk State University of Control Systems and Radioelectronics; [3]V.E. Zuev Institute of Atmospheric Optics SB RAS; [4]National Research Tomsk State University

ABSTRACT

In the report, spatiotemporal dynamics of the turbulent kinetic energy (TKE) retrieved from minisodar measurements of three wind velocity components in the range 5–200 m during 6 days in autumn is investigated. The results obtained demonstrated that the TKE increased with altitude, which is in agreement with the available literature data. In the surface 50–100 m layer, it slightly increases with altitude. The diurnal variations of the vertical profiles of the TKE are analyzed. The presence of maxima and minima in the daily behavior of the TKE was detected that can be explained by the effect of meteorological conditions. The influence of the averaging time was also estimated.

Keywords: acoustic sounding, atmospheric boundary layer, turbulence kinetic energy.

Characteristics of the atmospheric turbulence are of fundamental importance for a description of the structure and dynamics of the atmospheric boundary layer (ABL) and construction of its mathematical models. The application of Doppler acoustic radars (sodars) allows the spatiotemporal dynamics of both average values of three wind velocity components and their second moments – variances [1–3] – to be investigated together with the spatial variability of the turbulent kinetic energy (TKE) [4, 5]. This parameter is a measure of the turbulence intensity in the ABL and determines the momentum, heat, and moisture transport. It is also used to calculate the meteorological fields and to predict diffusion of pollutants in the atmosphere as well as for weather forecasting and analysis and prediction of the conditions for electromagnetic and acoustic radiation propagation.

In the present report, the spatiotemporal TKE dynamics is studied in the lower 5–200-meter layer of the atmosphere from minisodar measurements. Measurements were performed with a minisodar AV4000 having a working frequency of 4900 Hz and radiation pulse duration $\tau = 60$ ms. Acoustic radiation was sent at angles of 76°, 76°, and 90° to the horizon in two mutually orthogonal planes. The altitude profiles of three wind velocity components $V_{mij}\left(z_j, t_k\right)$, where $m = x, y, z$, i is the current number of measurements in a series, $i = 1, \ldots, N$, were measured in 40 strobes z_j of vertical extension $\Delta z = 5$ m in the kth measurement series started at time t_k. Each measurement series comprising N profiles ($N = 150$, 300, and 450) was processed, thereby providing averaging over time periods of 10, 20, and 30 min. The turbulence kinetic energy was calculated from the formula

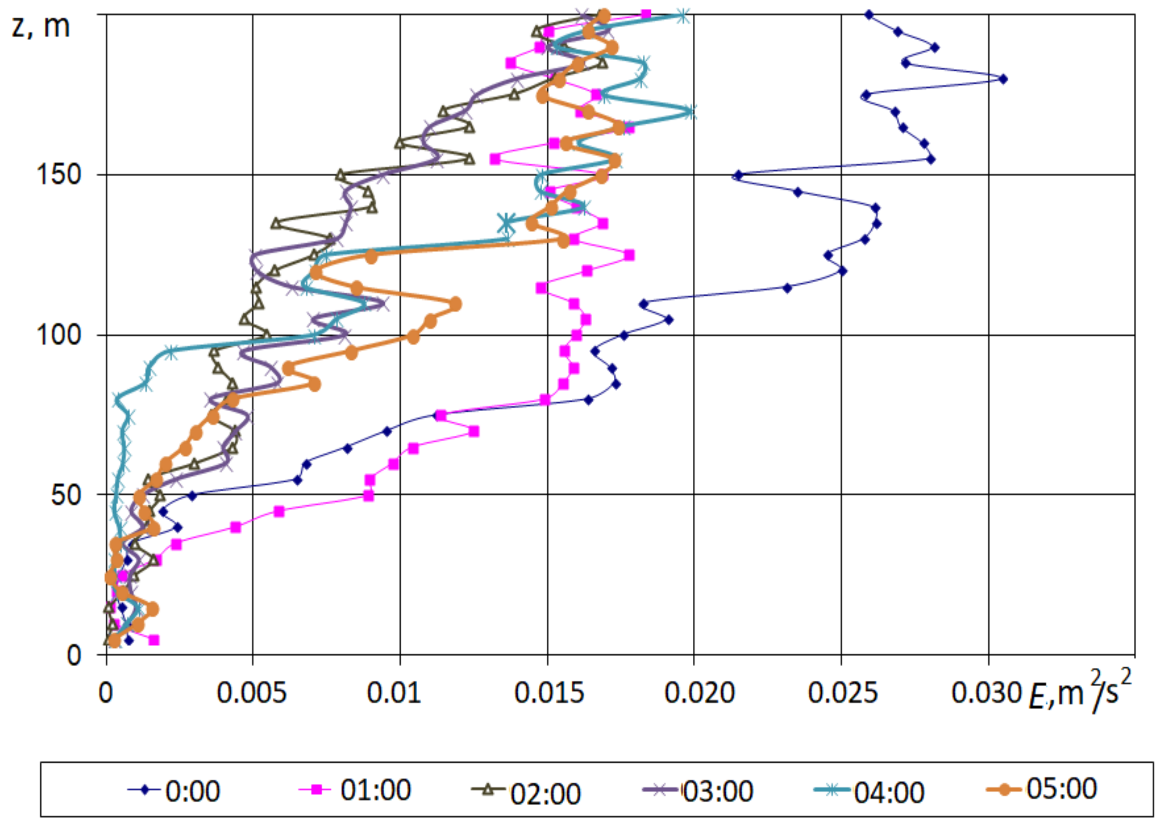
$$E(z_j,t_k) = 0,5\left(\sigma_x^2(z_j,t_k) + \sigma_y^2(z_j,t_k) + \sigma_z^2(z_j,t_k)\right) = \frac{1}{(N-1)^2}\left(\sum_{i=1}^{N} V_{xij}\left(z_j,t_k\right) - \left\langle V_x\left(z_j,t_k\right)\right\rangle\right)^2 + \sum_{i=1}^{N}\left(\left(V_{yij}(t_k)\right) - \left\langle V_y\left(z_j,t_k\right)\right\rangle\right)^2 + \sum_{i=1}^{N}\left(\left(V_{zij}(t_k)\right) - \left\langle V_z\left(z_j,t_k\right)\right\rangle\right)^2,$$

where $\sigma_x^2(z_j, t_k)$, $\sigma_y^2(z_j, t_k)$, and $\sigma_z^2(z_j, t_k)$ are variances of the x-, y-, and z-components of the wind velocity in the jth strobe z_j of the kth measurement series started at time t_k.

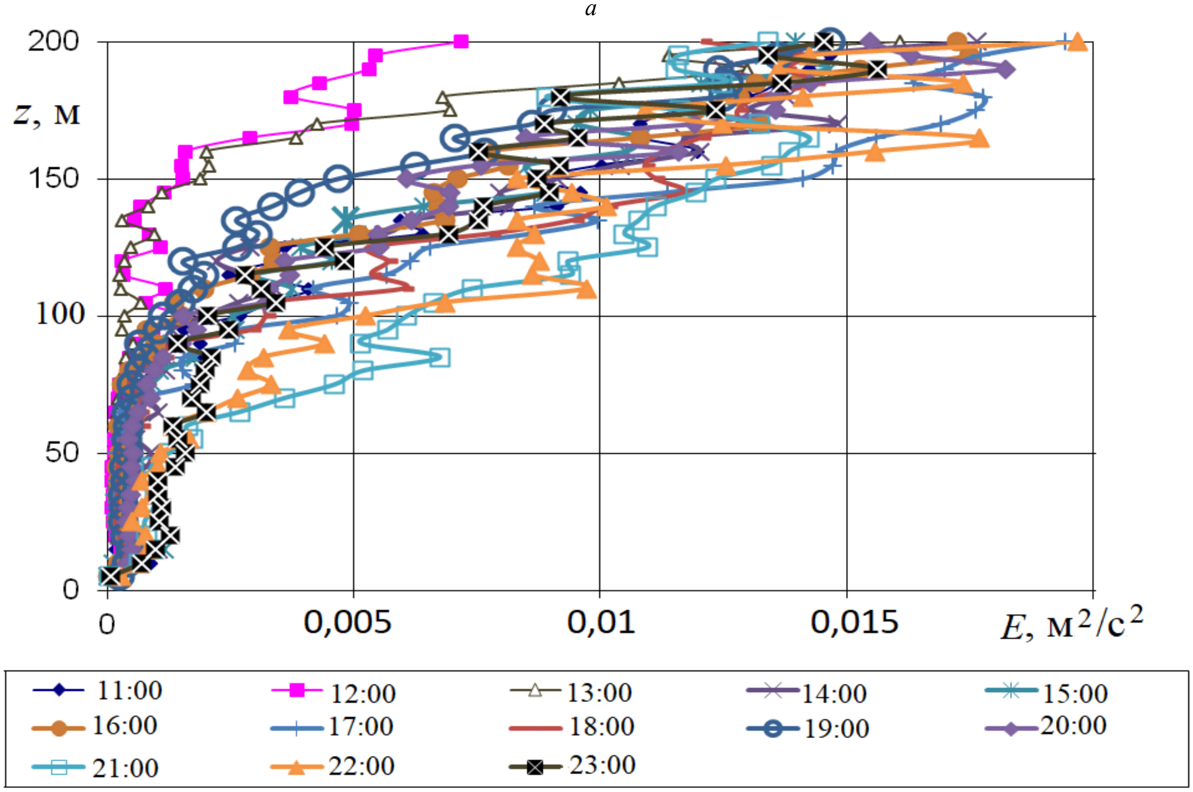
Figure 1*a–d* shows the time behavior of the vertical profiles of the turbulence kinetic energy retrieved from minisodar measurements during six days from September 12 to September 17, 2006. Start times of 10-minite measurement series are indicated under the figures. Here Fig. 1*a* shows the vertical TKE profiles observed at night and in the morning, from 0:00, local time till 05:00 on September 12. Attention is drawn to a small spread of E values in the lower 25-meter layer.

[a] krasnenko@imces.ru

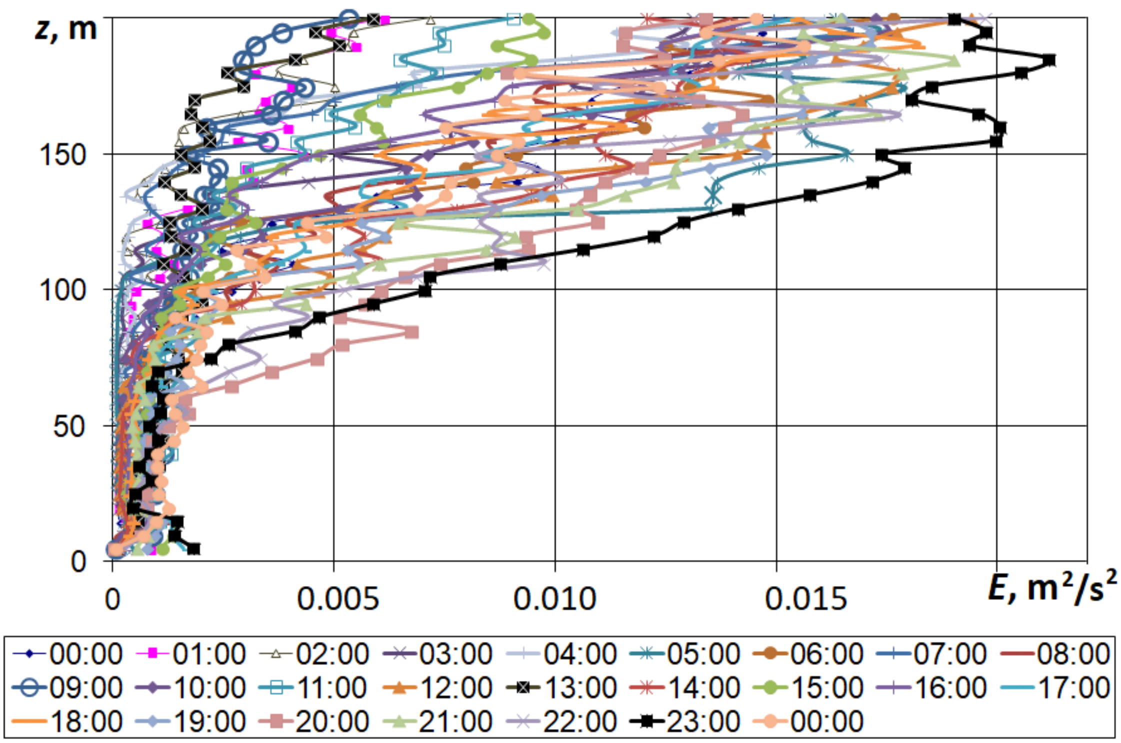
24th International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, edited by
Gennadii G. Matvienko, Oleg A. Romanovskii, Proc. of SPIE Vol. 10833, 108333Y
© 2018 SPIE · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2503904


z, m
150
100
50
0
0
0.005
0.01
0.015
0.020
0.025
0.030
E,m²/s²
0:00
01:00
02:00
03:00
04:00
05:00

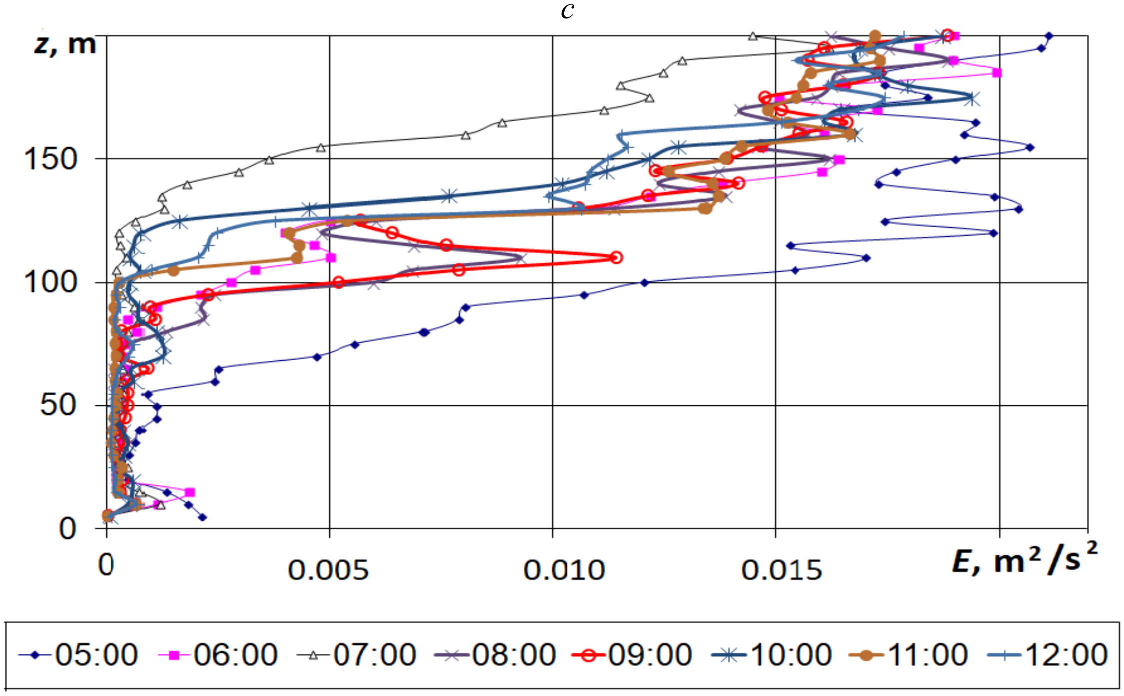
a


200
z, м
150
100
50
0
0
0,005
0,01
0,015
E, м²/с²
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

b



c



d

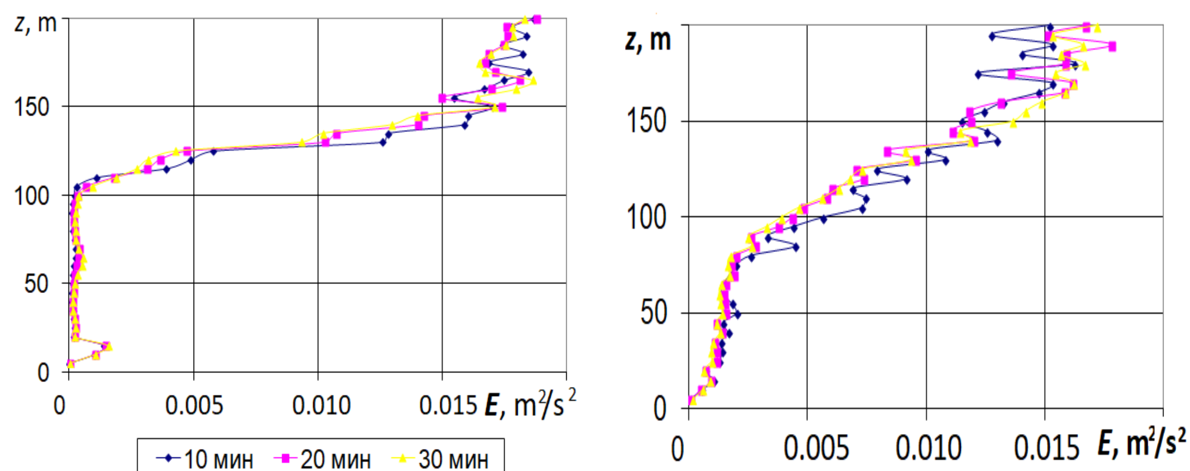
Figure. 1. Spatiotemporal dynamics of the TKE retrieved from the results of minisodar measurements on September 12 (*a*), 13 (*b*), 14 (*c*), and 15 (*d*) with 10-minute averaging. The start times of measurement series are indicated under the figures.

The maximal E values in the examined altitude range were observed at 0:00. Then at 02:00, E increased in the lower 75-meter layer, but decreased at higher altitudes. At $z = 200$ m, it decreased from 0.026 to 0.018, that is, by about 31%. This tendency to E decrease was observed till 03:00. Then the TKE continued to decrease till 04:00 in the lower 100-meter layer, but started to increase at higher altitudes. By 05:00, the TKE increased in the entire examined altitude range.

Figure 1*b* illustrates the half-day behavior of the vertical TKE profiles measured every 1 h from 11:00 in the morning till 23:00 in the evening on September 13. A small half-day spread of the TKE values was observed up to $z = 100$ m. The minimal E values were recorded at 12:00. They increased till 18:00, decreased till 19:00, and increased till 21:00. The maximal E values were observed at 22:00. Then they decreased again till 23:00. Analogous behavior of the TKE was also reported in [5], where the results of measurements of the TKE with a FAS64 sodar were presented. According to [5], the daily behavior of the TKE was characterized by the presence of several maxima and minima whose observation times depended on the meteorological conditions, and primarily, on the cloud-cover index.

The daily TKE behavior on September 14 from 0:00 till 0:00 is illustrated by Fig. 1*c*. Here the maximum spread of the TKE values was observed at $z = 200$ m, with minimal TKE value $E_{min} = 0.005$ m^2/s^2 at 09:00 and $E_{max} = 0.02$ m^2/s^2 at 23:00. Figure 1*d* shows the spatiotemporal behavior of the TKE on September 15 from 05:00 in the morning till noon. Here the maximum TKE values were observed at 05:00, and their minimum values were observed at 07:00.

During our measurements, the TKE changed from several thousandth to several hundredth m^2/s^2, which is in agreement with the data available from the literature [4, 5]. From the figures it can be seen that the TKE during observations increased with altitude. In the surface layer at altitudes up to 25–50 m, it slightly depended on the altitude. Thus, on September 12 it changed slightly with altitude up to 25 m, from 0.001 to 0.009 m^2/s^2; the other three days it changed slightly with altitude up to 50 m, increasing up to 0.002 m^2/s^2. The spread of the TKE values increased with altitude, and at an altitude of 200 m, the TKE changed already from 0.007 to 0.02 m^2/s^2, that is, almost doubled. Analogous altitude behavior of the TKE was also indicated in [4, 5].



b

a

Figure. 2. Kinetic energy of turbulence retrieved from mini-sodar measurements on September 16 at 10:00 (*a*) and 16:00 (*b*) for averaging times of 10 (diamonds), 20 (squares), and 30 min (triangles).

We also investigated the influence of the averaging time (10, 20, and 30 min) on the KTE. Figure 2 show the TKE values for these averaging periods. It can be seen that the E values changed only slightly, though their spread increased with altitude. In the morning (Fig. 2*a*) they remained practically constant in the lower 100-meter layer, whereas in the afternoon, they increased up to $E = 0.005$ m^2/s^2. At greater altitudes, they strongly increased.

The daily cycle of radiative heating causes the daily behavior of the TKE. Our results demonstrate that the daily behavior of the TKE is characterized by the presence of several maxima and minima whose observation times depend on the meteorological conditions.

REFERENCES

[1] Bradley S., [Atmospheric Acoustic Remote Sensing], CRC Pres. s Boca Raton, London. New York, (2008).

[2] Kapegesheva O.F., Krasnenko N.P., Stafeev P.G., Shamanaeva L.G., "Sodar studies of the structure and time dynamics of the wind velocity characteristics in the lower atmosphere," Materials of the VIIIth All-Russian Symposium on the Environmental and Climate Monitoring. Tomsk, 113–114 (2012).

[3] Krasnenko N.P., Kapegesheva O.F., Tarasenkov M.V., Shamanaeva L.G., "Spatiotemporal dynamics of the wind velocity variance from the data of acoustic sounding," Russ. Phys. J. 58(8), 1105–1110 (2015).

[4] Greenhut G.K., Mastrantonio G., "Turbulence kinetic energy budget profiles derived from Doppler sodar measurements," J. Appl. Meteor. 28, 99–106 (1989).

[5] Haggagy M.E.A., "A sodar-based investigation of the atmospheric boundary layer," Berichter des Meteorologischen Institutes der Universitat Freiburg, 8 (2003).