WIND PROFILE IN THE NEAR-WATER LAYER OVER LAKE LADOGA

1961

SovietRxiv

Figure 1

Figure 1: Figure 1

Abstract

Full Text

GEOPHYSICS

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WIND PROFILE IN THE NEAR-WATER LAYER OVER LAKE LADOGA

(Presented by Academician D. V. Nalivkin, 18 VI 1960)

Study of the wind profile in the near-water layer is necessary in investigations of turbulent exchange between the water surface and the overlying air layers. Experimental data on the vertical distribution of wind speed above a water surface are limited ([1–7]).

In the summer of 1959 (from 7 VII to 16 VIII), the Laboratory of Lake Science of the Academy of Sciences of the USSR carried out observations of the vertical distribution of wind speed on Lake Ladoga, with the aim of determining the character of the wind profile and its dependence on temperature stratification, and also of determining the values of the roughness parameter.

Observations were made with remote electric-contact anemometers of the system of the Main Geophysical Observatory named after A. I. Voeikov, installed on a mast about 6 m high. The mast stood at the water' s edge on the gently sloping shore of Khankhipasi Island, which is located 5 km southwest of Valaam Island. Khankhipasi Island is an elongated, smoothed granite ridge of average width 90 m, bent in a crescent shape with the concave side facing north. The island is covered with sparse herbaceous vegetation, lichens, and mosses. Its maximum extent from north to south reaches 200 m, and from west to east 300 m. The island' s area is 3.9 ha. Its maximum height relative to the water level on 9 VIII 1959 was 8 m, with an average height of 3 m. The bottom relief near Khankhipasi Island is characterized by a steep, uniform drop, with fairly considerable depths right by the island.

Fig. 1. Relationship between the surface temperatures of the water in open Ladoga near Khankhipasi Island (T_0'') and at the station on Khankhipasi Island (T_0') (1 –temperature relationship, 2 –bisector)

The mast with the anemometers was installed on the southern side of the island, and winds of SW, SSW, S, SSE, SE, ESE, and E directions were not affected by land; WNW, WSW, W, and WNW winds were directed parallel to the shoreline and partly experienced the influence of the island. Winds of NE, NNE, N, NNW, and NW directions passed over the island, and the character of the wind profile was distorted.

Contact anemometers were placed at levels of 6.15; 3.15; 1.65 and 0.75 m from the base of the mast. Their readings were recorded by a self-recorder of the MGO system. Processing was carried out using average data from recordings of wind speed over 60 min. During the period of work, 246 strips were obtained. To check the anemometers, 4 verifications were carried out (comparison with a control anemo-

meter). The discrepancies between the readings of individual anemometers did not exceed 0.2 m/sec.

The analysis of the materials was carried out with allowance for wind direction in two ways: 1) by averaging the data without taking thermal stratification into account, and 2) with thermal stratification taken into account; the latter was determined by the difference ΔT between the temperatures of the water and the air.

The small size of the island and the considerable depths close to the water’ s edge create hydrometeorological conditions characteristic of an open lake, which, for example, is evident in the graph showing the relation of the surface water temperature (Fig. 1).

In determining the conditions of thermal stratification, the values of the surface water temperature measured at Hanhinpasi Island were adopted, since in the groups of thermal stratification considered the limits were chosen broadly and conventionally.

Table 1 gives the mean wind speeds along the vertical profile for three groups by wind direction and for four groups of speed values at a height of 0.75 m: group I—up to 2.1 m/sec; group II—from 2.1 to 3.9 m/sec; group III—from 4.0 to 5.9 m/sec; group IV—more than 6.0 m/sec. Averaging of the wind-speed profile with allowance for thermal stratification was carried out by groups: $\Delta T < 2^{\circ}$, $\Delta T > 4^{\circ}$, and $2^{\circ} < \Delta T < 4^{\circ}$, which correspond to equilibrium conditions, inversion conditions, and conditions intermediate between them.

The mean wind-speed profiles without allowance for thermal stratification are presented in Fig. 2 (V—wind speed, h—height). For all directions and wind-speed groups the distribution of speed satisfies the logarithmic law. However, the velocity gradient increases with increasing wind speed and assumes the smallest values in an air flow coming from the open water surface.

Table 1 gives the values of the roughness parameter z_0. In

Table 1

Mean wind speeds V along the vertical profile and values of the roughness parameter z_0 without allowance for thermal stratification and with allowance for it

Wind direction	Stratification	I group 6.15 m	I group 3.15 m	I group 1.65 m	I group 0.75 m	No. of measurements	Weighted mean z_0, cm	II group 6.15 m	II group 3.15 m	II group 1.65 m	II group 0.75 m	No. of measurements	Weighted mean z_0, cm	III group 6.15 m	III group 3.15 m	III group 1.65 m	III group 0.75 m	No. of measurements	Weighted mean z_0, cm	IV group 6.15 m	IV group 3.15 m	IV group 1.65 m	IV group 0.75 m	No. of measurements	Weighted mean z_0, cm
SE – SSE – S – SSW – SW	Without thermal stratification	2.6	2.1	1.8	1.6	31	1.66	4.0	3.4	3.1	2.7	64	0.66	6.7	5.9	5.4	4.8	17	0.32	7.7	7.2	6.7	6.0	1	0.04
SE – SSE – S – SSW – SW	$\Delta T < 2°$	2.1	1.8	1.8	1.5	7	0.46	3.4	3.2	3.1	2.7	29	0.06	5.8	5.4	5.2	4.5	14	0.06	7.7	7.2	6.7	6.0	1	0.05
SE – SSE – S – SSW – SW	$\Delta T > 4°$	–	–	–	–	–	–	4.8	4.1	3.8	3.0	3	–	7.4	6.4	5.7	5.0	4	–	–	–	–	–	–	–
SE – SSE – S – SSW – SW	$2° < \Delta T < 4°$	3.1	2.4	2.0	1.6	11	–	4.4	3.7	3.2	2.6	10	–	–	–	–	–	–	–	–	–	–	–	–	–

Wind direction	Stratification	I group 6.15 m	I group 3.15 m	I group 1.60 m	I group 0.75 m	No. of measurements	Weighted mean z_0, cm	II group 6.15 m	II group 3.15 m	II group 1.60 m	II group 0.75 m	No. of measurements	Weighted mean z_0, cm	III group 6.15 m	III group 3.15 m	III group 1.60 m	III group 0.75 m	No. of measurements	Weighted mean z_0, cm	IV group 6.15 m	IV group 3.15 m	IV group 1.60 m	IV group 0.75 m	No. of measurements	Weighted mean z_0, cm
WNW – ESE – E – ENE	Without thermal stratification	2.5	2.0	1.8	1.6	15	3.02	4.1	3.8	3.2	2.8	30	1.83	6.0	5.5	4.9	4.4	8	0.72	7.8	7.4	6.2	6.0	2	0.11
WNW – ESE – E – ENE	$\Delta T < 2°$	2.2	2.1	2.1	1.9	2	0.00	4.1	3.6	3.2	2.9	18	0.72	5.8	5.5	4.8	4.5	7	0.06	7.9	7.5	5.5	6.0	1	0.14
WNW – ESE – E – ENE	$\Delta T > 4°$	3.0	2.4	2.0	1.7	10	–	4.2	3.8	3.3	2.6	7	–	7.9	6.9	5.8	4.8	3	–	–	–	–	–	–	–
WNW – ESE – E – ENE	$2° < \Delta T < 4°$	2.5	2.0	1.7	1.4	4	–	4.2	3.4	2.9	2.5	13	–	6.0	5.5	5.2	4.6	3	–	–	–	–	–	–	–
NE – NNE – N – NNW – NW	Without thermal stratification	2.7	2.1	1.8	1.5	31	7.62	4.8	4.2	3.4	2.7	22	6.61	8.4	7.5	5.6	4.4	3	7.62	–	–	–	–	–	–

Figure 2

Figure 2: Figure 2

Wind direction	Stratification allowance	I group 6.15 m	I group 3.15 m	I group 1.60 m	I group 0.75 m	No. of measurements	Weighted mean z_0, cm	II group 6.15 m	II group 3.15 m	II group 1.60 m	II group 0.75 m	No. of measurements	Weighted mean z_0, cm	III group 6.15 m	III group 3.15 m	III group 1.60 m	III group 0.75 m	No. of measurements	Weighted mean z_0, cm	IV group 6.15 m	IV group 3.15 m	IV group 1.60 m	IV group 0.75 m	No. of measurements	Weighted mean z_0, cm
NE – NNE – N – NNW – NW	$\Delta T < 2°$	2.0	1.6	1.6	1.45		–	5.6	5.1	3.9	3.17		–	8.8	7.9	5.9	4.62		–	–	–	–	–	–	–
NE – NNE – N – NNW – NW	$\Delta T > 4°$	2.8	2.3	1.9	1.48		–	4.2	3.5	3.0	2.53		–	–	–	–	–	–	–	–	–	–	–	–	–
NE – NNE – N – NNW – NW	$2° < \Delta T < 4°$	2.8	2.1	1.9	1.57		–	4.6	3.8	3.2	2.78		–	7.7	6.8	5.1	4.01		–	–	–	–	–	–	–

Fig. 2. Mean wind-speed profiles without allowance for thermal stratification. *I, II, III, IV*—speed groups according to Table 1 (dashed line—extrapolation to $V = 0$)

at wind speeds above 4 m/sec (group III) for a water surface $z_0 = 3$ mm. When the air flow passes over an island, z_0 increases to ~ 7 cm, and for a flow passing parallel to the shoreline, $z_0 \approx 7$ mm.

Experimental materials have confirmed the substantial influence of thermal

Figure 3

Figure 3: Figure 3

stratification on the wind profile over a land surface, and at present it is generally accepted that in the near-surface layer of air the generalized power law of Lettau is satisfied. Observational materials over water surfaces, taking thermal stratification into account, are, as a rule, not analyzed. Meanwhile, over water surfaces in certain seasons significant contrasts between the temperature of the water surface and that of the air are observed; this was also the case over Lake Ladoga during the observation period.

In Fig. 3 the mean wind profiles at its different speeds are presented with allowance for thermal stratification. Thermal stratification, as is evident from Fig. 3, affects the wind profile. Under inversion

Fig. 3. Mean wind-speed profiles constructed with allowance for thermal stratification (1—equilibrium conditions, 2—inversion conditions, 3—extrapolation to $V = 0$); *I, II, III, IV*—speed groups according to Table 1

a deviation of the wind profile from the logarithmic law is observed in the direction of larger values of the wind-speed gradient in comparison with equilibrium conditions, when the logarithmic law is fulfilled rather strictly. The roughness parameter from wind-speed data, determined—

under equilibrium conditions, considerably smaller than that determined without taking thermal stratification into account. Its magnitude over the water surface, at the most common wind speeds, is less than 1 mm; moreover, a tendency is observed for z_0 to decrease as wind speed increases (Table 1). The data reported in the literature on this question are contradictory, which is apparently connected with the character of wave formation on the body of water, depending on the size of the latter.

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Received
16 VI 1960

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Note: Figure translations are in progress. See original paper for figures.