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Momentum and heat exchange in the lowest atmosphere layer at the Arctowski Station

ABSTRACT: An attempt was made to determine the vertical momentum and heat exchange in the near-ground atmosphere layer in the specific conditions of a sub-Antarctic island. For this purpose, some of the results of the measurements of temperature and wind speed carried out at the levels 10, 2, 0.5 and 0.05 m, during the IVth Antarctic Expedition of the Polish Academy of Sciences in March 1980, were used. The vertical gradients of the two elements and the wind stress and the heat flux in the layers under study, were calculated.

KEY WORDS: Antarctica, momentum and heat exchange, the Arctowski Station.

1. Introduction

The heat contained in the air passing over a sub-Antarctic island is to greatest extent due to advection only. The portion of heat contributed to the air by heating from the warmer surface of the island is negligible small, the reason for this being the comparatively small temperature contrast between the air and the island and the usually great speed of the flowing air. Nevertheless, some patches of the island being free of snow-cover undergo considerable warming under the incoming radiation during day. A consequence of this is the warming though poor from beneath of the overflowing air.

The aim of this experiment was to contribute to the knowledge on the local air-surface interaction in heat exchange in the air layers closest to the surface, on an island, rocky and ice-covered, as it is the case in the vicinity of the station Arctowski. This was achieved by means of gradient measurements of wind speed and air temperature.

2. Methods of data acquisition and calculation

In order to carry out the gradient measurements, a tubular mast, 10 m high, was set on a hill, 50 m high, about 500 m south of the

Station. On it, on the levels 10, 2 and 0.5 m, sensors of the air temperature and wind speed, were installed. Cable-transmitted signals were recorded by NSK-type recorders. The instantaneous values recorded were subsequently read out by an analog tape reader. The data readout frequency, the same for the two parameters and all the levels, was 3 min. Only a short, i.e. 8.5-hour, period of the measurements carried out on 16 March, 1980, between 12^{30} and 21^{00} local time (LMT), was chosen for the elaboration. Each of the levels and parameters was defined by 170 measurement quantities.

In order to calculate the wind stress and the heat flux in the atmospheric layer studied, the following formulae, commonly applied in the literature [3, 7, 9], were used:

$$\tau = C_\tau \varrho (u_2 - u_1)^2; \quad -H = C_H c_p \varrho (u_2 - u_1)(T_2 - T_1),$$

where u_1 and T_1 are the wind speed and the air temperature on the level z_1, u_2 and T_2 are the wind speed and the air temperature on the level z_2, ϱ is the air density, c_p is the specific heat of air at constant pressure, C_H and C_τ are the transport coefficients of heat and momentum, respectively.

According to Monin and Obukhov's theory [10], the transport coefficients of momentum, C_τ, and heat, C_H, exchange can be defined by means of the nondimensional universal function φ, from the dependence

$$C_\tau = C_H = \varphi^2 (Ri, \xi),$$

whereas the dynamic parameter ξ, necessary for the determination of the function φ, can be calculated from the formula

$$\xi = \frac{(u_2 - u_1)^2}{g (z_2 - z_1)},$$

where z_2 and z_1 are the heights of the measurements levels and g is the acceleration of gravity. The Richardson number, Ri, used in the calculations, characterizing the stability of the atmospheric layer, was assumed as

$$Ri = \frac{g (T_2 - T_1)(z_2 - z_1)}{\bar{T} (u_2 - u_1)^2},$$

where $\bar{T}$ is the mean temperature of the layer. Knowledge of ξ and Ri permits the coefficients C_τ and C_H to be determined from the tables of the universal function φ.

By using the values of the air temperature and wind speed measured on the levels $z = 10$ m, 2 m, and 0.5 m, calculations were carried out for two adjacent air layers: the first, 1.5 m thick, between the levels 0.5 and 2 m, and the other, 8 m thick, between the levels 10 and 2 m. For these layers, the instantaneous values of the heat flux H and the wind stress τ were calculated and, subsequently, averaged over half-hour intervals.

3. Meteorological conditions accompanying the measurements

The period during which the chosen gradient measurements were carried out, was characterized by low — except for wind speed — variability of all the most important meteorological elements.

Clouds, stratiform in the night and in the early morning, with a low ceiling and 7/8 of the sky covered by Stratus, changed in the early afternoon into varying ones. Cumuliform clouds Cu and Ac dominated, while their amount varied between 6/8 and 7/8. The ceiling also rose and visibility improved.

Air temperature varied only slightly. Extreme values measured that day in the meteorological screen were -0.4°C (minimum) and 2.1°C (maximum). Thus, the daily amplitude was only 2.5°C. The gross minimum was -1.8°C at 09^{00} and 0.4°C at 21^{00}. In turn, the soil temperature at depth of 5 cm varied between 1.5°C at 03^{00} LMT, through 1.2 and 4.3°C in the day, and 2.2°C at 21^{00}. Unfortunately, the temperature of the ground surface itself is not known.

At first, the wind was variable, both in terms of direction and speed; however, during the period analysed, it always retained the south-west directions characterized by high gustiness in the vicinity of the station. The speed increased from 4 ms^{-1} beetween 12^{00} and 15^{00} LMT to more than 11 ms^{-1} at about 21^{00} LMT.

Atmospheric pressure slowly increased in the morning and began to drop gradually in the afternoon. Daily variation did not exceed 3 hPa. In the afternoon, the humidity and water vapour pressure were also observed to decrease.

4. Anemothermal conditions in the near-ground air layer

The vertical temperature distribution, defined by the values measured on the levels 0.05 m, 0.5 m, 2 m and 10 m, was characterized by large variability on the lowest level, compared with the higher ones, where the time differentiation of this element was much less. At the surface, the temperature varied between 4.5°C in the morning and 1.3° C in the evening, whereas on the levels 2 m and 10 m it stayed between 1.3 and 2.5°C. On all the levels, the variations were quite similar: the successive minima and maxima occurred at alomost the same time. To some extent, this harmony was distorted only in the period of stronger night cooling of the layer nearest to ground. These relationships are illustrated in Fig. 1a, representing the variation of the half-hour averages of temperatures for each of the levels.

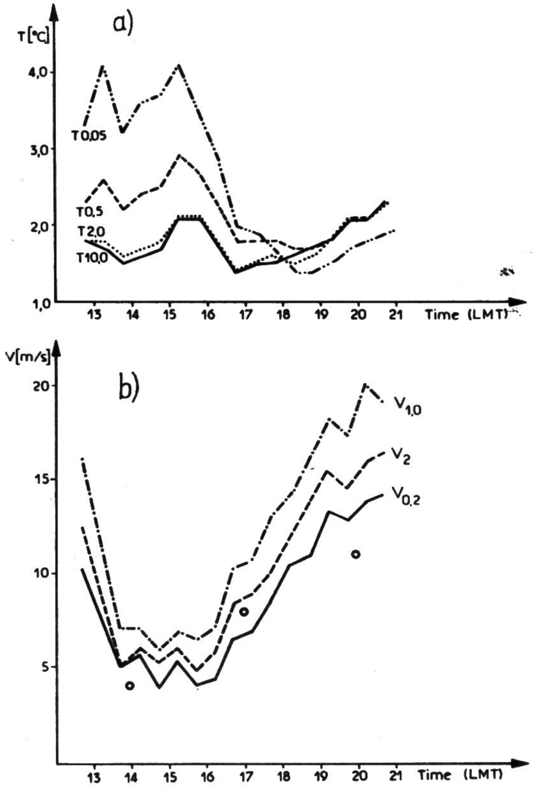

Fig. 1a. Variation of the air temperature on the levels 10 m, 2 m, 0.5 m and 0.05 m. Averaged over 30-minute intervals. 1b. Variation of the wind speed on the levels 10 m, 2 m and 0.5 m. Averaged over 30-minute intervals

The greatest differences resulting from the vertical distribution described above occurred between the levels 0.05, to 0.5 m and 0.5 to 2 m. They were about 1.5° C in the first of the layers and almost half as less in the other. In view of the different thicknesses of the layers, the differences were replaced by temperature gradient, calculated per 1 m of height.

In this approach, in the lowest 45-cm air layer one could observe, over the first afternoon hours, the highest gradient, exceeding 3° per 1m (Fig. 2a). In the adjacent layer, between 0.5 and 2 m, the gradient was already six times as less, with 0.5° C per 1 m, but it still continued to be highly superadiabatic. In the third, highest and thickest of the layers, the gradient was lower by a factor of a few hundred compared with the lowest layer, and, consequently, it should be considered as equal to zero and the layer as thermally homogeneous one. However, the calculations show distinct, though very low, positive gradients (negative differences from -0.011 to $-0.001°\,\mathrm{C\,m^{-1}}$) in the afternoon, and the negative ones (the values of the differences from 0.005 to $0.008°\,\mathrm{C\,m^{-1}}$) in the evening. Thus, it could be said that this layer is characterized in the first part of the period, by stability close to neutral, and, after 18^{00}, by stable equilibrium. The middle and lowest layers are initially unstable; in view, however, of the low thicknesses of these layers, the effect of their thermics on the intensity of exchange processes has very small vertical extent.

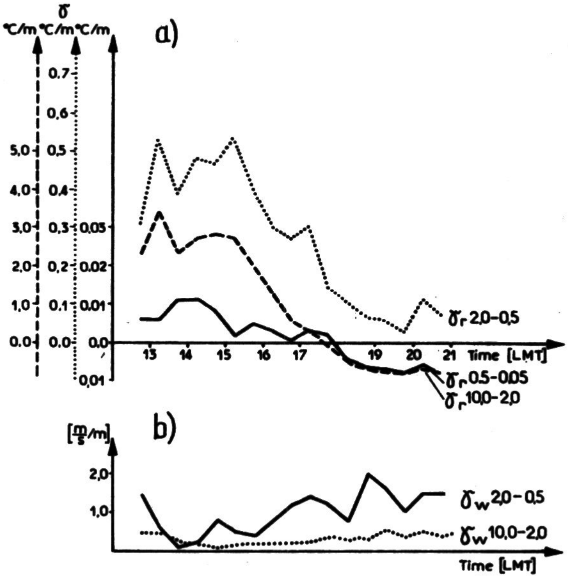

Fig. 2a. Variation of the temperature gradient γ_T between the levels considered. The variation curve and the respective vertical coordinate axes are drawn using the same type of line (solid, dashed and dotted line). 2b. Variation of the wind speed gradient γ_w between the levels considered

A change in the sign of the gradient, already mentioned when describing the top layer, is also observed in the lowest one, in a similar time, between 17^{00} and 18^{00} LMT; in the lower layer the gradient is, in terms of the absolute value, larger by a factor of about 100 than in the upper one. In the intermediate layer, between 0.5 and 2 m, the mean temperature gradient does not change in sign, but its values decrease towards the night almost tenfold. Thus, towards the end of the period the thermal stability of the whole layer up to 10 m is constant, with distinct inversion at the surface.

The gradient mast, set about 50 m higher than the Station, was differently exposed than the anemometer at the Station site. Therefore, the wind speed measured at the Station, as given in Section 2, was weaker than that registered on the gradient mast (Fig. 1b). The instantaneous gradient speeds varied greatly, as is illustrated by the rather large values of the standard deviation σ_u (Table I). The differences among the instantaneous speeds at the particular levels sometimes even changed in sign. However, after averaging over half-hour intervals, the wind speeds on all the levels appeared to be largely parallel (Fig. 1b). On the level 0.5 m the wind varied between 3.9 and 14.1 ms^{-1}, between 4.8 and 16.4 ms^{-1} on the level 2 m, and at 10 m its speed was the highest, varying between 5.9 ms^{-1} and 20.1 ms^{-1} (Table I).

The half-hour averages of wind speed gradients in two layers were calculated in a similar way. In the lower one, the variation of the gradient was not uniform, as quite large changes in its values were observed (Fig. 2b). The largest speed increment calculated per 1 m of height was 2 ms^{-1}, the lowest, in turn, was 0.1 ms^{-1}. Much more uniform variation of the average values of the wind gradient could be seen in the layer between 2 and 10 m, which is understandable, taking into account its thickness. The differences in the wind speed also calculated per 1 m did not usually exceed 0.5 ms^{-1}.

In the afternoon and night, in the both layers, it was possible to observe an increase in the gradient of wind speed as the latter increased, which was quite distinct between the levels 2 and 0.5 m and weaker between 10 and 2 m.

5. Wind stress τ

The process of momentum exchange, controlled by the vertical wind speed distribution described in Section 4, can be characterized by the wind stress τ. The values of τ calculated for the two adjacent layers, between 0.5 and 2 m, and between 2 and 10 m, were analysed. The calculations were carried out for each time point individually, obtaining

Table I

Dynamical characteristics of the air flow at the gradient mass on March 16, 1980

Time	$\bar{u}_{10}$	$\sigma_{u_{10}}$	$\bar{u}_2$	σ_{u_2}	$\bar{u}_{0.5}$	$\sigma_{u_{0.5}}$	$\overline{\Delta u}_{10-2}$	$\bar{\tau}_{10-2}$	$\tau_{\mathrm{extr.}} \cdot 10^4$	$\overline{\Delta u}_{2-0.5}$	$\bar{\tau}_{2-0.5} \cdot 10^4$	$\tau_{\mathrm{extr.}} \cdot 10^4$
12^{30}–13^{00}	16.2	1.7	12.5	1.6	10.3	1.7	3.7	119.4	300.8 6.5	2.2	91.7	269.9 5.6
13^{00}–13^{30}	11.7	1.0	8.4	1.8	7.5	1.5	3.3	105.4	253.8 0.9	0.8	34.0	247.9 0.0
13^{30}–14^{00}	7.1	1.1	5.0	1.1	5.0	1.1	2.0	31.4	66.6 0.2	0.1	22.9	92.0 0.1
14^{00}–14^{30}	7.1	0.9	6.1	0.7	5.7	0.8	1.1	7.3	41.4 0.0	0.4	17.1	56.7 0.0
14^{30}–15^{00}	5.9	1.4	5.2	1.6	3.9	1.9	0.8	3.7	19.1 0.0	1.1	23.3	100.0 0.5
15^{00}–15^{30}	6.8	2.4	6.0	1.9	5.3	2.5	1.0	6.2	20.5 0.0	0.7	18.7	92.1 0.0
15^{30}–16^{00}	6.5	1.1	4.8	1.2	4.0	1.3	1.5	37.1	168.2 0.0	0.6	25.2	154.9 0.0
16^{00}–16^{30}	7.1	1.5	5.7	1.1	4.3	1.3	1.4	22.1	72.5 0.0	1.3	22.8	89.6 0.0
16^{30}–17^{00}	10.3	2.1	8.4	1.9	6.7	1.2	1.7	59.6	179.2 0.0	1.8	44.8	112.9 0.0
17^{00}–17^{30}	10.7	1.8	8.9	2.1	6.9	1.5	1.8	33.6	145.4 0.4	2.1	89.4	306.5 0.0
17^{30}–18^{00}	13.0	1.8	10.0	1.8	8.4	1.7	2.7	38.1	180.0 0.0	1.7	22.1	69.3 0.7
18^{00}–18^{30}	14.1	1.8	11.9	2.2	10.4	1.1	2.3	29.4	95.4 0.1	1.3	58.8	283.4 2.9
18^{30}–19^{00}	16.1	3.5	13.6	2.9	10.8	2.5	2.4	56.1	245.3 13.5	2.9	138.4	305.9 0.3
19^{00}–19^{30}	18.3	2.6	15.5	2.2	13.3	1.5	2.8	84.8	291.4 0.0	2.3	68.2	222.0 0.1
19^{30}–20^{00}	17.4	2.0	14.4	1.3	12.8	1.8	2.8	37.0	84.5 11.0	1.5	63.1	205.4 0.0
20^{00}–20^{30}	20.0	1.2	15.9	1.1	13.8	1.5	3.9	117.5	229.8 30.1	2.2	78.6	185.8 1.2
20^{30}–21^{00}	19.1	1.9	16.4	1.6	14.1	1.7	2.9	40.5	139.6 0.1	2.2	86.3	305.6 0.1

Notation:

$\bar{u}_{10}, \bar{u}_2, \bar{u}_{0.5}$ — the mean wind speed, mps, averaged over 30-minute intervals, on the levels 10, 2 and 0.5 m, respectively;

$\sigma u_{10}, \sigma u_2, \sigma u_{0.5}$ — the standard deviation of the wind speed on the levels 10, 2 and 0.5 m, respectively, mps;

$\bar{\Delta} u_{10-2}, \bar{\Delta} u_{2-0.5}$ — the mean wind speed differences between the levels 10, 2 and 0.5 m, respectively, mps;

$\bar{\tau}_{10-2}, \bar{\tau}_{2-0.5}$ — the mean wind stress in the layers between 10, 2 and 0.5 m, respectively, Pa × 10^4;

$\tau_{\mathrm{extr}_{10-2}}, \tau_{\mathrm{extr}_{2-0.5}}$ — the extreme values of the wind stress in the adjacent layers, Pa × 10^4.

Table II

Characteristics of turbulent heat exchange

Time	$\bar{H}_{2-0.5}$	$\bar{H}_{\text{extr. }2-0.5}$	$\sigma_{H_{2-0.5}}$	$\overline{\Delta T}_{2-0.5}$	extr. Δu	$\bar{H}_{10-2}$	$H_{\text{extr. }10-2}$	$\sigma_{H_{10-2}}$	$\overline{\Delta T}_{10-2}$	extr. Δu
12^{30}–13^{00}	6464.3	21275.8	7026.2	−0.47	3.6	594.5	1325.4	477.9	−0.05	4.9
		1535.3			−1.1		88.8			1.4
13^{00}–13^{30}	4290.6	28052.2	8614.6	−0.79	3.5	247.2	1873.3	931.5	−0.05	4.7
		−930.6			−0.7		−395.2			1.3
13^{30}–14^{00}	−174.3	5260.8	3836.9	−0.59	2.1	380.7	879.3	390.3	−0.09	3.0
		−8195.2			−2.5		−158.3			0.6
14^{00}–14^{30}	1076.2	5586.7	3549.4	−0.72	2.1	77.6	164.6	115.4	−0.09	2.2
		−6340.3			−1.7		0.0			0.0
14^{30}–15^{00}	2501.7	8945.5	2969.8	−0.70	2.6	9.4	224.3	83.4	−0.06	2.0
		−1036.3			−0.7		−70.3			−1.5
15^{00}–15^{30}	3297.2	10724.6	4330.2	−0.80	2.5	−30.0	70.3	69.3	−0.01	2.0
		−1226.3			−0.7		−182.6			−0.3
15^{30}–16^{00}	1978.0	11214.3	3811.4	−0.60	3.0	171.3	1066.1	401.0	−0.04	4.0
		−944.3			−0.8		−182.3			−1.1
16^{00}–16^{30}	2056.3	6489.8	2081.5	−0.50	2.5	62.4	468.1	189.0	−0.02	3.0
		21.0			0.2		−175.1			−0.1
16^{30}–17^{00}	3368.1	9073.2	3071.8	−0.40	2.7	−82.5	269.8	171.1	−0.00	4.1
		−165.0			−0.5		−315.1			−1.4
17^{00}–17^{30}	2415.3	8760.6	2911.1	−0.30	3.8	230.3	623.8	248.7	−0.03	3.8
		−103.8			−0.5		−11.9			−1.2
17^{30}–18^{00}	914.6	2350.0	827.3	−0.21	2.3	72.4	267.0	116.6	−0.01	4.1
		103.8			0.5		−66.9			0.9
18^{00}–18^{30}	682.2	2797.7	1357.3	−0.15	3.7	−167.5	2.1	235.6	0.04	3.3
		−894.3			−1.9		−669.8			−0.8
18^{30}–19^{00}	1569.3	2915.2	1021.1	−0.10	3.8	−265.7	0.0	227.2	0.05	4.6
		27.5			0.4		−579.2			−0.1
19^{00}–19^{30}	606.4	2364.1	823.3	−0.08	3.4	−278.6	0.9	322.0	0.05	4.9
		0.0			0.3		−861.3			−0.1
19^{30}–20^{00}	128.5	853.5	320.0	−0.04	3.9	−354.4	0.0	279.7	0.06	3.2
		−173.2			−0.2		−767.4			0.7
20^{00}–20^{30}	791.9	1738.1	748.3	−0.17	3.2	−447.6	0.0	321.7	0.05	4.5
		−76.2			−0.9		−1030.5			2.3
20^{30}–21^{00}	109.2	2279.7	1337.6	−0.11	3.8	−107.0	1245.3	642.6	0.06	3.8
		−2605.6			−0.3		−1064.2			−0.3

Notation:

$\bar{H}_{2-0.5}$, $\bar{H}_{10-2}$ — the mean heat flux in the layers 2–0.5 m and 10–2 m, averaged over 30-minute intervals, $Jm^{-2}h^{-1}$;

$H_{\text{extr}_{2-0.5}}$, $H_{\text{extr}_{10-2}}$ — the extreme, out of ten values , heat flux in the layers 2–0.5 and 10 – 2 m, $Jm^{-2}h^{-1}$;

$\sigma H_{2-0.5}$, σH_{10-2} — the standard deviation of the heat flux in the layers considered, $Jm^{-2}h^{-1}$;

$T_{2-0.5}$, T_{10-2} — the mean temperature difference between the levels considered, °C;

extr $\Delta u_{2-0.5}$, extr Δu_{10-2} — the extreme, out of ten values of the wind speed differences between the levels considered, mps.

a very large scatter of the values of τ, resulting from the wide range of instantaneous wind speeds on the neighbouring levels. In order to characterize the variation of the momentum exchange, half-hour averages of τ were calculated for the two levels considered. They are given in Table I, which also shows the other flow characteristics on the particular levels. It can be noted that over the first one and half hours, when the air mass was presumably still stable and the air flow still laminar, the values of $\bar{\tau}$ were higher in the upper layer, exceeding there $100 \cdot 10^{-4}$ Pa (Table I). In those hours the weak winds dominated and wind speed differences between the levels were small and so was the momentum exchange between them. Simultaneously — in the quite early afternoon — the temperature gradient was, greater in the lower layer (Figs. 1a, b and 2a, b). Strong thermal activity caused stronger turbulence, which wasreflected in greater values of $\bar{\tau}$ compared with the upper one. In this period they varied from about 20×10^{-4} Pa between the levels 2 and 0.5 m to about 5×10^{-4} Pa between the levels 10 and 2 m.

With the instability of the air mass increasing in the next hours, there came an increase in the wind speed and gustiness and the already slight temperature differences between the layers considered vanished (with inversion occurring only in the lowest layer, where no wind measurements were carried out). The two layers were now equally favoured in terms of the intensity and character of the exchange. The variation of $\bar{\tau}$ in both of them was high, with values falling between about 20×10^{-4} Pa and about 140×10^{-4} Pa, the exchange being almost alternatively more intense in one or the other layer. The variation range of the instantaneous values of τ was also similar. In both layers, almost in each of the half-hour intervals, instantaneous τ was equal or close to zero, caused most often by the vanishing speed differences between the particular levels. The mean wind stress $\bar{\tau}$ calculated for the whole period of 17 half-hour intervals averaged between 10 and 2 m was 48.7×10^{-4} Pa, with the standard deviation $\sigma = 37{,}1 \times 10^{-4}$ Pa. Between the levels 2 and 0.5 m $\bar{\tau}$ was $53{,}3 \times 10^{-4}$ Pa, while its standard deviation σ was 35×10^{-4} Pa. The extreme values of $\bar{\tau}$ in the upper layer were $\bar{\tau}_{mx} = 119{,}4 \times 10^{-4}$ Pa and $\bar{\tau}_{mn} = 3{,}7 \times 10^{-4}$ Pa, while in the lower one $\bar{\tau}_{mx}$ was $138{,}4 \times 10^{-4}$ Pa and $\bar{\tau}_{mn}$ was $22{,}1 \times 10^{-4}$ Pa.

It can be seen from the data given above that the values of the wind stress in the two layers considered are similar, which would confirm the validity of the assumption of constant momentum flux throughout the lowest near-ground air layer several score cm thick, although there is difference of opinion about it among a number of authors [4, 5, 6]. However, the exchange analysed in this paper abstracts from this layer, which introduces the highest instability of momentum. This is the layer where a deciding effect is exerted by the speed jump on the very surface of contact between the soil and the atmosphere, i.e. at 0 m, where the wind speed is assumed as 0 m/s. On the basis of measurements carried out on one level only and assuming the above mentioned dynamic properties of the surface-atmosphere contact zone, other investigations, e.g. (2) have yielded similar values of momentum flux for the air layer between 0 and 10 m. This method, however, gave higher values of momentum flux when the winds were stronger.

6. Heat exchange

The two processes of turbulent heat and momentum transport are mutually related by strong interaction. Thus, the dynamic parameters discussed in the previous section are reflected in the heat transport.

Let us consider first the character of the heat exchange in the lower of the layers considered. During the first hour the average heat flux $\bar{H}$ was directed almost all the time from bottom to top, which was in agreement with the sign of the mean temperature difference $\bar{\Delta T}$ in this layer (Fig. 1a, Table II). The transported amount of heat varied depending on changes in the temperature and wind speed gradients. The largest amounts of heat, on average between more than 4000 and almost 6500 $\mathrm{Jm^{-2}h^{-1}}$ (Table II) were transported with a quite strong wind and relatively large temperature differences from 12^{30} to 13^{30}. The extreme values and the mean standard deviations given in Table II show a large scatter of the instantaneous fluxes forming the given mean $\bar{H}$. With decreasing absolute values of the mean temperature differences $\bar{\Delta T}$ (always positive) the mean fluxes $\bar{H}$ decrease gradually, although in a very nonuniform way, and remain positive to the end of the experiment, An exception is the mean flux from 13^{30} to 14^{00}, with the value $\bar{H} = 174.3$ $\mathrm{Jm^{-2}h^{-1}}$. The sign is here determined by the negative speed difference at the time of a few instantaneous measurements, and not by an inversion of the sign of the difference $\bar{\Delta T}$. Anyway, negative speed differences occurred in almost all the averaging periods (Table II). Throughout the period, in the layer between 2 and 0.5 m, the mean heat flux $\bar{H}$ was 1886.8 $\mathrm{Jm^{-2}h^{-1}}$, with the mean standard deviation $\sigma = 1733.9$ $\mathrm{Jm^{-2}h^{-1}}$.

There was different heat exchange in the upper (and thicker) layer, between 2 and 10 m, in view of a slightly different thermal and dynamic regime occurring there (Fig. 2, Tables I, II). In the first two hours, only positive speed differences occurred. With negative instantaneous ΔT dominating, this gave a positive upward-directed heat flux $\bar{H}$, with values falling between almost 600 and slightly less than 80 $\mathrm{Jm^{-2}h^{-1}}$. It decreased as the wind speed dropped. The period of weaker winds from 14^{30} to 18^{00}

was already characterized by more frequent inversion of the sign of the speed difference, still, however, with constantly negative $\bar{\Delta T}$. The heat fluxes $\bar{H}$ changed their sign a few times during this period. Whereas at 18^{00} ΔT took only positive values, with sporadically occurring nonnegative instantaneous Δu, with usually low absolute values, the heat flux changed its sign, keeping between -450 and -100 Jm^{-2}h^{-1}. In this layer, the mean heat flux for the whole period reached only 2.2 Jm^{-2}h^{-1}, but its mean standard deviation σ was 268.1 Jm^{-2}h^{-1}.

The analysis was carried out on the results gained in the conditions of strong turbulence, indicating high variation of the instantaneous heat fluxes, both in terms of magnitude and direction. The two layers considered differed greatly in the character of the exchange. Between 0.5 and 2 m there was much higher and less ordered — compared with the upper layer — variation of the instantaneous quantities; in the effect, the resultant heat flux was directed upwards. The layer between 2 and 10 m was characterized by a change in the sign of the temperature gradient in the other half of the period. This caused a change in the direction of the heat flux. As a result, in this layer, the resultant flux for the whole period was close to zero, althout its instantaneous values were quite large in terms of modulus.

A. N. Artemev [1] gave the mean intensity of turbulent heat exchange in the layer between 2 and 0.5 m at the Russian Antarctic Station "Vostok". It is difficult to compare the strongly turbulent conditions of the chosen case from the Arctowski Station with the mean values for the "Vostok". When it is considered that both the wind speed differences and the temperature differences at the limits of the layer given by Artemev are much lower at the station "Vostok" than in the considered case from the Arctowski Station, then comparable values are obtained.

Vugts and Businger's opinion [8] confirms the conclusion that the morphometry of the island and the measurements point itself has a deciding effect on the character and, accordingly, the magnitude of the exchange.

7. Conclusions

The selected part of the measurements involved the average conditions of the decline of the sub-Antarctic summer and a warmer time of the day. Thus, an attempt can be made to answer the question as to whether the air flow over the island can cause its noticeable heating and, as a consequence, an increase in the exchange. The analysis performed justifies the following conclusions:

— despite the fact that the lowest layers heat relatively weakly, in view of the usually low insolation and considerable flow turbulence, it is possible to discern up to 10 m a distinct thermal stratification with the temperature gradients between the levels 0.05 and 0.5 m greater by a factor of more than a hundred than those between the levels 2 and 10 m;

— in view, however, of the weak heating of the lower, layers the hest exchange is weak, while the exchange processes are mainly controlled by strong mechanical turbulence of the flow;

— relatively large amounts of heat are transported upwards from the layer between 0.5 and 2 m;

— despite the quite intense upward heat transport in the warmer part of the period, in the layer between 2 and 10 m there is a change, in the direction of exchange, in the colder part of the day, so that the net flux becomes close to zero;

— despite the large difference in the instantaneous wind stress values between the levels, the momentum flux for the whole period is approximately constant up to 10 m.

8. Резюме

В ближайшем окружении станции „Арцтовски", для которого характера очень высокая турбулентность течения воздуха, проведены грандиентные измерения с целью изучения ее динамических и термических характеристик. На основании результатов измерения температуры воздуха проведенные на четырех уровнях (10, 2, 0,5 м, 0,05 м) и ветра на трех уровнях (10,2 и 0,5 м) были высчитаны градиенты этих величин, их ход во времени и вертикальные потоки тепла, а также касательное напряжение ветра. Установлена определенная термическая стратификация воздуха до высоты 10 м при сравнительно небольшом однако нагревании слоев даже самых близких подстилающей подверхности. При слабом термическом импульсе процессы обмена происходили главным образом благодаря сильной механической турбулентности течения. В результате крупных колебаний разницы скоростей между отдельными уровнями наблюдался очень большой диапазон моментных величин касательного напряжения, от около 300.10^{-4} до О Ра. Однако в течение всего периода наблюдений средний поток количества движения до высоты 10 м был приблизительно одинаков и составлял около 50.10^{-4} Ра. Из слов между 0,5 и 2 м значительное количество тепла уходило вверх, в среднем около 1900 $J.m^{-2}h^{-1}$, но в слое между 2 и 10 м, где менялся знак градиента температуры, поток тепла нетто был близок нулю.

9. Streszczenie

W najbliższym otoczeniu stacji "Arctowski", charakteryzującym się bardzo dużą burzliwością przepływu, dokonano pomiarów gradientowych w celu zbadania dynamicznych

i termicznych charakterystyk turbulencji. Na podstawie wyników pomiarów temperatury powietrza, wykonanych na 4 poziomach (10, 2, 0.5 i 0.05 m) oraz wiatru na trzech poziomach (10, 2 i 0.5 m) obliczono gradienty tych wielkości, ich przebieg w czasie oraz pionowe strumienie ciepła i naprężenie styczne wiatru. Stwierdzono wyraźną stratyfikację termiczną powietrza do wysokości 10 m, przy stosunkowo jednak niewielkim nagrzewaniu się warstw najbliższych podłożu. Przy słabym impulsie termicznym procesy wymiany przebiegały głównie za sprawą silnej turbulencji mechanicznej przepływu. Na skutek dużych wahań różnic prędkości między poszczególnymi poziomami występowała bardzo duża rozpiętość chwilowych wartości naprężenia stycznego, od około $300 \cdot 10^{-4}$ do 0 Pa. Jednak za cały okres pomiarów średni strumień pędu do wysokości 10 m był w przybliżeniu stały i wynosił około $50 \cdot 10^{-4}$ Pa. Z warstwy między 0.5 i 2 m dosyć znaczne ilości ciepła odprowadzane były ku górze, średnio około 1900 $\mathrm{Jm}^{-2}\mathrm{h}^{-1}$, ale w warstwie między 2 i 10 m, charakteryzującej się zmianą znaku gradientu temperatury strumień ciepła netto był bliski zeru.

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