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# Wind structure at the Arctowski Station

ABSTRACT: On the basis of 35 one-hour series of the measurement of the wind velocity, read out every two minutes, the wind structure at the Arctowski Station, situated on Admiralty Bay, King George Island, was analysed. Very strong turbulence was found with air flow directions from over the area of the Island (S, SW, W and NW) and laminarity with directions from SE, E, NE and partly N, i.e. when the air flows from Admiralty Bay or from over the open waters of Bransfield Strait. The qustiness coefficient, the relationship between the maximum and mean velocities and the intensity of turbulence were determined for the two flow types. Two extremely different cases, in terms of flow character, were considered, by determining for them the distributions of instantaneous velocities and those of oscillations.

Key words: Antarctic Continent, wind structure

## 1. Introduction

The wind as a weather phenomenon at the Arctowski Station causes great interest, particularly in view of the high values of oscilations — gustiness. The main reasons for this extremely strong gustiness should be looked for in the peculari situation of the place where the station is localized (Fig. 1). The station stands on a flat promontory 3 m over the mean sea level, projecting into Admiralty Bay. From the west, in the closest vicinity, there is a very steep hill, Point Thomas, 174 m above sea level; behind it, there is Ezcurra Fiord separating the station from the major part of the Island, which is covered by a glacier. The glacier domes exceed 650 m above sea level. From the south there are also a rather high hill and a glacier. With air flow from these directions, the air subsides from the surrounding elevations and flows round the peaks. As a result, one can observe the development of strong wind gustiness

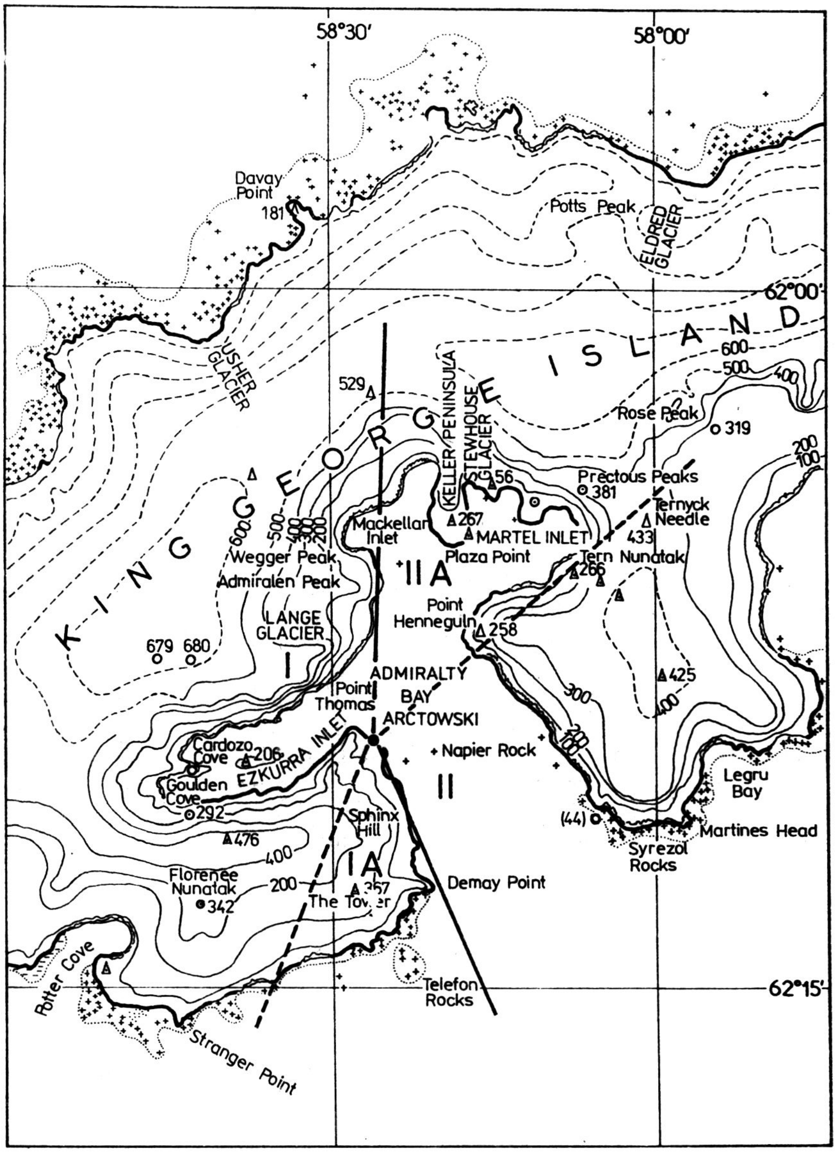


Fig. 1. The surroundings of the Arctowski Station. Arcs denote the sectors of air flows: strongly turbulent (I) and moderately turbulent (IA); laminar (II) and moderately laminar (IIA)

and large velocity differentiation, depending on the measurement point (Kowalewski, Wielbińska, 1982).

From the north and east the station is enclosed by the waters of Admiralty Bay (about 10 km wide), open from the southeast to Bransfield Strait. The winds blowing from this sector do not come across terrain barriers and indicate no turbulence. In the direction north of the station, the Bay is more articulated and, at a distance of about 10 km, it is enclosed by a glacier massif exceeding 500 m above sea level in height. In this direction low-gustiness winds dominate, however, sometimes the turbulent motions do not decay during their flow over the waters of the Bay.

The strong wind gustiness on the Sub-Antarctic islands is an essential problem, above all for building and the increasingly developing polar aviation.

The purpose of the present elaboration is to explain some relationships of the air flow in the real conditions of the Arctowski Station.

## 2. Short characteristic of the wind at the Arctowski Station in 1981

It follows from comparison with the observations made by previous expeditions that the year 1981 was average in terms of wind velocities and direction, and thus it can be recognized as representative in determining the characteristics of the wind at the Arctowski Station (Klimkiewicz and Kowalski, 1982, Meteorological Yearbook Arctowski 1978 and 1979, Nowosielski 1980, Meteorological Yearbook Arctowski (in Polish), 1980).

The annual mean wind velocity in 1981 was 6.4 m/s the lowest monthly mean came in March, 5.5 m/s, and the highest one in November, 8.2 m/s. The daily mean, exceeding 10 m/s, occurred from 14 days in March to 24 days in November. The maximum number of days when the wind speed exceeded 20 m/s also occurred in November, i.e. 9 days. Mean velocities over 30 m/s were recorded in October and December. Gusts exceeding 20 m/s occurred throughout the year. The number of days with gusts over 20 m/s varied from 3 days in January to 16 days in November. Gusts exceeding 50 m/s came in the spring season and the early summer: in September, October, November and December. The maximum wind gust of 62 m/s was recorded on 10 December.

Throughout the year, particularly in spring and autumn, the southwest direction dominated. In summer and winter the proportion of all the directions was rather uniform with the northeast prevailing slightly in summer. The highest wind velocities, particularly from October to December, were observed from the southwest to northeast directions. A detailed eleboration of the anemometric data for 1981, from which the present values were drawn, was given by Klimkiewicz and Kowalski (1982).

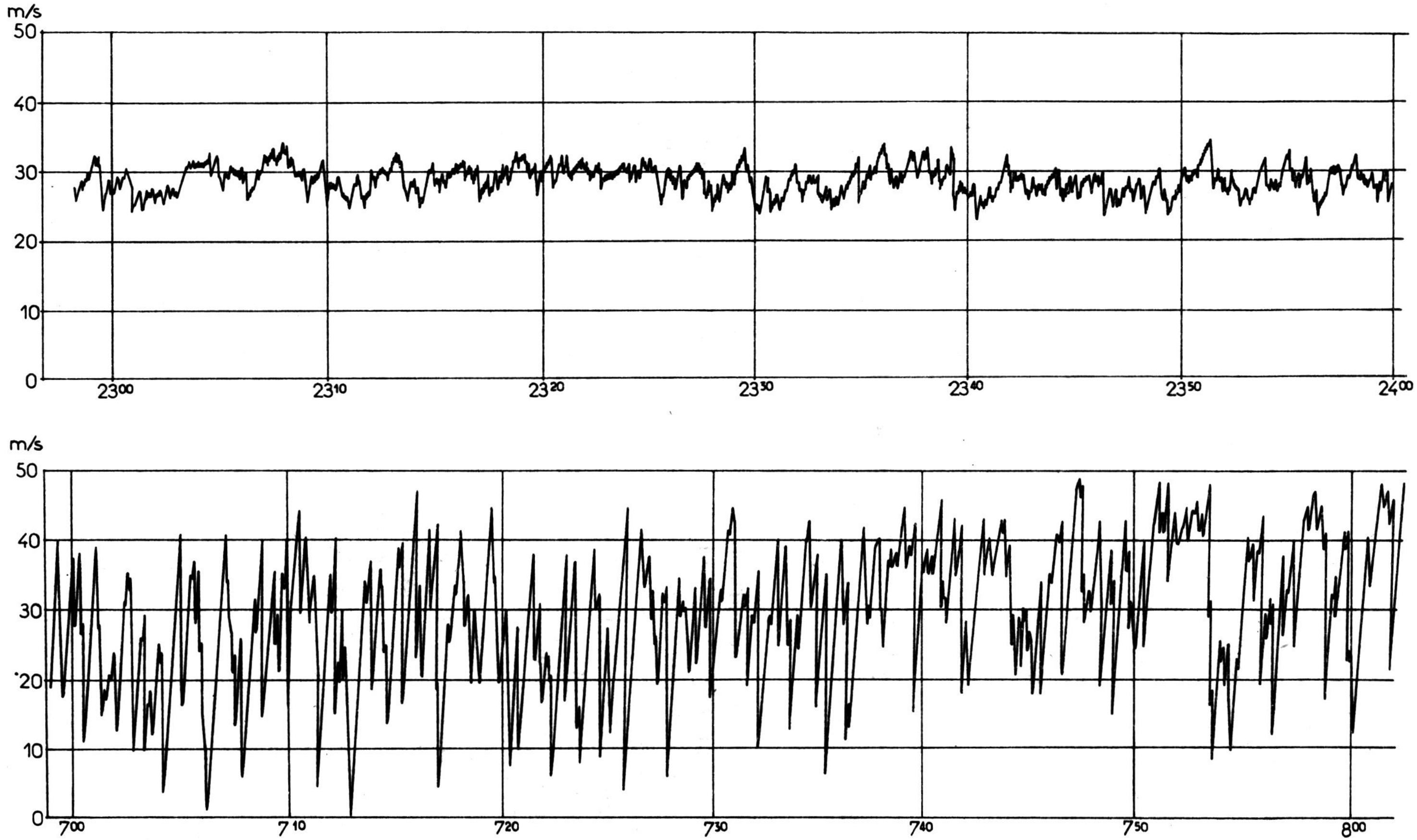


Fig. 2. Records of the wind velocities in two cases of extremely different flow character: a — laminar, on 11 July, 1981, b — turbulent, on 27 November, 1981.

# 3. Properties of gustiness

## 3.1. Properties of gusts — coefficient of gustiness

The simplest measure describing the wind structure (Davenport 1961, 1973, Harris 1971, Żurański 1978) is the coefficient of gustiness x:

$$x = \frac{v_{max}}{\bar{v}}$$

This is the ratio of the instantaneous maximum to the mean, velocity in some interval and it characterizes the velocity variations. The values of the coefficients were determined from the whole of the material analysed (35 one-hour periods), with division into turbulent flow (18 periods) and laminar flow (17 periods). Over those ene-hour intervals two-minute mean speeds were found and compared to maximal speed in these two minutes. (Figs. 3 and 4).

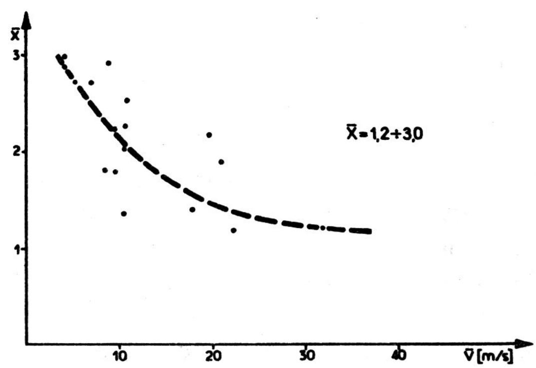


Fig. 3. The dependence of the coefficient of gustiness $\bar{x} = v_{max}/\bar{v}$ on the mean velocity $\bar{v}$ with air flow from the south, southwest, west and north

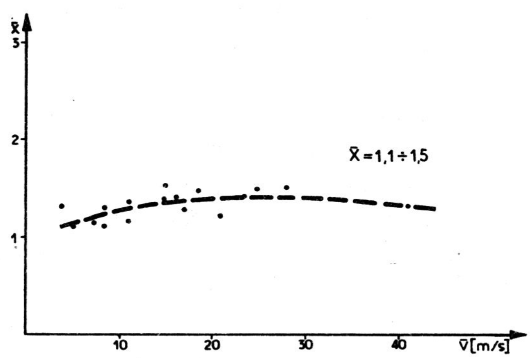


Fig. 4. The dependence of the coefficient of gustiness $\bar{x} = v_{max}/\bar{v}$ on the mean velocity. with air flow from the southeast, east, northeast and north.

The oscillations of the instantaneous velocity appeared to be distinctly different in the air flows from over the Island and from over Bransfield Strait. With turbulent air flow, the coefficient of gustiness varies from 3.0 for low mean velocities to 1.3 for mean velocities exceeding 30 m/s. With laminar flow from over the Strait, the coefficient of gustiness keeps at almost the same level at different mean velocities, from 1.1 to 1.5, which signifies that the maximum velocity oscillations represent the same ratio to the mean velocities.

A detailed analysis of the coefficient of gustiness, on the basis of the series of 27 November, 1981, with air flow from the west and unstable balance confirms the results obtained from the mean values: x varied from 2.6 for $\bar{v} = 12$ m/s to 1.5 for $\bar{v} = 27$ m/s, and was 1.99 on average for the whole period. With air flow from the southeast and stable balance, on 11 November, 1981, the coefficient of gustiness varied only between 1.1 and 1.3 with the mean value of 1.15.

## 3.2. Relationships between maximum and mean velocities.

In complementing the information on the wind structure at the station, resulting from an analysis of coefficients of gustiness, the relationship between the instantaneous maximum value to the mean one was determined (Fig. 5), where the instantaneous maximum value is understood to be the maximum velocity over a two-minute period.

The relationship is distinctly linear and, moreover, the two straight lines are parallel to each other (which is probably accidental) and can be expressed for laminar flow by an expression in the form $v_{max\ lam} = 1.3\,\bar{v} + 1.5$, whereas for turbulent flow the equation is $\bar{v}_{max\ turb} = 1.3\,\bar{v} + 8.8$. It should be noted, however, that with turbulent air flow a rather considerable scatter of results occurred. It follows from the course of the function that the differences between the instantaneous value $v_{max}$ and the mean value (in the interval analysed) increase as the velocity increases. With the wind blowing from over Bransfield Strait, they are on averege less by 7.3 m/s than with the wind coming in from over the Island.

A slightly different behaviour of this relationship occurred for analysis of the wind from chosen hourly periods on 27 November, 1981, and on 11 July, 1981. The equations of the respective straight lines have the form:

$$\bar{v}_{max\ turb} = 1.4\,\bar{v} + 10.8 \text{ for turbulent flow}$$

$$\bar{v}_{max\ lam} = 1.15\,\bar{v} + 0.2 \text{ for laminar flow}$$

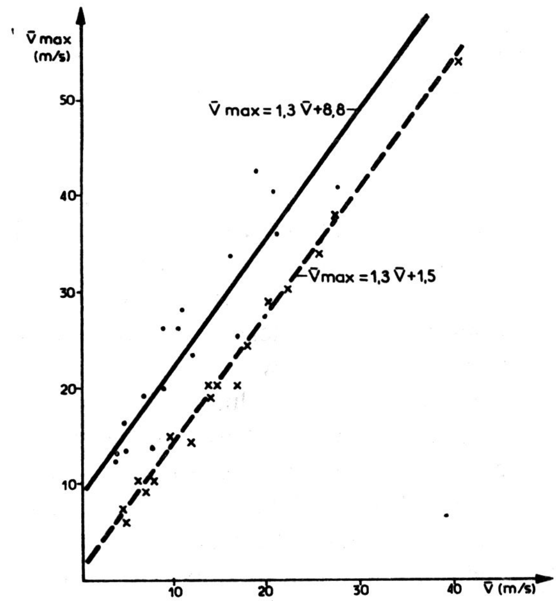


Fig. 5. The realtionship between the maximum, $v_{max}$, and mean, $\bar{v}$, velocities, calculated on the basis of two-minute periods from 35 one-hour observation series: a — air flow from the south to the northwest directions (turbulent) on 27 November, 1981; b — air flow from the southeast to the north directions (laminar) on 11 July, 1981.

The increments of the mean instantaneous velocity of the wind, with increasing mean velocity, were in the chosen periods much greater for the wind blowing from over the Island than from over Bransfield Strait.

### 3.3 Intensity of turbulence

The essential measure of the intensity of turbulence I is the ratio between the standard deviation of the instantaneous velocity and the mean velocity (Anapolska and Gandin 1958, Davenport 1963, 1973, Harris 1971, Sherlock 1958, Żurański 1978). Respectively, for the particular components:

$$I_x = \frac{d_v}{\bar{v}} \quad ; \quad I_y = \frac{d_u}{\bar{u}} \quad ; \quad I_z = \frac{d_w}{\bar{w}}$$

The (standard) cup anemometer by means of which the measurement was carried out, measures the resulting horizontal speed with the components $\bar{v} + \bar{u}$, and, is insensitive to changes in the wind direction in the vertical plane, i.e. to w. The measured velocity is the resultant $v_t$ at a given place (x,y,z). When it is assumed further, as is usually the case, that the component $\bar{v}$ is directed according to the wind direction, and the component $\bar{u}$ is perpendicular to it, the resultant velocity $v_t$ can be identified with the direction over a given averaging interval, i.e. $\bar{v}$. Hence, the intensity of turbulence at the measurement point will be

$$I = \frac{d_v}{\bar{v}}$$

In view of this, it was assumed that the wind velocity consists of a mean value and fluctuations, with the latter occurring only in the direction coinciding with the mean wind direction (over the averaging period considered).

To determine the intensity of turbulence, two periods with very close mean wind velocities (abount 20 m/s), with a stationary (over the period analysed) synoptic situation and with an almost constant pressure gradient, were chosen. A property distinguishing between the two cases was the direction of air flow over the Arctowski Station, and the related characteristics of laminarity or turbulence. The wind velocities were read out every 12 s from records for one-hour periods with air flow from over the Island and from over Bransfield Strait, achieving as the basis for calculations 300 readouts of instantaneous values apiece, separately for turbulent and laminar air flows (Fig. 2a and b). Even comparison of the two figures gives an idea of the differences in the character of air motion between the two cases. Numerical analysis permits these differences to be represented quantitatively. Thus, when for the wind blowing from over the area of the Island the standard deviation of instantaneous velocities was $d_v = 10.72$ the intensity of turbulence was very high, $I = 0.52$. For the wind direction from over the Strait, the standard deviation was $d_v = 2.45$ and the intensity was of turbulence $I = 0.11$.

The periods analysed are typical of air flow from over these two sectors the Strait and the Island acting aerodynamically sodifferently. The results obtained indicate a very strong development of turbulence with the wind directions from over the Island, with strongly developed orography, rich configuration, numerous narrowings, steep glacier drops, numerous nunataks and the main massif of the Island, where relative elevations reach 200 m over short horizontal distances. The cause of the strong turbulence — high velocity oscillations — is the mechanical mixing of flowing air streams, forced mainly by terrain barriers of the type mentioned, and to lesser extent by convection motions.

When encountering terrain barriers, air streams break into volumes with different values of energy and momentum. These different volumes, so-called turbulence elements, retain over some time their individual properties. At a large number of permanent terrain points, velocity oscillations and direction changes specific of these points can be observed. The results presented here are certainly characteristic of the measurement point, i.e. the meteorological station.

## 4. Frequency distributions

### 4.1 Characteristic of the instantaneous wind velocities for different flow types

As was mentioned in Chapter 1, the two periods of the strong wind considered in detail had very close mean velocities, exceeding slightly 20 m/s. They were, however, very different in terms of the instantaneous velocities, whose scatter was slight for laminar flow and very large for the highly turbulent air flow from the over Island. In order to determine these differences qualitatively, the distributions of instantaneous velocities were plotted for the two periods (Fig. 6 and 7) and the distribution parameters were determined. For the wind blowing from over the Island the range of variability was $R = 50$ m/s with the coefficient of variability $z = 52.31$ ($d_v = 10.72$, $v = 20.49$). At the same time, there is distinct right-handed asymmetry — the third moment $m = 654.56$. Velocities higher than the mean occur less frequently than those lower than it.

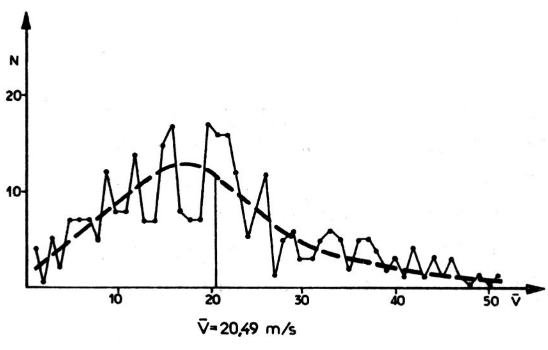


Fig. 6. The distribution of instantaneous wind velocities — read out every 12 s from a one-hour period on 27 November, 1981 — turbulent air flow.

A completely different character is exhibited by the distribution of instantaneous velocities of the wind for the air flow from over the Bay. The very low variability of instantaneous values gives $R = 11$ m/s and $z = 11.50$. The asymetry is slight: $m = 2.3$, $d_v = 2.45$ and $v = 21.31$ m/s.

### 4.2 Characteristic of the velocity oscillations

In characterizing instantaneous changes in the wind velocity — oscillation energy — use was also made of a one-hour section of the series of data recorded on 27 November, 1981 (Table 1). From the velocity behaviour

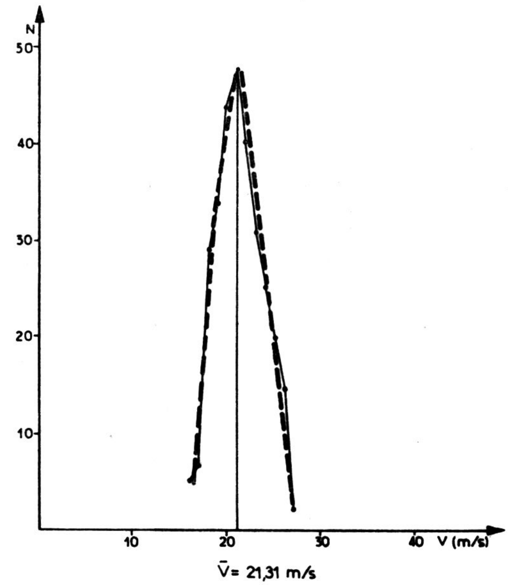


Fig. 7. The distribution of instantaneous wind velocities — read out every 12 s from a one-hour period on 11 July, 1981 — laminar air flow.

recorded, instantaneous changes exceeding 4 m/s ($d_v \geqslant 5$ m/s) were read out. Instantaneous changes are understood here to be rapid increments or drops in velocity, lasting only a few seconds, over which the plotter of the recorder takes a jump from one position to another, and then rapidly changes its direction of motion. In the period analysed, 233 oscillation changes in the wind velocity were distinguished. They are listed in Table 1.

Table 1

The frequency of wind oscillations with a given value for turbulent air flow on 27 November, 1981

| ΔV | Increment of instantaneous velocities Δv, m/s | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | 5—9 | 10—14 | 15—19 | 20—24 | 25—29 | 30—34 | 35—39 | 40—44 | |
| n | 62 | 61 | 36 | 30 | 25 | 13 | 14 | 2 | 233 |
| % | 27 | 26 | 15 | 13 | 10 | 6 | 2 | 1 | 100 |

In this period chosen as an example of the wind blowing from over the Island, highly turbulent, with the mean velocity of about 20 m/s and the distribution of instantaneous velocities discussed in Chapter 4.1, oscillations up to 14 m/s distinctly dominate, and changes exceeding even 40 m/s occur sporadically. The distribution indicates very high oscillation energy.

## 5. Summary of results

The analysis carried out permits the following conclusions to be drawn:

— Two sectors can be distinguished, the wind blowing from which, even at similar mean velocities, gives different dynamical effects:

a. With winds blowing from the south, southeast, west and northwest, the air streams flowing over the area of King George Island, with its strongly developed orography, undergo turbulent perturbations, which are expressed by very strong wind gustiness. The mean value of gusts can reach a value three times as much as the mean one. With high mean velocities, the mean value of gusts decreases. There is a very large scatter of instantaneous velocities. Their absolute values increase as the mean values increase. Values of the intensity of turbulence are several times as high as the calculated extremes for Warsaw, which, according to Żurański (1978), are $I = 0.19$.

b. The wind blowing towards the station from over Admiralty Bay and Bransfield Strait, i.e. from the southeast, east, northeast and north, has a structure similar to that of the winds blowing over the open sea. It is characterised by low gustiness and weak development of turbulence.

— The wind structure at the Arctowski Station is to a deciding extent determined by the orography.

— On all the coasts of King George Island (and the other islands of the Sub-Antarctic Archipelagoes), the sectors of turbulent and laminar air flows will depend on the exposition of these shores.

The present form of this elaboration is a result of considerable assistance, a large number of valuable suggestions, advice and complementations from the head of the Polar Department of the Institute of Meteorology and Water Management in Gdynia, Mrs. D. Wielbińska, and her collaborators, in particular Mrs. E. Skrzypczak I should like to thank them very much here. Also, I am grateful to the head of the 5th Expedition to the Arctowski Station, Mr L. Rościszewski, who encouraged this study and showed large interest in it.

## 6. Резюме

В результате анализа ветров на станции „Арцтовски", основанного на богатом материале, собранном в 1981 году, была выявлена характерная структура течения воздуха, зависящая прежде всего от направления. Итак при ветрах дующих с Ю, ЮЗ, З, СЗ потоки воздуха, проходящие над территорией острова Кинг Джордж¸ с богатой орографией и сложной береговой линией, подвержены турбулентным деформациям, выражающимся очень сильной порывистостью ветра. При средней скорости $\bar{v} = 10$ м/сек, средняя величина порывов может достигать величины в три раза болшей чем средняя

скорость: при больших средних скоростях, например $\bar{v} = 20$ м/сек средняя величина порывов достигает около 1,3 средней скорости. В период, являющийся основой исследований, проявлялись чаще всего пульсации до 14 м/сек, иногда достигали даже больше 40 м/сек. Границы изменений моментных скоростей были очень велики (до 50 м/сек). Величина моментных скоростей росла вместе с увеличением средних скоростей. Турбулентное течение отличалось исключительно большим напряжением турбулентности I = 0,52.

Контрастным в отношении структуры было течение с открытой со стороны залива Адмиралиции и пролива Брансфильда, т.е. с ЮВ, В, СВ и частично С. Течение отличалось небольшой порывистостью — коэффициенты порывистости составляли от 1,1 до 1,5, развитие турбулентности было слабым и выражалось I = 0,11. Можно сказать, что ветер, дующий на станцию из этого сектора отличается структурой похожей на ветер, дующий над открытой поверхностью моря.

# 7. Streszczenie

Na podstawie przeprowadzonej analizy wiatrów na stancji Arctowski, opartej na obszernym materiale z roku 1981, stwierdzono charakterystyczną strukturę przepływu powietrza, zależną przede wszystkim od kierunku. I tak przy wietrze wiejącym z kierunków S, SW, W, NW, strugi powietrza przepływające nad obszarem Wyspy King George o bogatej orografii i silnie rozwiniętej linii brzegowej ulegają zaburzeniom turbulencyjnym, których wyrazem jest bardzo silna porywistość wiatru. Przy prędkości średniej $\bar{v} = 10$ m/s, średnia wartość porywów może osiągnąć trzykrotną wartość prędkości średniej; przy większych prędkościach średnich, na przykład $\bar{v} = 20$ m/s średnia wartość porywów sięga około 1,3 prędkości średniej. W okresie stanowiącym podstawę badań przeważały pulsacje do 14 m/s, sporadycznie zaś sięgały nawet powyżej 40 m/s. Obszar zmienności prędkości chwilowych był bardzo duży (do 50 m/s). Wartość prędkości chwilowych wzrastała wraz ze wzrostem prędkości średnich. Przepływ turbulencyjny cechował się wyjątkowo dużym natężeniem turbulencji I = 0,52.

Kontrastowy pod względem struktury był przepływ od strony otwartej Zatoki Admiralicji i Cieśniny Bransfielda, a więc z kierunków SE, E, NE, i częściowo N. Cechowała go mała porywistość — współczynniki porywistości wynosiły od 1,1 do 1,5 i słaby rozwój turbulencji, wyrażający się przez I = 0,11. Można powiedzieć, że wiatr dochodzący na stację z tego sektora ma strukturę podobną do wiatru, wiejącego nad otwartą przestrzenią morską.

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