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Dynamics of sea-spray populations in the lower air layer — investigations during the 5th Antarctic Expedition to the H. Arctowski Station [1]

ABSTRACT: In the summer 1980-1981, in the Antarctic areas, in the coastal zone of Admiralty Bay (King George Island), complex measurements were carried out in order to investigate the proportion of wind gustiness in the processes generating marine spray systems and stimulating aerosol mass exchange between the sea and the atmosphere.

KEY WORDS: Antarctic, dynamics of marine spray wind gustines, H. Arctowski Station.

1. Introduction

The Fifth Antarctic Scientific Expedition of the Polish Academy of Sciences to the Arctowski Station on King George Island (South Shetlands, West Antarctic) came at the turn of two five-year research-organizational cycles in 1976-1980 and 1981-1985. Having gone through the period of preliminary reconnaissance of the natural environment in the chosen region of the Antarctic, it entered a subsequent stage. where it was decided to pay particular attention to the creation of more definite bases for the rational uses of the resources and the protection of this environment. Furthermore, it was realized that, in view of the extremely high variability of the aerodynamic characteristics and its wide scale in the Antarctic convergence zone, interesting opportunities arose for verifying and specifying the current theoretical and empirical schema related to the mechanisms of exchange and transport of mass and energy in the atmosphere-sea system. At the

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[1] The investigations were carried out within Project MR.I.15 and MR.I.29 coordinated by the Institute of Oceanology. Polish Academy of Sciences.

same time, there is an increasing need for explaining the effect of the peculiar conditions in this zone on the global climate characteristics, related to bilateral exchange of energy, humidity, pollution etc.

At the stage of the 5th Antarctic Expedition, research was carried out on one of the links of the general mass and energy exchange. This is the hydrosol-aerosol mass exchange occurring at these latitudes between the sea and the atmosphere. Accordingly, the objects of the research were to be peculiarities of the time-space wind structure in the lower air layer at the sea surface as a factor of the exchange and also its relationship with the micro-structural peculiarities of the suspension of maritime aerosols. Furthermore, main attention should be devoted, on the one hand, to measurements of wind characteristics, and, on the other, to parallel observations of the variability of the micro-structural characteristics of aerosol systems.

It follows from previous investigations [4, 7, 12] that, on average, over the Antarctic waters one should expect the occurrence of the highest, on the Earth, intensities of sea spray fluxes emitted from the surface of the sea. In fact, the present investigations found, at the Arctowski Station, the occurrence of very high concentrations of marine particles (with diameters below 5 μm) even for low wind speeds (up to 5 ms^{-1}). It can be expected that in the Antarctic conditions, the emission of drops from the sea, caused by air bubbles breaking on the sea surface, is intensified by the large oxygen amounts in these waters. In the present paper, this thesis is confirmed by the simultaneous control measurements of the amount of oxygen in the surface layer of the sea, for it was found that the state of oversaturation of the water by this gas is a frequent phenomenon in the waters of Admiralty Bay. Besides, the intensive emission is related to peculiar aerohydrodynamic characteristics, in particular to those of increased wind gustiness in these Antarctic regions occurring on the convection scale in the form of gustiness typical of squalls. In view of this, the study of the significance of wind gustiness for the processes generating marine spray systems and the related aerosol mass exchange, including that of humidity and heat, was a special problem for the research group engaged in it.

Admiralty Bay, elongated in the meridional direction (62°, 1 - 62°, 3 S; 58°, 3 - 58°, 4 W), on which the Arctowski Station is situated, has the nature of an articulated fjord with a wide mouth from the southeast to the ocean (through Bransfield Strait). The bay has the surface area of 131 km^2 and is, on average, several score *m* deep, with a maximum depth of 530 m. From the other three sides, it is surrounded by the shores of King George Island, whose highest elevation is 675 m over the sea level. This a typical Antarctic water region, affected by intensive atmospheric low circulation related to the Polar convergence zone and, from the point of view of investigations of the properties of the Antarctic waters and the aerodynamical characteristics of exchange and transport, it can essentially be considered a natural model basin. In particular, the conditions of variability of the wind field on the convection scale, probably partly modified by the orography of the island surrounding the bay, permit the investigations of a number of parameters with essential significance (including the parameter z_0, the dynamic exchange factor ξ_0 etc.).

Below are discussed the theoretical assumptions and the program of such investigations, giving in an outline the basic data obtained in the course of its implementation. Furthermore, the preliminary results of measurements carried out during the Expedition were summed up. It should be pointed out that the performance of a large number of special measurements, related to wind gustiness and the accompanying variability of aerosol characteristics, required original methodology. This is understandable when it is considered that in these extremely difficult natural conditions, no measurements had been carried out with the purpose of investigating such problems. Although, there are known measurements of the aerosol concentrations over the oceanic Antarctic regions [10, 12], including the Antarctic continent [10], however, these investigations did not aim to explain the effect of the complex dynamics of the interaction between the atmosphere and the sea on the coloidal mass exchange and the accompanying processes of the evolution and transformation of the micro-structure of particle systems over the sea surface. The problems of this type were the objects of the present investigations.

2. Theoretical assumptions of the experiment

The thickness of the layer able to catch air in the layer at the sea surface is controlled by the parameters of atmospheric-marine turbulence and the sea surface undulation, where it changes under the effect of variations in the wind speed and turbulent mixing of surface waters. At the same time, there is a change in the velocity of the formation in this layer, of air bubbles, salt, emitters, which in the crest area, close to the breaking wind waves, is of the order of several score $cm^{-2} s^{-1}$ for bubles with the radius $r > 1 \times 10^{-2}$ cm [2, 6]. With a wind increase from 11 to 23 ms^{-1} there is an almost triple increase in the concentration of bubbles with the radius $r > 1 \times 10^{-2}$ cm (with, at least, the respective triple increase in the number of drops emitted by them). Moreover, Blanchard and Woodcock [6] state that the concentrations depend on the bubble sizes greater on average by an order of magnitude in the case when the bubbles form under the effect of breaking wind waves, than compared with their concentration conditioned by waves colliding with the rocky shore.

The variability of the characteristics of sea spray populations in the air over the sea results from the variability of micro-scale generation characteristics of these systems and from the variability of turbulent-diffusive conditions. This variability can in addition undergo perturbation caused by the advection factor. Nevertheless, the investigations in isolated conditions permit attention to be focused on the particular elements of this system. One of them is the wind gustiness. In the Antarctic conditions, in the area affected by the Polar convergence zone and bordering on the area where an extensive system of descending atmospheric motions dominates, this element is well-exposed, favouring investigations of its role as the factor generating coloidal systems of marine origin.

According to the theory of aerosol mass exchange related the hydrodynamics of the atmosphere — sea interactions [4], the variations in the concentrations of particles emitted from the sea in the air layer at the sea surface can be described by the equation

$$\text{(1)} \qquad \frac{\partial q}{\sigma t} = \sum_{i=1}^{k} \frac{\partial}{\partial \xi_0} [\bar{N}_i \bar{q}_n + \bar{N}_i' \bar{q}_n'] + \sum_{i=1}^{3} \frac{\partial}{\gamma r_i} [\bar{w}_z \bar{q}_n + w_z' q_n'] - w_0 \frac{\partial q}{\partial r_z},$$

where $\frac{\partial q}{\partial r_i}$ is the change in the concentration of their mass along the axes x, y, z; $N_i = \frac{\partial \varepsilon_i}{\partial t}$ is the change in time t of the probability of nucleation of the particles; understood in the problem considered as the transition from the state of drops to that of salt particles, $\varepsilon_i = \frac{\bar{r}_n}{\bar{r}_m}$, where $\bar{r}_n$ is the mean radius of the particles in the part of the ith set, and $\bar{r}_m$ is the mean radius in the set of all drops, typical of the ith mechanism of their emission. Moreover, the values of $\bar{N}_i + N_i'$ and of $q_n = \bar{q}_n + q_n'$ define together the sum of the mean number of particles with the mass q_n and their pulsation value. Analogously the components of the wind speed, u_0 and w_0, are evaluated at the sea surface, and so is the vertical component of the air motion at the level $z: w_z = \bar{w}_z + w_z'$. It is assumed, at the same time, that the mean and pulsation characteristics discussed are subordinated to the unambiguously dynamic factor ξ_0, which occurs in the form of the ratio [3]

$$\text{(2)} \qquad \xi_0 = \frac{u_*^2 z_0}{u_0 \nu},$$

where z_0 is the parameter of roughness of the sea surface and ν is the kinematic coefficient of air viscosity.

According to the Kitaygorodski hypothesis [13], in the Charnock equation [3], confirmed by the wind profile measurements [8] and given by

$$z_0 = m_0 \, u_*^2 \, g^{-1}, \tag{3}$$

where g is the acceleration of the Earth's gravity, the dimensionless coefficient m_0 has not the nature of a constant, but is only a function of the degree of undulation development. Let the degree of undulation development in time t be characterized by the stages of developed or forced undulation. Then, however, it can be assumed that in the conditions of sufficient wind gustiness, there arise at the particular points of the wave field, moments of the transition from the first stage of undulation development to the second, and conversely. Here, for these moments, both rapid changes in the velocity modulus and in the instantaneous veering in the wind direction, in the plane approximately tangential to the undulated sea surface, should be of deciding significance. In order to consider this effect, it should be taken that $m_0\,(g_{v,t}, g_{\varphi,t})$, where $g_{v,t}, g_{\varphi,t}$ are gustiness coefficients.

The verification of the above assumptions requires the collection of a sufficient amount of data on the wind gustines, in particular, related to the storm conditions and the presence of squalls on the sea. Theoretically, the latter gustiness scale should affect the exchange intensity, as a result of the modifying influence of instantaneous changes in the wind vector on the parameter z_0.

3. Outline of the measurement/research program

According to the above, the basic part of the research program was the measurements at the Arctowski Station, where they were carried out to a broadly outlined scheme (Table I), by using conventional and original research-measurement techniques. They included the measurements of the characteristics of the wind profile in the atmospheric layer at the sea surface, including the recording of speed variations with simultaneous continuous recording of the dynamics of the wind veering in this layer. This part of the program also included parallel measurements of short-term variations in the concentration of particles in the suspension of drops and sea salt particles (NaCl). Important additional material was also obtained from the meteorological station, where parallel routine measurements were carried out in the framework of the service. Besides, it was significant

Table I. A schematic representation of the measurement program

Anemometer No. 1 1 m above sea level		Recording of aerodynamical characteristics
Anemometer No. 2 5 m above sea level		
Anemometer No. 3 10 m above sea level		
Anemorhumbometer 4 m above sea level		
Probe TO YSI	hydrological	Measurements of characteristics
Probe STDO Bisset Berman		
Single-cascade impactor and microscope 1250 ×	aerosolic	
Conimeter and microscope 200 ×		
Drop catcher and binocular 25 ×		
Freezing collector		
Conductometer Cl^{-1} electrodes		
Psychrometer		Synoptico-meteorological observations
Rain meter		
Indicating anemorhumbometer		
Satellite photographs		

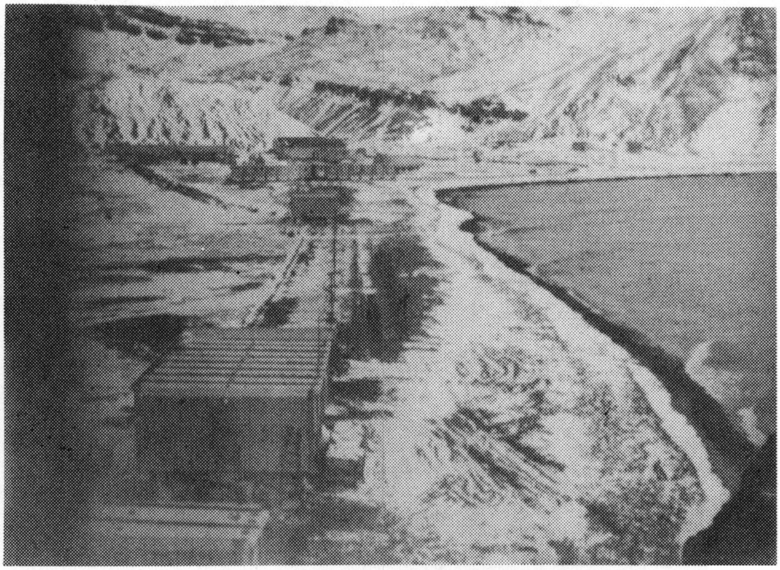

Fig. 1. A general view of the Arctowski Station and the shore of Admiralty Bay

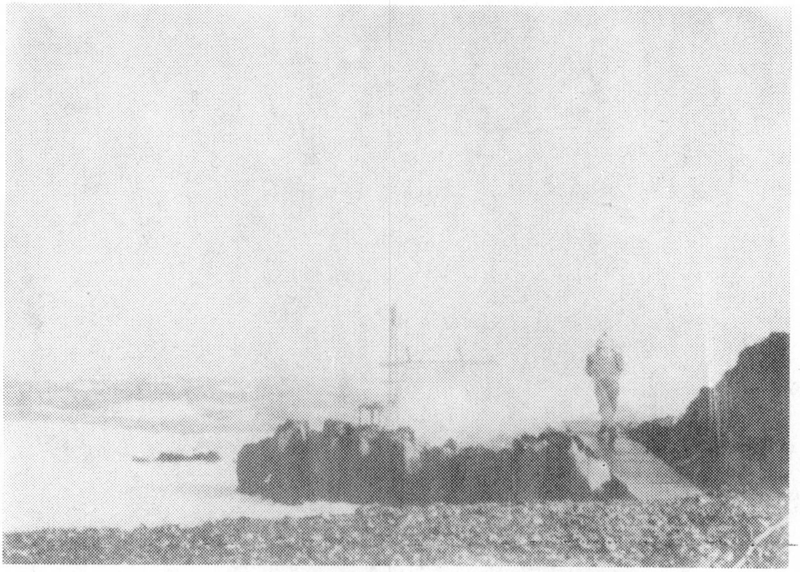

Fig. 2. Entrance to the platform for taking measurements in the coastal zone of Admiralty Bay

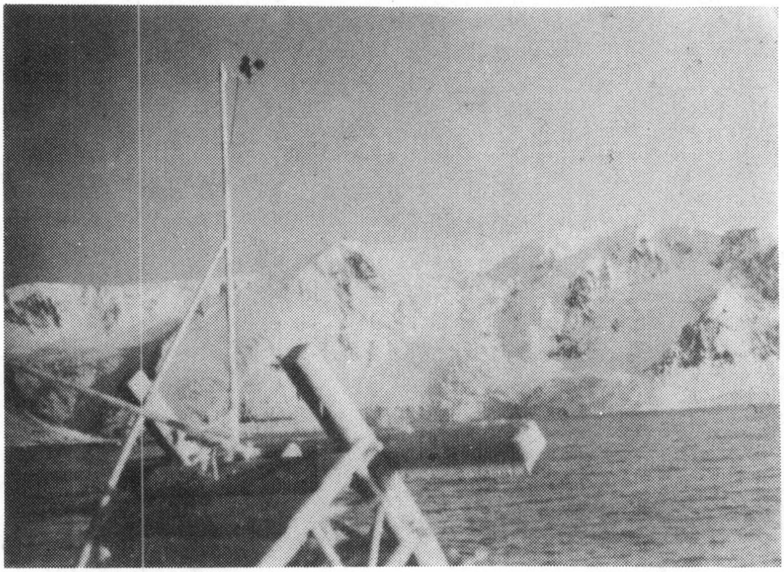

Fig. 3. Mast at the end of the platform with an anemometer set up at the top (5 m over the sea level)

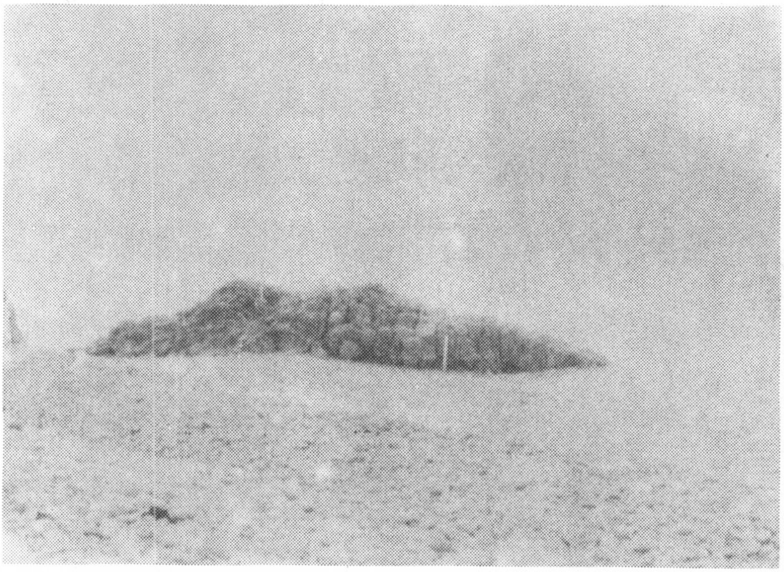

Fig. 4. Rocky islet with a mast set up on it 10 m over the sea level at an ebb-tide

that regular use could be made of the satellite photographs and facsimile maps, obtained at the Arctowski Station, illustrating the synoptic situations in the Antarctic region under study.

In order to carry out the task, special measurement equipment, including, apart from conventional devices, also, devices of the original construction designed for measurements of micro-structural characteristics, was prepared. In addition it was important to complete the set of sensors for performing continuous observations of the variability of the direction and modulus of the wind speed. In the last case, the basic equipment consisted of a potentiometric rhumbograph of the original construction and anemometers (Meratronik, N-188 type) working on the mechanical-contactron principle and recording gusts with sufficient resolution, by adding sensors to a four-channel recorder with analog notation. The equipment with basic significance also included devices for sampling aerosols, including a single — cascade impactor, permitting investigations of the micro-structure by using an immersion microscope and a collector of the original construction, working on the principle of freezing the marine aerosol. The system was complete with an anerhumbometer (type YW-11), conimeter (Zeiss, type 10) and a dyer drop catcher (using erythrosine for marking which could be employed in the conditions of the strongest storms. Apart from the principal part of the program of research carried out in stationary conditions, in addition some observations were to be made from a cruising ship.

The measurements at the Arctowski Station were performed from 10 January, 1980, to 20 March, 1981. The station is situated on a flat "terrace" at the very shore of Admiralty Bay and from the side of the island it is surrounded by a half-circle of hilly elevations partly covered despite low altitudes (about 200 m), by glaciers (Fig. 1). The width of the "terrace" descending horizontally to the sea reaches as much as about 600 m into the Bay, whereas the straight-line distance between the points of descent of the elevations to the sea is about 1 km. In selecting the spot for observations in the off-shore zone, it was decided that a cape, where a platform had been built (Fig. 2), reaching farthest into the sea, would be used for this purpose. The platform projecting, together with the rocky abutment, about 300 from the shoreline and occurring at a considerable distance from the hilly elevations, was in such a situation the optimum measurement post. A mast for measuring wind profiles was set up at the end of the platform (Fig. 3). The sensors installed on it were wired to a recorder set in the observer's booth on the coast, about 50 m away from the Bay. The other mast for measuring wind profiles was set on a tiny islet (Fig. 4) and only for short periods connected with the shore at ebbs. The mast on the islet was used only in the course of the first month of the expedition, after which the mast was destroyed in a strong storm and its functions were taken over by the mast on the platform.

By using the masts, measurements of wind characteristics were carried out in the atmospheric layer at the sea surface at about 1, 5 and 10 m over the sea level. Furthermore, simultaneous recordings of variations in the modulus of the wind speed were made at these elevations, and also those of changes in its direction (at about 4 m over the sea level). At the same time, discrete observations of the wind and other elements, both meteorological and hydrological, were made. In the latter case, they were concerned with temperature, salinity and oxygen content in the layer at the sea surface, and also with the dynamic characteristic of this surface.

4. Results of the research

4.1. Characteristics of wind gustiness

Among the characteristics of wind gustiness, it is interesting to note in the studies of exchange, sudden changes in the modulus of speed and instantaneous veering in the wind direction in a plane approximately tangent to the undulated sea sufface. In order to take this effect into account, the coefficient of lateral gustiness was introduced for a prescribed fluctuation period t, expressed in the form

$$g_{v,t} = \frac{u_{\max}}{\bar{u}_T} \tag{4.}$$

where $u_{\max}$ and $\bar{u}_T$ are, respectively, the maximum for a given fluctuation, and mean, for a chosen period T, wind speeds at the level z. At the same time, in order to take into account the corresponding characteristic changes in the wind direction, the following coefficient was introduced:

$$g_{\varphi,t} = \frac{\Delta\varphi_{\max}}{\Delta\bar{\varphi}}, \tag{5.}$$

where $\Delta\varphi_{\max}$ is the angle of the extreme deviation, recorded over the duration of the gust, from the mean angle of variations in the wind direction, $\Delta\bar{\varphi}$, typical of the period T.

The phenomenon of gustiness is also affected by the conditions of storm activity. These conditions are illustrated by the results of analysis of variations in the intensity of storm activity (Fig. 5), where an attempt was made to represent this intensity by introducing the coefficient $g_s =$

$= \frac{u_{10\max}}{\bar{u}_{10}}$ and the quantity $\psi = g_s \Delta t$, where $u_{10_{\max}}$ is the maximum wind speed, on particular days, u_{10} is its mean vatue alt10 m for the whole observation period and Δt is the duration of the storm. The observations made only in the summer season at the Arctowski Station indicate the large frequency of winds with storm strength at these Polar latitudes. During storms, the highest velocities observed reach in gusts more than 40 ms^{-1}. It can be assumed, however, that even for such strong winds, variations in their velocity and direction are not independent of the effect of local orography related to King George Island surrounding the Bay. It cannot be excluded that in terms of air motion the orography can give to the whole Bay the nature of a tunnel. This would be indicated to some extent by the statement that in the region under steady winds tend to come from some preferred directions, although the distinct domination of the north-west directions originates at these latidudes from the general atmospheric circulation. In turn, observations showed that speed increases typical of squalls are commonly accompanied at the

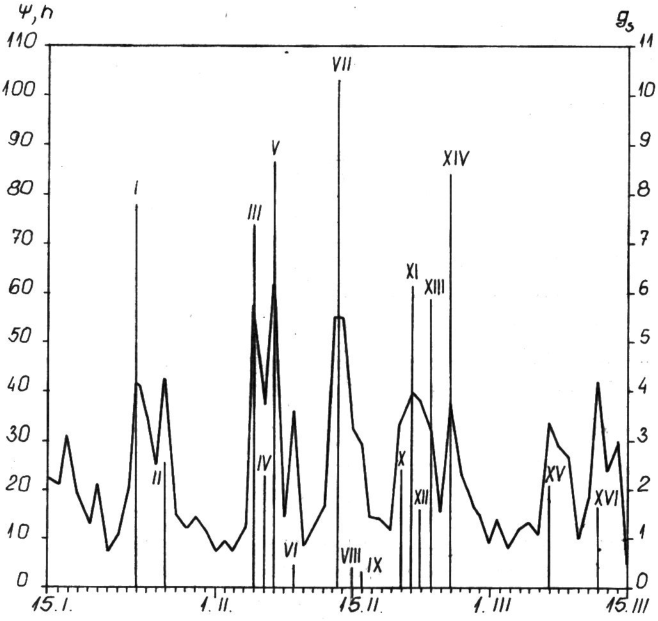

Fig. 5. Variations in the intensity of storm activity in the area of Admiralty Bay from 15 January, 1980, to 15 March, 1981. The solid curve represents variations in $g_s = u_{10,\max}/\bar{u}$; vertical lines — discrete values of the parameter $g_s \Delta t$, where Δt is the duration of the storm

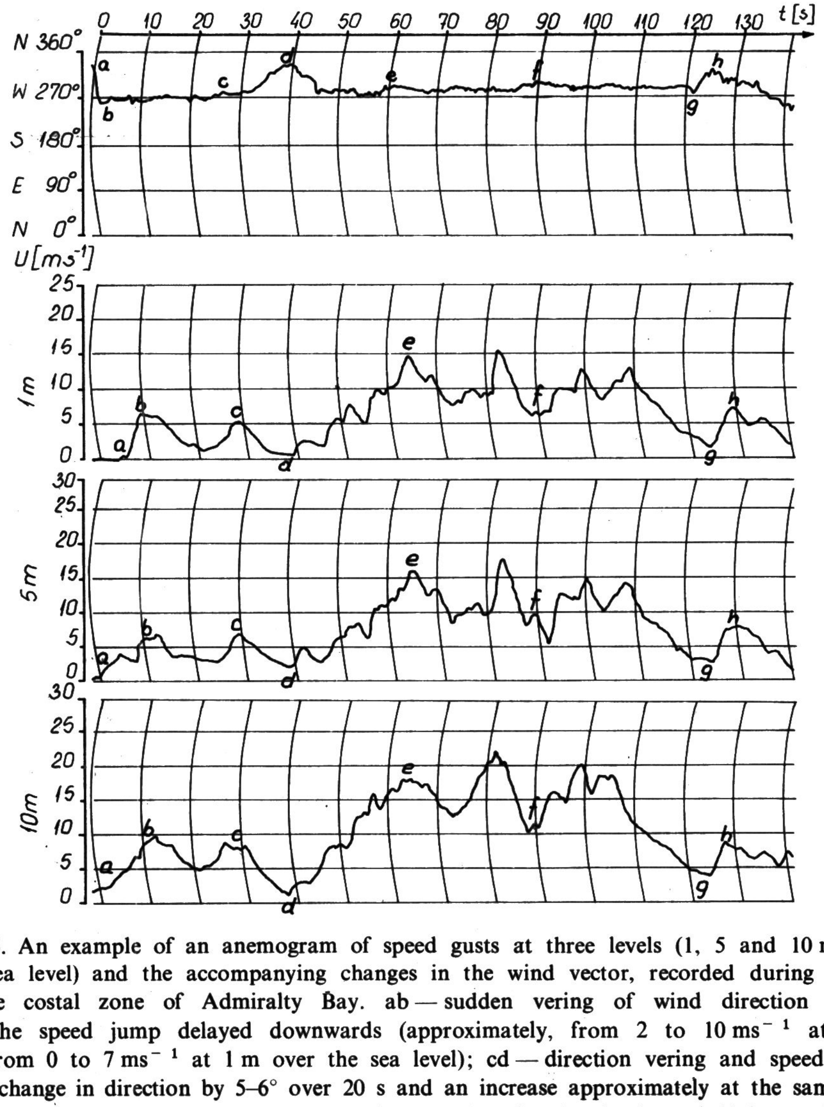

Fig. 6. An example of an anemogram of speed gusts at three levels (1, 5 and 10 m over the sea level) and the accompanying changes in the wind vector, recorded during squalls in the costal zone of Admiralty Bay. ab — sudden vering of wind direction by 8° and the speed jump delayed downwards (approximately, from 2 to 10 ms^{-1} at 10 m and from 0 to 7 ms^{-1} at 1 m over the sea level); cd — direction vering and speed drop; de — change in direction by 5–6° over 20 s and an increase approximately at the same time at the three levels from low to storm wind speeds; ef — domination of high speeds with slight direction variations; f_g — return from high to low velocities with an approximately constant direction; gh — sudden direction change (by about 5°) and a jump in the limits of low and mean wind speeds

same time by distinct veering in the direction (Fig. 6). Accordingly, analysis of the correlation of $g_{v,t}$ and $g_{\varphi,t}$, on the basis of all the data $\Delta u_{\max}$ and $\Delta \varphi_{\max}$ (Fig. 7), obtained in different aerodynamical conditions, does not negate essentially its occurrence between these quantities. Despite the large scatter of experimental points, by the least-squares method, lines of regression were obtained, indicating the general tendency for $\Delta\varphi$

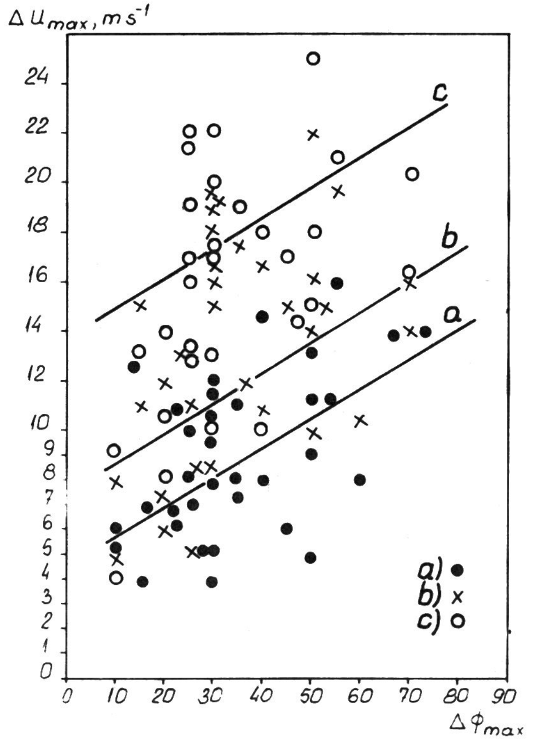

Fig. 7. Correlation of Δu_{max} and $\Delta\varphi_{max}$ obtained from measurements of the wind speed gusts. Points a, b and c apply to the results of measurements carried out at the respective elevations of 1, 5 and 10 m over the sea level; the regression curves, for which a mean value of the angle coefficient was assumed (because of deviations from the second decimal place), were calculated from the equations obtained:

a) $\Delta u_{max} = 4.77 + 0.12\ \Delta\varphi_{max}$;

b) $\Delta u_{max} = 7.55 + 0.12\ \Delta\varphi_{max}$;

c) $\Delta u_{max} = 13.82 + 0.12\ \Delta\varphi_{max}$

to increase as Δu increases. A still more distinctly expressed dependence was obtained for the derivatives of changes in these quantities over the duration of the gust (Fig. 8).

It is known from previous investigations [6, 7] that in the air layer at the sea surface, as the wind speed or the altitude over the sea level increase, a drop in the lateral gustiness $g_{v,t} = 1s$ is observed. With storm wind speeds on the sea ($\bar{u}_{600} = 34\ ms^{-1}$, the period $T = 600$ s) one-second gusts, as follows from the investigations by Goptarev [6], are mainly characterized by the values of $g_{v,t} = 1s = 1.0$ to 1.1 for horizontal gustiness, whereas the probability of $g_{v,t=1s} = 1.6$ can be expected only once per 14 hours. By investigating the characteristics of gusts with periods

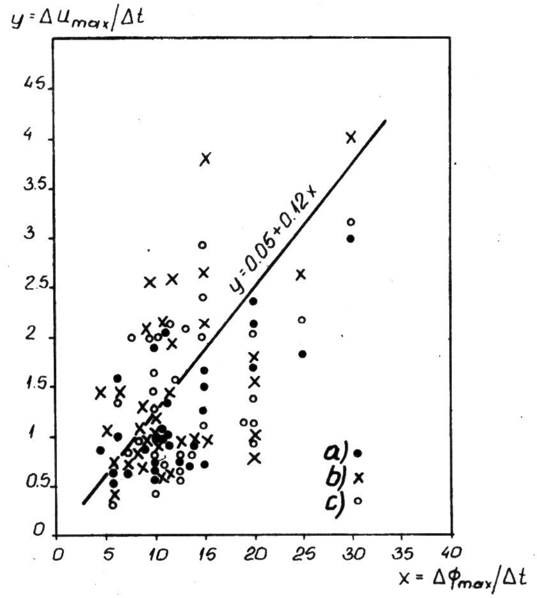

Fig. 8. Correlation of the derivatives $\Delta u_{\max}/\Delta t$ and $\Delta\varphi_{\max}/dt$ obtained for gusts in the coastal zone of Admiralty Bay. Points a, b and c apply, respectively, to the measurement elevations of 1, 5 and 10 m over the sea level

$t \geqslant 10$ s, in the present paper, results were obtained (Table II), indicating also a drop in $g_{v,t}$ with wind speed, with the difference that this drop occurs after exceeding u_{10} falling within the interval 10-15 ms^{-1}. It was found, in turn, that as the mean and pre-storm wind speeds increase (over the range of up to about 15 ms^{-1}), $g_{v,t \geqslant 10 s}$ also increases greatly. It is only the frequency of gusts (with the period $t > 10$ s) that distinctly

Table II

Characteristics of wind gustiness in the coastal zone of Admiralty Bay, based on the measurements carried out from 10 January, 1980, to 10 March 1981

Intervals $\bar{u}_{10}$ m s^{-1}	$g_{v,t} \geqslant 10$ s at		Frequency of gusts (n $\min^{-1}$) with period $t \geqslant 10$ s	
	5 m	10 m	extreme	mean
5–10	1.12–1.42	1.00–1.50	2.2–5.8	3.4
10–15	1.33–2.55	1.06–2.06	1.9–3.0	2.4
15–20	1.47–1.93	1.17–1.67	1.5–2.0	1.8
20–25	1.18–1.24	1.15–1.62	1.2–1.8	1.5

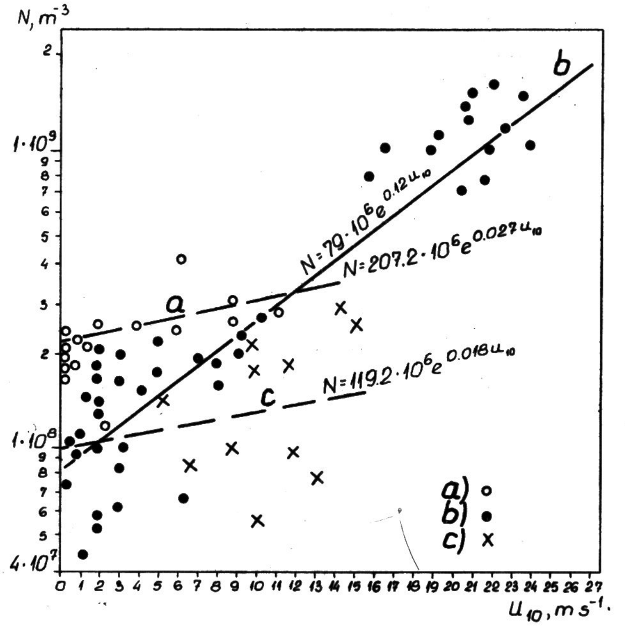

Fig. 9. Dependence of the number of sea-salt particles in the air at the sea surface on the wind speed. Points a, b and c apply to the cases:

a) air flowing directly from the open ocean (from E–SSE);
b) advection from W–N;
c) air flow from over the Antarctic continent

decreases as the speed increases over the whole range of its measured values — beginning from the mean and ending with strong storm ones. Furthermore, as far as changes with altitude go, in the atmospheric layer at the sea surface, one can speak of the tendency for $g_{v,t\geqslant 10\,s}$ to drop with increasing altitude essentially for all velocity intervals. Thus, the results obtained are interesting and provoke the need for further research.

4.2. The effect of gustiness on fluctuations in the intensity of the exchange of particle suspensions

It was found [8] earlier that the geography of the situation of land and oceanic areas in the Antarctic regions is the cause of distinct changes in the aerosol characteristics occurring for an appropriate change in the direction of air flow. Therefore, in order to explain the role of wind gustiness as one of the factors generating the coloidal mass exchange through the air-water interface in the atmosphere-sea system, in the first instance, analysis was carried out of the effect of advection on the general aerosol background in the research region. For it was to be expected that the variable directions of air mass advection should cause the occurrence of overwhelming changes in this background and thus perturb the image of the effect of micro-scale processes on the mass exchange.

In the present paper, in order to establish the effect of advection, transmission directions on a synoptic scale were determined from facsimile

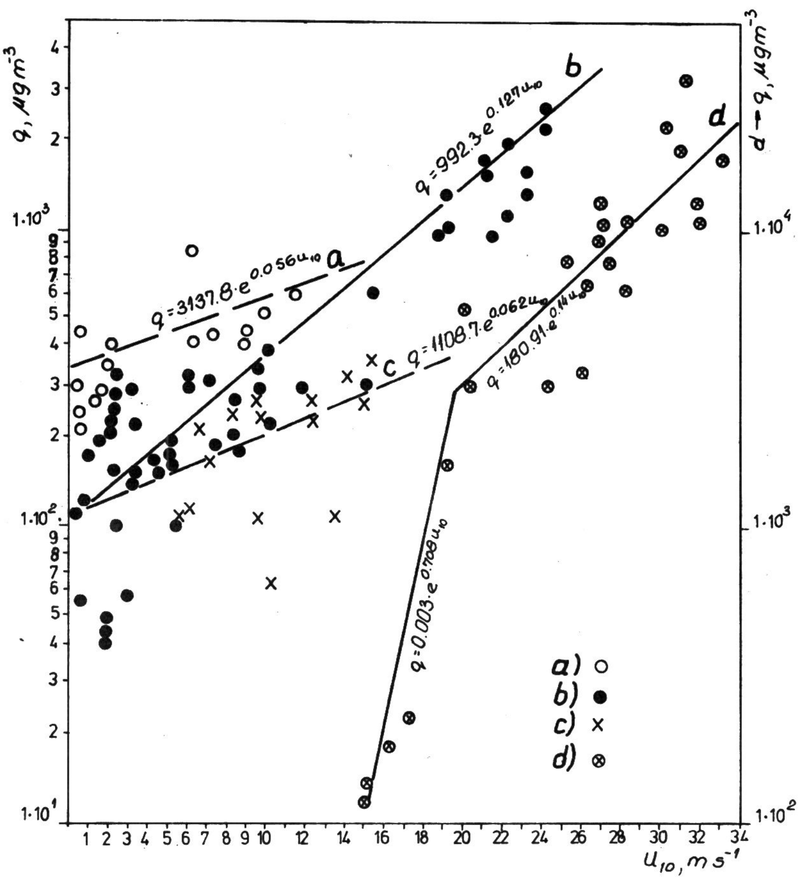

Fig. 10. Bulk mass concentration of sea salt particles (NaCl) in the air at the sea surface, depending on the wind speed over the sea. Points a, b, c and d apply to the cases:

a) air flowing directly from the open ocean (from E–SSE);
b) advection from W–N;
c) air flow over the Antarctic continent;
d) recording of drops in the air during strong storms (the salt mass was calculated from the mass of water drops)

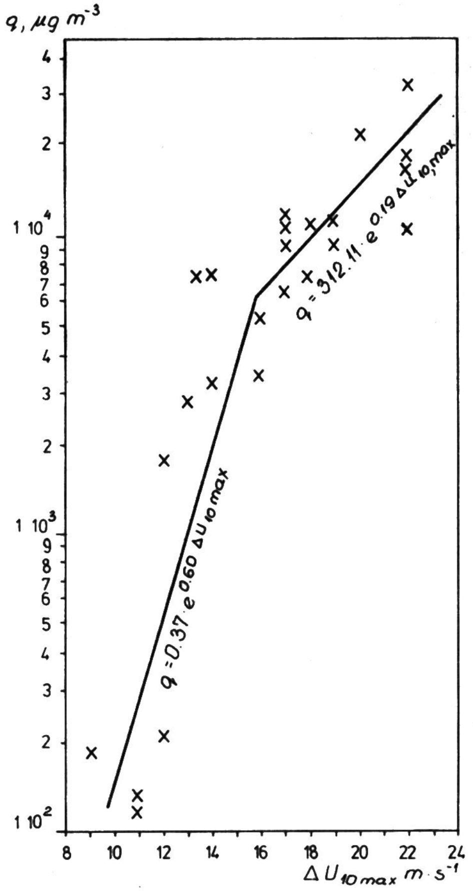

Fig. 11. An increase in the mass of sea spray in the air at the sea surface as a function of the maximum speed increments during strong wind gusts in the coastal zone of Admiralty Bay. The mass of drops recorded for storms was recalculated to that of sea salt emitted with it (NaCl)

maps and on the basis of analysis of the satellite photographs of the Antarctic macroregion detected at the Arctowski Station, where the measurements were carried out. By separating the measurement results obtained for the domination of advection from over the ocean from those typical of air flow from over the Antarctic continent, it was found that considerable differences occurred in the inclination angle of the regression curves for the dependence of air salinity on the wind speed. With the advection from over the Antarctic continent, it is possible to note a distinct decrease in the number N and the bulk mass concentration q of marine salt particles (NaCl) in the air at the sea surface (Fig. 9 and 10).

In turn, a distinctly larger increase, with increasing wind speed, of the number of marigenic drops and salinity of the air at the sea surface was obtained for western and northern transmission, i.e. the directions of advection from over the wide free oceanic areas. At the same time, it was found that in the conditions of mean wind speeds, even direct air flow from over the ocean through the wide Bransfield Strait (by the connecting Admiralty Bay), but from the east and only partly from the south, does not condition the similarly large increase in N and q. In this case, the character of the dependence of N and q on u_{10}; despite the generally higher values of N and q than during the proper

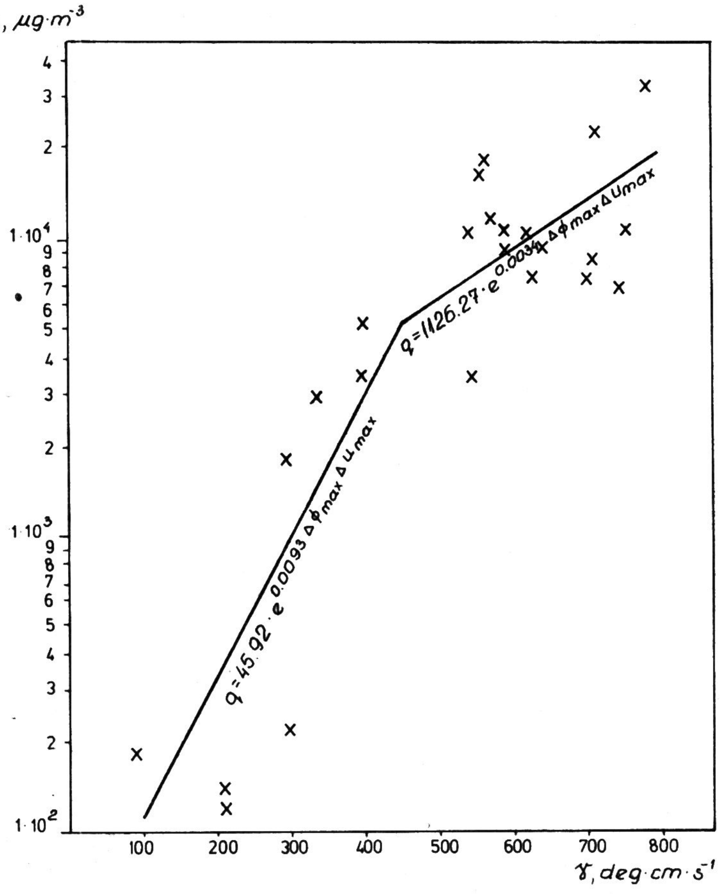

Fig. 12. Dependence of the bulk mass concentration of drops in the atmospheric layer at the sea surface on the wind speed (b) and the coefficient of gastiness $g_{v,\,t \geqslant 10\,s}$ (a). The mass of drops recorded for storms was recalculated to the mass of sea salt (NaCl) emitted with them

transmission from over the continent; is still close to the character of this dependence, typical of advection from over the Antarctic, and indicates its overwhelming influence.

In view of the above, the effect of gustiness on the aerosol mass

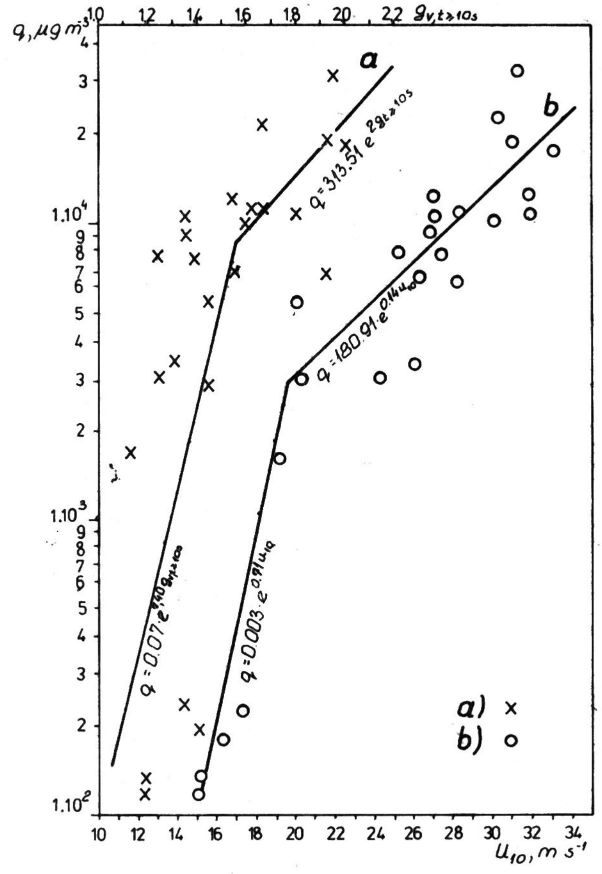

Fig. 13. Mass of drops emitted from the sea during storms as a function of $\gamma = \Delta\varphi_{\max}\,\Delta u_{\max}$ in the atmospheric layer at the sea surface. The mass of drops recorded was recalculated to that of sea salt (NaCl) emitted

emission from the sea was investigated by limiting studies to measurements in the conditions of full domination of local micro-scale factors. Such conditions occurred during strong storms, where the mitigation of the effect of the coastal rocks (by the interaction between the waves and the ice field blown by winds to the coastal zone), permitted the studies to include the open waters of the Bay. High intensity of the sea spray emission, with almost visually observed variability, permitted in these conditions the recording of concentration of drops in the air by using the dyer catcher. Despite the fact that this method permitted the recording of drops with diameters exceeding approximately 100 μm, measurements of the variability of q were performed with relatively low error -- the consideration of the share of smaller drops, respectively salt particles (NaCl) with diameters below 6 μm, only slightly increases the value of q with respect to the main mass of drops contained in these conditions within the interval between $r > 50$ μm to $r \approx 1000$ μm and higher. This conclusion agrees with the previous evaluation [5] of the share, in the total mass, of particles from the peripheral parts of the spectrum of their size and which cannot be fully measured due to limitations occurring already at the stage of sampling by the inertial technique. The material thus collected, permitted the explanation of the dependence of q on the wind gustiness (Fig. 11) and the coefficient $g_{v,t \geqslant 10\,s}$ (Fig. 12) characterizing the gustiness. By considering, at the same time, the effect of the wind vering twist accompanying the gusts, the quantity $\gamma = \Delta\varphi_{\max}\,\Delta u_{\max}$ was similarly analysed for the atmospheric layer at the sea surface (Fig. 13). Comparison between Fig. 13 and Figs. 11 and 12 can show that the computer-calculated regression curves of the variable q with respect to u_{10}, γ, $\Delta u_{\max}$ and $g_{v,t \geqslant 10\,s}$ have essentially the same character, where the curves tend to deflect. Presumably, this deflection can be identified with a similar effect noticed by Monahan [14] and related to the rapid jump in the emission of drops from the sea with wind speeds exceeding 8.5 ms^{-1}. Monahan obtained this jump in the emission and concentration of drops within the interval of r values between about 45–91 μm by carrying out measurements at about 0.5 m over the sea level. The relatively large size of particles and the low altitude where the measurements were carried out in this case permit the presumption that the jump effect can be related to the contribution to the emission, when exceeding $u_{0.5} \approx \mathrm{ms}^{-1}$, by still other mechanisms apart from that related to the breaking of gas bubbles raised from the waters. It is assumed that the additional mechanism occurs in this case in relation with the increasing degree of sea spray resulting from breaking wind waves. However, with sufficiently high wind speeds, particularly with gusts, an additional role in the intensification of the emission can also play the mechanism of direct blowing of the sea spray from the breaking wave ridges, accompanied by the shearing of the elements of roughness and the suction of drops from capillary waves. In the present studies, the velocity critical for the emission jump, u_{10}, was found to shift from 8.5 to more than 19 ms^{-1} (19.7 ms^{-1}), which is justified in the difference in the altitudes at which the measurements were carried out —

respectively 0.5 and 2.5 m over the sea level. At any rate, Munk [15] already pointed out the shift with the critical wind speed for the emission jump of drops. It is interesting to note, however, the occurrence of the emission jump in the conditions of storm wind velocities under which the measurements were usually carried out in the present studies. Hence, then, the conclusion follows that the emission jump in these conditions should be affected mainly by the domination, after exceeding some critical wind speed, of the mechanism of shearing the elements of the sea roughness. It cannot be excluded that this is the condition for the formation of the emission jump of the second degree with respect to the jump observed by Monahan, except that so far it cannot be established without additional studies.

Apart from the above fact, it is also interesting to note the unequal rate of increase in q (usually, the opposite flexion of curves in a semi-logarithmic diagram) with increasing wind speed in the research of Monahan et al. [1, 6, 14] compared with the increase obtained in this paper and by other authors [4, 6, 11]. The relatively faster increase in q with wind speed, as given by Monahan, is most probably caused by the effectively increasing proportion of large drops at the level of 0.5 m with increasing $u_{0.5}$. As a result of their elimination, the proportion of these drops at 2.5 m over the sea level should be much smaller. In turn, the results and their interpretation are different for the emission in the storm conditions, particularly over the Polar water region, where large drops are abundant in the whole layer at the sea surface already for the pre-storm velocities (about 10 $\mathrm{ms^{-1}}$). A further increase in their number with increasing u_{10} should be relatively less distinct against the generally considerable concentrations of large drops in the air at the sea surface. This is confirmed by the dependence of q on u_{10} obtained here for large drops, compared with the results of Monahan's investigations [14], although the increments tend to be considerable, while the character of the curves at sections separated by the critical velocity shows a tendency to resemble the parabolic dependence of q on u in its semi-logarithmic representation by Monahan. Further specification of this dependence, in particular the verification of the emission jump in the storm conditions, involves the interesting problem of the dynamics of the aerodynamic roughness z_0 in these conditions and the effect on this parameter of the interaction between the gusty structure of the wind and the undulated sea surface.

5. Conclusions

The high frequency of winds with storm strength in the conditions of the Admiralty Bay permitted the characteristics of gustiness to be determined and their effect on the aerosol mass exchange between the sea and the atmosphere to be evaluated. A relation was found to exist between gusts with periods close to or characteristic of squalls and rapid veering in the wind direction, allowing the curves of this correlation to be calculated. The results obtained for the storm conditions confirmed the occurrence of a drop in the coefficient of gustiness $g_{v,t \geqslant 10\,s}$ with increasing wind speed, when compared with the results obtained for $g_{v,t=1\,s}$ [6]. In turn, in the range of mean and pre-storm wind speeds, the inverse course of this dependence was obtained. This suggests the need for further studies, since the drop in the frequency of gusts with the wind speed does not show similar deviations. A distinct relation was found to exist between the characteristics of wind gustiness and the emission of drops from the sea. Hence, the conclusion follows that the effect of 'gustiness should also apply to the effectiveness of diffusive transmission of mass of aerosol particles to the sea.

The dependencies noted and the correlation curves calculated for them suggest the purposefulness of more specific explanation of some details, such as the emission jump and the accompanying critical wind speed in the storm conditions; the proportion in the increased efficiency of the emission, of the mechanism of shearing the elements of roughness together with the suction of drops from capillary waves, and also the effect of the gust-related variability of the wind vector on the roughness parameter z_0.

6. Резюмe

В летний период 1980—1981 на территории Антарктики в прибрежной зоне залива Адмиралиции (Остров Короля Георга) были проведены комплексные измерения для изучения участия порывистости ветра в процессах, вызывающих образование морских дисперсных систем о стимулирующих аэрозолевый массообмен между морем и атмосферой. Установлено существование связи между порывами с продолжительностью близкой или характерной для шквалов и резкими изменениями направления ветра. Высчитаны кривые этой корреляции. Результаты, полученные для штормовых условий подтвердили уменьшение коэффициента порывистости $g_{v,t \geqslant 10s}$ с увеличением скорости ветра, если их сравнить с результатами, полученными для $g_{v,t=1s}$. В границах же средних и предштормовых скоростей ветра получена обратная зависимость. Установлено, что между отличительными чертами порывистости ветра и выносом капель из моря су-

ществует определенная связь. Результаты могут свидетельствовать о значительном влиянии моментных сдвигов при порывах скорости на колебания аэродинамической шероховатости поверхности моря.

Статья является заключением предварительных результатов измерений, проведенных в рамках работы экспедиции. Предвидится продолжение начатых исследований.

7. Streszczenie

W okresie letnim1980–1981 na obszarach Antarktyki przeprowadzono w strefie przybrzeżnej Zatoki Admiralicji (Wyspa Króla Jerzego) kompleksowe pomiary mające na celu zbadanie udziału porywistości wiatru w procesach generujących morskie układy rozproszone i stymulujących aerozolową wymianę masy między morzem i atmosferą. Stwierdzono istnienie związku między porywami o okresach zbliżonych lub charakterystycznych dla szkwałów a nagłymi skrętami kierunku wiatru. Obliczono krzywe tej korelacji. Wyniki uzyskane dla warunków sztormowych potwierdziły występowanie spadku współczynnika porywistości $g_{v,t \geqslant 10\,s}$ wraz ze wzrostem prędkości wiatru, jeżeli je porównać z wynikami uzyskanymi dla $g_{v,t=1\,s}$. Natomiast w zakresie średnich i przedsztormowych prędkości wiatru uzyskano odwrotny przebieg tej zależności. Stwierdzono, że pomiędzy charakterystykami porywistości wiatru a wynoszeniem kropel z morza istnieje wyraźny związek. Wyniki mogą świadczyć o istotnym wpływie chwilowych skrętów i porywów prędkości na wahania aerodynamicznej szorstkości powierzchni morza.

Praca stanowi podsumowanie wstępnych wyników z zakresu pomiarów przeprowadzonych w ramach ekspedycji. Przewiduje się kontynuację rozpoczętych badań.

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