AMERICAN INSTITUTE OF CROP ECOLOGY
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AICE* SURVEY OF USSR AIR POLLUTION LITERATURE

Volume VI

AIR POLLUTION IN RELATION TO CERTAIN ATMOSPHERIC AND METEOROLOGICAL CONDITIONS AND SOME OF THE METHODS EMPLOYED IN THE SURVEY AND ANALYSIS OF AIR POLLUTANTS

Edited By

M. Y. Nuttonson

The material presented here is part of a survey of
USSR literature on air pollution
conducted by the Air Pollution Section
AMERICAN INSTITUTE OF CROP ECOLOGY

This survey is being conducted under GRANT 1 RO1 AP00786 – APC
AIR POLUTION CONTROL OFFICE
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ENVIRONMENTAL PROTECTION AGENCY

*AMERICAN INSTITUTE OF CROP ECOLOGY
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PREFACE

Much of the background material presented in the prefaces to the preceding volumes of this series is also relevant to the present volume.

The papers and data presented in this volume deal with a number of aspects of air pollution developed under the wide range of environmental conditions prevailing throughout the vast land area of the USSR with its numerous extractive and manufacturing industrial enterprises. Some background information on the distribution of the Soviet industry's production machine may be of interest in connection with that country's present and potential pollution problems and investigations. The planned distribution of production in the Soviet Union favors effective exploitation of the natural resources of the USSR, especially in its eastern areas where enormous natural resources are concentrated, and has led to the creation of large industrial centers and complexes of heavy industry in many of the country's economic areas (see page ix). The many diverse climatic conditions of the country and its major economic areas as well as the geographical distribution of the Soviet Union's principal industrial and mining centers and of its principal electric power stations and power systems can be seen from the various maps presented as background material in this volume.

Contamination of the natural environment constitutes a major problem in all industrial regions of the USSR. The country's industry and transport are continually bringing about massive qualitative changes in the habitat of man and vegetation through an ever-increasing pollution of air, soil, and streams. Pollution and the need to control it have become a matter of great concern among Soviet conservationists and scientists and they, like their colleagues in the West, have been warning their government of the colossal and sometimes irreparable damage that is being done to the environment and urging that serious and effective steps be taken to avert it.

Public awareness of the environmental crisis and the pollution problem has been greatly stimulated in the USSR by the description, in the local press, of such phenomena as dirty urban air, polluted rivers, ravaged forests and public parks, and poisoned wildlife as well as by the revealing of the causes of these conditions. "Pravda", the official Communist party newspaper, stated in a recent article that "... we are turning the atmosphere of our major industrial regions and large cities into a dump for poisonous industrial wastes". In the Soviet Union, like in the West, pollution now poses for the leaders of the country some fundamental choices between the economics of production, on one hand, and the progressively worsening living conditions, on the other. There appears to be, at present, a greater appreciation and a better understanding of the immense problems of air and water pollution on the part of the urban and rural administrative agencies. As a result of a mounting demand for the maintenance of a high quality physical environment, protective measures against the pollution threat are gradually taking shape in the USSR and much relevant air pollution research data are being developed in the various industrial regions of that country.

Studies of atmospheric diffusion and air pollution constitute a rapidly developing area of meteorological sciences in the USSR. Determination and analysis of the complex set of meteorological factors causing the processes of atmospheric diffusion are being extensively developed there in conjunction with theoretical and experimental studies of the pattern of progagation and distribution of contaminants in the atmosphere.

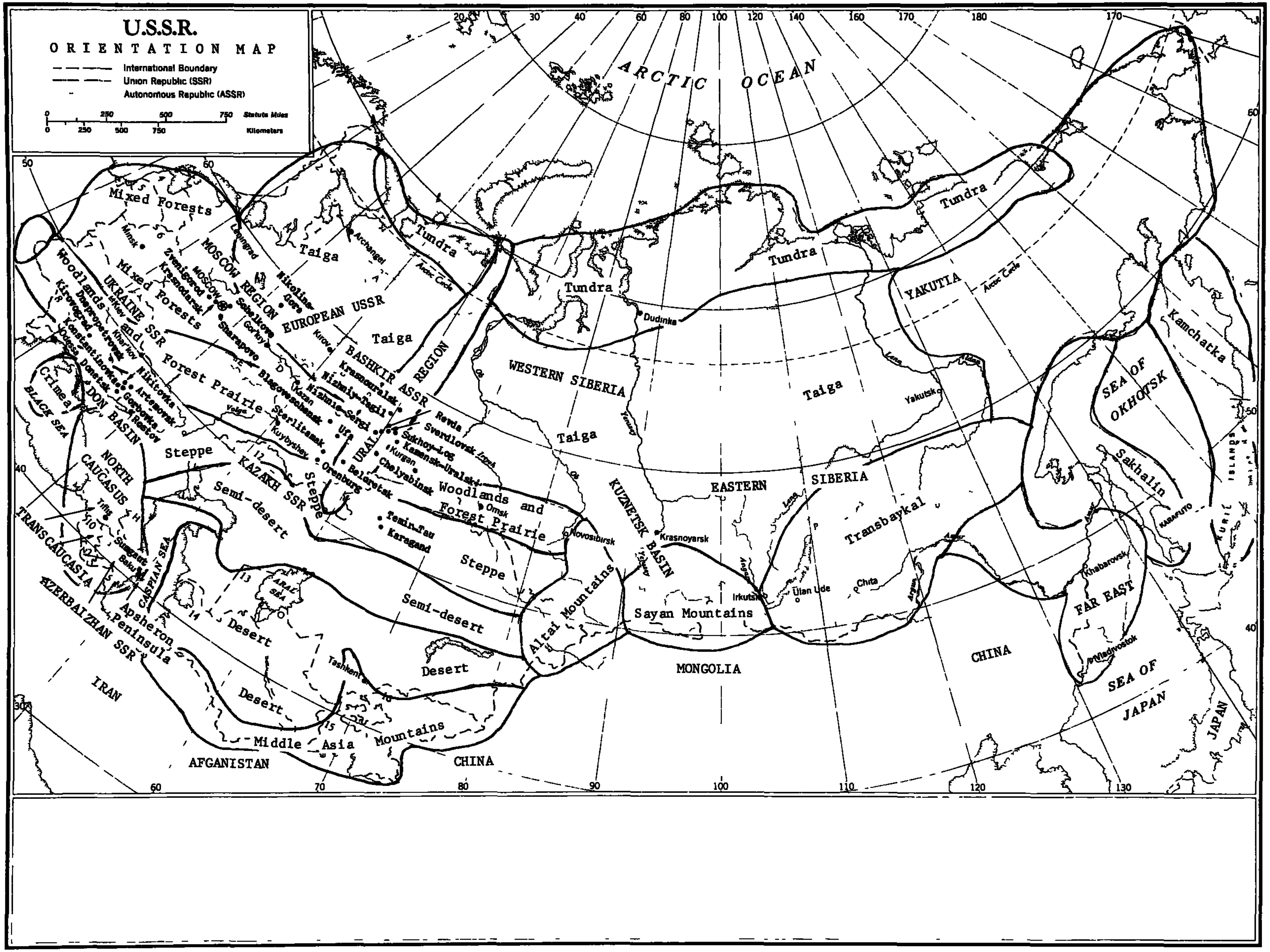
Most of the material brought together in this volume deals with some atmospheric and weather conditions as factors in the dispersal of air pollutants in a number of the industrial regions of the USSR, regions that are geographically far apart from each other and subject to different natural and man-made environmental conditions.

A number of papers presented here deal with the basic principles involved in the organization of air pollution surveys in cities. Other papers consist of reports relating to the operation of air pollution observation posts and to the statistical methods employed in the analysis of the observational data.

It is hoped that the papers selected for presentation in this volume will be conducive to a better appreciation of some of the air pollution investigations conducted in the USSR. As the editor of this volume I wish to thank my co-workers in the Air Pollution Section of the Institute for their valuable assistance.

M. Y. Nuttonson

March 1971



ADMINISTRATIVE DIVISIONS

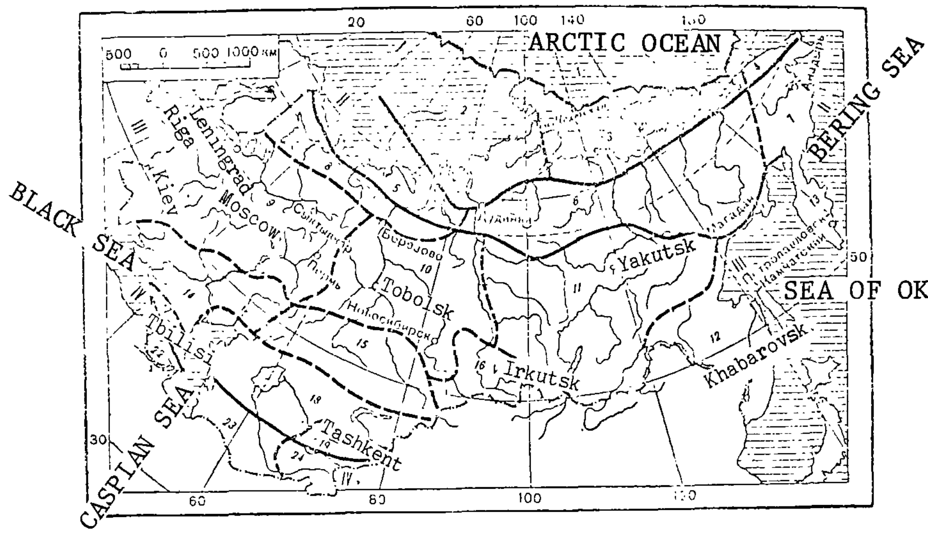
SSR

1 R S.F S.R
2 Karelo-Finnish S.S.R
3 Estonian S.S.R.
4 Latvian S.S.R
5 Lithuanian S.S R
6. White Russian S S R.
7 Ukrainian S.S R
8. Moldavian S S.R
9 Georgian S.S R.
10 Armenian S S R
11 Azerbaydzhan S S R.
12 Kazakh S S R.
13 Uzbek S S.R
14 Turkmen S.S.R
15 Tadzhik S S R
16 Kirgiz S.S.R

A.S.S.R

A. Komi ASSR
B Udmurtskaya ASSR
C. Mariyskaya ASSR
D Chuvashskaya ASSR
E. Mordovskaya ASSR
F Tatarskaya ASSR
G Bashkirskaya ASSR
H Dagestanskaya ASSR
J Severo-Osetinskaya ASSR
K. Kabardinskaya ASSR
L. Abkhazskaya ASSR
M Adzharskaya ASSR
N Nakhichevanskaya ASSR
O Kara Kalpakskaya ASSR
P Buryat Mongol skaya ASSR
Q Yakutskaya ASSR

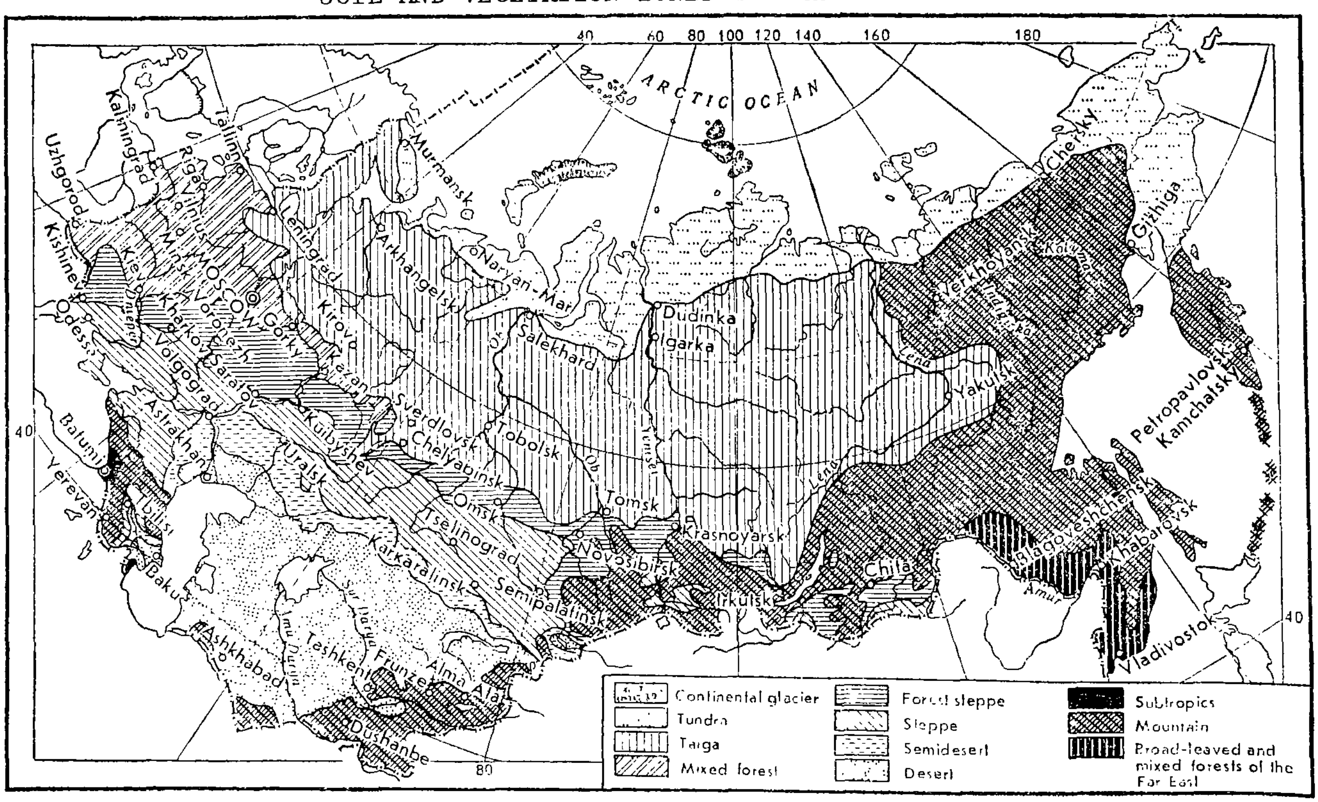
CLIMATIC ZONES AND REGIONS* OF THE USSR



Zones: I-arctic, II-subarctic, III-temperate, IV-subtropical
Regions: 1-polar, 2-Atlantic, 3-East Siberian, 4-Pacific, 5-Atlantic, 6-Siberian, 7-Pacific, 8-Atlantic-arctic, 9-Atlantic-continental forests, 10-continental forests West Siberian, 11-continental forests East Siberian, 12-monsoon forests, 13-Pacific forests, 14-Atlantic-continental steppe, 15-continental steppe West Siberian, 16-mountainous Altay and Sayan, 17-mountainous Northern Caucasus, 18-continental desert Central Asian, 19-mountainous Tyan-Shan, 20-western Transcaucasian, 21-eastern Transcaucasian, 22-mountainous Transcaucasian highlands, 23-desert south-Turanian, 24-mountainous Pamir-Alay

(After B. P. Alisov, "Climate of The USSR", Moscow 1956)

SOIL AND VEGETATION ZONES IN THE U.S.S.R.



(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

MAJOR ECONOMIC AREAS OF THE U.S.S.R.

PLANNED DISTRIBUTION OF INDUSTRIAL PRODUCTION IN ORDER TO BRING IT CLOSER TO RAW MATERIAL AND FUEL SOURCES

An example of the planned distribution of industrial production in the USSR is the creation of large industrial centers and complexes of heavy industry in many of the country's economic areas: the North-West (Kirovsk, Kandalaksha, Vorkuta), the Urals (Magnitogorsk, Chelyabinsk, Nizhny Tagil), Western and Eastern Siberia (Novosibirsk, Novokuznetsk, Kemerovo, Krasnoyarsk, Irkutsk, Bratsk), Kazakhstan (Karaganda, Rudny, Balkhash, Dzhezkazgan).

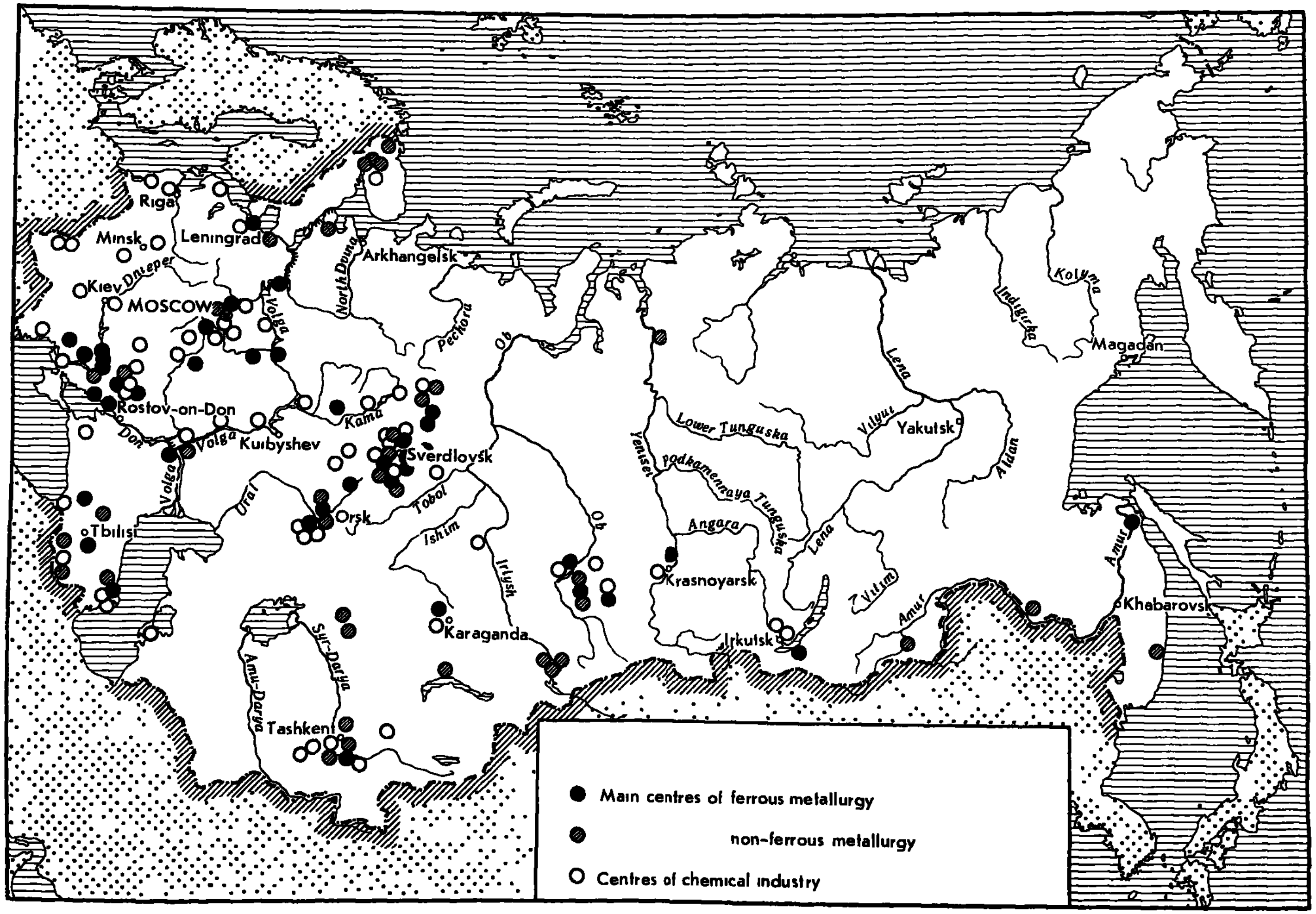
Large industrial systems are being created - Kustanai, Pavlodar-Ekibastuz, Achinsk-Krasnoyarsk, Bratsk-Taishet and a number of others. Ferrous and non-ferrous metallurgy, pulp and paper, hydrolysis and saw-milling industries are being established in the Bratsk-Taishet industrial system. The Achinsk-Krasnoyarsk industrial system is becoming one of the largest centers of aluminum and chemical industries, and production of ferrous metals, cellulose, paper, and oil products.

Construction of the third metallurgical base has been launched in Siberia, and a new base of ferrous metallurgy, using the enormous local iron and coal resources, has been created in Kazakhstan. A high-capacity power system is being organized in the same areas. Non-ferrous metallurgy is being further developed in Kazakhstan, Central Asia and in Transbaikal areas. The pulp and paper, as well as the timber, industries are being developed at a fast rate in the forest areas of Siberia and the Far East.

Ferrous metallurgy is also developing in the European part of the country by utilizing the enormous iron ore resources of the Kursk Magnetic Anomaly and the Ukrainian deposits. Large new production systems are under construction in the North-West, along the Volga, in the Northern Caucasus and the Ukraine.

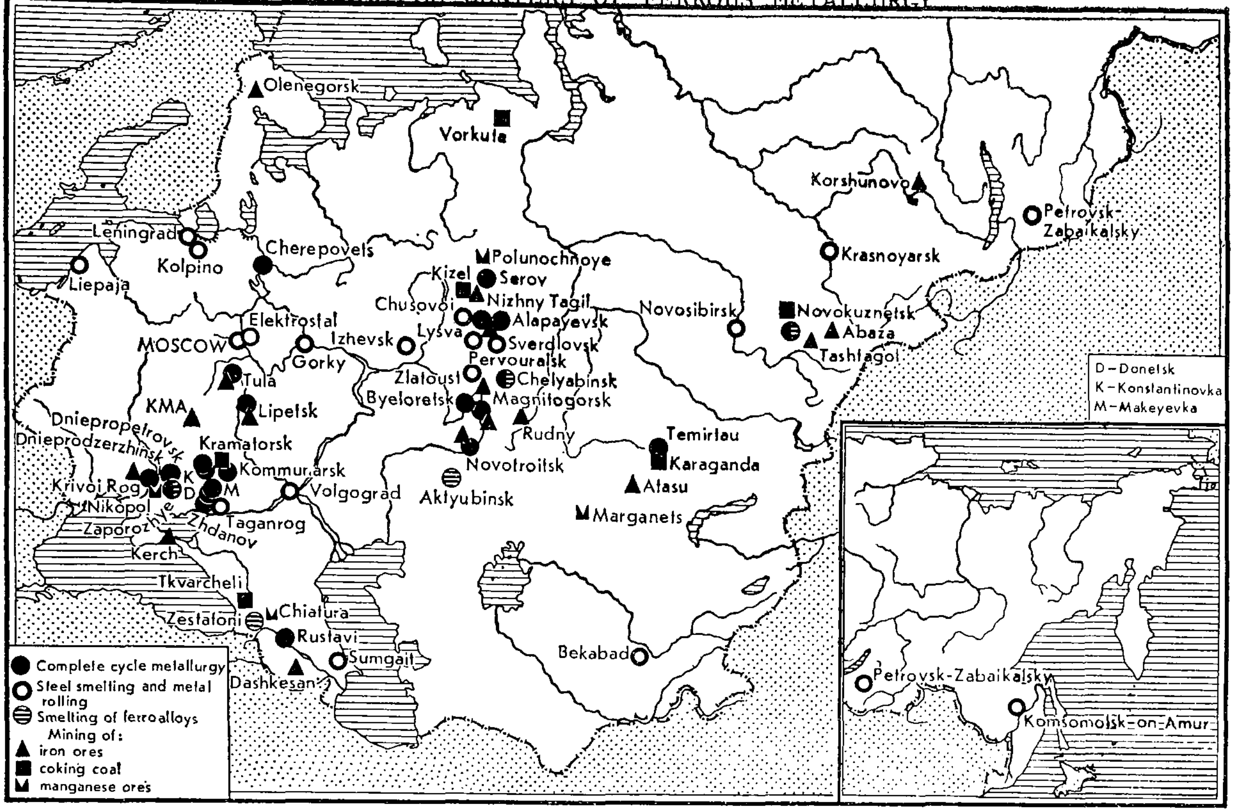
(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

THE MAJOR INDUSTRIAL CENTERS OF THE USSR

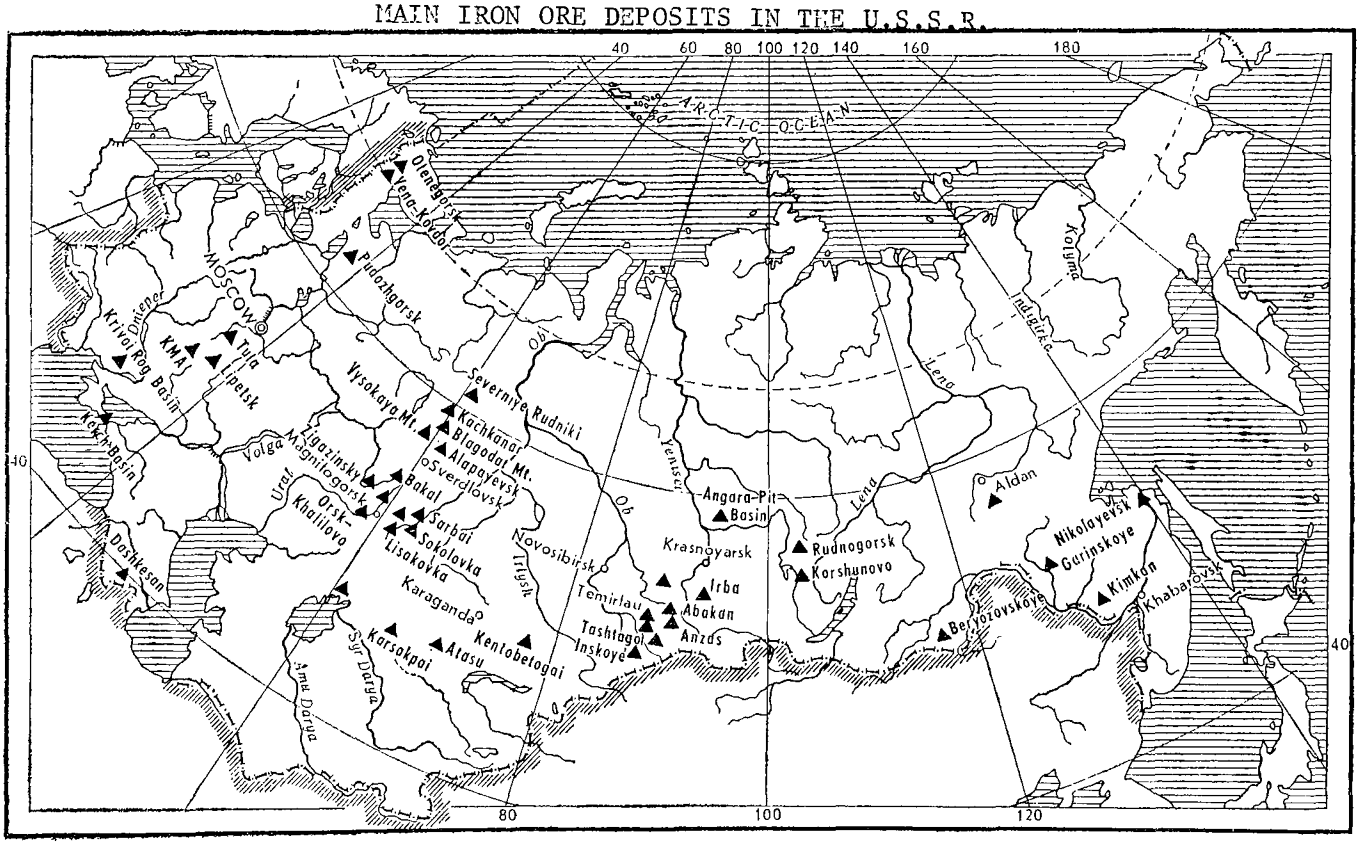


(After A. Efimov, "Soviet Industry", Moscow 1968)

PRINCIPAL CENTERS OF FERROUS METALLURGY

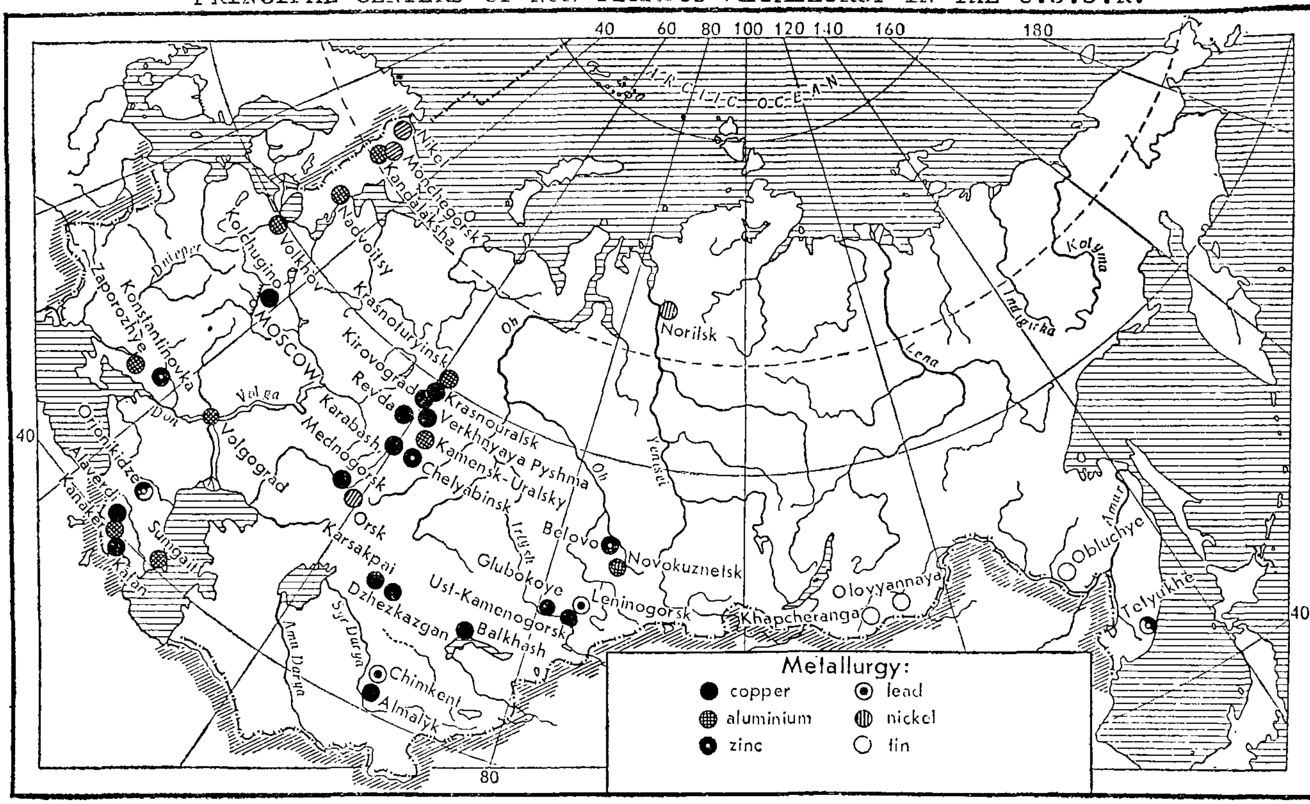


MAIN IRON ORE DEPOSITS IN THE U.S.S.R.

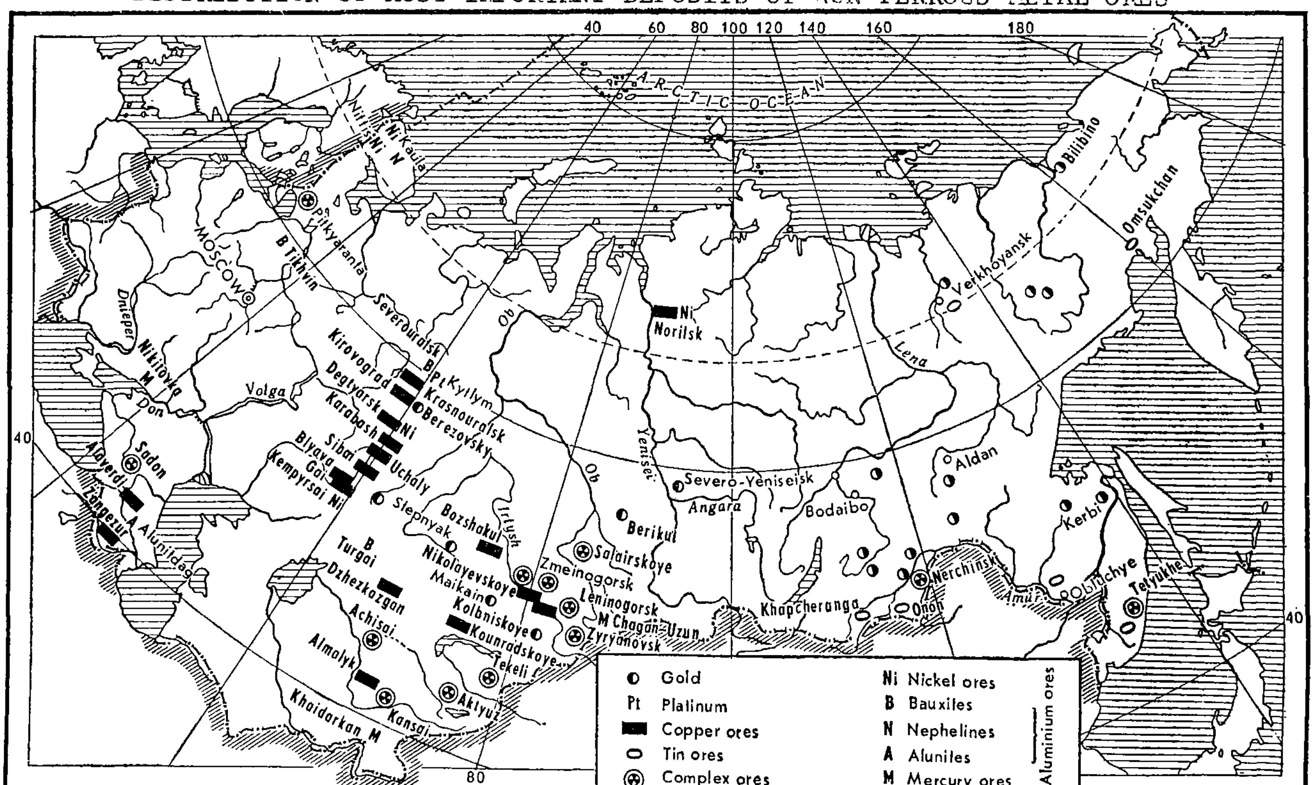


(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF NON-FERROUS METALLURGY IN THE U.S.S.R.

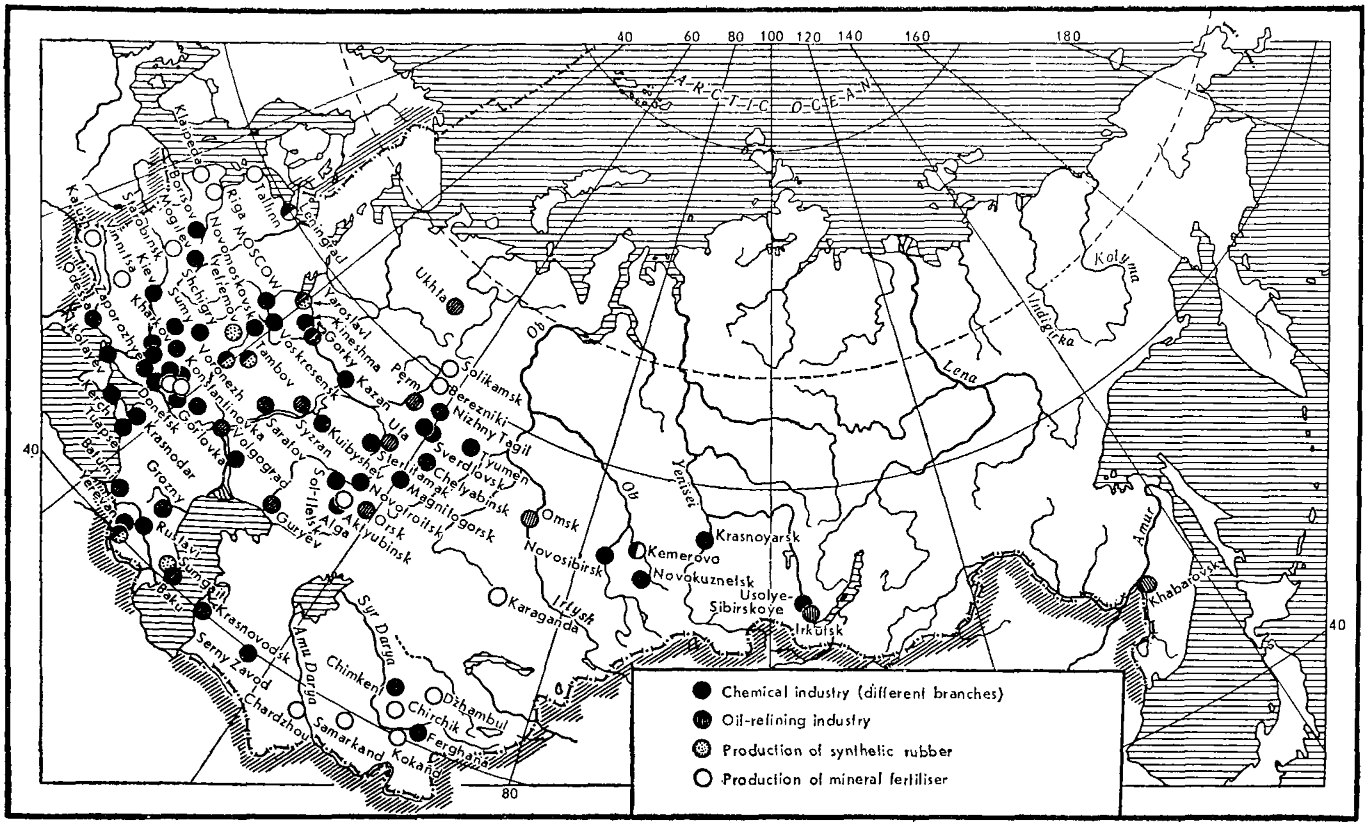


DISTRIBUTION OF MOST IMPORTANT DEPOSITS OF NON-FERROUS METAL ORES

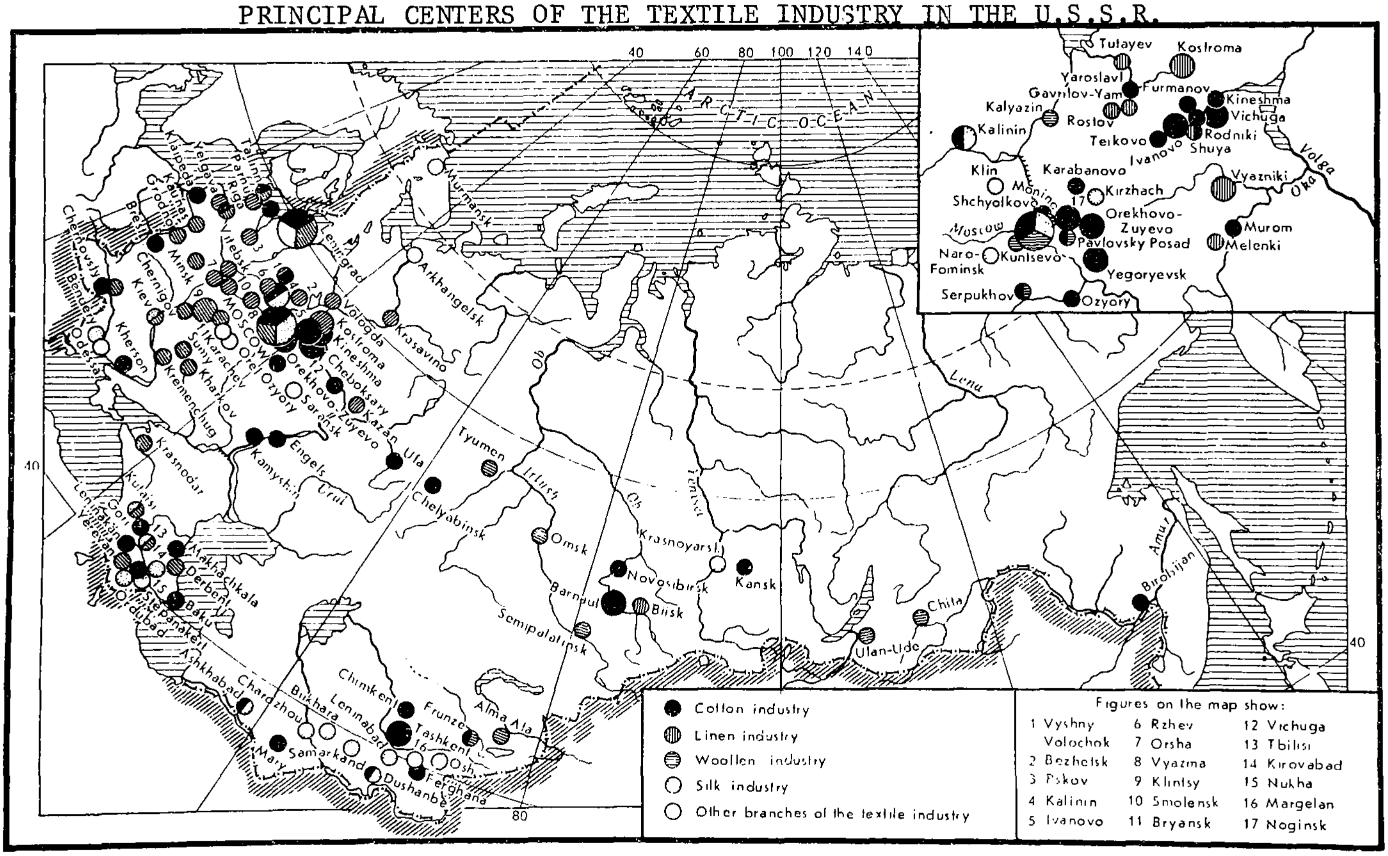


(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF THE CHEMICAL INDUSTRY IN THE U.S.S.R.

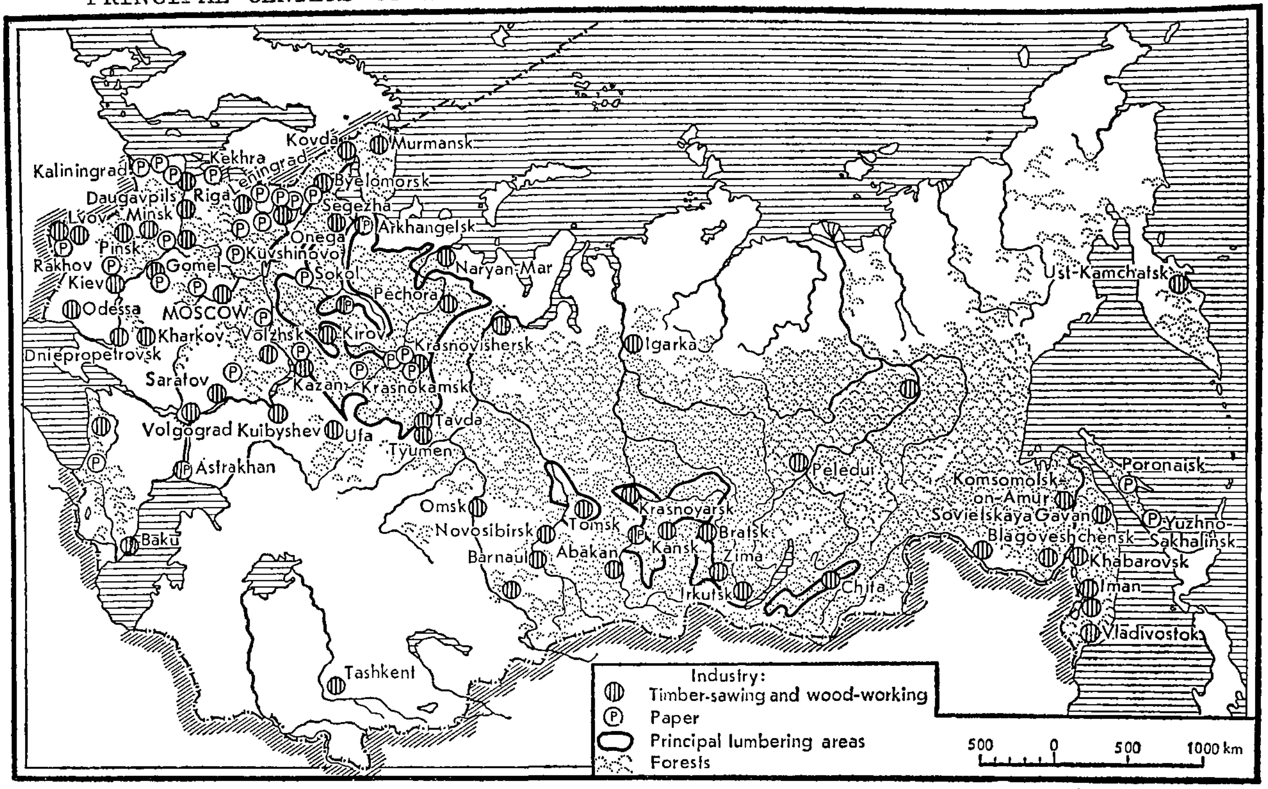


PRINCIPAL CENTERS OF THE TEXTILE INDUSTRY IN THE U.S.S.R.

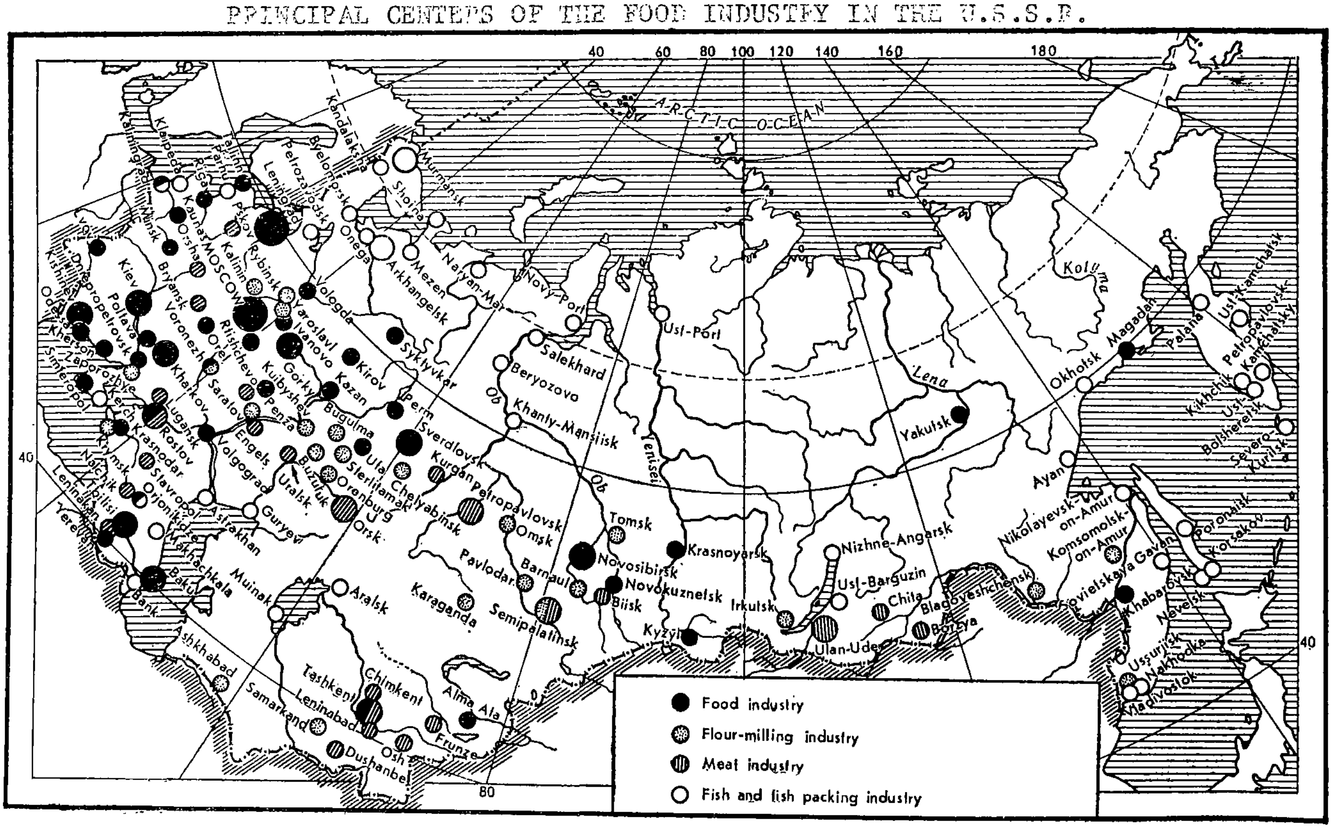


(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF WOOD-WORKING AND PAPER INDUSTRIES IN THE U.S.S.R.

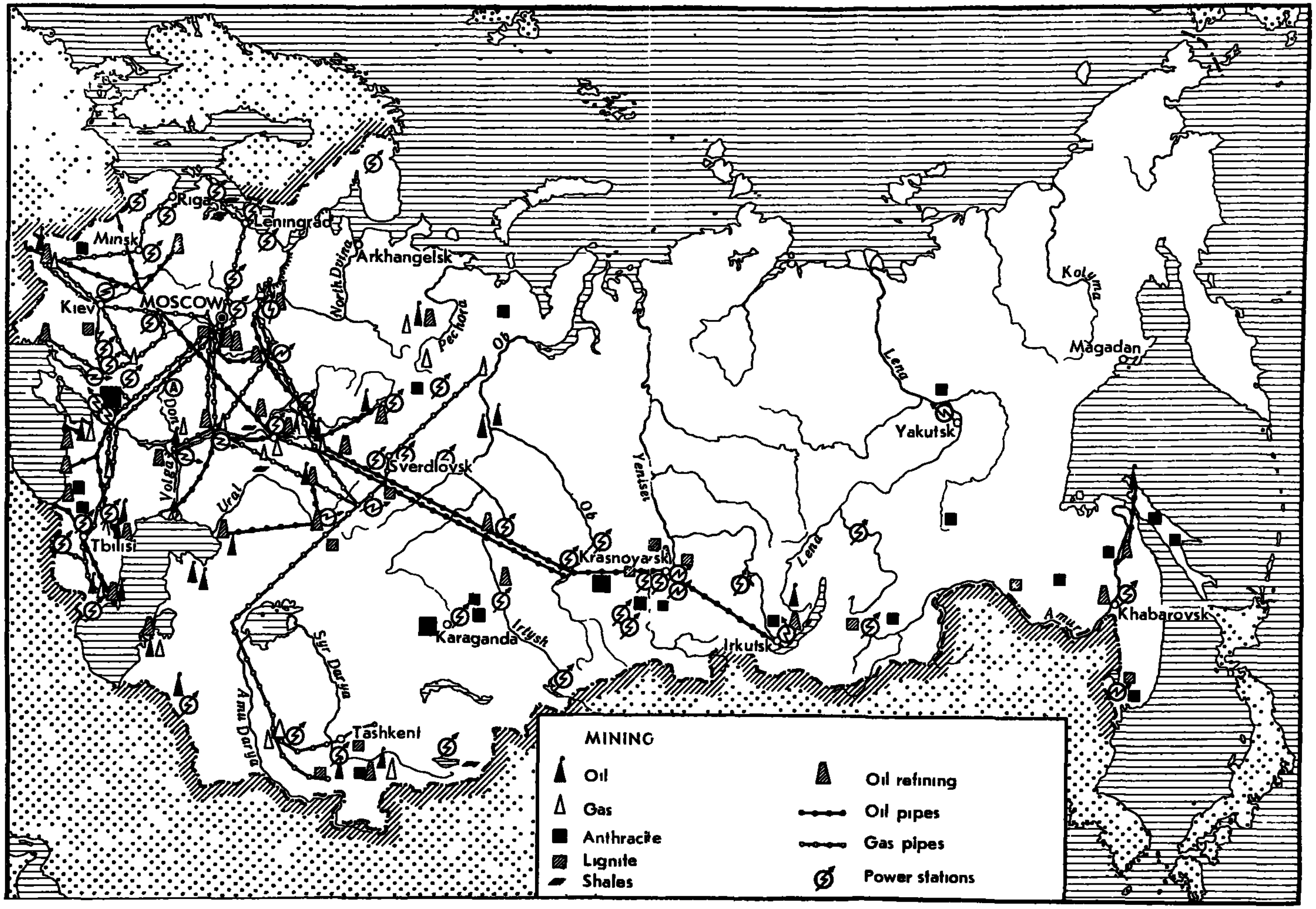


PRINCIPAL CENTERS OF THE FOOD INDUSTRY IN THE U.S.S.R.



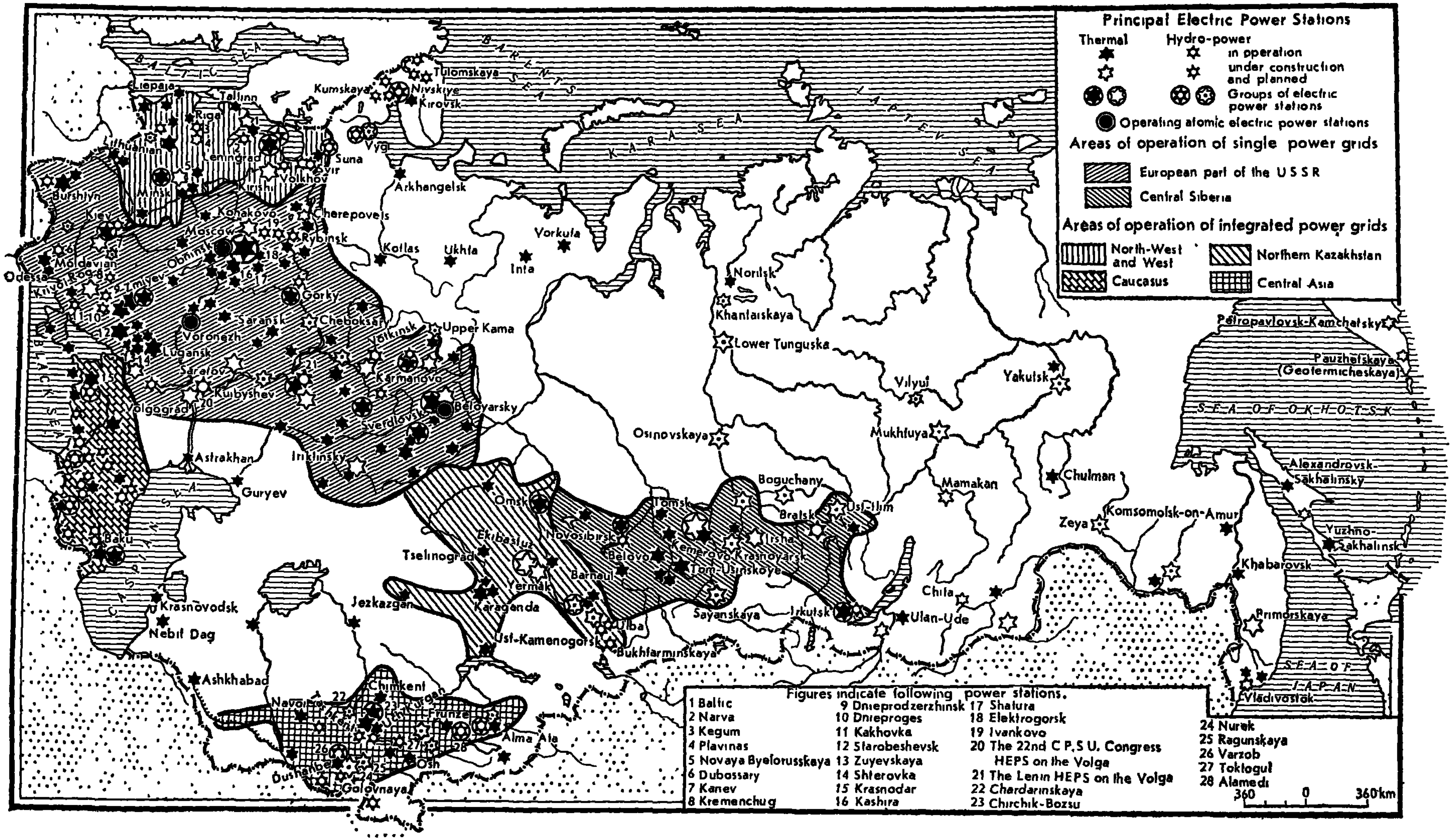
(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

THE MAIN MINING CENTERS OF THE USSR



(After A. Efimov, "Soviet Industry", Moscow 1968)

PRINCIPAL ELECTRIC POWER STATIONS AND POWER SYSTEMS IN THE U.S.S.R.



(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PROPAGATION OF ATMOSPHERIC IMPURITIES UNDER URBAN CONDITIONS*

Professor M. Ye. Berlyand

From Meteorologiya i Gidrologiya. No. 3, p. 45-56, (Mart 1970).

The article discusses some aspects of the variation of meteorological conditions in cities (formation of a "heat island" in the center of the city, increase in the frequency of fogs, elevated inversions, surface calms, etc.). It is noted that the majority of completed theoretical studies of atmospheric diffusion pertain to the conditions of an open, featureless landscape. The article explains to what extent the results obtained are applicable to the evaluation of impurity dispersal under urban conditions. It analyzes the characteristics of atmospheric diffusion and the role of factors determining the dispersal of impurities from high and low urban sources.

The analysis of the influence of meteorological factors on the study of impurities in the atmosphere is being given an increasing amount of attention at the present time. Knowledge of the relationships governing the spreading of an impurity is important for the formulation of recommendations aimed at protecting the air reservoir from pollution for the purpose of creating conditions where the concentration of pollutants would not exceed the permissible values. These values form the basis of an efficient organization of control of atmospheric purity, and in particular, the basis of the principles used for selecting a representative location and time of observation and analyzing the data obtained.

The solution of these problems, which pertain to urban conditions, involves the consideration of at least two key features. One is that under certain conditions, urban factors alone can have an appreciable effect on the meteorological conditions; the other has to do with the necessity of evaluating the overall effect of a large number of different polluting sources.

Studies of atmospheric diffusion of impurities and the methods developed for calculating the dispersal of discharges into the atmosphere pertain for the most part to individual sources and to conditions of an open flat country. The problems involved in the consideration of the total effect of a group of sources and of the change of the meteorological regime in the city have received relatively little study. Nevertheless, the results obtained for an open region are necessary, first of all, for evaluating the air pollution of populated areas. For this reason, they are frequently used formally without special basis also for the conditions of residential and, in particular, urban areas.

*Based on data of a paper given at a symposium on urban climate in Brussels (October, 1968).

To explain this possibility, it is necessary to consider the results of studies of urban meteorological conditions. An extensive literature on this problem is now available [13, 20, 34, 41, etc.], so in the present paper we shall attempt to discuss only some basic conclusions having a direct bearing on the problem under consideration.

It should be noted first of all that air pollution in many cities has reached such proportions that it is of itself one of the basic causes of the variations of the meteorological conditions mentioned here.

Dust frequently accumulates over a city, thus decreasing the transparency of air and reducing the solar radiation by 10-20%, and sometimes even more. Such an attenuation of the solar radiation, including its ultraviolet portion, is an important indicator of the adverse effect of air pollution, and should be considered by hygienists. The radiation effect is significantly related to changes in the heat balance and temperature conditions of the ground layer of air.

Many climatological studies have established that air in cities is on the average 0.5-1°C. warmer than in the surrounding area, this being frequently referred to as the "heat islands." In [13, 20, 30, 34, 41], a number of characteristics of these "islands" and their relationship to weather conditions have been discussed. It is shown that a temperature rise in cities is observed mainly at night in the presence of a slight wind and an almost cloudless sky, most frequently in winter, and almost never in daytime hours. A decrease of the temperature differences with increasing cloudiness and also on Sundays, when the air pollution is less than on working weekdays, indicates a direct relationship between the "heat island" and radiation factors. This relationship, noted by many authors, has received little study from the standpoint of the physics of the phenomenon and its quantitative evaluation. Leaving aside the problem of slight variation of the diurnal temperature maximum as the solar radiation is reduced, the increase of the nocturnal minimum temperature is frequently attributed to an attenuation of the long-wavelength radiation by urban aerosols. However, there are as yet no reliable data on the change of the long-wavelength balance in cities. Some estimates of the radiation effect have been made on the basis of theoretical investigations of the daily temperature variation [1, 27] for an open region in the presence of vegetation.

It follows from the results of calculation that a decrease in solar radiation, all the other conditions remaining the same in the case of clear weather, may lead to a 2-3°C. increase of the nocturnal temperature minimum in the ground layer of air. At the same time, the diurnal temperature maximum also decreases, but, because of the advective transfer and reinforcement of turbulent exchange in the daytime hours, this decrease is somewhat less.

The existing experimental data on the temperature conditions in a city pertain chiefly to the ground level. In the last few years, observations from television towers and special aerological observations have led to some conclusions regarding the vertical temperature profile above a city. It turns out that in daytime hours, this profile is close to that over an open region. In the presence of a "heat island", the temperature stratification in the layer of air up to a height of several tens of meters is close to the equilibrium stratification or slightly unstable, whereas outside the city an inversion is observed during that time [34, 37, 41, etc.]. Consequently, the formation of elevated inversion layers is more probable above a city.

In the streets and between buildings, the velocity and direction of the wind change considerably. In the general case, it is difficult to pinpoint any definite patterns to these changes, since they depend considerably on the specific elements of the city's structure. However, above the city's buildings, the wind profile and its variations with time acquire the features prevailing over an open region relatively rapidly. As follows from data now being accumulated from observations made from television towers, the influence of the city manifests itself chiefly as an effect of increase in the roughness of the underlying surface. Because of the diversity of the forms of urban construction, considerable possibilities lie in the simulation of the flow around them and the use of wind tunnels.

In this connection, interesting results have been obtained in joint studies made by the Main Geophysical Observatory and Moscow University [16], dealing with the distribution of the wind velocity and turbulence for various types of urban construction. They show that the wind velocity changes with the height, and more so in the presence of unlike buildings with different numbers of stories than in the case of construction with the same number of stories. On the average, the wind profiles are similar in both cases to the results of observations under natural urban conditions. Such conclusions pertain primarily to cases with well-defined horizontal flows of air over the city. In the presence of slight winds, the nature of the air currents may be substantially determined by the presence of a "heat island". The theory of this phenomenon has not yet been worked out. It follows from general considerations that a convective circulation arises in this case, and in the ground layer the wind velocity is directed toward the center of the city. The presence of these currents and their velocity, which amounts to 2-3 m/sec, have been confirmed. These results pertaining to variations of the wind temperature and velocity make it possible also to evaluate the nature of changes in the turbulent exchange over the city.

Summarizing the above, one can conclude that as a result of horizontal transfer and an intense vertical exchange of air over the city, there are frequently produced temperature and wind velocity distributions and hence turbulence coefficient distributions that are similar to those over an open region. Only in isolated cases are special conditions created which are unfavorable from the standpoint of atmospheric diffusion of impurities and require a special analysis.

This makes it possible to carry out an approximate calculation of the dispersal of impurities in a city (mainly, from fairly high sources) without a detailed consideration of the urban construction. In many cases, this approach can be validated by using the characteristics of diffusion of impurities from high sources. Analysis shows that as the distance from the source increases, the vertical impurity concentration profile is transformed in such fashion that in the zone where the ground concentration maximum is reached, the impurity becomes almost uniformly distributed in height. Consequently, even if the construction types do distort the conditions of mixing, they still cannot cause a considerable redistribution of the impurity (in this zone). As an example, we can refer to experimental studies in the region of the Shchekino SREPP (State Regional Electric Power Plant) [22]. Here, for the same wind directions, a change in the concentration of the impurities discharged from the SREPP's stacks was carried out in the city, and for other directions, over an open region. The results obtained showed that the influence of the city was slight.

Special experimental studies [40] dealing with the spreading of a tracer under urban conditions were made in St. Louis, USA. They showed that during the course of a day, the dispersions of impurities in the horizontal and vertical directions at a distance of 10 miles from the tracer source over the city and outside it differed little.

Thus far, (a) many studies have been made with the aim of developing various schemes and formulas for calculating the concentration of impurities around the sources [21, 41, etc.]. The effectiveness of the development of these studies is closely connected with the integration of the atmospheric diffusion equation:

$$u \frac{\partial q}{\partial x} - w \frac{\partial q}{\partial z} = \frac{\partial}{\partial z} k_z \frac{\partial q}{\partial z} + k_y \frac{\partial^2 q}{\partial y^2} \qquad (1)$$

for suitable boundary and initial conditions.

Here u is the wind velocity,
w is the vertical velocity of propagation of the impurity,
k_y, k_z are the horizontal and vertical components of the volume coefficient, respectively,
axis x is oriented along the direction of the average wind, axis y along the perpendicular to axis x in the horizontal plane, and axis z along the vertical.

In a city, because of the relatively large area it covers and also because of the presence of high sources, the layer of air in which the main transport of the impurity takes place extends to a height of several meters and higher. In such a case, and especially in the presence of elevated temperature inversions, the coefficients of (1) may be very complex functions of the coordinates. For this reason, considerable importance is assumed by methods of integration of equation (1) and by the use of computers in carrying out the calculations [8, 11].

In calculating the dispersal of pollutants in the atmosphere, it is necessary to consider the initial ascent of the impurity above the stack, caused by the entrainment velocity and the overheating of the stack gases. Because this ascent is a function of the wind velocity and of the meteorological factors, the dependence of the ground concentration on the weather conditions assumes an even more complex character. In particular, if we deal with the influence of the wind velocity u, then, on the one hand, at a fixed height of the discharge, the ground concentration q decreases with increasing u. On the other hand, a strengthening of the wind leads to a decrease of the initial ascent, as a result of which q increases. Consequently, there exists some unsafe velocity u_m at which the highest value of the maximum ground concentration C_m is reached.

If the discharge sources are located near the ground, the maximum concentrations are reached in the presence of ground inversions characterized by a weak turbulent exchange. When the impurities are discharged from stacks, the highest concentrations C_m near the ground are reached under conditions of convection with a developed turbulent exchange causing an intense transport of the impurity from the stacks downward, into the life-sustaining layer of air. In accordance with the theoretical studies cited [5, 11], the value of C_m for a uniform discharge of impurities into N stacks located close to each other may be determined from the formula

$$C_m = \frac{AMFm}{H^2} \sqrt[3]{\frac{N}{V \Delta T}}. \tag{2}$$

Here M and V are the amount of impurity and volume of stack gases discharged per unit time,

H is the stack height,

F and m are dimensionless coefficients. F depends on the settling rate of the impurity. F=1 for a light impurity and F > 1 for a heavy impurity. The value of m depends on the characteristics of the ejection of the gases from the stack. Coefficient A defines the influence of the vertical and horizontal distribution of the air temperature at the unsafe wind velocity, when the maximum value of the ground concentration is reached. Large values of A correspond to regions with a pronounced continental climate, which are characterized by an intense turbulent exchange as a result of large superadiabatic gradients in the summertime.

The value of the unsafe velocity is found from the formula

$$u_m = 0{,}65 \sqrt[3]{\frac{V \Delta T}{NH}}. \tag{3}$$

To evaluate the total effect of pollution from a group of sources with different unsafe velocities, it is desirable to determine the weighted mean value [11]:

$$u_{mi} = \frac{\sum_{i=1}^{N} u_{mi} C_{mi}}{\sum_{i=1}^{N} C_{mi}}, \tag{4}$$

where u_{mi} and C_{mi} are, respectively, the values of the unsafe velocity and highest concentration for the i-th source.

In the general case, when the sources are not grouped around a point or a straight line, as is frequently the case in large cities, it is necessary to sum up the concentration fields of the individual sources. It is necessary to consider the different wind directions since they determine the change of the relative positions of the sources. Such computations, particularly for cities with large numbers of sources, are extremely cumbersome. It is possible to simplify them to a certain extent because the concentrations in the direction perpendicular to the wind decrease much faster than those parallel to it. A computer program has been written for the computations in the case of a large number of sources according to the above [11].

The theoretical results cited pertaining to the patterns of the spreading of impurities from their sources have been confirmed by an extensive experimental material [17, 18, 21]. They were used as the basis for the development of a procedure and recommendations for calculating the dispersal of impurities in the atmosphere in connection with the design and operation of industrial enterprises [14, 25].

The results pertained to comparatively frequent unfavorable meteorological conditions. The calculations made use of the logarithmic law of variation of the wind velocity with height, and for the temperature, of its decrease with height, so that the exchange coefficient increased linearly with height in the ground layer and remained constant above it. At the same time, the turbulence is vigorous and an intense mixing takes place between the layers of air located above the stacks and those adjacent to the underlying surface.

The theoretical studies performed indicate, in accord with earlier studies by Hewson and others, that ground concentrations may reach even higher values in the presence of elevated inversion layers with an attenuated turbulence. This point is particularly essential in connection with the above-mentioned tendency toward an increased frequency of elevated inversions over a city.

It follows from the calculations of [3, 6] that under conditions where a layer with an attenuated turbulence is located immediately above the sources, the maximum concentration of light impurities sometimes increases by a factor of more than 2. However, in cases where such a layer is located at a height of 100-200 m above the sources, the concentration increase is much less. It should be noted that in the presence of a layer with an attenuated turbulence, there is not only an increase in the concentration maximum, but also a considerable increase in the area where it is observed. Moreover, the decrease of the concentration past its maximum takes place very slowly. Hence, as was noted in [9], the effect of mutual superposition of concentration fields from individual sources is enhanced. In addition, even if the concentrations from single sources are comparatively small, the city's total pollution caused by a large number of these sources may be very considerable.

Elevated inversions may have a much greater effect in the case of cold discharges [7]. Under such conditions, the initial ascent does not exceed a certain limit, independently of the decrease of the wind velocity and, hence, the value of the unsafe velocity decreases, and the ground concentrations increase abruptly.

Under urban conditions, it is essential to take into account the deviations in the vertical wind profile from the logarithmic profile, in particular, a possible attenuation of the wind velocity to a calm in the lowest layer of air. Such deviations in cities are because the buildings cause the air current to slow down. Up to the level of the height of buildings, the average wind velocity may frequently be close to zero, whereas turbulent exchange is fairly developed here. On the other hand, above the buildings, the wind velocity increases rapidly in approximately logarithmic fashion. The calculations performed [6, 28] show that the presence of still layers near the underlying surface leads to a substantial increase of the concentration.

Of major importance in evaluating the meteorological factors of urban air pollution is the analysis of the influence of fogs. They and their modification, the smog, are held responsible for cases of mass morbidity and increased death rate in cities, since the frequency of fogs under urban conditions is substantially higher than in rural areas. Their chief cause is heavy air pollution. This is not only a question of an increased quantity of condensation nuclei (analysis shows that there are enough of them for the formation of fogs, provided that moisture saturates the air outside the cities as well), but rather that the urban impurities contain a considerable amount of hygroscopic particles. The moisture condensation on such particles may begin at a relative humidity below 100%, and hence, the probability of formation of a fog increases.

The conditions of air pollution in the presence of fogs have received little study. The available experimental material has been inadequately analyzed. In [9], on the basis of the indicated numerical analyses, some theoretical aspects of the diffusion of gaseous impurities in the presence of fogs have been discussed. Fogs forming on the banks of rivers and water reservoirs have been investigated. The height of the fogs and the vertical and horizontal distributions of the moisture content and exchange coefficient were determined theoretically. Also studied were cases of radiation fogs, bearing in mind that an elevated temperature inversion might be located above them. The calculations revealed some interesting effects, in particular, the fact that in addition to a redistribution of the pollutants because of their absorption by water droplets, there occurs a substantial increase of the ground concentrations as a result of the transport of these pollutants from layers of air located above the fog.

Urban fogs are formed more frequently in the mornings, thus increasing the probability that they will be associated with elevated inversions. This in turn reinforces the effect of air pollution, particularly from many sources.

Topographic inequalities may have a substantial influence on the spreading of an impurity in a city. Under hilly topographical conditions, the character of the motion of air changes considerably. The use of modern methods of theoretical analysis has provided an approach to the solution of this difficult problem.

Thus far, calculations have been made for individual examples of a hilly topography. According to [6, 12], it has been found that under such conditions, the maximum ground concentration is mostly higher than on level ground. For a height of irregularities in excess of 50-100 m with slope angles of about 5-6° to the horizon, the difference in the concentration maximum is as high as 50% or more, depending on the location of the source in the different forms of the relief. An increase of the concentration is sometimes observed even when the pollution sources are in high locations, but the latter are in the vicinity of leeward slopes, where the wind velocity decreases markedly and descending currents are generated.

Analysis has shown that in the case of smooth relief forms, the latter are almost completely surrounded by air currents, and an increase of the concentration is manifested in areas where the wind velocity changes substantially at a fixed height. The combination of the boundary layer method and the method of construction of potential flows has provided an explanation for certain characteristics of the velocity field necessary for calculating the turbulent diffusion [12]. The wind tunnel experiments briefly discussed above were set up under close to self-similar conditions, permitting the extension of the results of the simulation to atmospheric processes. As a result, data were obtained on the vertical wind profile in various parts of the relief depending on the slope angle of the underlying surface, the height drop, etc. [16, 19, 28].

In modelling studies conducted in wind tunnels, there is a certain common approach to the investigation of the flow around the irregularities of the relief and to the detetmination of the structure of the air current around residential and industrial structures. In both cases, perturbations in the field of vertical and horizontal velocities are studied. The experiments cited, performed on models of individual industrial enterprises and buildings, revealed the zones in which descending currents and stagnations of the impurity are possible.

In order to avoid a substantial increase in the concentration of the noxious substances discharged from the stacks in such zones, Khokinsom and Naneblom and others recommend that the stacks be 2.5 times as high as the nearest building.

The results mentioned above, pertaining to the wind profile and turbulence, obtained with models may be used directly in accordance with the above scheme of numerical analysis of atmospheric diffusion. For the study of the transport of impurities from low sources, it is convenient to determine the velocity and direction of the air currents in the streets and between buildings. To this end, the studies made by the Main Geophysical Observatory and Moscow University dealt with the ground flow field on models of urban constructions. It was found that the character of the motion in different parts of the city blocks depends not only on the direction of the wind over the city but also on the degree of turbulence of the air flow.

The above formulas made it possible to calculate the values of the impurity concentration pertaining to a twenty-minute withdrawal of air samples. In the derivation of the original formulas, particularly for C_m (2), account was taken of the probability $\omega(\varphi)$ of deviation of the wind direction with time in the horizontal plane at angle φ, usually described by the Gauss law [5, 15]:

$$\omega(\varphi)=\frac{1}{\varphi_0\sqrt{2\pi}}\,e^{-\frac{\varphi^2}{2\varphi_0^2}}. \tag{5}$$

If the duration of the sampling is increased, the dispersion of the oscillations of the wind direction φ_0 increases, and as a result, the concentration along the direction of the mean wind becomes less, and in the transverse direction, smoother. In order to give a sanitary evaluation of air purity, the concentration values obtained should be compared with the highest single maximum permissible concentrations, which also pertain to a time interval of approximately 20 minutes.

If the study deals with air pollution from an individual source during long periods, including periods of time T* covering many years, it is necessary to consider the probability of the wind direction $\Omega(\alpha)$ at angle α, this probability being determined by large-scale eddies and usually characterized by the wind rose [11]. In these cases, the average concentration $\overline{C}$ during period T* at a stationary observation point is determined on the basis of the above values by means of the relation

$$C=\int_{-\pi}^{\pi} C\,\Omega(\alpha)\,d\alpha. \tag{6}$$

For a single source, the value of $\Omega(\alpha)$ is different from zero in a comparatively small angle in which one can assume that $\Omega(\alpha)=\Omega_\alpha$ = const. Here the frequency of oscillations of the wind direction $\omega(\varphi)$, caused by the action of smaller-scale eddies, is described by (5). Then

$$\overline{C}=\sqrt{2\pi}\,\varphi_0\,\Omega_\alpha\,C. \tag{7}$$

Usually, $\varphi_0\approx 0{,}1$. For this reason, the average values of the concentration $\overline{C}$ are much lower than the single values C. A similar averaging procedure may be carried out in the determination of the concentration at a stationary point surrounded by many pollution sources. In the latter case, the impurity may fall at a point for any wind direction. The concentration at this point over a long period of time will be determined as the result of the combined action of all the surrounding sources. This principle underlies a series of simple schemes for calculating air pollution in a city, for example, in the work of Clarke [31], and others.

A somewhat different scheme, but essentially similar to the above, was developed by Turner [43], Pooler [39], and others. The authors divided the city into a grid of squares and carried out an approximate evaluation of the discharge of pollutants in each square (inventory of the sources). Then, at a point of the city under consideration, they determined the total surface concentration produced as a result of the action of the sources surrounding that point, assuming their height and the initial ascent to be the same all over the city. Lucas [36], Miller and Holtzworth [37] and others treated the city as a set of fine sources distributed in comparatively uniform fashion over the urban area. The total concentration near the ground was determined by integrating the expressions for the concentration from a point source at a certain average height over the area. In an evaluation of the concentration from a flow of moving automobiles, Neiburger [42] treats this as a stationary plane source.

The results of the theoretical studies discussed provide certain grounds for predicting the degree of air pollution. On the basis of forecasts of weather conditions, in particular, elevated inversions, calms, fogs, and also intense turbulence, in the case of comparatively high sources, one can identify the periods when large values of the ground concentration of pollutants should be expected.

It should be noted at the same time that, despite the considerable possibilities of application of the theory of atmospheric diffusion to the calculation and forecasting of the spreading of impurities in a city, substantial difficulties still exist. They are due to the scantiness and lack of certain data, including data on the nature of discharges and on a number of meteorological parameters necessary for such calculations. It is also necessary to take into consideration the partially random nature of the operating factors.

For this reason, the organization of the most complete possible set of observations in a city and a physical-statistical analysis of the data obtained assume an essential importance. In many cities throughout the world, areas have now been set aside for systematic observations of atmospheric pollution. Special pavilions are being set up for this purpose in the USSR; they are placed at intersections of streets or in city squares in areas of highest air pollution. Moreover, observations are made several times a day on the concentration of the most common ingredients and a number of meteorological elements. Automobiles are also used to measure the concentrations along certain routes and under the plumes of high-capacity industrial plants. A number of cities have already collected relatively large amounts of data which permit the analysis of certain patterns of variation of the maximum concentration, frequency of heavy air pollution, etc. [10, 26].

In the USSR, as in other countries, the heaviest air pollution is, of course, observed in large industrial centers. Moreover, observational data indicate that urban air is most heavily polluted in areas where unfavorable weather conditions prevail [8, 23]. According to measurements of the concentration of dust, sulfur dioxide, etc., such regions show maximum concentration values and high frequencies of days when the concentration exceeds the maximum permissible values. At the same time, these areas are characterized by the development of intense turbulence, which causes the ground concentrations in regions of large and high sources to increase. In the calculations of the maximum concentrations, the values of coefficient A in formula (2) are assumed to be the highest for these areas.

It is common knowledge that a considerable portion of ash and sulfur dioxide enters the atmosphere as a result of the combustion of fuel, the fuel consumption being much lower in summer than in winter. Nevertheless, in many cities the concentrations of these impurities were observed during the warm half of the year in the presence of an intense turbulent exchange [23]. According to observational data, particularly for regions of low and cold impurity sources, there are, as was indicated above, unsafe pollution levels under temperature inversion and air stagnation conditions as well.

Analysis of the experimental data is also used to study the influence of the synoptic situation, washing out of the impurities by precipitation, etc. It is of interest to study cases in which either an increase or a decrease of the concentration of one of several ingredients is simultaneously observed at a large number of points in the city. It turns out that cases of heavy air pollution, particularly during the cold half of the year, are mostly observed during stationary anticyclones in the zone of low atmospheric pressure gradients. A comparatively clean air is observed in cyclonic weather. This is illustrated by Table 1, compiled on the basis of observational data for Moscow, Leningrad and Magnitogorsk [24].

Table 1

Deviation From Average Frequency of the Impurity Concentration Greater than the Maximum Permissible Value During Stationary Anticyclones, %.

City	Dust		Sulfur Dioxide	
	Cold Period	Warm Period	Cold Period	Warm Period
Moscow	+7	+1	+18	−2
Leningrad	+21	+13	+13	−1
Magnitogorsk	+34	+21	+19	+4

The studies performed, essentially on a statistical plane, pertain basically to the investigation of the correlation dependence between the concentration of the impurity at one or several points and individual factors, provided that the influence of other factors can be kept constant. Estimates of the correlation factors, analyses of certain structural functions, etc., were carried out in this manner. For example, on the basis of the indicated studies it was found that for a number of cities, the correlation factor between the frequency of the concentration above the permissible values in the course of a month and the monthly pressure anomalies was about 0.5. In [33] it was found that under certain urban conditions, the correlation factor between the dust concentration and certain meteorological elements was higher than between this concentration and the amount of fuel burned.

At the present time, several approaches to a more complete statistical analysis of observational data are being developed at the Main Geophysical Observatory. One approach involves the study of a multiple correlation, i.e., taking into account the influence of a set of factors. Here the separation of the principal factors is not always successful, and the effectiveness of this approach proves limited. Another approach consists in using the method of expansion in a statistically orthogonal system, that is to say, in real functions of the concentration field of the impurity. To this end, the covariant matrices are calculated from data on unnormalized correlations between the concentrations at different points of the city, and the eigenvalues are obtained. The first terms of the expansion reveal the influence of the set of principal factors. The study of the behavior of these terms with time may serve as the basis for a statistical prediction of urban air pollution. In order to exclude random effects, first a certain averaging of the coefficients over time and a normalization of the measured concentrations to their average values over a sufficiently long period of time are carried out. Analysis of variance and factor analysis may also be useful in the study of the concentration field of impurities in a city.

In addition, it should be kept in mind that urban air pollution is caused by the action of a very large number of factors, and the observational data are limited. For this reason, the use of even the most perfect modern methods of statistical analysis, particularly for purposes of forecasting air pollution, is inadequate, and in order to increase their effectiveness, it is important to separate the influence of a number of principal factors on the basis of physical considerations.

In the study of the weather conditions associated with urban air pollution, it is also very important to examine the problem of the spreading of the impurity beyond the city limits, both vertically and horizontally. Of late, in addition to ground observations, the impurity concentrations have also been measured by means of helicopters and airplanes [18, 35]. Thus it was found that several concentration maxima may be observed in the vertical distribution of an impurity. In particular, high concentrations of carbon monoxide were found over Leningrad and Budapest at heights of 100-300 m. This is due to discharges of carbon monoxide from high stacks, and also to the characteristics of the temperature stratification, which determines the variations of the exchange coefficient in height. The study of the vertical distribution of an impurity is now assuming a special interest in connection with the construction of air intakes that supply clean air to industrial plants [10].

The spreading of an impurity from the city as a whole is now being followed over distances of several tens of kilometers. Given the modern tendency toward urban sprawl and the merging of cities in many countries, there is danger of polluting vast territories extending over hundreds of kilometers.

The results discussed above demonstrate certain advances in the study of the relationships governing the spreading of impurities in the atmosphere. Nevertheless, the investigation of many important aspects of urban air pollution is only beginning, and their solution will require a further development of the theory of atmospheric diffusion, physical-statistical analysis, and experimental studies under natural and laboratory conditions.

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DANGEROUS CONDITIONS OF POLLUTION OF THE ATMOSPHERE BY INDUSTRIAL DISCHARGES

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The initial ascent of impurities from smokestacks is studied as a function of the coefficient of turbulent exchange and temperature gradient in the atmosphere. Conditions are indicated for which the initial ascent of the impurity in the presence of a temperature inversion may be slight. In cases where such conditions are associated with low wind velocities, an abnormally dangerous situation arises in which the surface concentrations of the impurity reach very high values.

1. Introduction

The surface concentrations of impurities discharged through smokestacks and air ducts substantially depend on the meteorological conditions. For a constant discharge of these impurities, their concentration at a given distance from the stacks may change by a factor of tens and even hundreds depending on the wind velocity, stability of the atmosphere and some other meteorological characteristics. Cases with the highest concentrations of noxious substances in the ground layer of air pertain to dangerous conditions of atmospheric pollution.

Dangerous conditions are frequently related to the presence of layers of an elevated temperature inversion. It is assumed that elevated inversions were observed during periods of known "disasters" in London and other places where considerable pollution of air was observed, associated with human victims and a marked increase of the disease rate among the population. The dangerous character of such stratification of the atmosphere is usually determined from qualitative considerations. It is assumed that the layer of an elevated inversion is characterized by an attenuated turbulent exchange hindering the transport of impurities to higher levels. As a result, the bulk of the impurity mass concentrates under the inversion layer near the earth's surface.

The published literature gives little experimental material on the increase of the concentration under these conditions. Lowry [8] points out that according to the observational data, when the inversions are located above the source, the concentrations increase by a factor of up to 20. The same results, without mention of the specific conditions of observation, are cited in [5] and in some other studies. In the presence of elevated inversions, an increase in concentration, but much smaller, by a factor of approximately 1.5-2, is shown by the data of [11] and of others. According to the existing classification of plume forms [5, etc.], these cases pertain to conditions of "smoke pollution" of the ground layer of air. A series of attempts at a theoretical evaluation of the concentration of an impurity from a source have been made under such conditions (Bierly and Hewson [6], Holland [7], etc.). However, the calculations in these studies were based on very primitive assumptions of a uniform vertical distribution of the impurity in the subinversion layer.

A more rigorous approach to this problem was developed in [1] and [2] as a result of a numerical solution of the equation of turbulent diffusion of the impurity from the source, solution which made it possible to take into consideration the complex character of the variation of the exchange coefficient with the height. The studies give calculations of the surface concentration for cases in which the inversion layers are located at different heights above the level of the source. It was assumed that the vertical component of the exchange coefficient in the inversion layer is sharply attenuated. It was found that the increase of the impurity concentration substantially depends on the height of the lower inversion boundary above the source and on the height of the source. This increase is greater the closer the base of the inversion layer is to the source and the lower the level of the source. If the layer of attenuated turbulence is located at a sufficient distance (about 200 m or more) above the source, the increase of the surface concentration is relatively slight, and it is substantial only at very large distances. In cases where the blocking layer begins immediately above the source, the increase in the maximum of the ground concentration amounts to 50-70% and sometimes to more than 100%.

Cases of elevated inversion pertain to abnormal stratification conditions. Some cases of abnormal distribution of the wind velocity with the height were examined in [4]. It was found that the presence of still layers in the propagation zone of the impurity causes an increase of its ground concentration. When a layer with an attenuated wind velocity is located at a certain level, the lower this level, the stronger the influence of the given layer. According to the performed calculations, in the presence of a surface calm up to a height of 30 m, the maximum concentration q from a source 100-150 m high increases by approximately 70% as compared to the values of q in the absence of a calm.

The solution of the problem of determination of the highest concentrations under normal conditions, when the temperature decreases continuously with the height and the wind velocity increases with the height in an approximately logarithmic manner, was investigated in [3]. Such conditions are usually characteristic of summer daytime in fair weather. Analysis of this solution shows that the values of the highest concentrations depend in a complex manner on the wind velocity. On the one hand, for a fixed discharge, the maximum of the ground concentration increases with decreasing wind velocity. On the other hand, an attenuation of the wind leads to an increase in the initial ascent of the impurity, so that its surface concentration decreases. Consequently, there exists some dangerous wind velocity u_m at which the highest value of the surface concentration q_m is reached. We obtained a formula for determining u_m and q_m in [3].

In evaluating dangerous conditions, it is of interest to determine the distribution of the air temperature in height, particularly the distribution of elevated inversions and wind velocity. The present paper is devoted to an analysis of this problem.

2. Influence of the Temperature Gradient on the Initial Ascent of the Impurity.

In recent years, the initial ascent of an impurity caused by its overheating has been studied, and a number of works have been devoted to the vertical escape velocity from the stack.

One of the most extensive investigations of the jet stream of a heated gas in stationary air is due to Pristley and Boll [10]. Certain restrictions in the application of their results to atmospheric problems are due to the fact that they excluded the influence of turbulent exchange by introducing a new, unknown parameter.

In [4] and [3] we dwelt on a rigorous formulation of this problem. Certain difficulties in its solution pertain to the consideration of the driving effect of the wind velocity. However, for many aspects which will be discussed below, it is sufficient to obtain the solution for simpler conditions of consideration of this effect.

We shall examine the Pristley-Boll problem by generalizing it with respect to the consideration of the intensity of atmospheric turbulence.

As the initial conditions for an axisymmetric jet, we shall take the following equation of motion

$$\frac{\partial}{\partial r}(ruw)+\frac{\partial}{\partial z}(rw^2)=\frac{\partial}{\partial r}rk\frac{\partial w}{\partial z}+rg\frac{\vartheta}{\theta}, \qquad (1)$$

the equation of influx of heat

$$\frac{\partial}{\partial r}(ru\vartheta)+\frac{\partial}{\partial z}[rw(\vartheta+\theta)]=\frac{\partial}{\partial r}rk\frac{\partial\vartheta}{\partial r} \qquad (2)$$

and the energy equation obtained directly from the equation of motion by multiplying the latter by w

$$\frac{\partial}{\partial r}\left(\frac{ruw^2}{2}\right)+\frac{\partial}{\partial z}\left(\frac{rw^3}{2}\right)=w\frac{\partial}{\partial r}rk\frac{\partial w}{\partial r}+rgw\frac{\vartheta}{\theta} \qquad (3)$$

the above equations having been transformed by using the continuity equation in the cylindrical coordinate system (r being the radius and z the height). Here u is the radial and w the vertical component of the displacement velocity; ϑ is the deviation of the temperature in the jet from θ, where θ is the temperature of the surrounding atmosphere on the absolute scale (θ is assumed to be a function of only the vertical coordinate z); k is the turbulent exchange coefficient; g is the acceleration due to gravity.

It is assumed that the changes of air density in the jet and also the difference in the densities of air in the jet and the surrounding medium are slight.

According to the boundary conditions, on the axis of the jet ($r = 0$), u, $\frac{\partial w}{\partial r}$ and $\frac{\partial \vartheta}{\partial r}$ disappear, at a large distance from the axis ($r \to \infty$), w and θ turn to zero, and at $z = 0$, w and θ take the assigned values.

We obtain for the axisymmetric jet

$$w = w_m f(\eta), \quad \vartheta = \vartheta_m f(\eta); \tag{4}$$

$$f(\eta) = e^{-\frac{\eta^2}{2}}, \quad \eta = \frac{r}{R}, \tag{5}$$

where R is some effective radius of the jet, and the subscript m pertains to values of w and θ on the jet axis.

Integrating equations (1), (3) and the boundary conditions with respect to r from 0 to ∞, we obtain the following system of ordinary equations

$$\frac{d}{dz} w_m^2 R^2 = \frac{2g}{\theta} \vartheta_m R^2, \tag{6}$$

$$\frac{d}{dz} w_m \vartheta_m R^2 = -2 w_m R^2 \frac{\partial \theta}{\partial z}, \tag{7}$$

$$\frac{d}{dz} w_m^3 R^2 = \frac{3g}{\theta} w_m \vartheta_m R^2 - 3k w_m^2 \tag{8}$$

with the boundary condition

$$\text{at } z = 0 \quad w_m = w_0, \quad \vartheta_m = \Delta T_0,$$

where w_0 is the escape velocity of the stack gases from the stack and ΔT_0 is the difference in the temperature of the gases and of the surrounding atmosphere at the level of the mouth of the stack.

It follows from (6) and (7) that

$$\frac{d}{dz} (w_m \vartheta_m R^2)^2 + \frac{\theta}{g} \frac{\partial \theta}{\partial z} \frac{d}{dz} (w_m R)^4 = 0 \tag{9}$$

or for a constant value of $\frac{\partial \theta}{\partial z}$

$$(w_m \vartheta_m R^2)^2 + \frac{\theta}{g} \frac{\partial \theta}{\partial z} (w_m R)^4 = A^2, \tag{10}$$

where A is the integration constant.

Further, determining ϑ_m from (10) and substituting into (9), we obtain

$$\frac{d}{dz} (w_m R)^2 = \frac{2gA}{\theta w_m} \left(1 - B w_m^4 R^4\right)^{\frac{1}{2}}, \tag{11}$$

where $B = \frac{\theta}{gA^2} \frac{\partial \vartheta}{\partial z}$.

From (6) and (8) it follows that

$$\frac{dR^2}{dz}=\frac{6k}{w_m}. \quad (12)$$

Substituting (12) into (11), we get

$$\frac{d}{dR^2}(w_m R)^2=\frac{gA}{3k\theta}(1-Bw^4R^4)^{\frac{1}{2}}. \quad (13)$$

We introduce the substitution of variables

$$s=w_m RB^{\frac{1}{4}} \quad (14)$$

and integrate (13); then

$$\int_0^s \frac{ds^2}{\sqrt{1-s^4}}=fR^2+E, \quad (15)$$

where $f=\frac{gA\sqrt{B}}{3k\theta}$, E is the integration constant found from initial data.

When the integration is carried out in (15), it is necessary to distinguish two cases depending on the sign of the temperature gradient $\frac{\partial\theta}{\partial z}$. For the case of a positive gradient $\frac{\partial\theta}{\partial z}$ (hence, B > 0 also), i.e., in the presence of an inversion stratification, when the potential temperature increases with the height, we introduce the substitution of variables

$$s^2=\sin\varphi, \quad (16)$$

and for $\frac{\partial\theta}{\partial z}<0$

$$s^2=\sinh\varphi. \quad (17)$$

We then find that the integral in the left-hand part of (15) is equal to φ. Hence, for $\frac{\partial\theta}{\partial z}>0$ in accordance with (14) and (15)

$$\arcsin w_m^2 R^2\sqrt{B}=fR^2+E, \quad (18)$$

whence

$$w_m=\frac{1}{RB^{\frac{1}{4}}}\sin^{\frac{1}{2}}(fR^2+E) \quad (19)$$

and in accordance with the initial data

$$E=\arcsin w_0^2 R_0^2\sqrt{B}-fR_0^2.$$

From (11) amd (18) we get the following expression for ϑ_m

$$\vartheta_m=\frac{AB^{\frac{1}{4}}\cos(fR^2+E)}{R\sin^{\frac{1}{2}}(fR^2+E)}. \quad (20)$$

Let us now consider the problem of the exchange coefficient k.

In cases where the jet arises in a laminar medium, it becomes turbulent under certain conditions. For these conditions, k is the turbulence coefficient in the jet, and it should increase with the distance from the source or with increasing radius of the jet, since the exchange includes large-sized eddies, and also with increasing traveling speed in the jet.

When the jet propagates in a turbulent medium, these considerations with respect to k are insufficient. Obviously, the exchange in the jet and the turbulence in the surrounding medium should be closely related. When the turbulent mixing in the medium is sufficiently vigorous, it will practically determine the exchange in the jet as well, with the exception of the region in the immediate vicinity of the origin of the jet. This is usually the case with the conditions of propagation of discharges from smokestacks, and k in the case under consideration may be taken to mean the coefficient of turbulent exchange in the atmosphere, whereas above stack level the turbulence is usually approximately isotropic, and the exchange coefficient is approximately constant with the height, or is some function of height z.

Substitution of (19) into (12) and integration of the relation obtained gives the dependence of R on z, according to which

$$\int_{R_0}^{R} \sin^{\frac{1}{2}}(fR^2+E)\frac{dR^2}{R} = 3B^{\frac{1}{4}}\int_0^z k\,dz, \tag{21}$$

where R_0 is the radius of the mouth of the stack (at z=0).

Relations (19) and (21) define the dependence of w_m on z. We obtain similar expressions for the case $\frac{\partial\theta}{\partial z} < 0$, using the substitution of variables (17):

$$w_m = \frac{1}{RB^{\frac{1}{4}}}\sin h^{\frac{1}{2}}(fR^2+E), \tag{22}$$

$$\int_{R_0}^{R} \sin h^{\frac{1}{2}}(fR^2+E) = 3B^{\frac{1}{4}}\int_0^z k\,dz. \tag{23}$$

It can be readily seen that despite a certain similarity in the external appearance of formulas for cases of gradients of potential temperature $\frac{\partial\theta}{\partial z}$ with different signs, the character of the dependence of the jet parameters on $\frac{\partial\theta}{\partial z}$ is substantially different in the two cases. The main difference lies in the fact that when $\frac{\partial\theta}{\partial z} > 0$ at a height of $z = z_c$, when

$fR^2+E=\pi$, according to (18), $w_m = 0$. In this case, the ascent of the jet ceases, having reached a certain "ceiling".

The corresponding value of R_c is given by the formula

$$R_c^2 = \frac{1}{f}(\pi - E).$$

Substituting this value of R_c into (21) at constant k, we obtain

$$z_n = \frac{1}{3kB^{\frac{1}{4}}} \int_{R_0}^{R_n} \sin^{\frac{1}{2}}(fR^2+E)\,dR.$$

We transform this expression by introducing a substitution of the integration variables

$$fR^2+E=t.$$

Then

$$z_n = I_E \sqrt{\frac{A}{k\frac{\partial\theta}{\partial z}}}, \tag{24}$$

where

$$I_E = \frac{1}{2\sqrt{3}} \int_{\varphi_0}^{\pi} \sqrt{\frac{\sin t}{t-E}}\,dt$$

and

$$\varphi_0 = E + fR^2.$$

Values of I_E for different values of E, which in practice change from -0.01 to 0.1, are given in Table 1. It is apparent that I_E undergoes relatively little change.

Table 1

E	—0,01	0,001	0,01	0,1
I_E	—0,601	0,607	0,509	0,656

There are errors in the determination of the level z_c, since as the velocity falls off to 0, the temperature of the jet decreases indefinitely, this being obviously due to the nonrigorousness of the formulation of the problem [no account is taken of the vertical exchange and of certain other secondary factors whose influence may be felt at the boundaries of propagation of the jet; there are also limits to the application of the selected relations (4), (5), etc.]. Therefore the conclusion that a "ceiling" is present should be considered approximate.

Similar conclusions were also reached in [9, 10, etc.], where it was also proposed to determine the level z_t, where $\vartheta_m=0$. From the expression for ϑ_m one can readily see that z_t can be found if $\varphi=\frac{\pi}{2}$. In the general case $z_t < z_c$. According to [10], $z_t \approx 0.7\ z_c$. As follows from the formulas, there is no "ceiling" when $\frac{\partial\theta}{\partial z}<0$.

Let us also consider some special cases resulting from the formulas obtained. We shall first consider the solution of the given problem without taking the influence of $\frac{\partial\theta}{\partial z}$ into account, i.e., for the equilibrium case $\left(\frac{\partial\theta}{\partial z}=0\right)$. The study of the general solution for this case is complicated by the fact that it is necessary to achieve passage to the limit. It is more convenient to proceed from the intermediate formulas (10) and (11). According to (10), when $\frac{\partial\theta}{\partial z}=0$,

$$w_m \vartheta_m R^2 = A_0$$

and from (13)

$$\frac{d\,(w_m R)^2}{dR^2}=\frac{gA_0}{3k\theta}. \tag{25}$$

Hence

$$(w_m R)^2 = DR^2 + M$$

and

$$R^2=\frac{M}{w_m^2-D}, \tag{26}$$

where $D=\frac{gA_0}{3k\theta}$ and M is the integration constant.

Substituting (26) into (25) and integrating the equation obtained, we find an expression relating w_m to the height z

$$\frac{w_m}{w_m^2-D}-\frac{1}{2\sqrt{D}}\ln\frac{w_m-\sqrt{D}}{w_m+\sqrt{D}}=\frac{6}{M}\int_0^z k\,dz+L,$$

where L is the integration constant.

The values of A_0, L and M are found directly from the initial data, in particular,

$$A_0=w_0\Delta T_0 R_0^2, \quad M=R_0^2(w_0^2-D),$$

and the value of L follows from (26) at z = 0. The working formulas for the determination of w_m then assume the following form:

$$\frac{w_m}{w_m-D}-\frac{w_0}{w_0^2-D}-\frac{1}{2\sqrt{2}}\ln\left(\frac{w_m-\sqrt{D}}{w_m+\sqrt{D}}\cdot\frac{w_0+\sqrt{D}}{w_0-\sqrt{D}}\right)=$$

$$=\frac{6}{R_0^2}\,\frac{\int_0^z k\,dz}{(w_0^2-D)}. \tag{27}$$

Thus far, k has been considered the exchange coefficient in the atmosphere, excluding a small region of the jet close to its origin, where k may depend on the parameters of the jet. For the latter region, it may be postulated as the simplest assumption that k increases in proportion to the traveling speed and scale of the jet (the jet scale being related to the jet radius R), setting

$$k=\frac{1}{3}cRw_m. \tag{28}$$

Here c is the proportionality constant, the coefficient 1/3 being introduced for convenience. From (12) and (28) it follows directly that

$$R=cz+R_0. \tag{29}$$

If a coordinate system is introduced such that $R_0 = 0$, then in this case (29) and other formulas for the determination of w_m and $\overline{\vartheta_m}$ practically coincide with the results of Pristley and Boll [10].

It is true that k is not introduced directly in [10], but a turbulent stress is assumed in the jet. Obviously, that such an assumption is equivalent to selecting the dependence of the exchange coefficient in the form (28), which results in an indefinite increase of k with z.

It is of interest to compare the formulas for calculating w_m in cases of constant k and indefinitely increasing z. One can readily ascertain that according to (27), in the first case (k constant) for $z\to\infty$, the vertical velocity w_m decreases to a certain constant value. In the second case for $z\to\infty$ $k\to\infty$ and $w_m\to 0$ (at large heights $w_m\sim z^{-1/3}$).

From an evaluation of the terms of the energy equation, taking into account the fact that in the case under consideration the quantity A_0 proportional to heat flux from the source remains constant, it may be concluded that the value of kw_m^2 for $z\to\infty$ remains constant. Hence, when $z\to\infty$ in the case of constant k, w_m remains constant, and in the case $k\to\infty$ $w_m\to 0$. It is evident that neither of the two schemes corresponds to actual conditions in the range of large z values, and the two schemes are inapplicable in this range. For small z values, the two schemes yield similar results with suitable parameters.

It is useful to consider one special case, the propagation in a stratified atmosphere of a cold jet whose initial temperature coincides with the temperature of the surrounding medium. For the conditions of the equilibrium state of the atmosphere $\left(\frac{\partial\theta}{\partial z}=0\right)$, the solution of the problem is considerably simplified, and for the accepted premises concerning the function $f(\eta)$ in form (5), we obtain from (25) as a special case for $A_0=0$,

$$w_mR=\sqrt{M} \text{ и } \sqrt{M}=w_0R_0, \tag{30}$$

and from (12), using (30), we obtain

$$R=\frac{3k}{w_0R_0}z+R_0 \tag{31}$$

and consequently,

$$w_m=\frac{w_0}{1+\frac{3k}{w_0R_0^2}z}. \tag{32}$$

It should be noted that a more rigorous solution may be obtained for the case under consideration by introducing stream functions into the initial equation and without specifying a definite dependence $f(\eta)$ in form (5). In so doing, one can utilize the ready solutions of equations of a given type given in known papers of hydrodynamics. Results thus obtained essentially coincide with (31) and (32). If $\frac{\partial\theta}{\partial z}\neq 0$ is taken into consideration, the working formulas are found as a special case from the ones obtained above after substituting in them the value of A corresponding to the initial value of $\Delta T_0 = 0$.

3. Characteristics of Dangerous Conditions

The preceding section gives some results of an analysis of the change of the vertical velocity in a warm and a cold jet. These results are related to the evaluation of the level of the initial ascent of the impurity at which the ratio of the vertical ascent velocity to the wind velocity is comparatively small, and further propagation of the impurity in the atmosphere is chiefly determined by processes of horizontal transport and turbulent diffusion. The value of the ratio may be obtained, in particular, from experimental data on the initial ascent of the jet for individual cases. Subsequent generalization makes it possible to obtain the dependence of the initial ascent, or as it is otherwise termed, the effective ascent ΔH, from the initial parameters of the discharge and atmospheric characteristics. Thus, in [3], the following formulas was obtained for determining the initial ascent

$$\Delta H=\frac{1,5w_0R_0}{u}\left(2,5+\frac{3,3gR_0\Delta T_0}{\theta u^2}\right), \tag{33}$$

where u is the wind velocity at the height of the vane, and the remaining symbols are the same as above.

For inversion conditions it was found above that at some height z_c the velocity w_c turns to zero. It is understandable that the effective height ΔH for the given conditions should be less than z_c. Differences between z_c and ΔH substantially depend on the wind velocity u. However, in cases where z_c is small, and the stack height sufficiently large, the absolute differences between z_c and ΔH should not play an appreciable part in the evaluation of the surface concentration from a high source. It is of interest therefore to study cases where z_c is small. It is obvious that the problem of the difference between the ceiling heights z_c and z_t determined from the decrease of the vertical velocity w_c to zero and from the temperature difference is of no practical importance in these cases.

In order to determine the conditions for which z_c is small, we shall cite the results of calculations for two characteristic examples, taking in both cases the value of the inversion gradient to be $\frac{\partial\theta}{\partial z}=10^{-2}$ °/м and $k=1\div5$ м²/sec. In the first example, we shall consider the condition of a large heat source corresponding to discharges from stacks of thermal power stations, setting $w_0\approx10\div20$ м/sec., $R_0=2\div3$ м, $\Delta T_0=100°$. The second example pertains to conditions characteristic of many chemical plants, with $w_0\sim10$ м/sec, $R_0=0{,}5$ м, $\Delta T_0=20°$.

It is easy to see that in both cases, according to (10), the expression for A is simplified

$$A=\sqrt{(w_0\Delta T_0R_0^2)+\frac{g}{\theta}\frac{\partial\theta}{\partial z}(w_0R_0)^4}\sim w_0\Delta T_0R_0^2,$$

and on the basis of (24) and Table 1

$$z_п\approx0{,}61\sqrt{\frac{w_0\Delta T_0R_0^2}{k\frac{\partial\theta}{\partial z}}} \qquad (34)$$

In the first case for large thermal sources z_c = 200-800 m, and in the second, for comparatively cold discharges from stacks of moderate diameter, z_c = 20-40 m. Consequently, in the second case z_c takes relatively small values and it is obvious that for stacks over 50-100 m high, the refinement of z_c by taking the influence of the velocity into consideration should not play an appreciable part. Thus, for the first approximation, the effective ascent can be determined from z_c.

Formula (34) leads to the fully understandable result that the smaller the capacity of a thermal source, i.e., the lower the amount of heat in the volume of air emerging from the stack (this amount is proportional to $w_0\Delta T_0R_0^2$), the smaller the height z_c. The value of z_c also decreases with increasing inversion temperature gradient $\frac{\partial\theta}{\partial z}$. The dependence on $\frac{\partial\theta}{\partial z}$ is complex in character, since the exchange coefficient k also depends on $\frac{\partial\theta}{\partial z}$. It may be assumed that for a given thermal capacity of the source z_c reaches the minimum value at some inversions, not too deep, when $k\frac{\partial\theta}{\partial z}$ is not too small (in layers of isotropic turbulence $k\frac{\partial\theta}{\partial z}$ is proportional to the turbulent heat flow).

It is understandable that on the basis of the above, the results obtained relative to z_c should be regarded as very approximate. Furthermore, in cases where z_c is small, even with considerable errors in the determination of z_c, the basic conclusion that the initial ascent of the impurity from the stacks will be limited to small heights regardless of the magnitude of the wind velocity seems convincing.

In regard to the influence of the temperature gradient in an unstable atmosphere we shall note that according to the formulas of the preceding section, this influence on the vertical traveling speed and hence on the initial ascent of the impurity is chiefly determined via the quantity A. On the basis of the above calculations, covering a wide range of conditions of practical interest, the value of A is essentially relatively independent of $\left|\frac{\partial\theta}{\partial z}\right|$. This leads to the conclusion that the change of the velocity of the vertical motion and the initial ascent of the impurity in an unstable state of the atmosphere also depend only slightly on the magnitude of the temperature gradient.

Let us note that formula (33) was obtained for conditions of equilibrium and unstable stratification, for which the highest values of surface concentrations could be expected. At the same time, the problem of the influence of the temperature gradient was not considered. From the conclusions just reached it follows that this influence is slight, and this permits a broader application of the formula obtained.

Let us now consider the problem of dangerous wind velocity. According to [3], the magnitude of the dangerous wind velocity u_m at the level of the vane for the discharge of an impurity from a stack of height H is given approximately by the formula

$$u_м = 0{,}65 \sqrt[3]{\frac{\pi w_0 \Delta T_0 R_0^2}{H}}.$$

For large sources such as smokestacks of thermal power stations, $u_м \approx 5$ м/sec. For other types of sources, u_m may change appreciably. Thus, for the above example of comparatively cold discharges with parameters pertaining to many chemical plants, etc., $u_м \approx 1 \div 2$ м/sec. It must be remembered that the lower the dangerous velocity, the higher the maximum concentration q, other things being equal. Indeed, according to [3], in the very general case, q as a function of the discharge capacity Q, wind velocity and source height H may be calculated from the formula

$$q = \frac{cQ}{uH^{\beta}}, \tag{35}$$

where c and β are some constants.

For u = u_m and suitable stratification conditions, q reaches its highest value q_m and thus, q_m is inversely proportional to u_m. However, the highest concentration values usually are not reached at very low wind velocities, since this causes a sharp increase of the effective source height H (sum of the stack height and initial ascent ΔH). In all of the formulas for the determination of ΔH employed at the present time, and in particular according to (33), as u decreases to zero, ΔH increases indefinitely. In addition, from the results obtained above it follows, under inversion conditions, that this does not occur, since some "ceiling" may exist for the initial ascent of the impurity. It is understandable that if the "ceiling" is located relatively low over the stack, the impurity concentration can increase substantially in the presence of slight winds. Thus, in the presence of an inversion above the stack and of a marked attentuation of the wind, very unsafe conditions should arise in the surface layer under certain conditions. This may explain the cases of particularly high concentrations indicated in the beginning [5, etc.].

Such cases must be thoroughly investigated when analyzing the conditions of atmospheric pollution by industrial discharges.

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THEORY OF THE DEPENDENCE BETWEEN THE CONCENTRATION OF AEROSOLS IN THE ATMOSPHERE AND THEIR FLOW ONTO A HORIZONTAL BOARD

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A theoretical study of the deposition of aerosols from the atmosphere on horizontal boards has been made. The surface of the board is assumed to be adhesive, causing the impurity concentration of the incoming air flow to change. The process of concentration change is described by the equation of turbulent diffusion. A theory of flow past the board in a turbulent atmosphere is developed, and the field of the traveling speeds and of the exchange coefficient in the boundary layer above the board is determined. The equation of turbulent diffusion of the impurity, taking into account the field of the traveling speeds and of the exchange coefficient, is solved by a numerical method. Results of a calculation with an "Ural-4" computer are given. The dependence of the ratio of the vertical flow of aerosols to their concentration on the wind velocity and exchange coefficient in the incoming air flow and also on the size of the board and height at which it is mounted above the underlying surface is established.

1. Introduction

The study of many problems of propagation of aerosols in the atmosphere involves the necessity to determine their concentration and flow onto a horizontal board. One can mention here mainly the problem of evaluating the degree of pollution of the ground layer of the atmosphere with dust or ash from industrial plants. Usually, such an evaluation is made from data on the concentration of dust in air. In addition, attempts are made to use the results of measurement of the amount of dust depositing on a horizontal board. The use of the latter is much simpler than the measurement of concentration, which requires a special apparatus, particularly air flowers operating on line current, high-capacity batteries or motors, etc.

Attempts also are made to use the flow of aerosols onto a board for the determination of their deposition on the surface of the ground. The literature frequently provides data on the amount of dust settling on the ground from industrial sources, the dust pollution of the snow cover, etc. Some formulas for calculating the deposition of industrial aerosols are known [9, etc.].

However, the practical application of the results obtained is very difficult, since there are at present no indicators for the deposition of aerosols on a horizontal surface analogous to maximum permissible concentration values (MPC).

Considering the simplicity of obtaining board data, it appears essential to relate these data to the concentration values, and then, using MPC, to establish the pattern of unsafe pollution of an air layer and of the earth's surface with aerosols.

The solution of this problem is of major importance for the study of the spatial distribution of aerosols originating from various sources and of the background pollution on the earth's surface. It is well known that at some points the collection of dust, including radioactive dust [1, 7, 8], is made on adhesive boards, in vessels sometimes filled with water, etc., and that at other points the dust concentration is measured by means of filtering-ventilating devices. As already noted, such devices are much more complex than boards, and the number of places where they are used is considerably smaller than the number of points where board measurements are made. Switching from the readings of one set of observations to those of the other set permits the establishment of a relationship between them and a considerable expansion of the potential of the analysis of spatial aerosol distribution.

Recently, in the USSR [2, 3] and abroad, studies of atmospheric diffusion have made use of the method of dumping of fluorescent and luminescent powders from towers. These powders are then collected on adhesive boards located at various distances around the source. Such powders are relatively easy to observe on the board, this being a definite advantage of the method. In this case also, the problem of the relationship between the amount of impurity deposited on the board and its concentration at the point where the board is located is of essential importance. Such problems also arise in the study of the effectiveness of aerosol methods of treatment of agricultural crops for the purpose of controlling pests, in the collection of aerosols [6], and also in the solution of other practical problems.

It is obvious that the empirical establishment of a relationship between the concentration of aerosols and their vertical flow onto a board is highly complex. This relationship is determined by a large number of parameters (meteorological elements, characteristics of aerosols and of the board). For this reason, despite numerous attempts to find this relationship by processing experimental data, no satisfactory results have been obtained thus far. Not enough attention has been given to the theoretical solution of this problem. We know of only one study of this nature, by V. I. Bekoryukov and M. L. Karol' [4], which dealt with the problem of the effectiveness of trapping aerosols from a high source on adhesive boards placed on the earth's surface. However, even here the problem of the relationship between the concentration and the vertical flow of aerosols was not studied.

In addition to the fundamental importance of the problem of finding the indicated relationship, of great practical importance is the study of the effect of the size of the board, the height at which it is mounted, and an evaluation of the influence of meteorological factors, etc. The present paper is devoted to a study of these problems.

2. Statement of the Problem

Usually, the boards used for the collection of depositing dust are a few tens of centimeters in size and are mostly placed at the height of one to several meters above the earth's surface in order to avoid their contamination with dust rising from the ground. Boards with a specially deposited adhesive coating and containers with water, since a water surface almost completely absorbs the aerosol particles falling on it, may be considered to be absolutely absorbent. The aerosol concentration on their surface is equal to zero. The remaining cases deal with a partial adhesiveness of the board; they include boards coated with gauze [1, 8] and certain other materials designed for collecting aerosols. These cases deal with the trapping coefficient σ, which stands for the ratio of the flows of deposited impurity above the board under consideration and above an absolutely adhesive board under identical conditions.

The presence of the board causes a certain disturbance in the natural distribution of aerosol particles in space, and differences arise in their concentration on the board and in the surrounding medium. The process of turbulent diffusion of aerosols above the board in the general case is described by the differential equation

$$u\frac{\partial q'}{\partial x} + w\frac{\partial q'}{\partial z} = \frac{\partial}{\partial x} k_x \frac{\partial q'}{\partial x} + \frac{\partial}{\partial y} k_y \frac{\partial q'}{\partial y} + \frac{\partial}{\partial z} k_z \frac{\partial q'}{\partial z}, \qquad (1)$$

where q' is the concentration of the aerosol in air, u and w are the horizontal and vertical components of the displacement velocity, and k_x, k_y, and k_z are the components of the exchange coefficient along axes x, y, and z respectively. Axis x is parallel to the direction of the wind velocity, axis y is oriented in a transverse direction along the horizontal, and axis z is oriented along the vertical upward. We shall refer the level $z=0$ to the plane of the board, and the level $x=0$ to its windward edge.

Usually, the effect of diffusion along the direction of the wind is relatively slight and may be neglected. Considering the small size of the board and the instability of the wind direction in the horizontal plane, we can also neglect to a first approximation the term in (1) describing the diffusion along axis y, assuming that the aerosol particles are uniformly distributed along this axis. As the boundary conditions we shall take

$$\text{at } x=0 \quad q'=q_0, \qquad (2)$$

$$\text{at } z=0 \quad q'=0, \qquad (3)$$

where q_0 is the aerosol concentration in the atmosphere.

The latter condition corresponds to the fact that the surface of the board is assumed to be absolutely absorbent. For other surfaces, the conversion of the aerosol flow is done by multiplying the corresponding quantities obtained for absolutely absorbent boards by the trapping coefficient.

We shall assume that at sufficiently large distance from the board $(z \to \infty)$, the influence of the latter on the distribution of the impurity concentration in the atmosphere dies out.

In cases where the board is located at some height above the underlying surface, it has a disturbing influence not only on the process of transport of the aerosol, but also on the nature of the incoming air flow. As a result of the flow past the board, a boundary layer is created in which the horizontal velocity u does not coincide with the wind velocity, a vertical component of the motion of air arises, and the exchange coefficient differs substantially from the corresponding values in the surrounding atmosphere. For this reason, in studying the diffusion process, it is necessary to supplement equation (1) with a system of equations and boundary conditions describing the flow of air past the board. The solution of such a system should precede a study of the diffusion of the impurity, and this solution is discussed in the next section of the paper.

Since the size of the board is small, the thickness of the boundary layer is also small. This size is also much smaller than the distance from the sources of pollution to the board. This makes it possible to consider the initial concentration in the atmosphere q_0 to be constant in height, something that is fulfilled with a great accuracy in practically all of the cases of interest to us.

We shall now transform the initial equations and boundary conditions, taking into account the indicated simplifications, and introduce the notation

$$q = \frac{q_0 - q'}{q_0}. \tag{4}$$

We then obtain

$$u\frac{\partial q}{\partial x} + w\frac{\partial q}{\partial z} = \frac{\partial}{\partial z} k \frac{\partial q}{\partial z} \tag{5}$$

$$\left.\begin{array}{ll} \text{at } x = 0 & q = 0 \\ \text{at } z = 0 & q = 1 \\ \text{at } z \to \infty & q \to 0 \end{array}\right\} \tag{6}$$

The flow of impurity onto the board P_x at point x is given by the formula

$$P_x = q_0\left(k\frac{\partial q}{\partial z} - w_0\right). \tag{7}$$

The total flow of impurity onto the board P of length L and unit width is found by integrating P_x with respect to x, i.e., $P = \int_0^L P_x dx.$

It is convenient to separate the turbulent flow

$$P_T = q_0 \int_0^L k\frac{\partial q}{\partial z} dx. \tag{8}$$

Then

$$P = P_\tau - w_0 q_0 L.$$

3. Theory of Flow Past a Horizontal Board in a Turbulent Atmosphere.

The theory of air flow past plates has been treated extensively in the literature. Cases of laminar and turbulent boundary layers on plates have been studied in detail. However, in both cases the studies performed refer chiefly to conditions in which the plate is in a laminar flow. In the study of flow past a board, it is essential to take into consideration the turbulent exchange of the atmosphere. This is particularly important in the determination of the turbulent flow Pt, which is directly dependent on the exchange of coefficient k, bearing in mind that the values of k in the boundary layer above the board and in the surrounding medium differ appreciably. The exchange coefficient k changes from the value of the molecular viscosity of air on the surface of the board to relatively high values characteristic of the atmosphere at the level of the board outside the boundary layer.

The process of the flow of air past a board, taking the above simplifications into consideration, may be described by the equation of motion

$$\frac{z\varrho}{n\varrho} y \frac{z\varrho}{\varrho} = \frac{x\varrho}{n\varrho} \varpi + \frac{x\varrho}{n\varrho} n \tag{9}$$

and by the continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0. \tag{10}$$

The following boundary conditions at the board surface are taken:

$$\text{at } z = 0 \quad u = 0, \quad w = w_0, \tag{11}$$

which for convenience of presentation includes w_0, the gravity settling rate of the aerosols.

It is assumed that at a sufficiently large height above the board, the disturbing influence dies out, i.e., the traveling speed coincides with the wind velocity and the turbulent flow of momentum disappears.

We solve the problem by familiar boundary layer methods.

We introduce the thickness of the boundary layer δ and assume that

$$\text{at } z = \delta \quad u = V, \tag{12}$$

where V is the wind velocity in the incoming flow.

For an elevated board (usually more than 1 m above ground), considering a small thickness of the boundary layer corresponding to the small size of the board, the quantity V may be considered constant with height.

Equation (9) will be transformed to the integral form. To this end, considering (10), we reduce it to the form

$$\frac{\partial}{\partial x} u(V-u) + \frac{\partial}{\partial z} w(V-u) = -\frac{\partial}{\partial z} k_z \frac{\partial u}{\partial z}. \qquad (13)$$

Integrating (13) with respect to z from 0 to δ and taking the boundary conditions into consideration, we obtain the so-called "equation of momenta"

$$\frac{\partial}{\partial x} \int_0^\delta u(V-u)\,dz = k \frac{\partial u}{\partial z}\Big|_{z=0}. \qquad (14)$$

In addition to the unknown traveling speeds, equations (13) and (14) also contain the exchange coefficient, which itself depends on the traveling speeds. From general considerations one can only state that at the surface of the board, the coefficient k should reach the value of the molecular viscosity ν, and at a certain level δ_1 above the board it will practically take the value of the turbulent exchange coefficient in the incoming flow K. The level δ_1 may not necessarily coincide with the height of the boundary layer δ for the displacement velocity u, i.e., $\delta_1 = \frac{\delta}{r}$, where $r \neq 1$.

The above equations are insufficient for finding k. Therefore, we shall also introduce an energy equation. To do so, we multiply (9) by u and exclude w on the basis of the continuity equation. The relation obtained is then integrated with respect to z from 0 to δ. After some simple transformations, we obtain an integral expression for the energy equation

$$\frac{\partial}{\partial x} \int_0^\delta u(V^2-u^2)\,dz = 2\int_0^\delta k\left(\frac{\partial u}{\partial z}\right)^2 dz. \qquad (15)$$

Equations (14) and (15) contain two unknown quantities, u and k. To find them, one can make approximate use of known experimental facts, according to which the displacement velocity in the boundary layer increases with the height in an approximately logarithmic manner, whereas the exchange coefficient increases linearly. Therefore, satisfying the boundary conditions as well, we shall seek the solution of the problem by assuming

$$u = V\frac{\ln\frac{\eta}{\nu}}{\ln\frac{\eta_1}{\nu}} \quad \text{for } z < \delta \text{ and } u = V \quad \text{for } z \geqslant \delta \qquad (16)$$

and

$$k = \eta \quad \text{for} \quad z < \delta_1 = \frac{\delta}{r} \text{ and } k = K \text{ for } z \geqslant \delta_1, \qquad (17)$$

where $\eta = \nu + (K-\nu)\frac{rz}{\delta}$ and $\eta_1 = \eta|_{r=1}$.

For an elevated board, K like V may be assumed independent of the height.

Substituting (16) and (17) into (14) and (15), we obtain

$$\frac{V}{r(K-\nu)\ln\frac{\eta_1}{\nu}}\left(\eta_1+\nu-2\frac{\eta_1-\nu}{\ln\frac{\eta_1}{\nu}}\right)\frac{d\delta}{dx}=\frac{\eta_1-\nu}{\delta\ln\frac{\eta_1}{\nu}} \tag{18}$$

and

$$\frac{V}{r(K-\nu)\ln\frac{\eta_1}{\nu}}\left(r\eta+\nu-\frac{6\eta_1}{\ln\frac{\eta_1}{\nu}}+\frac{6\eta_1-\nu}{\ln\frac{r\eta_1}{\nu}}\right)\frac{d\delta}{dx}=\frac{2(\eta_1-\nu)}{\delta\ln\frac{r\eta_1}{\nu}}\left(\ln\frac{K}{\nu}-\frac{K}{\eta_1}\right). \tag{19}$$

These two equations contain two unknown quantities, δ and r. Excluding δ first, we obtain an algebraic equation for determining r.

$$f(r)=0,$$

where

$$f(r)=\frac{\eta_1-\nu}{\ln\frac{\eta_1}{\nu}}\left[5+2\ln\frac{K}{\nu}-\frac{2K}{\eta_1}\right]-5\nu-4(\eta_1-\nu)-(\eta_1+\nu)\times$$
$$\times\left(\ln\frac{K}{\nu}-\frac{K}{\eta_1}\right)+\left(\frac{\nu}{2}+\eta_1\right)\ln\frac{\eta_1}{\nu}. \tag{20}$$

Integrating equation (18), we then find a comparatively simple expression for the height of the boundary layer

$$\delta=\sqrt{\frac{2(K-\nu)^2r^2x}{V\left(\eta_1+\nu-2\frac{\eta_1-\nu}{\ln\frac{\eta_1}{\nu}}\right)}}. \tag{21}$$

Since the function f(r) changes sign on passing through the root, to find r we made use of the algorithm of division in half of the interval at the ends of which f(r) takes values of different signs.

To find the roots r_n by this method, a program was written for the "Ural-4" computer. The calculations cited showed that r changes relatively little from the values of V and K, and its average value amounts to about 5.5. Thus, the boundary layer for the exchange coefficient is approximately 5.5 times thinner than the traveling speed.

After finding δ and r, we determine u and k in accordance with (16) and (17). Then, after integrating the continuity equation (10), w is found from the value of u obtained. It is considered that w also includes the gravity settling rate of aerosols w_0.

The results obtained relative to the field of velocities and exchange coefficient for the flow past the plate may also be of interest in themselves. However, we shall not dwell on a detailed discussion of these results, since they are of an auxiliary nature in the present paper and are used here for the purpose of calculating the process of diffusion of aerosols above the board.

4. Numerical Solution of the Problem and Analysis of Results of the Calculation.

Since the coefficients of the equation of turbulent diffusion of an aerosol (5) are complex functions of the coordinates, its solution was carried out numerically. To this end, a standard program (SP) was written for the solution on the "Ural-4" computer of a parabolic equation in the form

$$a\frac{\partial q}{\partial x}+b\frac{\partial q}{\partial z}=\frac{\partial}{\partial z}c\frac{\partial q}{\partial z}+dq+e,$$

where a, b, c, d, and e are functions of x and z with boundary conditions in the general form:

$$\text{at } x=0 \quad q=F(z),$$

$$\text{at } z=0 \quad A\frac{\partial q}{\partial z}+Bq=C,$$

$$\text{at } z\to\infty \quad D\frac{\partial q}{\partial z}+Eq=G,$$

where A, B, C, D, E, and G are functions of x.

The solution of the corresponding difference equation was obtained by the method of successive differences.

The SP program was written in symbolic addresses according to a system of subroutines; in the solution of a specific problem, the use of this system makes it necessary to prepare subroutines which are determined directly by the equation being solved (for example, the subroutine for calculating the coefficient of the equation), and the program is then revised by means of the component program (CSP). A more detailed description of the program will be published separately.

The revised program used for the computations on the "Ural-4" computer made it possible to store in the memory up to 400 points on a single x layer (i.e., for a fixed x, up to 400 values of this solution could be stored).

Ratios for determining u, w and k obtained in the preceding section were used as the working formulas in the subprogram for calculating the coefficients of the equation.

Since in the vicinity of the surface of the board the impurity concentration q changes markedly with the height because the exchange coefficient k is close to zero at the boundary of the board, the "effective exchange coefficient" was used to determine the coefficients of the difference equation, as was done in (5).

When the solution of equations of the boundary layer are used, difficulties are known to arise in the determination of the vertical velocity at the upper boundary of the layer δ since the corresponding boundary conditions are not imposed here. In order to elucidate the possible error in the calculations caused by this situation, the computations were made by retaining for $z > \delta$ the value of w reached when $z = \delta$, and for a rapid decrease of w to zero for $z > \delta$. It was found that such changes of the values of w above the boundary layer had practically no effect on the magnitude of the turbulent flow of the aerosol onto the board. This is quite natural, since outside the boundary layer the concentration gradients are close to zero, and the variations of w taking place here should not have any appreciable influence on the distribution of the concentration at the surface of the board.

The calculations were made at different values of the input parameters V, K, w_0, and L. It follows from the results of the calculations that the turbulent flow of aerosol onto the board depends relatively little on changes in the gravity settling rate of the aerosol w_0 from 0 to 0.1 m/sec. As an example, Table 1 lists the data of the calculation of $-K\frac{\partial q}{\partial z}\Big|_{z=0}$ at V = 1 m/sec for $w_0 = 0$ and $w_0 = 0.1$ m/sec.

Table 1

x м		0,05	0,10	0,15	0,20	0,25	0,30	0,36	0,40	0,45	0,50
$-K\frac{\partial q}{\partial z}\Big\vert_{z=0}$	$w_0=0$	0,276	0,190	0,154	0,133	0,118	0,108	1,100	0,093	0,088	0,083
	$w_0=0,1$	0,267	0,173	0,140	0,119	0,101	0,090	0,082	0,075	0,069	0,065

The results of the calculations also show that the values of q are practically independent of the variation of ν, which is understandable, since the coefficient of molecular viscosity of air ν is many times smaller than the exchange coefficient k.

Results of the numerical calculation show that power complexes may be taken for the local flow P_t as the approximating expressions in the range of arguments K, V which is of interest to us.

On the basis of the results of the calculation, we can set

$$-K\frac{\partial q}{\partial z}\Big|_{z=0} = K^{0,4}V^{0,5}\varphi_1(x), \qquad (22)$$

where $\phi_1(x)$ is some function of x.

Fig. 1 and Table 2 are given as illustrations.

Table 2

x м	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
R	1,989	1,992	1,993	1,994	1,995	1,996	1,997	1,997	1,998	1,998

Fig. 1 gives the quantity $-K\frac{\partial q}{\partial z}\Big|_{z=0}$ as a function of x for different values of V and a fixed K. Table 2 shows the quantity R, equal to the ratio of the flows $-K\frac{\partial q}{\partial z}\Big|_{z=0}$ at velocities V = 1 m/sec and V = 4 m/sec.

According to (22) and (8), the total turbulent flow of aerosol onto a board of unit width may be represented by the formula

$$P_\text{т} = q_0 \varphi(L) K^{0,4} V^{0,6}. \tag{23}$$

The values of the function $\varphi(L)$ as a function of L are given graphically in Fig. 2. They are satisfactorily approximated by the function $\varphi(L) = 0,215L^{0,6}$ for L in meters.

The formulas obtained make it possible to evaluate the dependence of a vertical flow of aerosol on the dimensions of the board and the meteorological conditions, which in our problem are characterized by the values of the wind velocity and exchange coefficient at the level of the board. Since K and V increase with the height, the turbulent flow of aerosol correspondingly increases with the height z. Taking into consideration the change of K and V with z, one can determine the parametric dependence of the ratio $\frac{P_\text{т}}{q_0}$ on the height H at which the board is mounted. However, this dependence applies only for sufficiently large H (usually about 1 m and higher), where, as was indicated above, the assumptions of constant V and K within the confines of the boundary layer above the board are valid.

It is of interest to compare the results obtained with the solution of the equation of turbulent diffusion (5) for the simplest case, in which the flow past the board is not taken into account, and the wind velocity u and the exchange coefficient k are assumed to be constant in height, respectively equal to V and K, and the velocity w is assumed to be equal to the gravity settling rate w_0. To this end, we shall subject all the functions (5) and boundary conditions (6) to the Laplace transformation

$$\bar{q} = \int_0^\infty e^{-px} q \, dx.$$

We then obtain for $\bar{q}$ the equation

$$K\frac{d^2\bar{q}}{dz^2} - Vp\bar{q} - w_0\frac{d\bar{q}}{dz} = 0 \tag{24}$$

and the boundary conditions:

at $z=0$ $\bar{q}=\frac{1}{p}$ and at $z\to\infty$ $\bar{q}=0$.

Hence we find that

$$\bar{q}=\frac{1}{p}e^{\left(\frac{w_0}{2K}-\sqrt{\frac{w_0^2}{4K^2}+\frac{Vp}{K}}\right)z}$$

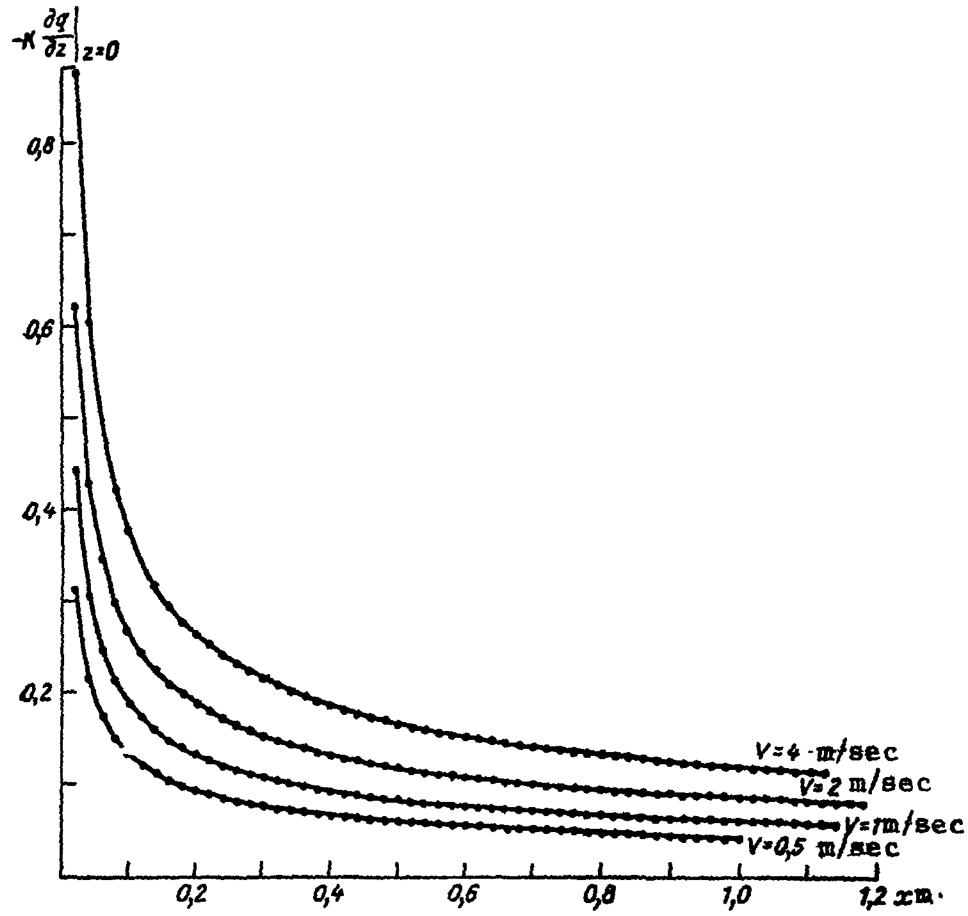

Fig. 1.

Switching to the functions of a transform and determining the turbulent flow onto the board, we find

$$-K\frac{\partial q}{\partial z}\Big|_{z=0}=q_0\left(\frac{w_0}{2}+\frac{1}{\sqrt{\frac{\pi}{K}\frac{x}{V}}}e^{-\frac{w_0^2x}{4KV}}-\frac{w_0}{2}\operatorname{erf}\frac{w_0}{2K}\sqrt{\frac{x}{V}}\right) \tag{25}$$

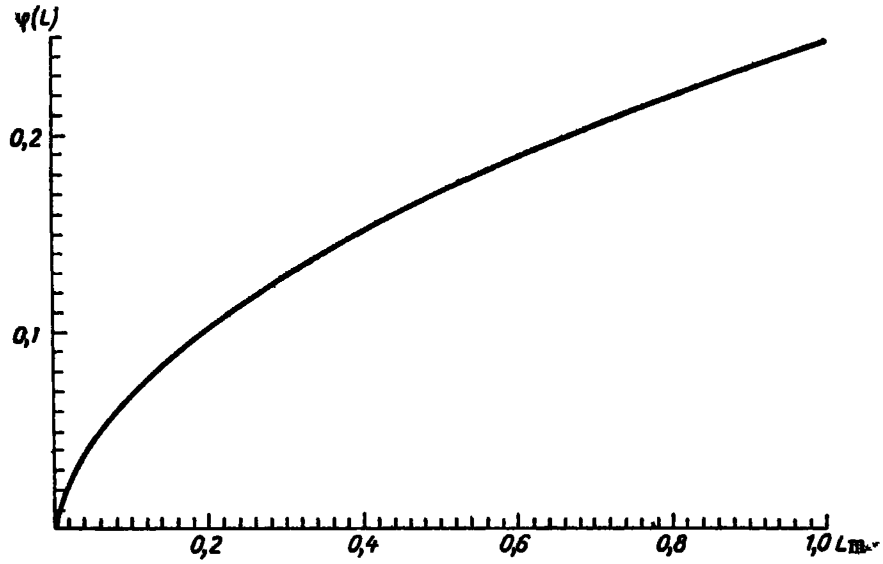

Fig. 2.

For the cases which are of practical interest to us, the second term in (25) may be neglected, and in the third, it is sufficient to retain the first term of the series expansion of the probability integral. Formula (25) is thus simplified and

$$-K\frac{\partial q}{\partial z}\bigg|_{z=0} = q_0\left(\frac{w_0}{2} + \sqrt{\frac{VK}{\pi x}}\right)$$

or at small w_0 values (usually up to 0.1-0.2 m/sec)

$$-K\frac{\partial q}{\partial z}\bigg|_{z=0} = q_0\sqrt{\frac{VK}{\pi x}}. \qquad (26)$$

Hence, the total turbulent flow onto the board determined in accordance with (18) is

$$P_т = 2q_0\sqrt{\frac{VKL}{\pi}}. \qquad (27)$$

Formula (27) is somewhat analogous in structure to formula (23) obtained above if one considers that $\varphi(L)\approx 0{,}27\sqrt{L}$. However, the factor in front of this power complex of arguments is substantially different in the two cases. In (23) it is approximately equal to 0.27, whereas in (26) it is equal to $\frac{2}{\sqrt{\pi}}$, i.e., is approximately 4.3 times larger. The turbulent flows at different distances x also differ substantially in the two cases. This is illustrated by the graph of Fig. 3, which shows the dependence of $K\frac{\partial q}{\partial z}\Big|_{z=0}$ on L at V = 2 m/sec, K = 0.2 m/sec, w_0 = 0. The lower curve was plotted from results of the numerical solution allowing for flow past the board, and the upper curve was plotted on the basis of formula (27).

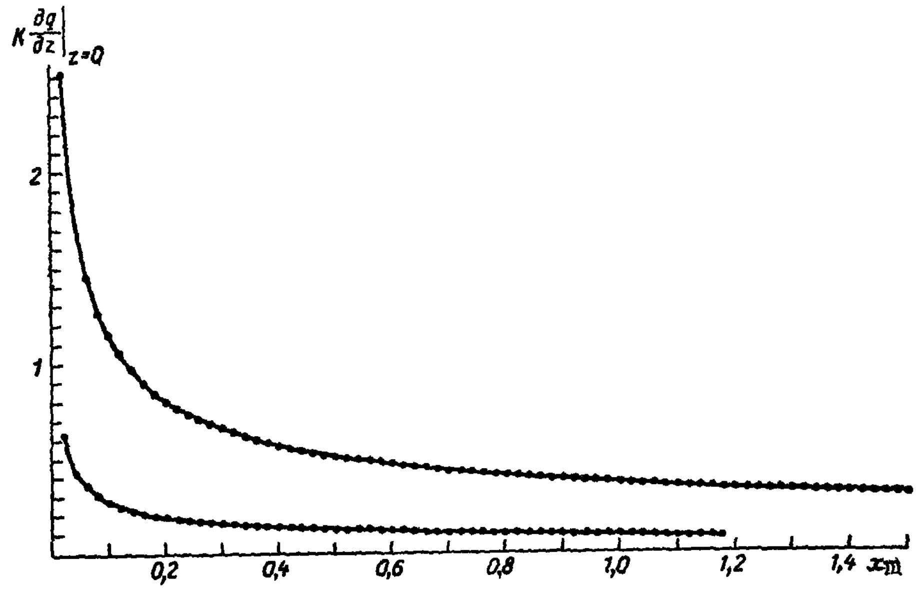

Fig. 3.

The result obtained appears natural. The use of constant K and V should indeed result in values of the turbulent flow of impurity that are much too high, since no account is taken of the abrupt decrease of the exchange coefficient at the board surface and of the influence of vertical currents, which reduce the transport of the impurity to the board.

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METEOROLOGICAL OBSERVATIONS IN THE STUDY OF INDUSTRIAL POLLUTION OF THE GROUND LAYER OF AIR

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From Trudy, Glavnaya Geofiz. Observat. im. A. I. Voeykova, No. 138, p. 18-30, (1963).

The paper discusses the program of meteorological observations for the purpose of studying the conditions of propagation of discharges from industrial enterprises, and also the results of expeditionary studies in the region of the Shchekino State Regional Electric Power Plant, carried out in the autumn of 1961. The program of observations consisted of gradient measurements including measurements of the air temperature and huditity and wind velocity at heights from 0.2 to 17 m, measurements of the soil temperature at depths up to 20 cm, and also actinometric observations. Average data on meteorological elements and results of calculations of the turbulent exchange coefficient by various methods are given.

Experimental studies of atmospheric pollution by discharges of various industrial enterprises are now being conducted in many areas. In determining the meteorological conditions, the authors usually confine themselves to measurements of the wind velocity and sometimes of the air temperature at the same level. However, the transport of impurities in the atmosphere substantially depends on the turbulent exchange, the evaluation of which requires a considerably more complete set of meteorological elements.

At the present time, the problem of an accurate determination of meteorological conditions arises with particular urgency in connection with the growth of large enterprises and electric power stations, around which the danger of atmospheric pollution may increase substantially if necessary preventive measures are not taken.

At the present time, special studies have been started to determine the meteorological conditions around the Shchekino State Regional Electric Power Plant (SREPP). The power plant is located in characteristic topographical conditions of the Middle Russian elevation in a river valley. The valley follows a nearly meridional direction. In the immediate vicinity of the station there is a water reservoir whose shores consist of slopes of hills 30-50 m high. There are no forests in the immediate vicinity of the power station, if some small groves are not considered. About 80% of the surface area of the hills has been plowed for field crops, and only the low-lying parts are covered with grassy vegetation. The soil of the region consists of chernozem, and in some areas, in low spots, clay and outcrops of limestone are present. The region has only a few populated areas, the closest of which are located 1-3 km to the southeast and southwest of the power station.

In line with the formulated objective, most of the attention was concentrated on obtaining the characteristics of turbulent exchange in the boundary layer of the atmosphere. For this reason, as complete a set of observations as possible was obtained, including stationary and expeditionary measurements permitting an evaluation of the characteristics of turbulent exchange by various methods and thus a check of the conclusions reached.

The experimental work was carried out during the period when the ground concentration of sulfur dioxide and dust was measured on the basis of the plume from the smokestacks of the power station. It was done by the Main Geophysical Observatory in collaboration with the Moscow Scientific Research Institute of Hygiene, the All-Union Heat Engineering Institute, and the Southern State Trust for the Organization and Efficiency of Electric Power Plants. The present paper gives the results of meteorological observations only. These observations make it possible to determine the meteorological conditions of atmospheric pollution and to compare the results of the calculation with the experimental data.

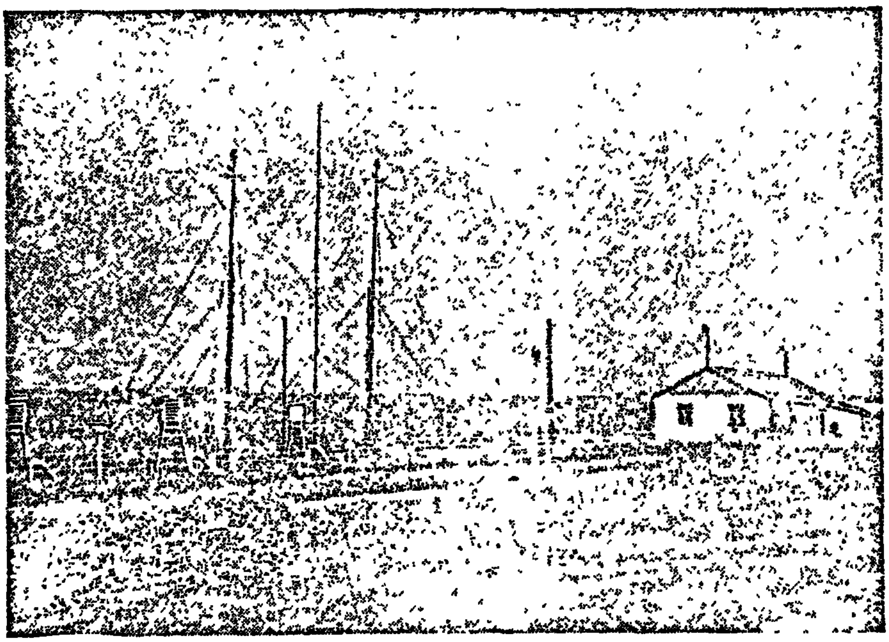

Fig. 1. General view of observational platform.

The station observations should yield the necessary meteorological data for calculating the concentration of noxious impurities in the air during the period when no direct measurements of this concentration were made.

The observation platform was located in an open area on a hill, at the foot of which a state regional electric power plant was located at a distance of approximately 1 km. The level difference was approximately 40 m.

During the period of the studies, in September-October, the platform was covered with a sparse grass 3-5 cm high. The size of the platform on which the instruments were set up was 70 x 20 m. Its overall appearance is shown in Fig. 1.

During the period of the expedition, the program combined station-based and expeditionary observations and included gradient and balance measurements.

In line with the program of gradient observations, the wind velocity, air temperature and humidity, and soil temperature at various depths were measured.

The wind velocity was measured with contact anemometers set up at heights of 0.25, 0.5, 1.0, 2.0, 5.2, 9.7, 11.7, 16.0; up to a height of 2.0 m the anemometers were mounted on poles, and above this height, on a telescopic mast, where they were braced with brackets. The anemometer readings were taken with electromagnetic counters.

To measure the air temperature and humidity, Assman psychrometers were used, in which ordinary thermometers were replaced with resistance thermometers. The positions of the thermometers was measured with a Wheatstone bridge. The psychrometers were installed at levels of 0.5, 2.0, 4.8, 9.7 and 16.7 m; up to a height of 2.0 m they were mounted on poles, and above, on a second telescopic mast. In addition, the air temperature and humidity were measured simultaneously with ordinary Assman psychrometers installed at heights of 0.25, 0.5 and 2.0 m. At levels of 0.25 and 0.5 m, the psychrometers were mounted horizontally, and at 2.0 m, vertically.

The soil temperature was measured with resistance thermometers (of the same design as for measuring the air temperature), mounted at depths of 2, 5, 15, and 20 cm and on the surface of the ground. Simultaneously, at the same depths, the temperature was measured with "Savin" thermometers, and the temperature of the surface of the soil was also measured with a periodic thermometer.

The balance observations included the determination of evaporation from the soil and actinometric measurements.

The evaporation was measured by means of microevaporators, consisting of cylindrical metal containers 11.2 cm in diameter and 7.0 cm high. Every day, before each period of observations, the evaporators were filled with soil, with the structure of the soil being left as undisturbed as possible. The microevaporators were set out on the platform every hour, during which gradient and balance observations were made.

For actinometric observations, thermoelectric instruments were installed on the platform: an actinometer, a pyranometer and a balansometer, which were used to determine the radiation balance of the underlying surface, the direct solar radiation on the perpendicular and horizontal surfaces, the reflected shortwave radiation, scattered and total radiation, and also the albedo and effective earth radiation.

The observations were made from 12 September through 12 October 1961. In September, the observations were performed only in the daytime, mainly during the period when the concentration was measured (at 9:30 - 10:30 AM, 11:30 AM - 12:30 PM, 1:30 PM - 2:30 PM, and 3:30 PM - 4:30 PM).

In order to calculate the atmospheric pollution under conditions when no direct measurement of dust and gas concentrations were taken, round-the-clock series of observations were performed at 1-hour intervals. They were set up daily from 2 through 12 October and also on 25-26 September.

Upon completion of the work of the expedition, regular observations were continued at the station. The program of these observations included the determination of the wind direction by means of the M-12 recorder, measurement of the wind velocity with contact anemometers at heights of 0.25, 0.5, 1.0, 2.0, and 5.0 m, measurement of the air temperature at heights of 0.25, 0.5, and 2.0 m (with Assman psychrometers) and 0.5 and 2.0 m (with resistance thermometers), measurement of the soil temperature on the surface and at depths of 2, 5, 10, 15 and 20 cm with resistance thermometers, actinometric observations with the balansometer, pyranometer, actinometer, and visual observations of the cloud cover, visibility, and atmospheric phenomena.

During the first days of the work of the expedition (12-15 September) the weather was primarily determined by the influence of a large cyclone with a number of centers and fronts associated with this cyclone. Starting on 15 September over the central part of the European territory of the USSR, an anticyclonic transformation began, which resulted in the onset of a general high-pressure band stretched from west to east.

Starting on 18 September, the slow moving high lost its independent significance and changed into an extension of a newly formed, larger, and developing anticyclone over the Scandanavian peninsula. However, up to 20 September, the region of the expedition remained under the influence of passing diffuse fronts, which caused cloudy weather.

Later, the anticyclone from the Scandinavian peninsula, growing stronger, began to move in a southeastern direction, and its influence spread to the region of the expedition.

From 20 September to 12 October, the weather was determined by the influence of this anticyclone (Fig. 2 and 3), and for this reason fair weather prevailed, sometimes with a poor visibility.

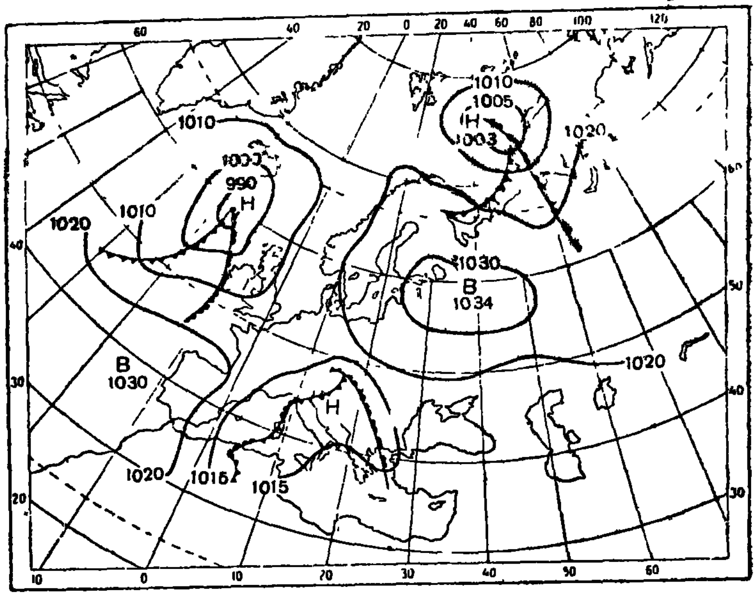

Fig. 2. Synoptic map for 3 P.M., 1 October 1961.

The weather was considered fair when during the observation period the upper and middle cloud cover did not exceed 7 points, and the lower cover, 3-4 points.

In the processing of actinometric observations, a recording of the state of the solar disc ($\odot^{0}$, $\odot$, $\odot^{2}$, П) was taken into consideration. For an upper and middle cloud cover of 8-10 points and a lower cloud cover of over 6 points, the weather was considered overcast.

Results of all the observations were collected in a table and average values for 1 hour of the measured meteorological elements were found.

Let us first examine the results of actinometric measurements, made from 9 A.M. to ' P.M., i.e., during the period when the concentration of impurities in the atmosphere was measured. The magnitude of total radiation Q during these hours varied on overcast days from 0.05 to 0.40 cal/cm^2 min., and on fair days, from 0.2 to 1.0 cal/cm^2 min. At the same time, the direct solar radiation on a horizontal surface S' measured 0.1 to 0.9 cal/cm^2 min, and the direct solar radiation on the perpendicular surface S, from 0.3 to 1.3 cal/cm^2 min. The radiation balance B of the underlying surface measured from 0 to 0.9 cal/cm^2 min. On the average, the radiation balance amounted to 0.15 cal/cm^2 min on overcast days and 0.30 cal/cm^2 min on fair days.

The diurnal variation of the direct radiation, total radiation, and radiation balance averaged over the period of the expedition and calculated for overcast and fair days is shown in Fig. 4. It is apparent that the maximum value of all these quantities is observed between 11 A.M. and 12 m.

On overcast days, the total radiation and radiation balance undergo relatively little change, and the amplitude of their value does not exceed 0.15 cal/cm^2 min. On clear days, the amplitude and maximum values of Q and B are 3 times the values on overcast days. According to the observational data, the albedo was equal to an average of 0.18, and in some cases amounted to 0.14-0.30.

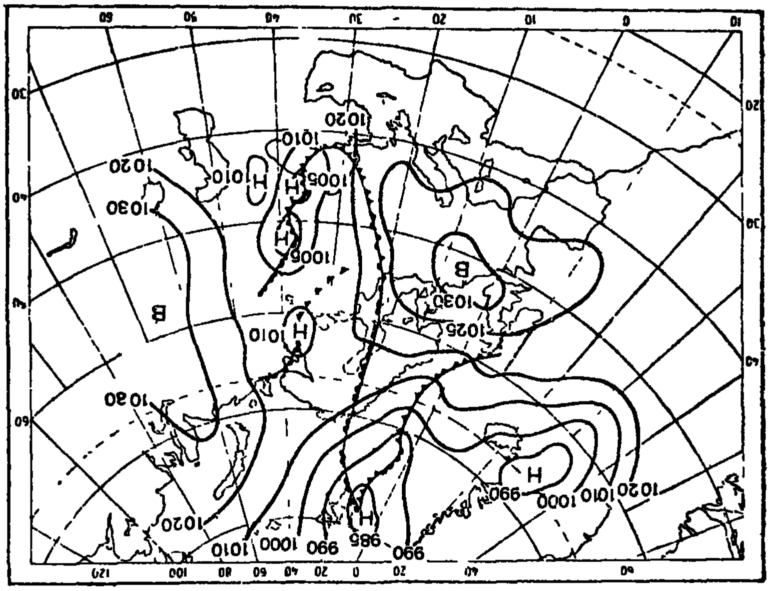

Fig. 3. Synoptic map for 9 A.M., 14 October 1961.

On the average, the effective emission E for the period observed changed from 0.08 to 0.18 cal/cm^2 min. Since the effective emission in the daytime was determined as the remainder term of the radiation balance equation, it was useful to compare the values obtained with the results of calculations of E. To this end, calculations of E were made according to M. Ye. Berlyand and T. G. Berlyand [1], using data on the air temperature and humidity at a height of 2.0 m and on the air - soil temperature difference. The results of the calculations and observations were in mutual agreement.

Let us now consider the gradient observations. Average data for each hour were used to plot the profiles of the air temperature and humidity, soil temperature, and also wind velocity. All the profiles were obtained on the semilog scale. The plotted profiles made it possible to check the quality of the observations, analyze the material, and compare synchronous observations of one and the same element by means of different instruments. In addition, mean profiles of the values of meteorological elements were plotted for cases of fair and overcast weather.

Fig. 5 and 6 show mean velocity profiles for fair and overcast days. The profiles for overcast days for periods from 6 P.M. to 8 A.M. were plotted on the basis of only two available serial observations. It is evident that, on the average, the wind velocity adequately follows a logarithmic distribution. In the majority of cases, the deviation of the values from straight lines does not exceed 0.1-0.2 m/sec, and only in some isolated cases does the maximum deviation amount to 0.3 m/sec.

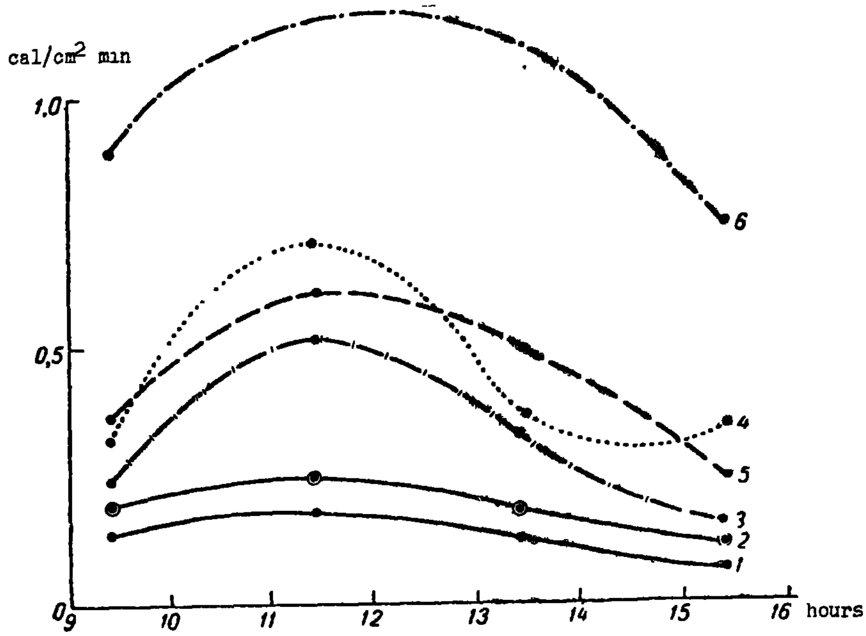

Fig. 4. Diurnal variation of components of radiation balance in fair ($B_{\odot}$, $Q_{\odot}$, $S_{\odot}$) and in overcast (B_0, Q_0, S_0) weather. 1 - B_0, 2 - Q_0, 3 - $B_{\odot}$, 4 - $Q_{\odot}$, 5 - S_0, 6 - $S_{\odot}$.

The mean values of the wind velocity in fair weather ranged from 0.5 to 2.5 m/sec at a height of 0.25 m and from 1.5 to 3.5 m/sec at a height of 16.0 m; in cloudy weather, from 1.5 to 3.0 m/sec at the lower level and from 3.0 to 5.0 m/sec at the upper level.

The highest wind velocity at the uppermost level (16.0 m) was 6.0 m/sec in fair weather and 11.0 m/sec in overcast weather based on periodic observations.

Tables 1 and 2 list data on the daily variation of the wind velocity averaged over fair and over overcast days at various heights. As is evident from the table, the maximum wind velocity at all heights was observed during the period from 12 m. to 4 P.M. and the minimum, between 10 P.M. and 12 P.M.

The mean amplitude of the daily variation of the wind velocity A on fair days was approximately the same at all heights and equal 1.9-2.3 m/sec. On overcast days an amplitude of about 2.0 m/sec is preserved up to a height of 1.0 m, and starting at 2.0 m, it increases to 3.5 m/sec.

As was noted above, the measurement of temperature and humidity at heights of 0.5 and 2.0 m was made with Assman psychrometers and resistance thermometers simultaneously. Comparison of the temperature and humidity values obtained with both instruments showed that the difference between them was slight (Tables 3 and 4) and subsequently the material was treated only by using data of the resistance thermometers.

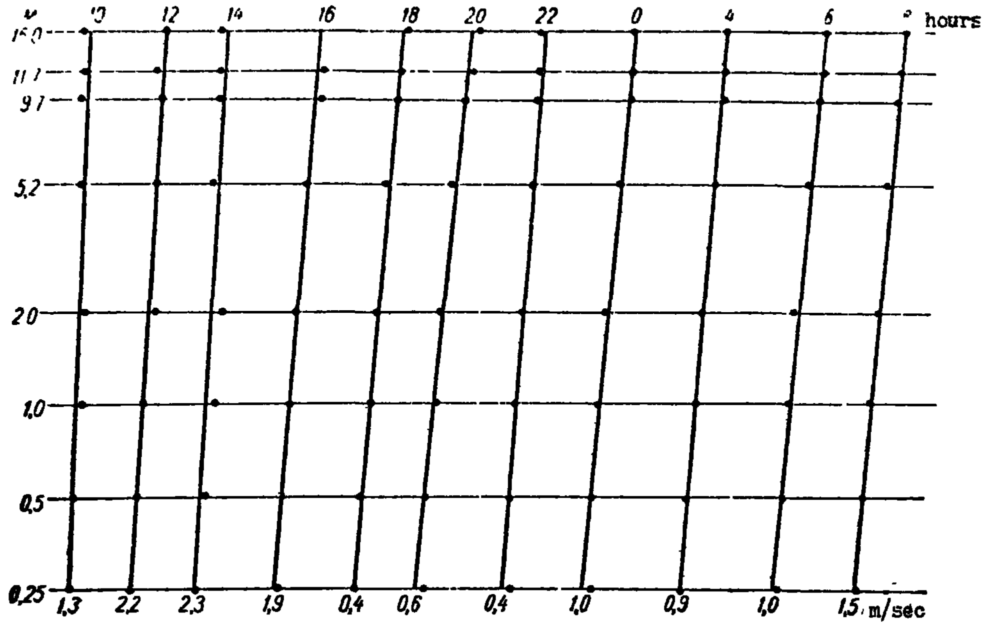

Fig. 5. Profile of mean wind velocity for fair days.

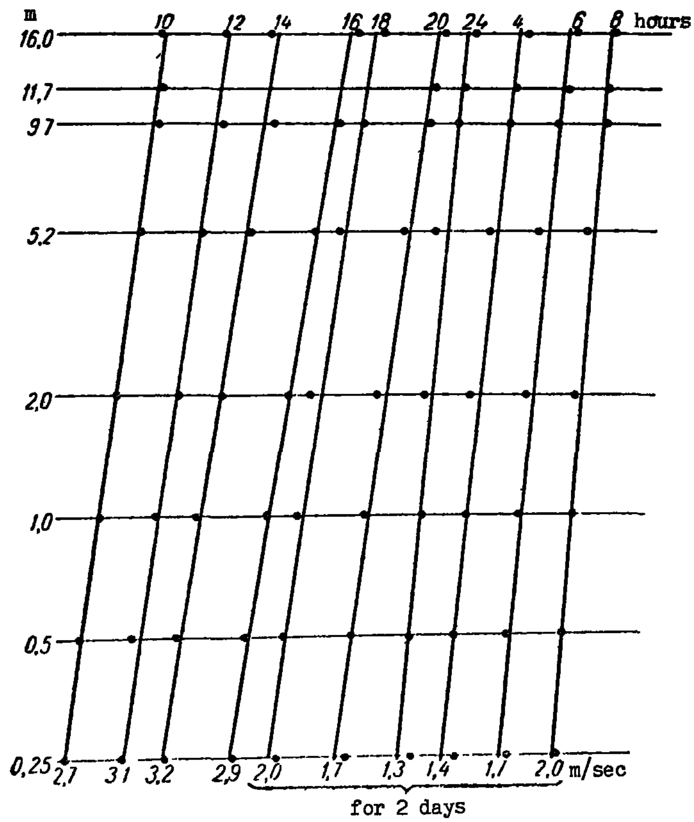

Fig. 6. Profile of mean wind velocity for overcast days.

Table 1

Daily Variation of Wind Velocity (m/sec) in Fair Weather.

z m	Hours											A
	10	12	14	16	18	20	22	0	4	6	8	
0,25	1,3	2,2	2,3	1,9	0,4	0,6	0,4	1,0	0,9	1,0	1,5	1,9
0,5	1,4	2,4	2,6	2,1	0,6	0,7	0,4	1,0	1,0	1,1	1,7	2,2
1,0	1,7	2,7	2,9	2,3	0,9	1,0	0,6	1,2	1,3	1,3	1,9	2,3
2,0	1,8	3,0	3,2	2,5	1,2	1,2	0,9	1,4	1,5	1,5	2,1	2,3
5,2	1,7	3,1	2,9	2,9	1,4	1,6	1,2	1,9	2,0	1,9	2,4	1,9
9,7	1,7	3,3	3,1	3,3	1,8	2,0	1,4	2,3	2,3	2,3	2,8	1,9
11,7	1,8	3,1	3,2	3,4	1,9	2,2	1,4	2,3	2,3	2,5	2,9	2,0
16,0	1,8	3,4	3,2	3,4	2,1	2,4	1,4	2,4	2,3	2,5	3,1	2,0

Table 2

Daily Variation of Wind Velocity (m/sec) on Overcast Days.

z m	Hours									
	10	12	14	16	18	20	0	4	6	8
0,25	2,7	3,1	3,2	2,9	2,0	1,7	1,3	1,4	1,7	2,0
0,5	3,1	3,4	3,5	3,2	2,2	1,8	1,3	1,4	1,7	2,1
1,0	3,6	4,0	4,0	3,8	2,5	2,2	1,6	1,7	2,0	2,4
2,0	4,0	4,5	4,6	4,3	2,8	2,5	1,7	1,8	2,2	2,4
5,2	4,6	5,2	5,4	5,0	3,6	3,2	2,0	2,4	2,6	2,8
9,7	5,1	5,7	6,0	5,6	4,2	3,9	2,6	2,9	3,1	3,3
11,7	5,2	5,7	6,0	5,8	4,4	4,1	2,8	3,1	3,4	3,4
16,0	5,2	5,8	6,0	6,1	4,7	4,3	3,0	3,4	3,6	3,6

Table 3

Average Distances of Air Temperature Values (deg.) Based on the Resistance Thermometers and Assman Psychrometers at Heights of 0.5 and 2.0 m.

z m	Hours										
	10	12	14	16	18	20	22	0	4	6	8
0,5	0,1	0,5	0,5	0,1	0,3	0,0	0,0	—0,2	—0,2	—0,5	0,1
2,0	0,0	0,2	0,0	0,0	0,1	0,0	-0,2	-0,2	0,0	-0,3	0,1

Table 4

Mean Monthly Differences of Air Humidity Values (mb) Based on Resistance Thermometers and Assman Psychrometers at Heights of 0.5 and 2.0 m.

z m	Hours										
	10	12	14	16	18	20	22	0	4	6	8
0,5	0,9	0,8	1,0	0,7	0,8	1,3	0,6	0,8	0,7	0,6	0,6
2,0	0,5	0,6	0,8	1,2	1,8	1,6	0,7	0,8	0,6	0,4	0,9

Table 5 lists data on the daily variation of the air temperature at all the heights. Since on days of serial observations primarily fair weather was observed, for overcast days it was possible to detect only a diurnal temperature variation at the different heights. Data for overcast days are given in Table 6.

Table 5

Daily Variation of Air Temperature (deg. C.) in Fair Weather.

z m	Hours											*A*
	10	12	14	16	18	20	22	0	4	6	8	
0,5	7,7	13,1	13,7	12,7	8,8	6,3	4,9	4,4	2,7	2,1	3,4	11,6
2,0	6,9	11,9	12,1	12,0	9,6	7,1	5,2	4,8	3,4	2,6	3,4	10,3
4,8	7,0	11,0	11,5	11,8	9,9	7,6	5,6	5,3	4,5	3,0	3,6	9,0
9,7	7,0	11,5	11,5	11,8	10,2	8,2	6,0	5,6	4,3	3,2	3,7	9,3
16,7	6,9	11,3	11,2	11,4	10,3	8,7	6,6	6,0	4,2	3,3	3,8	9,0

As is evident from Table 5, the daily amplitude of the air temperature on clear days at heights of 0.5 and 2.0 m is 10-12°C., and above 2.0 m, 9.0-9.5°C. The diurnal amplitude on overcast days is slight and amounts to 2.0-2.5°C. at all the heights.

Table 6

Diurnal Variation of Air Temperature (deg. C.) on Overcast Days.

z m	Hours			
	10	12	14	16
0,5	10,0	12,0	12,7	12,2
2,0	9,4	11,3	11,9	11,8
4,8	9,4	11,2	11,8	11,6
9,7	9,4	11,2	11,7	11,6
16,7	9,1	10,8	11,6	11,3

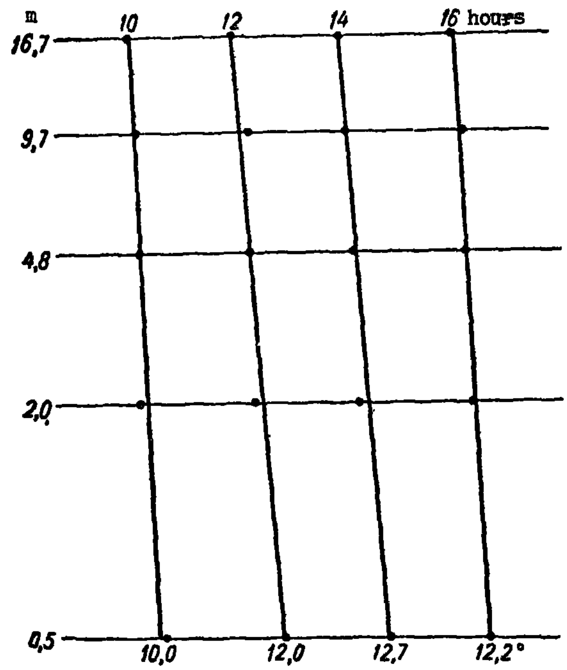

Fig. 7. Profile of mean air temperature for overcast days.

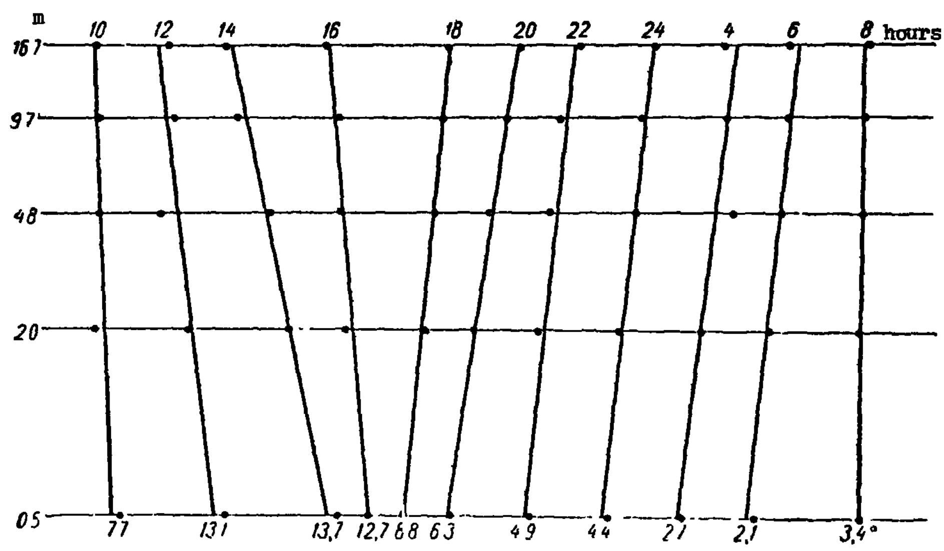

Fig. 8. Profile of mean air temperature in fair weather.

The maximum value of the air temperature on fair and on overcast days was observed at 2 P.M. and amounted to 13.7°C. at a height of 0.5 m and 11.3°C. at a height of 16.7 m in fair weather. On overcast days, the maximum was rather indistinct and amounted to 12.7°C. at a height of 0.5 m and 11.6°C. at 16.7 m. The minimum in fair weather was observed before sunrise at about 6 A.M. The temperature values averaged over the overcast and over clear days were used to plot the profiles (Fig. 7 and 8). The illustrated figures show that on the average, to within 0.3°C., the temperature at all the heights falls on straight lines of a logarithmic profile.

The temperature differences between the heights of 0.5 and 2.0 m amounted to 0.8-1.2°C. during the day and -0.4, -0.8°C. at night during fair weather and 0.2-0.4°C. during the day and 0.0-0.2°C. at night on overcast days.

The humidity observations were subjected to a similar treatment. The data obtained show that the daily variation of the humidity is rather indistinct. Its average amplitude for clear days at all the heights ranges from 0.5 to 1.5 mb.

The maximum value of the absolute humidity, based on the same averaged data, is observed at a height of 0.5 m and amounts to 8.4 mb; it decreases with increasing height.

On overcast days, the absolute humidity is higher than in fair weather and equal to 11-12 mb in the daytime at a height of 0.5 m and to 9.5-10.5 mb at a height of 9.7 m.

Vertical profiles were plotted from average values of the absolute humidity for overcast and fair days (Fig. 9 and 10).

The roughness of the underlying surface was determined from the plotted wind profiles under close-to-equilibrium conditions. The equilibrium conditions taken were those in which the parameter $\frac{\Delta T}{u_1^2}$ (where ΔT is the difference in air temperatures at the levels of 0.5 and 2.0 m and u_1 is the wind velocity at a height of 1 m), characterizing the state of constancy, was equal to or less than 0.05 in absolute value. The average value of the roughness parameter of the underlying surface was found to be approximately equal to 1 cm.

Table 7

Mean Values of the Turbulence Coefficient (m^2/sec) at a Height of 1 m on Overcast Days.

	Hours			
	10	12	14	16
by M. I. Budyko's method	0,13	0,14	0,14	0,12
by D. L. Laykhtman's method	0,14	0,11	0,17	0,12
by M. P. Timofeyev's method	0,12	0,12	0,11	0,10
by the heat balance method		0,12	0,05	0,06

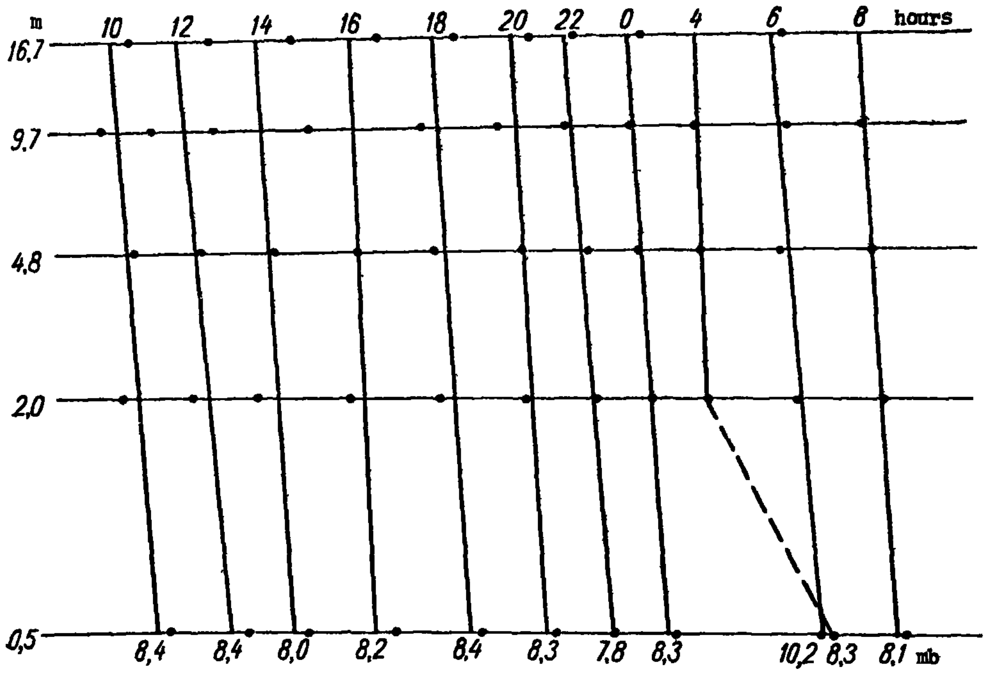

Fig. 9. Profile of mean absolute humidity in fair weather.

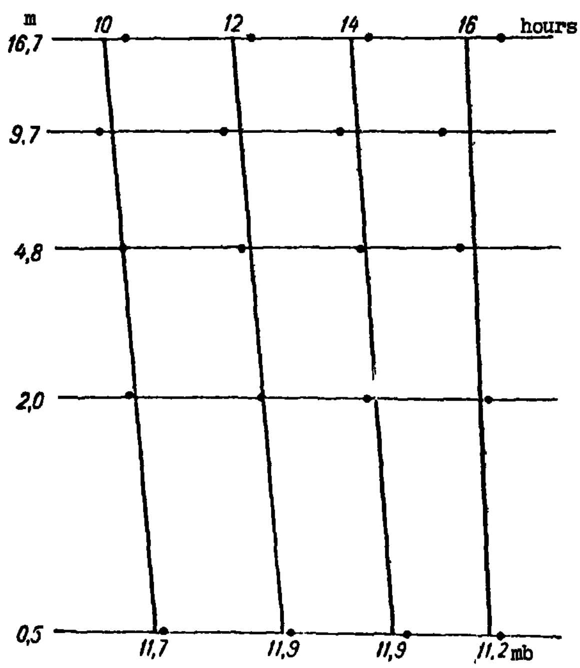

Fig. 10. Profile of mean absolute humidity on overcast days.

In order to characterize the turbulent exchange from observational data for every hour in the daytime, values of the turbulence coefficients were calculated at a height of 1 m by various methods based on gradient observations, according to [2, 3, 5], and by the heat balance method [3, 4]. Results of the calculations are shown in Tables 7 and 8, which list mean values of the turbulence coefficient for overcast (Table 7) and for fair (Table 8) weather.

The turbulence coefficient in fair weather ranges from 0.09 to 0.12 m^2/sec according to the methods of M. I. Budyko and M. P. Timofeyev and from 0.05 to 0.11 m^2/sec according to the method of D. L. Laykhtman and to the heat balance method.

Table 8

Mean Values of the Turbulence Coefficient (m^2/sec) at a Height of 1 m on Fair Days.

	Hours			
	10	12	14	16
by M. I. Budyko's method	0,11	0,09	0,12	0,10
by D. L. Laykhtman's method	0,05	0,10	0,05	0,06
by M. P. Timofeyev's method	0,10	0,11	0,11	0,09
by the heat balance method	—	0,10	0,11	0,05

In overcast weather, the absolute values of the turbulence coefficient as given by all the methods are higher than in clear weather, and range from 0.05 to 0.12 m^2/sec as given by the heat balance method and from 0.10 to 0.15 m^2/sec according to all the other methods.

The fluctuations of the turbulence coefficient from noon to 4 P.M., calculated by using the heat balance method, are approximately the same for fair and for overcast weather.

The turbulence coefficient for a 10-hour period could not be calculated by using the heat balance method because of the lack of observations for an eight-hour period or because of the slight difference (less than 0.1 cal/cm^2 min) between the radiation balance values and the heat flow into the ground.

The results obtained make it possible to characterize the meteorological conditions of the distribution of discharges from stacks in the ground layer of air.

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CHARACTERISTICS OF THERMAL STABILITY IN THE GROUND LAYER OF AIR

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From Trudy, Glavnaya Geofiz. Observat. im. A. I. Voeykova, No. 238, p. 153-179, (1969).

Richardson's number is usually employed as a stability characteristic allowing not only for thermal factors (temperature distribution in height) but also for dynamic factors (change of the wind velocity with height). This number is frequently replaced by a parameter that is readily determinable and functionally associated with it, equal to the ratio of the temperature difference at two levels to the square of the wind velocity at a third level in the ground layer of air ($B = \frac{\Delta t_{z_1, z_2}}{u_{z_3}^2}$). Parameter B has been widely employed in studies of the turbulent regime in the ground layer of the atmosphere by M. I. Budyko, A. R. Konstantinova, D. L. Laykhtman, T. A. Ogneva, M. P. Timofeyeva, and others.

Different levels are taken as z_i (i = 1, 2, 3), but in the Soviet literature they are most frequently 0.5 and 2.0 m for the temperature and 1 m for the wind velocity. The use of gradient observations of heat balance stations makes it possible to identify certain characteristics of the distribution of the stability parameter at different points of the territory of the Soviet Union at different times of the day and year and, in addition, to elucidate the associated patterns of distribution of certain characteristics of the turbulent exchange. B is essentially a basic parameter on which the turbulence factor depends in any of the schemes now in use. Other characteristics of turbulent exchange dependent on the meteorological conditions and associated, in particular, with the horizontal components of the mixing factor also are determined via this stability parameter.

The knowledge of the characteristics of a turbulent regime is necessary for studying the diffusion of impurities and air pollution under various meteorological conditions [2, 3, 5, 15]. Thus, the study of the variation of the stability parameter in different regions of the Soviet Union is of considerable interest.

Despite the numerous studies where this parameter is used, the problem of its distribution in space and time has been inadequately investigated. Most significant in this connection is the study by T. A. Ogneva [10], where the annual and daily variation of $\frac{\Delta t}{u_1^2}$ for various weather conditions is given on the basis of observations made at Koltushy (Leningrad Oblast') in 1947-1951. Basically, however, we know from the literature the daily course of the stability parameter, determined on the basis of expeditionary data collected for individual months in certain regions.

The object of our study was therefore to investigate the distribution of the stability parameter in the ground layer of the atmosphere $\left(\frac{\Delta t}{u_1^2}\right)$ over the territory of the USSR and in time. The distribution over the territory was considered for the most unfavorable weather conditions of impurity propagation from high smoke stacks, namely, in a developed turbulent exchange. The latter was assumed to be most probable around midday in summer. As a result, the material of gradient observations for the 1 P.M. period in July was used. Data of 67 stations for the 1955-1967 period were treated.

To study the change of the stability parameter with time, its daily and annual course was analyzed, as determined from a five-year interval (1963-1967) for seven stations of different landscape zones. The calculation of B was based on daily temperature difference data for each period at the 0.5 and 2 m levels ($\Delta t_{0.5-2.0}$) and wind velocity data at a height of 1 m (u_1). Since the wind velocity observations were made at the stations at the 0.5 and 2.0 m levels only, the wind velocity at the height of 1 m was taken as the average of these levels (corresponding to the logarithmic law of wind velocity distribution with height). In the absence of data on the wind velocity at the height of 0.5 m, or since its value was dubious, u_1 was taken equal to 0.85 u_2 (in accordance with the logarithmic law for a roughness of the underlying surface of 2 cm) or taken with another factor according to the table in Ref. [6] for other values of the roughness of the underlying surface. According to the instructions, no gradient observations were made during a strong wind, precipitation, fog, dust storm or thunderstorm. The air temperature was measured only at the height of 2 m (in a psychrometer booth), and the gradient was assumed equal to zero in these cases. In the calculation of average monthly values of B, such cases were not considered, since a gradient equal to zero does not always correspond to the reality, especially in the summertime in the southern regions. Cases with a wind velocity of less than 1 m/sec at a height of 1 m were also discarded.

It should be noted that the relative errors in the calculation of parameter $\frac{\Delta t}{u_1^2}$, with the existing accuracy of temperature and wind velocity measurement at the stations ($\delta(\Delta t) = 0.2°$ and $\delta u = 0.1 + 0.03\,u$) are generally very large. For example, when $|\Delta t| \leq 0.6°$ and u ranges from 0.5 to 10 m/sec, $\delta\left(\frac{\Delta t}{u_1^2}\right) > 40\%$. It was therefore impossible to use only cases with an error of, say, less than 40%. Consequently, one would have to reevaluate an excessive amount of data, and in the central and northern regions, almost all of the data, since $\Delta t > 0.6°$ is seldom observed in these regions. Averages for the period 1955-1967 were then calculated from the computed average monthly values of B for the individual years.

Because of a change in the method of temperature observations in 1965 (vertical mounting of the psychrometer at the 2-meter level replaced by horizontal mounting) the mean monthly values of $\overline{\frac{\Delta t}{u_1^2}}$ were analyzed separately before and after 1965 in individual years. At a number of stations, the values of the stability parameter during the first period (up to 1965) were systematically lower than after 1965. At all of these stations except three (Aydarly, Fort Shevchenko and Artema Island), the wind velocities in summer in the daytime were usually below 3 m/sec. However, according to Ref. [11, 12], the divergences in gradients due to different modes of suspension of the psychrometers are insignificant. Gradient values which were too low (a vertically suspended psychrometer gave a diurnal air temperature that was too high) could have been given only at those stations under consideration where the wind velocity was above 3 m/sec, namely, at the stations of Aydarly, Fort Shevchenko and Artema Island, and this should be taken into account in the analysis of the data.

At 56 stations, $\overline{\frac{\Delta t}{u_1^2}}$ were calculated for a period of over 2 years, and at the remaining 11 stations, for 1-2 years. Series of observations obtained at different stations were highly heterogeneous. As a result, in accordance with Ref. [6], successive averaging over all the longer periods was used, beginning with the last year of observations, then the data of averaging over short periods were compared with data for the longest periods of averaging at a series of stations. As a result, the values of B were found to depend very strongly on the period of averaging. Comparison of averages for an 8-13 year period at 24 stations with averages for the 1-3 year period showed that at only nine stations during the three year period did the relative error fall below or at 30%, whereas it exceeded 30% at 15 stations. Therefore, in order to obtain more comparable values, it was necessary to average the most uniform data for the latest years beginning with 1961.

At 39 stations, average B were calculated for a 5-7 year period. Values of B determined during short periods were treated as tentative. Average values of B in July at 1 P.M. for the 1961-1967 period for different regions of the USSR are shown in Table 1. The last column of Table 1 gives the average wind velocity at a height of 1 m, calculated for the same period as $\overline{\frac{\Delta t}{u_1^2}}$.

To analyze the results obtained, we shall use L. S. Berg's scheme for classifying the territory of the USSR according to landscape zones [1]. By natural landscape zones Berg meant areas similar in predominant character of the relief, climate, and plant and soil covers. Eight landscape zones are considered. It should be noted that some stations located in zones of semideserts, deserts, desert sands and mountain landscapes do not characterize these zones as such, since the stations are usually located on floodplains, river shores, and also irrigated sites (oases). Therefore, in the indicated zones, the quantity $\frac{\Delta t}{u_1^2}$ substantially depends on the water facilities situated in the vicinity and on the degree of sheltering of the stations. Thus, at the Artema Island and Fort Shevchenko stations, located on the Caspian Sea coast in an open area, the values of the stability parameter are small because of the slight temperature differences in height and high wind velocities. (According to the data for 1965-1967, the values of $\frac{\overline{\Delta t}}{u_1^2}$ are 0.09 and 0.11 respectively).

At the Dushanbe and Fergana stations, located in oases, where the wind velocities are small and Δt substantial, the values of $\frac{\Delta t}{u_1^2}$ are higher.

Analysis of the material presented in Table 1 indicates that for summer conditions at noon, the highest values of the stability parameter (above 0.20) are characteristic of submontane regions or foothills, Central Asia, south of the European territory of the USSR, and central regions of eastern Siberia. In the southeast of the European territory, in Kazakhstan and Central Asia, as a result of high wind velocities in the summertime and somewhat decreased values of the radiation balance in the desert zone [11, 12], and hence, of Δt, the stability parameter has a lower value, of the order of 0.15-0.20. In the central and northern regions of the European territory and Ukraine, and Baltic regions, $\frac{\Delta t}{u_1^2}$ is of the order of 0.10.

The stability parameter values obtained are somewhat higher than those given in Ref. [7]. The divergences are explained by different methods of calculation. In the present study the stability parameter is calculated from daily initial data for Δt and u_1, whereas in Ref. [7] it was based on mean monthly values.

It is well known that average values alone do not constitute a complete characterization. Therefore, for a number of stations located in different landscape zones, the frequency of the different limits of $\frac{\Delta t}{u_1^2}$ was calculated under the following weather conditions: clear, overcast, variable cloudiness and average conditions. The weather conditions were determined from the degree of masking of the solar disc by the clouds. Daily values of B in July for the 1 P.M. period during 1955-1967 were used for this purpose. Table 2 gives the frequency of the different limits of $\frac{\Delta t}{u_1^2}$ under different weather conditions in percent of the number of cases under corresponding weather conditions, and also the frequency in percent of the total number of cases under average conditions and when the wind velocity at a height of 1 m was less than 1 m/sec or when the gradient observations were not made.

The data of Table 2 show what kind of weather conditions predominated in any given landscape zone during the period considered, and also what changes of the stability parameter were the most probable under different weather conditions. At all stations with the exception of Smolensk, Fergana, Chardzhou, Tamdy, and Dushanbe, weather conditions with variable cloudiness predominated (in approximately 40-60% of all cases).

The remaining cases were distributed with the predominance of clear weather at the stations of Siberia and south of the European territory of the USSR and overcast weather in the northern and central regions of the European territory.

Table 1

Average Values of $\frac{\Delta t}{u_1^2}$ in Different Landscape Zones of the USSR. July, 1 P.M.

Zone No.	Zone	Station	Period of Observation	$\frac{\Delta t}{u_1^2}$	u_1
1	Tundra	Kotkino[1]	1964—1967	0,09	2,6
		Srednekolymsk[1]	1966—1967	0,14	2,1
2	Tayga	Khibiny	1963—1967	0,15	2,4
		Arkhangel'sk	1964—1967	0,10	2,2
		Ust'-Vym'	1964—1967	0,10	2,4
		Petrozavodsk	1962—1967	0,06	2,6
		Kargopol'	1964—1967	0,10	2,2
		Nolinsk	1661—1967	0,09	2,5
		Tura	1965—1966	0,12	2,1
		Turukhansk	1965—1967	0,18	2,4
		Verkhoyansk	1964—1966	0,26	2,2
		Oymyakon	1967	0,15	1,7
		Yakutsk	1961—1967	0,29	2,1
		Aldan	1966—1967	0,27	1,9
	Tayga with an admixture of broad-leaved species	Kostroma[1]	1961—1967	0,13	2,3
		Nikolayevskoye	1961—1667	0,15	2,5
		Riga	1961—1967	0,09	2,5
		Tiyrikoyya	1961—1967	0,07	2,7
		Pinsk	1963—1967	0,13	2,3
		Smolensk	1961—1967	0,08	2,7
		Torzhok	1961—1967	0,07	2,5
		Toropets	1961—1967	0,09	2,7
		im. Nebol'sin	1961—1967	0,09	2,4
		Khomutovo[1]	1963—1967	0,30	2,0
3	Forest steppe	Kushnarenkovo	1963—1967	0,10	2,4
		Pavelets	1961—1967	0,12	2,6
		Sovetsk	1965—1967	0,12	3,5
		Cheben'ki	1967	0,21	3,2
		Beregovo	1961—1967	0,16	1,9
		Ogurtsovo	1961—1963, 1965—1966	0,12	2,9
		Solyanka	1961—1967	0,23	2,3
		Khakasskaya	1965—1967	0,37	1,7
		Kuybyshev[1] (flood-plain of Volga River)	1961, 1963—1967	0,19	2,1
4	Chernozem steppe	Borispol'	1961—1967	0,11	2,8
		Poltava	1961—1967	0,10	2,9
		Kamennaya Step'	1963—1967	0,05	2,8
		Chita	1964—1967	0,26	2,2
		Mangut	1966—1967	0,17	2,2
		Askaniya-Nova[1]	1961—1967	0,21	2,7

Table 1 (Cont'd)

Zone No.	Zone	Station	Period of Observation	$\frac{\Delta t}{t}$	[illegible]
5	Dry steppe	Rudnyy	1962—1967	0,16	3,3
		Tselinograd	1963—1967	0,17	3,6
		Yershov	1966—1967	0,14	3,4
6	Semi-desert	Astrakhan' (Flood-plain of Volga River)	1963—1967	0,24	2,4
		Gigant	1961—1967	0,22	2,3
		Nakhichevan'	1966—1967	0,24	2,4
		Kalmykovo	1961—1966	0,16	3,5
		Balkhash	1965—1967	0,14	4,2
		Karasuat	1965—1967	0,15	3,8
	Desert	Telavi	1962—1967	0,17	1,9
		Fort Shevchenko	1961—1964, 1966—1967	0,01	4,8
			1966—1967	0,11	4,8
		Churuk	1965—1967	0,21	3,3
		Aydarly	1962—1967	0,25	3,0
		Beki-Bent	1961—1967	0,29	2,6
		Fergana (Oasis)	1964—1967	0,34	1,2
	Sands of desert zone	Ak-Molla	1961, 1963—1967	0,11	3,7
		Chardzhou	1963—1967	0,10	2,0
		Tamdy	1961—1967	0,17	3,7
		Frunze[1]	1964—1967	0,43	1,6
7	Mountain landscape	Artema Island	1961—1967	0,07	4,7
			1965—1967	0,09	4,3
		Nikitskiy Sad	1966—1967	0,37	1,7
		Dushanbe (Oas s)	1961—1967	0,48	1,2
		Termez (Oasis)	1964—1967	0,22	2,5
		Skovorodino	1962—1967	0,15	1,9
		Kyzyl	1965—1967	0,19	1,8
		Bomnak	1967	0,23	1,1
8	Lowlands of the Amur and Ussuri border with Manchurian-type forests	Primoraksya	1965—1967	0,11	2,9
		Tolstovka	1966—1967	0,15	2,5

1 Stations located in transition zones

Frequency of Different Limits

Station	Clear <−0,100	−0,100<0,0	0,0–0,100	0,101–0,200	0,201–0,300	0,301–0,100	>0,400	Number of Cases	Percent of Total No. of Cases
									Tay
Khibiny			46	36		18		11	8
Petrozavodsk		12	60	20	4		4	25	14
Nolinsk		26	47	12	3	6	6	34	11
Verkhoyansk			8	15	38	5	41	13	21
Yakutsk		2	7	38	26	7	20	55	22
							Taiga with admixture of		
Kostroma	5		52	19	5		19	21	6
Nikolayevskoye		6	50	16	16	6	6	32	9
Riga		7	63	23	5	2		56	15
Smolensk	6	31	45	11	3	1	4	101	27
Khomutovo			30	35	10	25		20	13
									Forest
Solyanka			12	42	23	4	19	26	21
Kuybyshev		3	43	21	13	3	17	61	20
									Chernozem
Poltava		10	43	33	14			21	13,5
Chita			7	21	36	14	22	14	15
Askaniya-Nova			44	23	15	5	13	85	25
									Dry
Rudnyy		2	23	40	10	15	10	40	22
									Semi
Gigant	4	1	31	26	16	5	17	77	28
Kalmykovo			45	27	15	3	10	60	32
									Des
Aydarly			18	27	23	8	24	66	43
Beki-Bent		2	21	25	16	12	24	115	47
Fergana (oasis)	11	7	12	17	9	6	38	66	53
									Sands of
Chardzhou	2	7	54	18	7	7	5	44	71
Tamdy			38	26	12	6	18	156	63
									Mountain
Dushanbe (oasis)	4	1	8	14	17	7	49	101	41
Skovorodino		10	37		21	16	19	19	12

Table 2

of $\frac{\Delta t}{u_1^2}$ (%). July, 1 P.M.

Variable Cloudiness								
<−0,100	−0,100<0,0	0,0–0,100	0,101–0,200	0,201–0,300	0,301–0,400	>0,400	Number of Cases	Percent of Total No. of Cases
ga								
2	3	46	19	5	13	12	59	48
4	18	52	14	8	2	2	88	48
2	13	57	11	8	5	4	178	58
		23	26	16	6	29	31	50
1		28	26	18	8	19	128	52
broad-leaved species								
1	20	38	18	11	3	9	198	59
1	12	48	17	8	5	9	211	57
	10	54	24	5	4	3	178	48
2	22	50	19	2	3	2	115	31
	3	35	11	7	11	33	67	43
steppe								
	3	28	25	9	10	25	64	52
	2	45	27	9	6	11	170	55
steppe								
1	9	46	29	6	5	4	97	63
	2	32	25	11	11	19	47	51
	1	41	20	11	11	16	177	52
steppe								
	1	55	20	7	5	12	95	51
desert								
2	2	29	25	15	9	18	130	47
	1	49	29	12	5	4	77	41
ert								
	1	26	27	16	15	15	74	48
	4	34	22	12	7	21	100	40
8		8	17	17	8	42	12	10
desert zone								
	7	57	15	14		7	14	23
		61	13	7	5	14	79	32
landscapes								
		13	13	8	15	51	39	16
4	11	35	24	5	4	17	78	50

Station	<−0,100	−0,100<0,0	0,0−0,100	0,101−0,200	0,201−0,300	0,301−0,400	>0,400	Number of Cases	Percent of Total No. of Cases
	Overcast								
									Tay
Khibiny	3	7	66	17	4		3	29	23
Petrozavodsk		26	51	14	3	6		35	19
Nolinsk	2	16	60	9	5	4	4	55	18
Verkhoyansk			50		17		33	6	10
Yakutsk	2		41	24	12	12	9	42	17
									Taiga with admixture of
Kostroma	3	22	59	10	2		4	68	20
Nikolayevskoye	1	24	53	17	4	1		83	22
Riga		14	66	8	8	3	1	88	24
Smolensk		25	65	5	4	1		130	35
Khomutovo		6	55	28	11			18	12
									Forest
Solyanka			56	13	13	6	12	16	13
Kuybyshev		9	60	21	4	2	4	53	17
									Chernozem
Poltava	5	19	62	9	5			21	13,5
Chita	4	9	57	17	9		4	23	25
Askaniya-Nova		9	58	13	9	2	9	55	16
									Dry
Rudnyy		11	71	11		7		28	15
									Semi
Gigant	3	11	53	17	6	5	5	36	13
Kalmykovo		4	56	28	8	4		25	14
									Des
Aydarly	5		75		25			4	2
Beki-Bent		5	71	19				21	9
Fergana (oasis)		33			33	34		3	3
									Sands of
Chardzhou			100					2	3
Tamdy			82		9		9	11	4
									Mountain
Dushanbe (oasis)	50		50					2	1
Skovorodino	7	36	39	4	7	4	3	28	18

Table 2 (Cont'd)

Average Conditions									
< −0,100	−0,100 <0,0	0,0—0,100	0,101—0,200	0,201—0,300	0,301—0,400	>0,400	u_1 <1 m/sec	T^*_{2m}	Total Number of Cases
ga									
2	3	41	16	3	7	7	11	10	124
2	16	43	12	5	2	1	7	12	183
1	13	49	9	5	5	5	4	9	309
		16	15	13	11	26	8	11	62
		24	26	17	8	16	5	4	248
broad-leaved species									
2	16	38	13	7	2	7	5	10	337
1	13	43	14	7	4	6	4	8	372
	9	51	17	5	3	2	4	9	370
3	24	50	11	3	1	1	4	3	371
	3	21	12	8	6	18	15	17	155
steppe									
	2	23	24	11	7	18,5	10	4	124
	4	42	23	9	4	10	3	5	310
steppe									
2	10	42	23	7	3	3	4	6	155
1	3	31	21	13	8	14	4	5	93
	2	42	18	12	7	12	2	5	340
steppe									
	3	44	20	6	7	8	1	11	186
desert									
3	2	29	21	12	6	15	11	1	279
	2	41	25	11	3,5	4,5	1	12	186
ert									
	0,5	22	25	18,5	10	17	2	5	155
	3	30	22	12	9	20	3	1	248
6	5	7	11	8	5	24	32	2	124
desert zone									
2	6,5	55	16	8	5	4,5		3	62
		47	20	11	6	15	1		248
landscapes									
2	1	6	8	8	5	28	41	1	247
3	13	29	13	7	5	11	14	5	155

Values of the limits of B with the highest frequency under average weather conditions are in fairly good agreement with the average values of the stability parameter listed in Table 1, thus confirming the validity of the calculated average values.

As already noted, in order to study the characteristics of the variation of the stability parameter with time, the annual and daily course or variations of this parameter were analyzed at a number of stations located in the zones of the tayga, forest steppe, and mountain landscapes. The calculations were made for the five-year period from 1963 to 1967 with the exception of the winter months of 1963 and 1964, when no gradient observations were made at the stations.

The annual course was determined for the 1 A.M. and 1 P.M. periods, and the daily course, for January and July. However, since no observations were made in winter at 7 and 10 A.M. and 4 and 7 P.M., the daily course in January is given only in terms of two periods of observations, nocturnal and diurnal. Results of the calculations are shown in Tables 3 and 4.

In analyzing the daily variation of $\overline{\frac{\Delta t}{u_1^2}}$, one must note first of all its large amplitudes in summer and small amplitudes in winter, the increase in amplitudes from the tayga zone to the steppe zone, and a considerably larger daily amplitude on the Asian territory of the Soviet Union, particularly in the summer period as compared to the daily amplitude on the European territory of the USSR.

The maximum values of the stability parameter in the daily course in summer were observed between 10 A.M. and 1 P.M. and the minimum values, primarily at night. The transition from negative to positive values in the morning and from positive to negative values in the evening is difficult to determine because of large gaps between the periods of observations, but it may be stated, nevertheless, that in summer during the 7 A.M. period the average values of B are positive for all stations, and negative during the 7 P.M. period. In winter, the values of B are positive at noon for the southern regions and negative for the northern and mountainous regions; during the 1 P.M. period, the B values are negative for both the northern and southern regions.

In the annual course of the stability parameter, the maximum values at noon are observed in the summer months, and the minimum values in the winter period. In the forest steppe and steppe zone, the average values of the stability parameter are positive the year round during the 1 P.M. period, and negative in the zone of the tayga and mountainous landscapes. The annual course of $\frac{\Delta t}{u_1^2}$ is different for different landscape zones at night. Whereas for the dry steppe regions (Askaniya-Nova and Poltava) the annual course of $\overline{\frac{\Delta t}{u_1^2}}$ at night is the opposite of the one during the day, i.e., with a maximum in winter and a minimum in summer, in the more humid regions of the tayga zone

Table 3

Annual Course of $\left.\frac{\Delta t}{u_1^2}\right|$ (1963-1967)

Hour	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Amplitude
						Torzhok (Tayga with admixture of broad-leaved species)							
1 A.M.	—0,112	—0,146	—0,094	—0,071	—0,129	—0,219	—0,093	—0,124	—0,102	—0,049	—0,101	—0,025	0,107
1 P.M.	—0,070	—0,038	—0,007	—0,006	0,076	0,100	0,084	0,072	0,058	0,025	0,042	—0,034	0,170
						Solyanka (forest steppe)							
1 A.M.	—0,140	—0,252	—0,322	—0,226	—0,219	—0,199	—0,291	—0,236	—0,265	—0,113	—0,080	—0,148	0,242
1 P.M.	0,036	0,015	0,054	0,097	0,106	0,179	0,282	0,210	0,201	0,119	0,030	0,015	0,267
						Askaniya-Nova (steppe)							
1 A.M.	—0,016	—0,040	—0,052	—0,101	—0,136	—0,121	—0,162	—0,111	—0,117	—0,090	—0,027	—0,033	0,146
1 P.M.	0,021	0,020	0,071	0,083	0,119	0,150	0,222	0,171	0,201	0,127	0,084	0,029	0,202
						Turukhansk (tayga)							
1 A.M.	—	—0,174	—0,144	—0,208	—0,127	—0,170	—0,309	—0,203	—0,085	—0,015	—0,079	—	0,230
1 P.M.	—	—0,032	0,040	0,012	0,003	0,107	0,185	0,173	0,079	0,001	—0,039	—0,103	0,288
						Poltava (steppe)							
1 A.M.	—0,022	—0,067	—0,054	—0,111	—0,211	—0,194	—0,193	—0,165	—0,144	—0,119	—0,074	—0,035	0,189
1 P.M.	0,011	0,011	0,002	0,067	0,075	0,113	0,111	0,123	0,072	0,072	0,028	0,000	0,123
						Skovorodino (mountain landscape)							
1 A.M.	—	—	—0,288	—0,312	—0,133	—	—	—	—	—	—	—	—
1 P.M.	—0,048	—0,031	0,035	0,111	0,121	0,114	0,184	0,146	0,127	0,114	—0,024	—0,017	0,232
						Beregovo (1963—1964, 1966—1967) (forest steppe)							
1 A.M.	—0,028	—0,094	—0,109	—0,200	—0,205	—0,268	—0,163	—0,175	—0,074	- 0,099	—0,051	—0,006	0,274
1 P.M.	0,004	0,029	0,070	0,102	0,126	0,206	0,238	0,206	0,181	0,072	0,077	0,030	0,234

Table 4

Daily Course of $\frac{\Delta t}{u_1^2}$ (1963-1967)

Month	Hour 1	7	10	13	16	19	Amplitude
Torzhok (Tayga with admixture of broad-leaved species)							
I	−0,112			−0,070			0,042
VII	−0,093	0,088	0,148	0,084	0,044	−0,102	0,250
Solyanka (forest steppe)							
I	−0,016			0,021			0,037
VII	−0,293	0,179	0,236	0,282	0,162	−0,041	0,577
Askaniya-Nova (steppe)							
I	−0,140			0,036			0,176
VII	−0,162	0,099	0,198	0,222	0,111	−0,048	0,384
Turukhansk (tayga)							
I	—			—			—
VII	−0,309	0,106	0,221	0,185	0,152	−0,034	0,530
Poltava (steppe)							
I	−0,022			0,011			0,033
VII	−0,193	0,042	0,109	0,111	0,060	−0,072	0,304
Skovorodino (mountain landscape)							
I	—			−0,048			—
VII	—	0,106	0,206	0,184	0,040	0,153	—
Beregovo (1963—1964, 1966—1967) (forest steppe)							
I	−0,028			0,004			0,032
VII	−0,163	0,097	0,197	0,238	0,105	−0,055	0,401

(Turukhansk and Torzhok) a second minimum is observed at the end of winter or in spring, and a second maximum is observed at the end of spring and beginning of summer. This maximum is apparently due to a decrease in the effective radiation in these regions at night, because of a higher air humidity, a lower temperature of the underlying surface, a heavier cloudiness, etc. At night during the entire year, $\frac{\Delta t}{u_3^2}$ are negative at all the stations considered. The annual amplitude, like the daily amplitude, is larger on the Asian territory of the USSR in both the daytime and nighttime.

We shall now consider the validation of the use of the commonly employed climatological method of calculation of the stability parameter in the ground layer of the atmosphere from daily initial data. To this end, we shall examine the dependence between the initial parameters: the temperature difference at two levels and the wind velocity. The establishment of this relationship may also be significant in solving a number of other problems. For example, problems connected with the determination of climatic characteristics of the heat balance (determination of the heat flow, calculation of the vertical component of the mixing factor, etc.) through the use of various formulas expressing the dependences of the indicated characteristics on the values of other meteorological quantities measured directly.

The relationship between the wind velocity and the magnitude of the temperature gradient (temperature difference at two levels) in the ground layer has been pointed out in a number of studies. Thus, according to the data of Best [16], during the superadiabatic period (noonday period), the temperature gradients decrease as the wind velocity increases above 4 m/sec (wind velocity at a height of 13.4 m above the surface). At a wind velocity below 4 m/sec, the temperature gradient falls as the wind weakens. In the presence of inversions, the temperature gradient decreases very rapidly (in absolute value) as the wind grows stronger from zero to 2 m/sec (z = 13.4 m), and at high velocities a strengthening of the wind has a slight influence. The studies of A. S. Monin [8, 9] also note strong temperature inversions in the presence of a weak wind, the weakening of inversions as the wind increases in strength, and the absence of calms in the presence of a strong instability.

The conclusions of the indicated studies were based on materials of observations at a single point (Porton in England in the case of Best, and the region of the 1959 Tsimlyansk expedition of the Atmospheric Physics Institute, in the case of Monin). These studies made use of data for a very brief period: March and June, 1932 and 1933; and July and August, 1959.

It was of interest, therefore, to study this dependence by using data of a large number of points of different landscape zones. To this end, the dependences of the temperature difference between the 0.5 and 2.0 m levels (Δt) on the wind velocity at a height of 1 m (u_1) were sought on the basis of gradient observations of a series of heat balance stations for 1967. Graphs of the relationship were plotted for each month during all the hours of observation. Envolope curves were drawn through the points obtained on each graph.

Individual points that protruded sharply were neglected.

As an example, Fig. 1 shows a graph of the temperature difference $\Delta t_{0.5-2.0}$ versus the wind velocity u_1 for the Nebol'sin station for July, 1967, and Fig. 2 gives the envelope curves for the superadiabatic and inversion states for all months of 1967 at the Rudnyy station.

The maximum monthly values of the temperature difference (positive and negative) and the corresponding wind velocities, taken from the curves, are shown in Tables 5 and 6. The tables also list data for a number of points where observations were made during the expedition of the Main Geophysical

Maximum Values of $\Delta t_{0,5-2,0}$ under Superadiabatic Conditions and at which Maximum Values

Station	Year	I	II	III	IV	V
						Tay
Arkhangel'sk . .	1967	0,1	0,0	0,5	0,7	1,0
		2,3—3	1—4	2,0	1,3	3,8
Kargopol' .	1967	0,6	0,6	0,9		1,7
		0,0	5,8	2,4—4,3		1,6—3,1
Nolinsk	1967	0,0	0,3	0,3	0,8	0,9
		3	0,3	0,2—0,8; 5,6	1,1	1,5; 4,3
Turukhansk . . .	1967		0,1	1,6	0,6	0,9
			1,0; 4,0	0,5	1,2; 1,6	3,2
	1966					
	1965					
Yakutsk	1967				0,6	1,3
					1,3; 2,7	2,2, 3,0
						Tayga with admixture
Voyeykovo	1967	0,4	0,1	0,4	1,2	1,1
		2,0	0,6; 1,4; 3,6	2,4	5,0	1,9; 3,7
	1966				1,3	1,4
					2,6	3,5; 3,8
Riga	1967	0,2	0,2	0,4	1,5	1,4
		0,0; 0,9; 1,6	2,1	2,6; 5,8	2,0; 2,8	2,8
Tiyrikoyya . . .	1967					
	1966					
Pinsk	1967	0,2	0,1	1,0	0,8	1,1
		0,2—3,6	0,6—3,3	1,5—2,4	1,2; 3,6	1,8
Smolensk	1967					
im. Nebol'sin	1967					
						Forest
Pavelets	1967	0,3	0,1	0,3	1,2	1,9
		0,0	2,2	2,6; 5,2	2,0	3,0
Sovetsk	1967	0,5	0,7	0,2		
		3,4	3,4	2,3		
	1966	0,5	0,8	0,8	1,0	
		3,2; 3,8	5,3, 6,1	4,3	2,2; 4,0	

Table 5

Wind Velocity u_1 at Height of 1m
are observed (First Line Δt, Second Line u_1)

VI	VII	VIII	IX	X	XI	XII
ga						
1,1	0,8	0,8	0,8	0,3	0,2	0,1
1,8	1,6—2,0	1,7	3,1	1,0—2,6	1,3—2,3	0,6
	1,6	1,0	0,9	0,5	0,3	0,0
	1,4	1,2	1,6	1,5	1,3; 2,3	1,0; 1,8
2,2	1,4	1,8	1,2		0,5	0,1
1,8	1,2	0,4	2,0		0,7	2,8
2,5	2,0	1,3	1,2	1,1	0,1	0,2
1,0	1,2	1,6	3,4	1,8	1,3	0,6; 1,8
	1,5					
	1,2					
	2,1					
	1,4					
2,5	2,0	1,6	1,0	0,8		
1,6	3,1	2,6	3,1	1,6		
of broad-leaved species						
1,8	1,4	1,1	0,9	0,8		
1,4	1,6	2,9	1,6; 3,9	2,7		
1,4	1,2	1,5	1,1	0,6	0,4	0,2
4,9	2,6	2,6	1,4	2,4	2,7	1,0
1,5	1,6	1,6	1,0	0,7	0,5	0,2
2,2	2,6	2,8	2,9	2,0	2,7	1,6; 2,2; 3,0
	1,8					
	2,0					
	1,5					
	2,8					
1,4	1,2	1,3	1,2	0,7	0,5	0,3
1,4	1,6—1,8	2,4	2,6	2,3; 2,9	0,8; 3,0	1,8; 2,6
	1,4					
	1,5					
	2,0					
	2,5					
steppe						
1,6	1,6	1,4	1,2	1,1	0,9	0,2
4,6	4,6	2,0	3,5	2,2	3,8	1,6; 3,0
	1,7				0,7	0,2
	3,3				3,7	2,4, 5,2
	1,4			1,1	0,7	0,2
	2,2, 2,9			2,6; 3,1	3,8	3,4; 4,6

Station	Year	I	II	III	IV	V
Sovetsk	1965			0,6	1,7	1,5
				5,2	4,7	3,4
	1965[1]				0,6	
					2,3	
	1963[1]					
Solyanka	1967	1,0	0,3	1,1	1,5	1,8
		2,2	0,2–2,4	1,2	4,2	3,8
						St
Kamennaya Step'	1967	0,7	0,5	0,8	1,2	1,7
		2,9	1,9	1,1	4,0	5,9
Askaniya-Nova . .	1967	0,5	0,7	1,3	1,5	1,7
		2,1–2,9	2,4; 4,8	0,8, 5,5	2,8	2,5
Dnestrovsk . . .	1967[1]					
Rudnyy	1967	0,4	0,7	1,0	1,7	2,2
		4,9	3,4	2,0	3,0	2,8
	1966	0,7	0,5	0,3	1,3	1,6
		4,2	3,0	2,4–4,4	2,1	0,5, 3,0; 4,0
Balakovo	1967[1]					
						Semi
Balkhash	1967	0,8	1,3	1,6	2,0	2,2
		4,3	1,8; 4,2	4,7	3,4	3,8
Karasuat	1967					
	1966					
	1965					
Sovkhoz "30 let Oktyabrya"	1952[1]					
Makhtaly	1959[1]					
						Des
Aydarly	1967	0,4	0,6	1,4	1,6	2,2
		0,6; 1,8, 4,7	1,0, 1,5; 1,9	3,6	2,2	1,9
Beki-Bent	1967	1,9	1,6	2,2	2,2	2,6
		1,7	1,5; 1,8, 3,2	1,4	1,5	4,2
						Mountain
Telavi	1967					
Kyzyl	1967	1,0				
		1,5				

[1] In these years, the observations were carried out by an expedition of the Main Geophysical Observatory.

Table 5 (Cont'd)

	VI	VII	VIII	IX'	X	XI	XII
	1,5	1,8	1,3		0,8	0,5	0,3
	2,8	2,3	3,8		3,8, 5,0	0,0; 4,0	3,8
			1,6				
			2,2; 2,6, 3,7				
	1,7	2,2	1,8	1,5	1,6	0,3	0,3
	1,8	2,2	3,9	2,1	1,8	0,0	2,1
eppe							
	1,4	1,4	1,2	1,3	0,9		
	1,0	2,0	2,5	3,6	1,8		
	1,4	1,7	2,3	2,1	1,6	1,1	0,4
	2,0; 2,2	1,8; 3,1; 3,8	1,6	2,6	2,8	3,0	2,8; 4,2
				1,8			
				3,1			
	1,4	1,6	2,1	1,5	1,0	0,7	0,4
	3,0	3,2	4,0	2,7	2,3; 3,8	1,8	2,5
	2,1	2,2	2,1	2,0	1,2	0,7	0,3
	2,4	0,8	2,8	4,2	4,2	2,0; 2,7	0,6—3,7
			1,5				
			2,3				
desert -							
	2,9	2,4	2,3	2,1	1,5	1,0	
	4,2	5,2	3,8	3,6	2,6	3,6	
		2,7					
		2,8					
		2,4					
		2,4; 4,0					
		2,1					
		3,0					
		2,0					
		3,0					
				1,6			
				2,2; 2,6			
ert							
	2,3	2,6	2,5	2,2		1,1	1,1
	1,7	5,1	2,2	2,0		1,4—3,9	1,2
	2,7	2,2	2,0	2,1	1,8	1,6	0,9
	2,0	2,2	5,8	2,4	2,2, 4,2	1,4; 4,2	3,6, 4,0
landscape							
		1,2					
		1,3—3,4					
		0,9					
		1,2; 3,2					

Largest Negative Values of $\Delta t_{0,5-2,0}$ in the Presence of Inversion and Wind Velocity u_1 (First Line Δt,

Station	Year	I	II	III	IV	V
						Tay
Arkhangel'sk	1967	—0,7	—0,3	—0,5	—0,6	—0,5
		0,9	0,2—3,6	2,4	0,2	0,5
Kargopol' . .	1967	—0,9	—1,0	—0,9		—2,6
		1,9	1,1	0,0		0,0
Nolinsk . . .	1967	—1,5	—0,9	—0,8	—2,1	—1,1
		0,0	1,0	0,4; 1,3	0,4	0,3
Turukhansk . .	1967		—0,5	—1,7	—1,4	—1,3
			1,6	0,6; 1,0	1,1	0,7
	1966					
	1965					
Yakutsk. . . .	1967				—2,7	—2,0
					0,0	0,2, 0,7
					Tayga with admixture	
Voyeykovo. . .	1967	—1,5	—1,0	—1,1	—1,4	—1,4
		1,4	0,7	1,0	0,2; 0,8	1,6
	1966				—1,0	—1,6
					1,0	0,8
Riga	1967	—1,0	—0,3	—0,6	—0,9	—2,2
		0,0	0,2—3,5	0,0	0,8	0,0
Tiyrikoyya . .	1967					
	1966					
Pinsk	1967	—2,1	—0,3	—0,4	—1,1	—1,8
		0,0	2,8	1,5; 2,6; 3,8	0,0	0.0
Smolensk . .	1967					
im. Nebol'sin	1967					
						Forest
Pavelets . .	1967	—0,4	—0,6	—0,2	—0,7	—1,9
		0,9	3,4	0,0—4,0	2,2	0,0
Sovetsk . . .	1967	—0,8	—1,7	—0,2		
		1,4	1,3	3,7		
	1966	—0,2	—0,4	—0,2	—0,9	
		1,2	2,1	2,2; 3,4; 3,6	0,4	

Table 6

at a Height of 1m at which the Largest Negative Values are Observed
Second Line u1).

VI	VII	VIII	IX	X	XI	XII
ga						
—1,7	—1,4	—1,4	—2,4	—0,8	—0,3	—0,8
0,3	0,0	0,2	0,0	0,0	0,2, 2,0	0,0
	—1,6	—1,8	—1,2	—0,6	—0,5	—1,3
	0,0	0,6	0,4	2,3	1,7	0,9
—2,2	—1,6	—2,4	—1,9		—0,4	—0,3
0,0	0,0	0,0	0,0		1,4	1,8
—1,6	—1,6	—2,0	—1,5	—0,5	—1,0	—0,5
0,8	0,5	0,5	0,5	0,8	2,2	2,8
	—2,0					
	0,5					
	—2,9					
	0,8					
—2,1	—1,4	—2,1	—2,6	—1,3		
1,0	0,0	0,0	0,2	0,0		
of broad-leaved species						
—1,1	—1,0	—1,3	—0,9	—0,6		
0,7	0,3	0,2	1,7	5,8		
—1,0	—0,8	—0,5	—1,0	—1,1	—0,3	—0,7
1,4	0,8	1,5	1,0	0,8	1,9, 4,1	0,7
—2,7	—3,5	—1,4	—4,2	—2,3	—0,7	—2,3
0,0	0,0	0,0	0,0	0,0	1,6	0,3
	—0,9					
	0,5					
	—0,7					
	0,6					
—2,0	—2,7	—2,9	—2,6	—1,5	—0,7	—2,0
0,0	0,0	0,0	0,0	0,6	1,9	0,6
	—2,5					
	0,0					
	—2,0					
	0,0					
steppe						
—1,3	—1,3	—1,2	—1,4	—1,0	—0,5	—0,3
0,0	0,0	0,0	0,0	0,6	0,0, 2,2—3,1	2,4
	—0,7				—0,8	—0,6
	0,2					
	—1,0			—1,2	—0,3	—0,1
	1,0			0,0; 0,8; 1,0	2,0	1,4; 1,7

Station	Year	I	II	III	IV	V
Sovetsk . . .	1965			—0,8 1,1	—0,9 1,9, 2,4	—1,1 1,2
Solyanka . . .	1967	—1,2 0,9	—1,3 0,2; 1,2	—1,4 0,2	—1,1 0,5, 2,0	—2,4 1,1
						St
Kamennaya Step	1967	—2,4 0,0	—3,0 0,0	—2,5 1,3	—1,2 1,3, 2,9	—3,5 0,0
Askaniya-Nova	1967	—0,5 1,8	—0,5 1,5	—0,5 2,6	—1,3 0,2	—2,3 0,3
Rudnyy . . .	1967	—0,4 1,7	—0,5 0,0; 0,4; 1,2	—0,3 0,0; 1,8, 2,6	—1,9 0,3	—1,0 0,4
	1966	—0,4 0,4; 2,2; 4,4	—0,9 2,0	—1,3 0,2	—2,4 0,4	—1,1 0,8
						Semi
Balkhash . . .	1967	—0,5 0,3	—0,4 3,0	—0,7 2,0	—1,9 0,0	—1,4 0,6
Karasuat . . .	1967					
	1966					
	1965					
						Des
Aydarly . . .	1967	—4,3 1,2	—0,7 0,0	—2,3 0,2	—1,4 0,8	—1,4 2,8
Beki-Bent . .	1967	—2,5 0,9	—2,2 1,2	—1,2 1,6	—1,2 0,7	—0,8 1,7
						Mountain
Telavi	1967					
Kyzyl	1967	0,0 0,5; 1,0				

Table 6 (Cont'd)

	VI	VII	VIII	IX	X	XI	XII
	−1,6	−1,4	−1,1		−0,8	−0,4	−0,1
	1,4	0,0	0,2		1,2	3,8	5,5
	−2,9	−2,5	−1,1	−2,4	−1,6	−0,7	−0,9
	0,8	0,2	0,6	1,0	0,7	0,8	0,0; 1,0
eppe							
	−3,6	−2,7	−2,0	−3,9	−3,4		
	0,0	0,0	0,0, 0,5	0,0	0,8		
	−1,8	−1,7	−1,1	−2,2	−1,8	−0,5	−0,3
	0,4	0,8	0,6	0,0	0,0; 0,3	1,8	0,7, 1,8; 2,8
	−0,7	−1,0	−1,9	−2,5	−1,5	−0,6	−0,2
	2,3	0,0	0,6	0,4	0,7	0,4	3,4
	−1,9	−1,5	−1,5	−2,6	−1,6	−0,4	−0,5
	0,4	0,7	0,4	0,3	1,0	0,0	0,5
desert							
	−1,1	−1,0	−1,1	−1,7	−2,0	−1,1	
	0,8	1,2	0,6	1,0	0,0	0,5	
		−1,5					
		0,2					
		−1,6					
		0,0					
		−2,7					
		0,6					
ert							
	−1,9	−1,6	−3,4	−1,8		−0,8	−3,2
	0,3, 2,0	1,4	0,5	0,5		1,7; 2,0	0,7
	−0,9	−0,6	−0,6	−1,1	−2,3	−1,6	−3,2
	0 6	2,7	1,6	1,6	1,0	1,2	0,9
landscape							
		−1,6					
		1,8					
		−2,4					
		0,5					

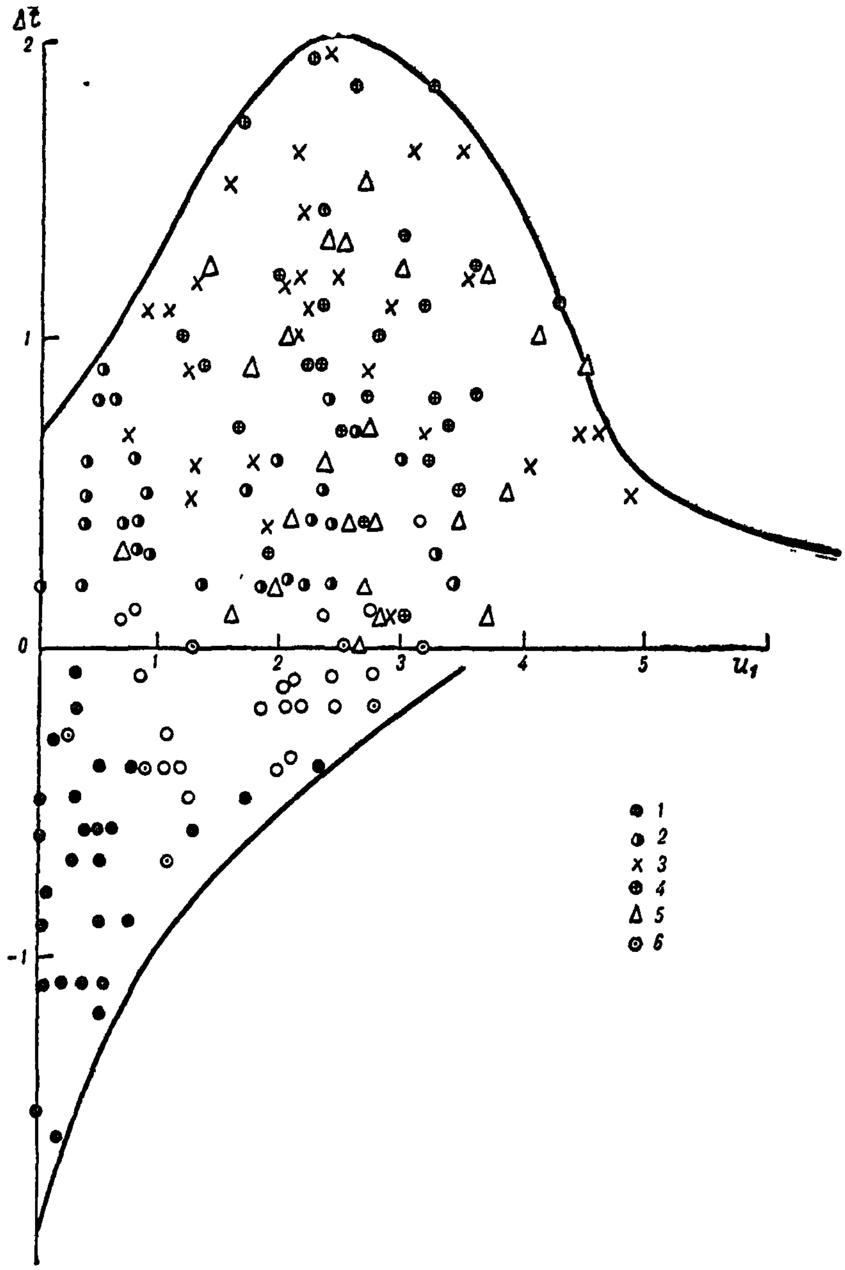

Fig. 1. Temperature difference in the 0.5 and 2.0 m layer as a function of velocity at a height of 1 m. Nebol'sin station, July 1967.
1 - 1 A.M., 2 - 7 A.M., 3 - 10 A.M., 4 - 1 P.M., 5 - 4 P.M., 6 - 7 P.M.

Observatory. Analysis of the plotted graphs and data of Tables 5 and 6 shows that there is indeed a correlation between Δt and u_1. In the great majority of cases, the largest values of the temperature differences in the presence of inversions are usually observed in a calm or in a slight wind, and the

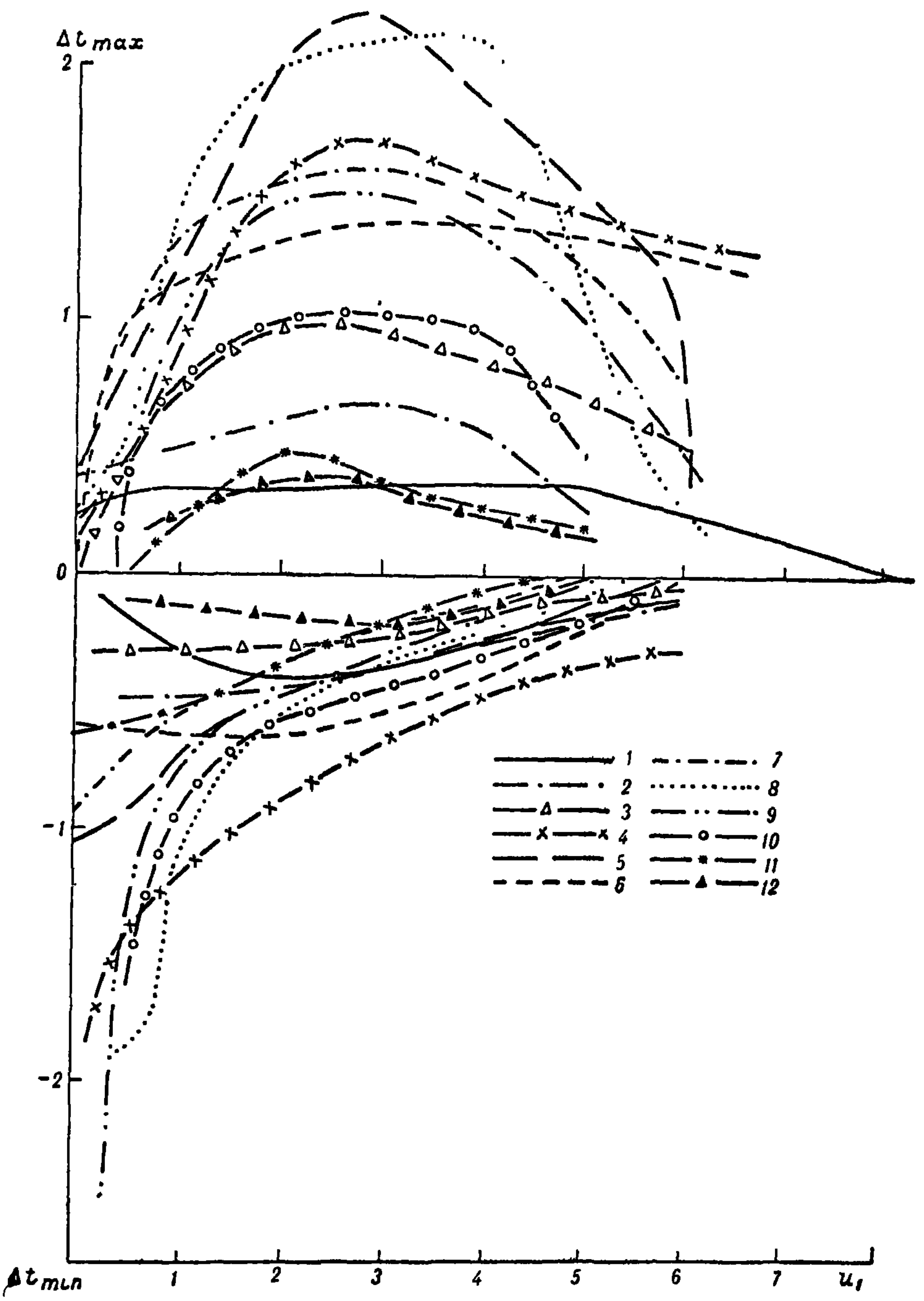

Fig. 2. Envelope curves of the dependence of Δt on u_1 during superadiabatic and inversion state. Rudnyy, January-December 1967.
1 - January, 2 - February, 3 - March, 4 - April, 5 - May, 6 - June, 7 - July, 8 - August, 9 - September, 10 - October, 11 - November, 12 - December.

largest positive gradients, in the presence of a moderate wind, and in some months, at a number of stations, even in the presence of a stronger wind (4-5 m/sec). The wind velocity at which the largest positive and negative temperature differences are observed changes within certain limits from one station to another and from month to month. It is most frequently below 1.0-1.5 m/sec, or close to calm for the largest negative gradients in the presence of inversions and amounts to 2-3 m/sec for the largest

Table 7

Frequency of Weak Wind in the Presence of Positive Temperature Gradients

Station	Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total number of Observations in each Month
Rudnyy	1967	5	2	1	4	3	6	6	1	1	3	2	0	90—93 IV—X 28—31 XI—III
Rudnyy	1966	2	0	2	2	2	0	3	2	3	3	0	3	90—93 IV—X 28—31 XI—III
Kamennaya Step'	1967	2	0	0	1	0	6	2	4	2	3	0	0	90—93 V—X 28—31 XI—IV
Balkhash	1967	2	1	0	6	1	1	0	1	3	1	2	—	90—93 IV—X 28—31 XI—III
Aydarly	1967	4	3	10	2	11	1	6	3	7	—	1	5	90—93 III—X 28—31 XI—II
Beki-Bent	1967	8	2	2	4	1	1	2	0	1	6	6	7	84—93 I—XII
Yakutsk	1967	—	—	—	1	1	4	8	5	9	3	—	—	90—93 VI—IX 28—31 X—V
Turukhansk	1967		0	1	0	0	2	11	7	3	1	1	1	90—93 VI—IX 28—31 X—V

positive gradients under superadiabatic conditions. Occasionally, mainly during the cold period, some deviations from this relationship are observed: the most negative gradients take place in the presence of a moderate wind and conversely, the largest positive differences occur during a calm and a slight wind. The number of such cases, particularly under superadiabatic conditions, is small. After reaching its maximum value at a certain wind velocity, the superadiabatic gradient begins to decrease as the wind velocity increases further. The rate of this decrease varies at different stations and in different seasons of the year. In some cases this decrease occurs very rapidly (Fig. 2, August) and in others, very slowly (Fig. 2, April).

When the role of turbulent exchange is decisive in the formation of the daily variation of the wind velocity, it may be assumed that during the

Table 8

Values of the Temperature Difference at High Wind Velocities

Station	Month	u_1	Δt	Station	Month	u_1	Δt
Sovetsk	VI	6,0	0,7	Aydarly	IV	6,0	0,7
	VI	6,8	0,8		IV	6,2	0,9
	VI	7,1	0,5		IV	6,8	1,1
	VII	6,2	0,5		V	6,0	1,8
	VIII	6,0	0,9		V	6,2	0,6
	IV	6,8	0,7		VII	5,9	1,5
	IV	8,0	1,2	Balkhash	V	6,6	0,5
Kamennaya Step'	V	6,0	1,4		VI	5,9	0,8
	V	5,9	0,8		VII	6,2	0,5
Rudnyy	III	6,5	0,5		VII	5,9	0,5
	IV	6,0	0,5		VII	6,1	0,8
	V	6,0	1,2		VII	6,6	0,8
	V	6,3	1,3		VII	6,8	1,5
	V	6,4	1,1		VII	6,8	1,8
	V	7,4	1,3		VIII	6,2	1,4
	V	7,8	1,2		VIII	6,6	0,9
	V	7,4	0,5	Beki-Bent	III	6,5	0,6
	V	7,6	0,5		V	6,1	0,5
	VI	6,8	1,3		V	7,6	1,4
	VI	7,6	0,8		V	7,4	2,1
	VI	6,8	1,2		VI	6,5	0,8
	VII	6,2	0,6		VI	5,9	1,3
	IX	6,2	0,8		VIII	6,2	1,1
Rega	IV	6,3	0,7		VIII	6,3	0,9
Voyeykovo	V	6,1	0,7		IX	6,0	1,1
					IX	6,6	1,0
					IX	6,4	0,9

periods of 10 A.M., 1 P.M. and 4 P.M., when the largest positive temperature differences can be observed, calms and slight winds occur very seldom. This is confirmed by Table 7, which lists the frequency of cases of slight wind ($u_1 \leqslant 1$ m/sec), based on data of several stations, during the 10 A.M., 1 P.M. and 4 P.M. periods at positive and zero values of the temperature gradients.

It is evident from Table 7 that a slight wind is observed in no more than 10% of the cases during the warm period and the 10 A.M., 1 P.M. and 4 P.M. periods.

As the wind increases from a calm to 1.5-2.5 m/sec, the negative temperature gradient decreases very rapidly in most cases, and slowly as the wind strength increases further. In some cases, an irregular rate of decline of the negative temperature gradient was observed in the entire range of wind velocity, and even a completely insignificant dependence of the gradient on the wind velocity was observed. If the largest negative gradient takes place in the presence of a moderate wind, then both a strengthening and a weakening of the wind cause a regular decrease of the temperature gradient.

The largest values of the gradients, both positive and negative, are observed during the warm period of the year, with the exception of stations in the desert zone, where the largest gradient values in the presence of inversions are observed during the winter months. At the same time, the largest positive values in summer are several times greater than the winter values, whereas the largest negative temperature differences change insignificantly from season to season.

It is usually assumed that at a high wind velocity (for example, above 10 m/sec as given by the wind vane), the temperature differences at two levels in the ground layer of the atmosphere is slight. This is not always so, however. At such wind velocities, the positive temperature gradients may still be relatively considerable. They are sometimes even greater than one degree, especially in summer in the southern regions. This is confirmed by single values of temperature differences at high wind velocities, given in Table 8 (wind velocity at a height of 1 m, temperature difference in the 0.5-2.0 m layer). The values of the gradients (largest positive and negative ones) and wind velocities at which they are observed will of course change from year to year according to the synoptic situation. Nevertheless, the general nature of the dependence of the temperature gradient on the wind velocity, judging from many graphs, plotted on the basis of observational data for several years, remains unchanged.

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BASIC PRINCIPLES OF ORGANIZATION OF THE SURVEY OF ATMOSPHERIC POLLUTION IN CITIES

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The main sources of air pollution in cities are large industrial enterprises and motor transport, which discharge large amounts of noxious ingredients into the atmosphere. The most common are sulfur dioxide, carbon monoxide, nitrogen dioxide, phenol, hydrogen sulfide, carbon disulfide, soot, etc.

The degree of air pollution is characterized by the single concentration of the impurity if the sampling is carried out for 20-30 min, and by corresponding average values of the concentrations for sampling lasting longer periods (days, months, a year). According to observational data, in a number of cities with an extensive industry, there are frequent cases where the concentrations of noxious impurities considerably exceed the maximum permissible ones (MPC), and the frequency of such values amounts to up to 50% of the days per year. As was noted in [3, 6, 9, 13, 17, 18, etc.], the concentrations increase particularly under unfavorable meteorological conditions, at "dangerous" wind velocities, in the presence of a temperature inversion, fog, etc.

The basic principles of organization of surveys of atmospheric pollution in cities result from the characteristics of propagation of the impurities.

The basis for a survey of the pollution of a city air reservoir is the determination of the concentrations of noxious substances in its various parts under different meteorological conditions, the measurement of meteorological elements determining the dispersal of impurities, the collection of quantitative characteristics of discharge of noxious impurities into the atmosphere, and various kinds of medical-biological data.

The existing methods of air sample collection are divided into four types: at stationary observation points, in the area of individual industrial enterprises, and itinerary and episodic observations. The choice of the type of observation is determined by the size and character of the built-up area of the city, the capacity and number of the pollution sources and their relative location with respect to the residential districts. In the majority of cases, these methods of sampling are combined and mutually supplement each other.

The organization of stationary observation points is particularly important in large cities, where in addition to large-capacity industrial enterprises there are many low and small pollution sources spread over the whole area of the city. Such an arrangement of the sources of discharges produces a heavily polluted general background. The creation of a large network of stationary points involves a large economic investment, and for this reason, when a more detailed survey is to be made and the linear dimensions of the city are greater, it is desirable to use a specially equipped motor car as a moving point. The latter makes it possible to select representative points of sampling, to determine the zones of maximum concentrations and thus to obtain a more detailed picture of the concentration field.

Analysis of the observational material shows that the concentrations of noxious substances undergo a marked change in different parts of the city, and for this reason, in order to obtain a complete characterization of the degree of pollution of a city, it is necessary to organize one sampling area of 10-20 km^2 on flat terrain and one area of 5-10 km^2 on rugged terrain. After conducting a detailed survey, it is sufficient to take regular measurements at 3 to 4 of the most representative points located in different sections of the city, so that it will be possible to estimate variations in the degree of atmospheric pollution. If, however, the territory of the city has large pollution sources, which play a definite part in atmospheric pollution, and particularly if they are concentrated on a single industrial site, then in addition to stationary points it is desirable to set up the collection of samples at various distances from the center of the site under the axis of the visible plume.

Stationary points of sample collection are organized by taking into account the planning and layout of the city districts, the location of air pollution sources, the topography of the area, etc., in order that the selected samples characterize not the local, but the general pollution of the air reservoir, determined by the action of turbulent diffusion, in all sections of the city. A suitable distribution of the collection points is very important, since it largely determines the concentration values. In [19] it is shown that the concentrations of noxious substances in the vicinity of highways are much higher than the average pollution background. This is where the maximum number of pedestrians and passengers in private and public motor transport are concentrated, where they are subjected to the influence of these higher concentrations. In addition, high concentrations also act on residents in apartments located in buildings along the highways. In organizing the studies, it is indispensable to consider the laws of distribution of impurities as a function of the meteorological conditions. In the absence of unorganized discharges near a high source, the concentration is zero, then along the direction of the wind, it increases, reaches its highest values at distances equal to 10-40 stack heights, then gradually diminishes to zero. In [2, 4, 8, 16, etc.] it is shown that the maximum value depends on the capacity of the discharge, stack height, temperature and velocity of the ejected gases, and also to a considerable extent on the weather conditions. The higher the source, the more the impurity is dispersed in the atmosphere before the noxious substances reach the underlying surface.

The dispersing capacity of the atmosphere depends primarily on the wind velocity and vertical distribution of the temperature. If a temperature drop with the height is observed, an unstable state of the atmosphere is established, and conditions of intense turbulent exchange are created, which on dry land are mostly observed during the summer in the daytime. Under such conditions at the earth's surface, under the plumes of high sources with a gas ejection temperature of about 100°C, maximum concentrations are observed [4, 8, 16], and their large fluctuations with time are possible. If the temperature increases with the height in the ground layer of air, i. e., an inversion is observed, the eddy motions and the impurity dispersal become considerably attenuated. Under these conditions, high concentrations are produced at the surface of the ground as a result of discharges from low sources, and, conversely, low concentrations are observed due to discharges from high sources. For this reason, in the presence of large and lasting ground inverstions and in the presence of low or random discharges, the concentrations of noxious substances may rise sharply on industrial sites and in adjacent areas.

The magnitude of the ground concentration in the presence of elevated inversions will substantially depend on the relative positions of the lower inversion boundary and source of the discharge: if the inverstion boundary is located above the source and prevents the penetration of noxious substances into the upper layers of the atmosphere, the bulk of the impurity will concentrate near the ground and this will result in high concentrations. These most unfavorable conditions for impurity dispersal are produced during the spring period, when the stable ground inverstion breaks down, and under certain synoptic conditions, and sometimes also in the course of a brief period in the mornings during the warm part of the year.

The wind velocity also has different effects on the field of concentrations near the ground, depending on the method of discharge of the noxious substances [1, 6, 8]. When the discharges are low and not organized, low wind velocities result in the formation of stagnant situations and in an increase of the concentration. When the discharges are high, the concentrations near the ground decrease as a result of an increase in the ascent of the plume and the transport of the impurity upward, particularly when the discharge is strongly overheated. At high wind velocities, the initial ascent of the impurity decreases, but because of an increase in the transport velocity of the impurity, the ground concentration decreases. For this reason, the maximum concentrations are observed at a certain wind velocity (3-6 m/sec), called the "dangerous" wind velocity.

An instability of the wind direction promotes an increase of the dispersal along the horizontal. Large areas are thus subjected to the influence of lower concentrations.

In the presence of fog, a stronger influence of pollution is observed, because on the one hand, water solutions of certain ingredients such as sulfur dioxide are more toxic; and on the other hand, the meteorological conditions associated with fogs promote the accumulation of discharged impurities in the ground layer of air. Sometimes smogs are produced, which are considered to be associated with known cases [10] of sharp increase of illness among the population and in some cases with large numbers of victims.

As shown by theoretical theses and studies made in wind tunnels [5, 7], under conditions of a rugged terrain and above a city with modern buildings, there takes place a disturbance of the air stream leading to an increase in concentrations in certain situations. In some forms of the relief, for example in basins, the stagnation of air causes the accumulation of noxious substances near the underlying surface, particularly in the presence of a temperature inversion and low sources of discharge. On the whole, in the presence of roughness of the terrain, the maximum of the ground concentration is usually higher than above an even area. The dispersal of impurities under urban conditions is substantially affected by the layout of the streets, their width and direction, height of the buildings, presence of green tracts, water reservoirs, and even the planning and location of individual buildings [15], since these factors create an irregular surface, form different types of obstacles to an airstream and produce special meteorological conditions i.e., the microclimate of a city.

The concentrations of noxious substances undergo considerable changes in space. They are observed when the territory of the city contains a relatively large number of points of sample collection. Therefore, in order to obtain a detailed and complete picture of the pollution of a city area and to identify the sections with maximum and minimum concentrations of any ingredients, it is necessary to set up an extensive observational network.

Treatment of the experimental data obtained makes it possible to draw a number of important conclusions. Table 1 gives the mean monthly and maximum concentrations of sulfur dioxide and nitrogen oxides for two cities located under identical climatic conditions but with different arrangements of the main sources of pollution.

The upper part of the table characterizes the atmospheric pollution of a city where the industry is scattered over the entire territory, and the lower part, a city in which the industrial complex is located on a single industrial site. In each city there were eight points of sample collection. In Figs. 1-4 these results are represented in graphical form for clarity. A detailed examination of the data given in the table and in the figures show that the concentrations undergo considerable changes from one point to another and from one month to the next, i.e., in space and time. At the same time, there is a pronounced tendency on the part of the variations of mean monthly and maximum monthly concentrations to coincide in time at all points, i.e., over the entire area of the city. This tendency is particularly characteristic of a city where the industry is distributed over its entire area, and less pronounced in a city where the atmospheric pollution sources are located on the same industrial site. This is due to the fact that when the sources of discharge are distributed over the entire territory of the city, a city "cap", i.e., a general pollution of the

Values of Concentrations Based on Data for 1967 on the Territory

No. of points of collect.	I Av.	I Max.	II Av.	II Max.	III Av.	III Max.	IV Av.	IV Max.	V Av.	V Max.
Sources of Pollution Sulfur										
1	0,20	0,30	0,20	0,30	0,23	0,41	0,24	0,40	0,14	0,30
2	0,17	0,30	0,18	0,28	0,24	0,40	0,26	0,41	0,17	0,30
3	0,14	0,30	0,15	0,20	0,18	0,30	0,13	0,38	0,14	0,30
4	0,15	0,30	0,15	0,30	0,18	0,40	0,18	0,35	0,11	0,30
5	0,13	0,20	0,13	0,20	0,20	0,53	0,19	0,34	0,12	0,30
6	0,15	0,30	0,14	0,27	0,19	0,40	0,19	0,35	0,15	0,30
7	0,11	0,20	0,11	0,17	0,16	0,40	0,17	0,42	0,11	0,30
8	0,14	0,20	0,10	0,17	0,16	0,40	0,22	0,43	0,19	0,30
Nitrogen										
1	0,12	0,30	0,16	0,37	0,16	0,36	0,13	0,58	0,26	0,55
2	0,14	0,30	0,15	0,39	0,15	0,29	0,22	0,49	0,23	0,60
3	0,13	0,30	0,15	0,34	0,14	0,31	0,17	0,35	0 19	0,58
4	0,10	0,30	0,14	0,33	0,13	0,29	0,15	0,36	0,19	0,52
5	0,10	0,20	0,12	0,27	0,16	0,45	0,19	0,47	0,20	0,42
6	0,10	0,30	0,13	0,33	0,15	0,40	0,17	0,41	0,15	0,39
7	0,10	0,20	0,10	0,12	0,12	0,23	0,12	0,31	0,17	0,42
8	0,10	0,20	0,10	0,28	0,13	0,28	0,19	0,35	0,17	0,50
Pollution Sources Concentrated on a Phen										
1	0,26	0,96	0,30	0,72	0,40	1,40	0,39	0,73	0,32	0,80
2	0,32	0,72	0,36	0,84	0,31	1,00	0,36	1,20	0,41	1,06
3	0,22	0,72	0,34	0,84	0,15	0,60	0,31	1,00	0,46	1,07
4	0,29	0,78	0,40	1,08	0,35	0,90	0,54	0,93	0,54	1,20
5	0,27	0,96	0,49	1,04	0,26	0,72	0,56	1,66	0,56	1,07
6	0,35	1,20	0,53	1,08	0,47	1,08	0,79	1,09	0,77	1,46
7	0,26	0,60	0,32	0,72	0,33	0,72	0,38	0,84	0,51	1,90
8	0,26	0,54	0,36	0,76	0,32	0,72	0,42	0,73	0,44	0,93
Carbon										
1	13	20	14	30	25	35	15	29	12	30
2	19	30	10	20	10	20	7	10	10	30
3	11	20	12	20	9	25	1	10	10	40
4	18	30	6	30	12	20	6	15	17	45
5	15	30	12	40	11	28	9	20	12	45
6	16	30	8	30	16	35	12	38	11	27
7	13	20	15	30	16	28	7	15	8	40
8	7	10	10	40	13	20	10	20	8	40

Table 1

of Two Cities with Different Arrangements of Sources of Pollution

VI		VIII		IX		X		XI		XII	
Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.	Av.	Max.
Scattered all over the City Dioxide											
0,17	0,30	0,22	0,30	0,17	0,88	0,35	0,80	0,35	0,75	0,18	0,48
0,12	0,37	0,18	0,29	0.19	0,81	0,45	0,70	0,28	0,68	0,15	0,40
0,21	0,44	0,22	0,37	0,17	0,29	0,45	0,68	0,27	0,75	0,15	0,33
0,21	0,44	0.16	0,22	0,10	0,88	0,41	1,06	0,30	0,57	0,16	0,27
0,23	0,51	0,17	0,22	0,18	0,29	0,56	1,55	0,26	0,35	0,29	0,75
0,15	0,44	0,17	0,22	0,24	0,80	0,34	1,20	0,27	0,58	0,16	0,34
0,19	0,38	0,21	0,40	0,19	0,84	0,39	0,87	0,26	0,38	0,18	0,39
0,21	0,37	0,20	0,37	0,07	0,89	0,41	0,94	0,29	0,49	0,18	0,61
Oxides											
0,18	0,43	0,17	0,31	0,15	0,59	0,22	0,61	0,20	0,66	0,26	0,58
0,16	0,40	0,15	0,25	0,14	0,29	0,25	0,90	0,16	0,42	0,20	0,36
0,18	0,38	0,15	0,31	0,14	0,38	0,23	0,86	0,13	0,20	0,22	0,47
0,19	0,43	0 14	0,19	0,13	0,31	0,31	1,14	0,15	0,35	0,20	0,29
0,18	0,37	0,12	0,32	0,10	0,37	0,20	0,50	0,13	0,30	0,23	0,58
0,10	0,31	0,14	0,25	0,17	0,48	0,20	0,50	0,16	0,29	0,21	0,47
0,14	0,38	0,14	0,25	0,08	0,30	0,23	0,72	0,14	0,28	0,18	0,34
0,15	0,50	0,15	0,25	0,11	0,27	0,23	0,82	0,15	0,35	0,19	0,32
Single Industrial Site ols											
0,29	0,53	0,37	0,53	0,50	0,77	0,37	0,85	0,16	0,51	0,45	0,90
0,40	1,33	0,41	1,30	0,48	0,77	0,32	0,83	0,32	1,63	0,52	1,20
0,44	1,55	0,39	0,80	0,47	0,80	0,34	0,74	0,33	1,23	0,57	1,22
0,57	1,55	0,40	0,67	0,50	0,65	0,43	0,56	0,56	1,42	0,55	1,03
0,43	0,80	0,38	0,53	0,50	0,65	0,52	1,71	0,41	1,04	0,68	1,22
0,49	1,55	0,39	0,67	0,46	0,79	0,66	1,93	0,46	1,25	0,73	1,20
0,31	0,66	0,29	0,53	0,49	0,76	0,24	0,59	0,37	1,25	0,73	1,23
0,19	0,53	0,37	0,67	0,45	0,67	0,37	1,08	0,36	1,00	0,40	1,13
Monoxide											
12	40	12	20	13	31	12	38	6	12	9	23
13	45	11	40	7	14	8	15	10	20	11	23
15	50	7	20	3	10	6	31	11	32	7	16
16	50	11	23	8	20	13	31	12	32	10	14
18	41	11	22	12	23	12	24	15	37	10	28
14	35	20	30	17	27	15	26	15	42	14	28
10	35	6	17	8	16	3	19	13	44	6	15
9	25	11	25	3	8	2	12	7	18	7	30

atmosphere up to several hundred meters, is formed above it. Because of exchange, noxious substances migrate from the cap into the ground layer. Thus, the city cap becomes a kind of storage space for the noxious substances, which then spread with the wind over the entire territory of the city and far beyond its limits. This cap is a volume source of pollution.

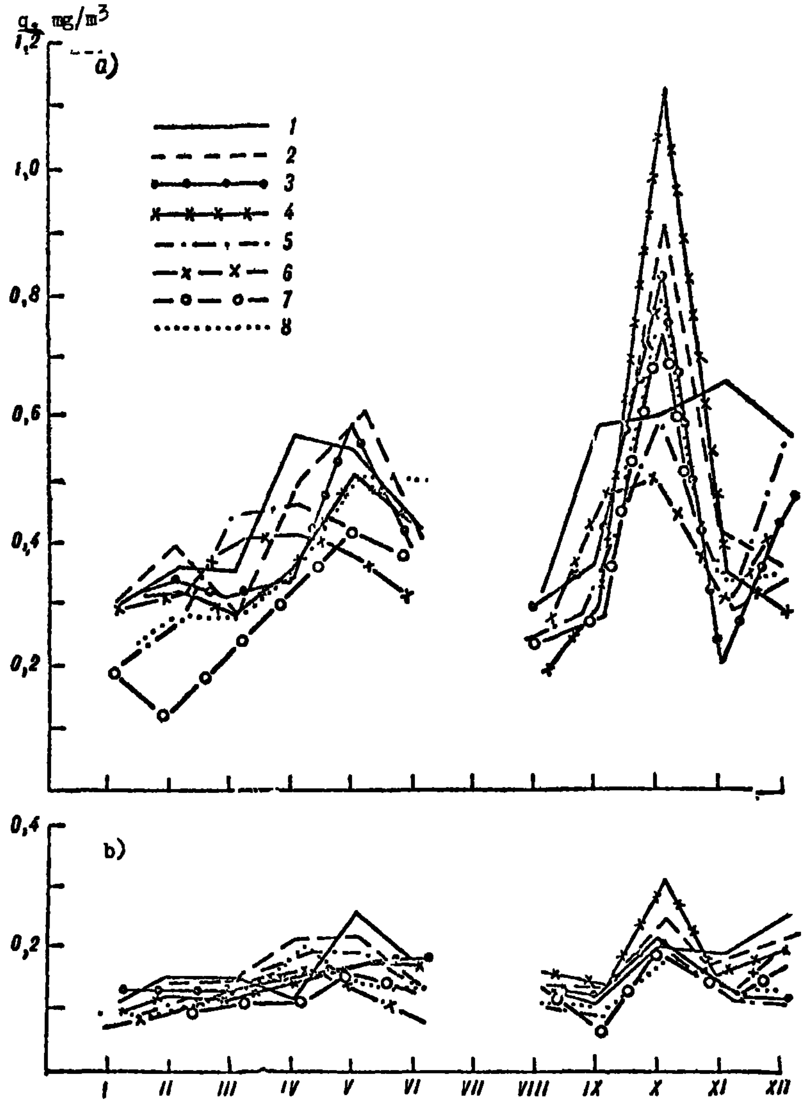

Fig. 1. Annual variation of maximum (A) and mean monthly (B) concentrations of nitrogen oxides over the territory of a city at eight points when the pollution sources are scattered over the entire area of the city.
1-8 - points of sample collection.

As a result, high concentrations are observed even in areas where obvious pollution sources are absent. It is for this reason that samples taken in different parts of the city show a good correlation. The correlation is poorer in cities where the industry is concentrated on a single site, since

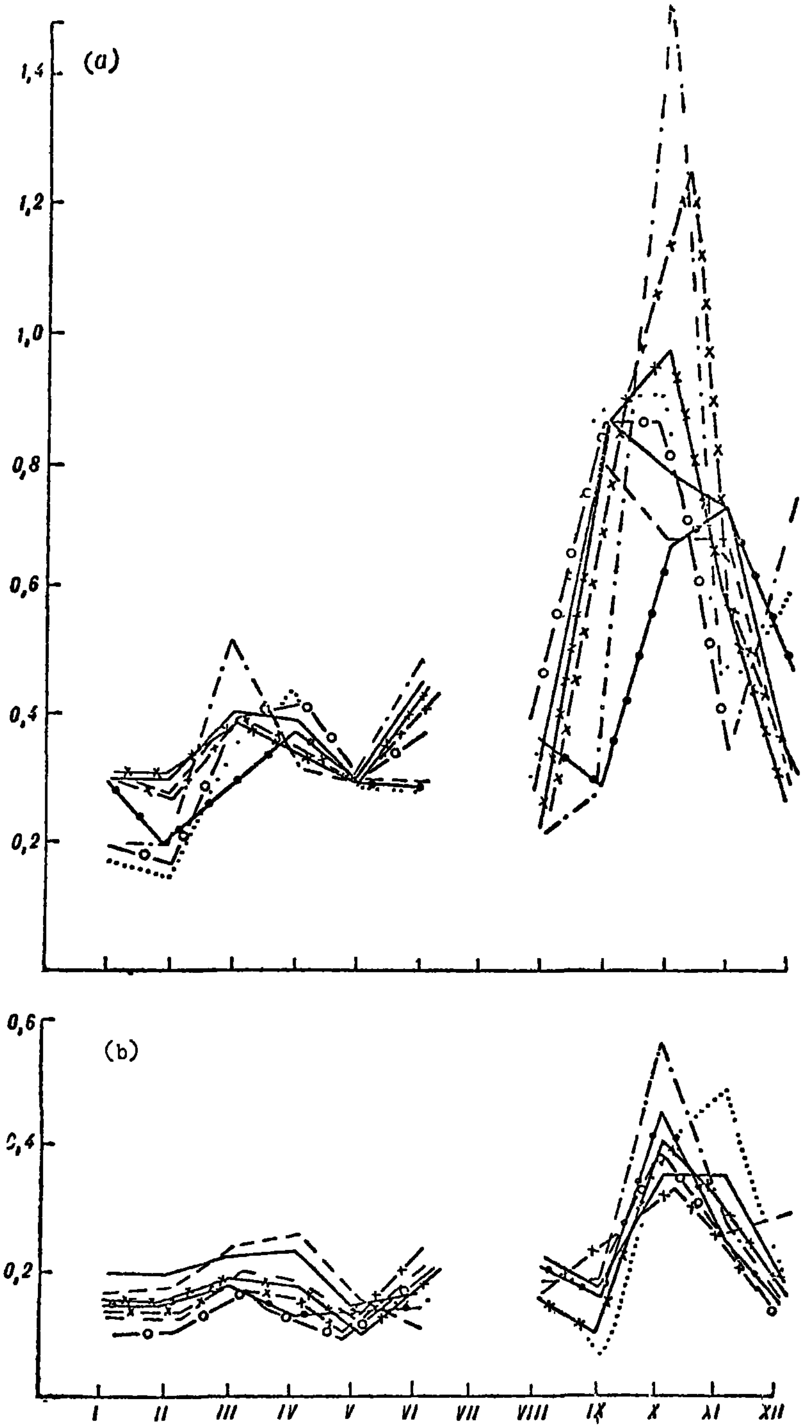

Fig. 2. Annual variation of maximum (a) and mean monthly (b) sulfur dioxide concentrations over the territory of a city at eight points when the pollution sources are scattered over the entire area of the city.
For the designation of each of the eight sampling points, see Fig. 1.

in this case the concentration is determined by the location of the point under the plumes of the sources.

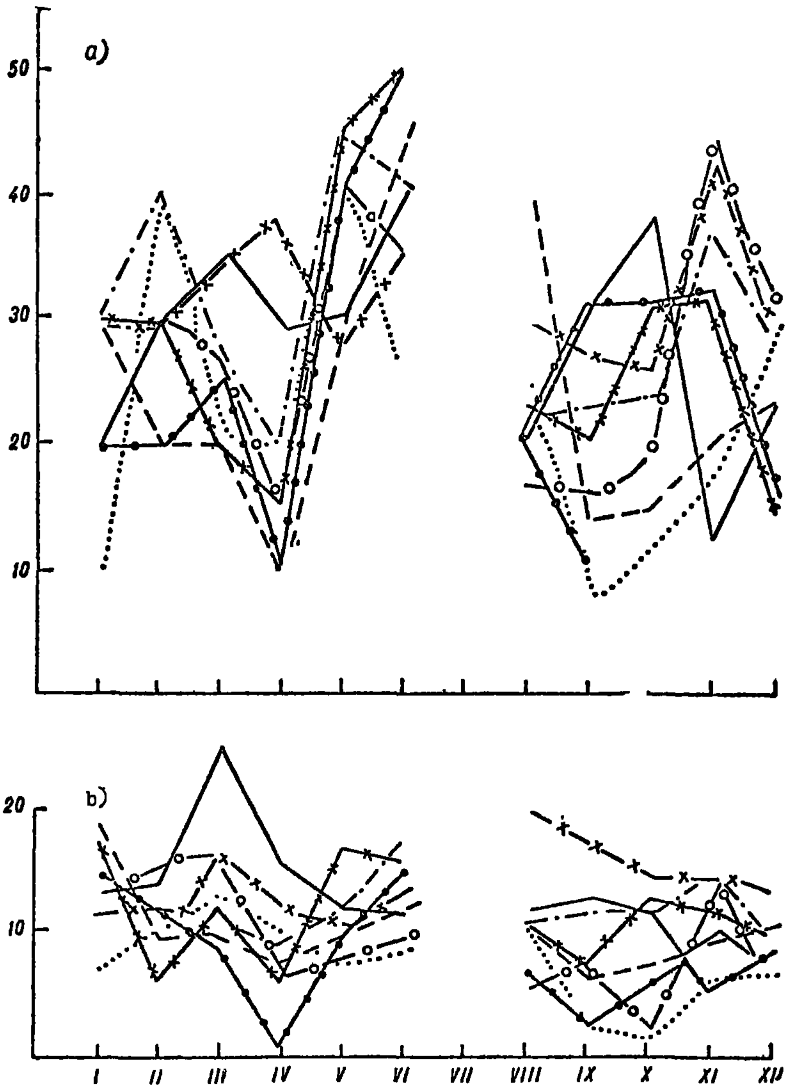

Fig. 3. Annual variation of maximum (a) and mean monthly (b) carbon monoxide concentrations over the territory of a city at eight points when the main pollution sources are located on the same industrial site. For the designation of each of the eight sampling points, see Fig. 1.

Major sources of discharge of noxious substances make a significant contribution to atmospheric pollution, and it may be expected that maximum concentrations will be observed under their plumes, directed toward the

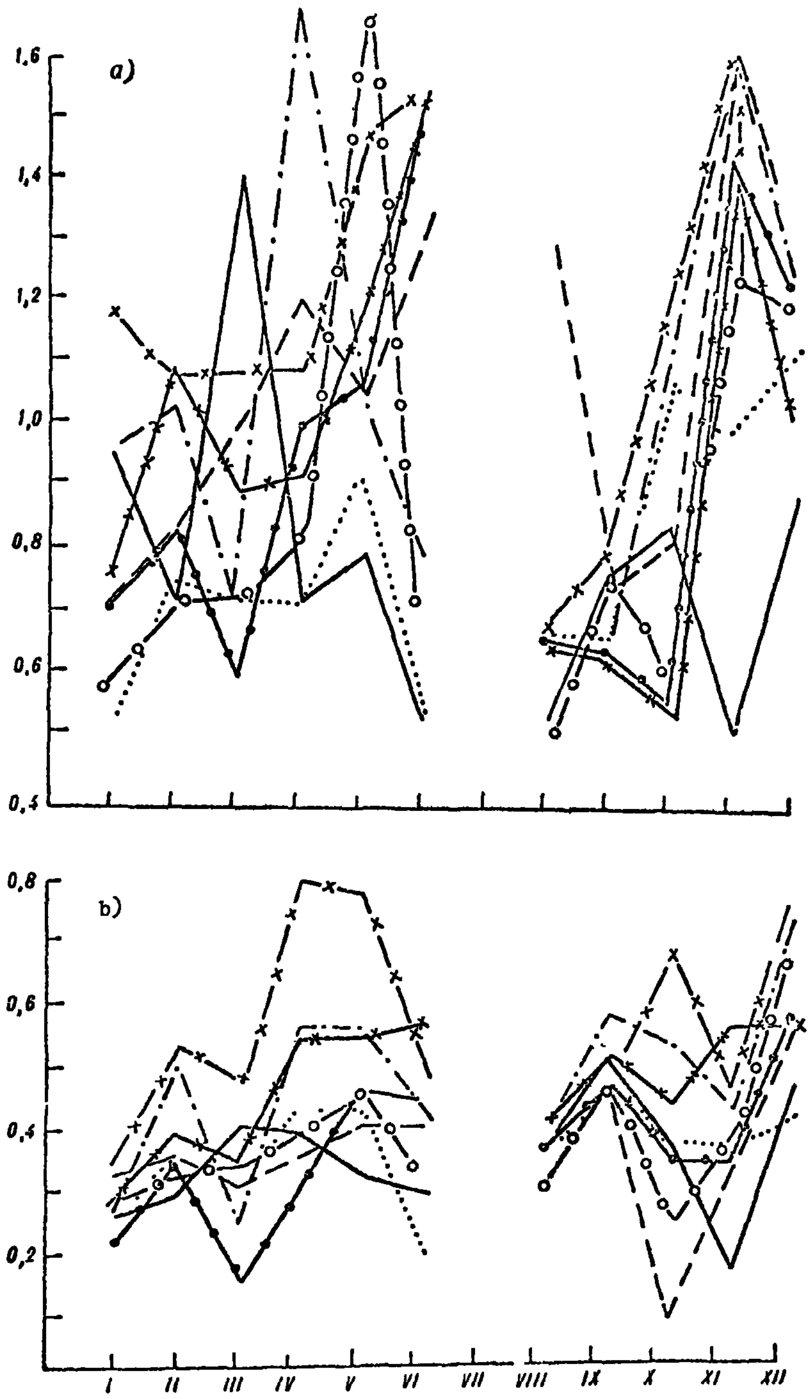

Fig. 4. Annual variation of maximum (a) and mean monthly (b) phenol concentrations over the territory of a city at eight points when the main pollution sources are located on the same industrial site.
For the designation of each of the eight sampling points, see Fig. 1.

residential districts. Therefore, in order to obtain the maximum possible concentrations in residential districts, observations are conducted under the plumes of the sources at different distances from the center of the discharge.

If the sources of noxious substances are concentrated on a single industrial site, it is useful to organize the determination of the concentrations under the general plume at various distances from this site, and particularly when the plume is directed toward the city. At the same time, it is also necessary to conduct observations at one to two points on the territory of the city to determine the background pollution.

In surveying the atmospheric pollution of a city, it is necessary to study the change of the concentrations with time in the neighborhood of individual sources as well. It is necessary to investigate fluctuations in the daily and annual course of air pollution. It must be kept in mind that the pollution level is determined by many factors, including changes in meteorological elements, which determine the dispersal of noxious substances in the atmosphere. Of major importance is the schedule of operations of enterprises and other sources of discharges of noxious substances. For example, motor transport and small enterprises discharging a considerable part of noxious substances into the atmosphere operate mainly from 8 A.M. to 4-6 P.M., and the heating system, during the cold part of the year. It is essential also to consider the arrangement of the sources over the territory of the city and the method of discharge of noxious substances (low and unorganized discharges or discharges through high stacks).

Several studies [12, 15] indicate the presence of a concentration maximum in the annual variation in spring, or two maxima in spring and autumn [10].

In [8] it is shown that as noxious substances spread from a single source (SREPP), an increase in concentration from the morning to the daytime period takes place in the effective range of this plume, followed by a decrease toward the evening, this being due to an increase of turbulent exchange in the daytime. The daily variation of concentrations under city conditions is more complex in character and shows differences in different seasons of the year, as is evident from the example of a region in southern Ukraine [6]. During the spring and autumn periods, a maximum is observed during morning and evening hours, and a minimum at 1-2 P.M. In summer, a small maximum is observed during the day; in winter, there is first a decrease of the concentrations from morning to midday, then the concentration increases again and reaches maximum values at 4-5 P.M. with subsequent decrease by 9 P.M.

These changes are accounted for by the nature of the discharge of noxious substances and by the variation of meteorological elements. In modern cities and in the majority of industrial centers, there are large individual high sources and many small ones. In spring and autumn, the morning and evening maxima are due to discharges mainly from small sources in the presence of a slight turbulent exchange and the accumulation of noxious substances in the lowest layer of the atmosphere. In the daytime, these areas (southern Ukraine) are characterized by an increased turbulent exchange, causing the elimination of stagnant zones in the ground layer. However, the turbulence is still insufficient and does not promote the transport of noxious substances from high sources which lead to an increase of the concentrations. Such conditions are observed in summer, when the pollution level undergoes little change during the day, since in the mornings and evenings in the presence of weaker turbulence, this level is determined primarily by discharges from low sources, and as a strong turbulent exchange develops, a more substantial role is played by high sources. Besides meteorological factors, an additional contribution of discharges from furnaces probably determines the winter maxima in the morning and at 4-5 P.M.

Considerable attention should be given to meteorological observations in surveys of atmospheric pollution in cities. In particular, it is necessary to consider the general synoptic situation, which is determined by macrocirculation processes. The nearest weather bureau is used for this purpose. In analyzing the pollution, use should be made of indices of the type of weather and synoptic situation.

Data on the structure of the boundary layer of the atmosphere, mainly in regard to the distribution of temperature and wind up to heights of 2-3 km, are more local in character. Their collection requires the organization of special observations at a specific point of the survey. They should include data on the distribution of air temperature and wind, obtainable by means of a set of aerological observations, observations at heights and from television towers, by means of helicopter and airplane sounding, and also gradient observations in the ground layer in the area of the weather station. It is essential to obtain a set of measurements that supplement each other and provide an adequate representation of the structure of the atmosphere from the standpoint of mixing of the impurities. Aerological observations can provide a general idea of the thermal stratification and wind characteristics of a city district. At the same time, the lowest 100-meter layer has been described in insufficient detail, and it is difficult to separate the influence of the built-up area of the city as the active surface on the structure of the air current. This makes it possible to emphasize aircraft, or better, special helicopter sounding, on the basis of which one can study not only the vertical structure but also the spatial variations under the influence of the city's buildings.

A more detailed distribution of the meteorological elements in the 100-200 meter layer of the atmosphere, where the chief sources of impurities are concentrated, can be obtained by setting up special observations at heights and on television towers.

Gradient observations in the ground layer make it possible to calculate the values of the turbulence coefficient which make up the basis for calculations of the dispersal of impurities. Also needed are data on the general meteorological characteristics of the region being surveyed, which can be readily obtained from current observations of the weather station, and if the latter is absent, observations conforming to its program should be specially organized for the period of the survey.

Since the city's buildings and the city as such lead to the formation of a particular and complex active surface, a substantial change also takes place in the meteorological regime, particularly in regard to the characteristics of the temperature and wind. Methods of studying the meteorological regime of the city itself include observations at points of collection of air samples. They provide data on deviations of meteorological characteristics (during the period of determination of the chemical composition of air) in various parts of the city as compared to macro- and mesoconditions, which provide synoptic maps and observational data at meteorological stations. One can also plan special micrometeorological surveys: they provide the spatial distribution of the air temperature and wind direction and velocity for the city and the ground layer. This makes it possible to compile, for the territory of the city, the characteristic of air currents caused both by the direct deflection of the main air current under the influence of buildings and layout of the city and by the possible generation of local currents [11, etc.].

In the set of special observations involved in the surveys of cities, one should also include comparative actinometric observations of shortwave solar radiation (within the city in the most polluted part and outise the city when no significant pollution is present). The evaluation of the degree of attenuation of radiation in the city may serve as an index of the general state of pollution of air.

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ORGANIZATION AND METHOD OF OPERATION OF

. ATMOSPHERIC POLLUTION OBSERVATION POSTS

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From Trudy, Glavnaya Geofiz. Observat. im. A. I. Voeykova, No. 238, p. 222-228, (1969).

Recently, considerable efforts have been made toward further improvements of observations of atmospheric pollution. This has been measureably promoted by steps taken to improve the methods and technical principles of collection of air samples, their chemical analysis, and the treatment of measurement data.

It should be noted that some success has now been achieved in the organization of sound observations of the content of noxious impurities in the atmosphere taking into account weather conditions. Some use has been made of materials of a series of seminars conducted by the A. I. Voyeykov Main Geophysical Observatory in close collaboration with the territorial offices of the Hydrometeorological Service (OHMS).

This article will deal with the most essential steps taken by the OHMS that can be applied in the practical operation of stationary posts and hydrochemical laboratories.

Of prime interest in this connection is an improvement, suggested by P. N. Zaytsev of the Far Eastern OHMS, of a device developed earlier at the Kamchatka OHMS [1] for automobile rotation of the intake tube acted upon by the wind, which is analyzed for gaseous ingredients.

The advantage of the proposed device (Fig. 1) is that it causes the rotation of the intake tube against the forward flow, at different velocities of the latter. In addition, it permits the determination of the wind direction without having to step out of the pavilion in which the air sampling is being carried out.

In this device, in contrast to the one developed at the Kamchatka OHMS, the moving tube is somewhat longer, and of such length that its lower end protrudes 4-5 cm from the stationary tube passing through the ceiling and roof of the pavilion. A metal arrow showing the direction of the wind is firmly attached to this protruding part of the tube.

To determine the wind direction, a metal disc with a hole at the center is mounted under the ceiling of the pavilion. The moving intake tube passes through this hole. Divisions giving the 16 main bearings are marked on the disc. The disc is oriented toward the points of the compass. Its diameter is about 40 cm.

As the vane is turned by the wind, the upper L-shaped end of the moving intake tube is set against the wind and its direction, and hence the direction of the wind is recorded by the arrow (i.e., by the bearing against which it has come to rest).

The device under consideration has a relatively high sensitivity; at a wind velocity of 0.5 m/sec, the vane turns the intake tube freely. The use of this device provides more reliable data on the concentration of the ingredients being measured. This is apparent from a large number of observations of sulfur dioxide and nitrogen dioxide at stationary posts in the city of Khabarovsk. The concentrations of the indicated ingredients at points equipped with the automatic device were found to be 25-50% higher than the concentrations obtained in observations at the same points but without this device. The results of measurements by means of the automatic device are in good agreement with data of sanitary epidemiological stations.

In discussing the equipment of stationary posts, we should point out the successful solution of this problem in the Georgian SSR. Here the construction of pavilions for observations at stationary posts is carried out by using the resources and facilities of industrial enterprises in accordance with the objectives set down by the OHMS. A general view of such a pavilion is shown in Fig. 2. The framework, facing and inner paneling consist of boards. The roof is covered with roofing iron. The entire exterior of the pavilion is coated with multicolored oil paints.

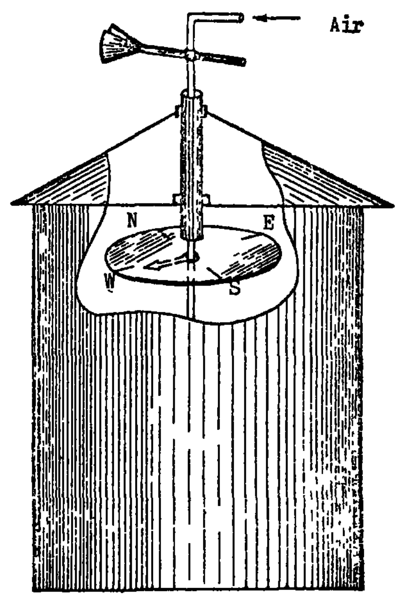

Fig. 1. Improved device for automatic rotation of intake tube acted upon by the wind and for the determination of the wind direction.

In Leningrad, Dzerzhinsk, Saransk, Belgorod and other cities, the construction of pavilions has also been organized within the framewo:k of industrial enterprises.

In many offices of the Hydrometeorological Service (OHMS of the Uzbek, Tajik, Turkmen, Azerbaijan, Ukrainian and White Russian SSR), pavilions built by the Tashkent hydrometeorological instrument plant have been introduced (Fig. 3) The main element of the design of this pavilion is a GR-70 hydrometric booth (control cabin). Inside, the pavilion walls are covered with a heat-insulating layer and lined with plywood, and outside they are faced with a wood laminated plastic. The pavilion is illuminated in the daytime and aerated by means of a window in its front wall. Heating in winter is done with electrically operated oil-burning* heaters.

* Russian description refers to "maslenymi elektronagrev-atelyami".

In addition, a new group of pavilions will be equipped with the automatic device for rotating the intake tube.

In an experiment at the OHMS of the Uzbek SSR in Tashkent, at one of the points of observation of atmospheric pollution, a rotating pavilion was installed in which the holes for the intake of air samples to be analyzed for both gaseous and mechanical impurities were located in one of its walls. During the collection of samples, the observer rotates the pavilion so that the wall with the holes faces in the direction from which the wind is blowing.

Experience has shown that the proposed design of the pavilion cannot be widely applied in a hydrometeorological network, especially during the cold period of the year.

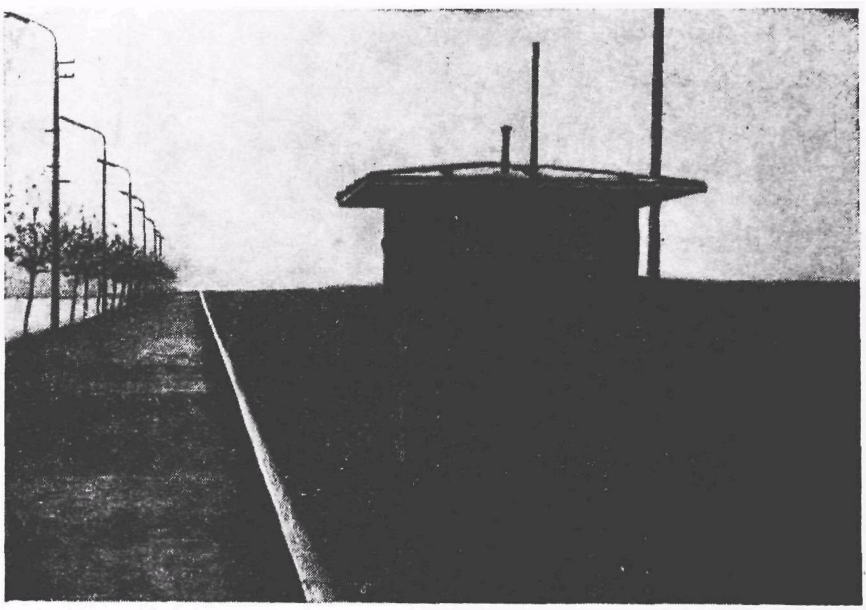

Fig. 2. General view of the pavilion of the Georgian OHMS.

The practical experience with various types of observations at the OHMS of the Kazakh SSR deserves some attention. In determining the dust concentration by means of an automobile aspirator, AFA-V-18 filters are used instead of filters prepared on the spot out of FPP-15 cloth.

However, since the AFA-V-18 filters are smaller in size (working area) than the filters specified by the design of the automobile aspirator [2], it was necessary to alter the filter holder to some extent by increasing the width of the ring of the holder on which the filter was placed by the amount that the working area of the first filter exceeded that of the second, i.e., 18 cm^2.

These changes in the filter holder required a new calibration of the set of rheometers.

The use of ready-made standard filters at the OHMS of the Kazah SSR chiefly saves considerable time, which the chemical laboratory staff would otherwise have to spend preparing the filters, and also permits a certain improvement in the quality of the dust observations.

At the present time, simultaneously with the collection of air samples, meteorological observations are invariably made on the direction and velocity of the wind, temperature and humidity of air, and condition of the weather and underlying surface. Certain difficulties arise in the implementation of this observation program. Various instruments are used to measure the wind velocity and direction: an 8-Yu-01-M wind meter, a manual anemometer, wind vanes, and even a pendant. Obviously, their accuracies are different. When a wind meter is used, relatively little time is required for its assembly, mounting, and dismantling, particularly in itinerary and under-the-plume observations.

In this connection, G. M. Imam-Aliyev and Yu. V. Manukoyan of the OHMS of the Azerbaijan SSR have prepared experimental models of meteorological field instruments: a wind indicator, a barothermohygrometer, and a weather station. A brief description of the instruments follows.

Fig. 3. General view of the pavilion of the Tashkent plant of hydrometeorological instruments.

The wind indicator is designed for measuring the wind velocity and direction under field conditions. The velocity indicator used is a manual ARI-49 induction anemometer. A manual anemometer of a different type can also be employed. A small weather vane was used to determine the wind direction.

In general, the design of the wind gauge was as follows. A two-stage ebonite rod is mounted on the screw thread of the ARI-49 anemometer in place of the crank: The first stage is 22 mm high and 8 mm in diameter, and the second, respectively 10 and 27 mm with a lower groove of 7 x 25 mm. To this rod is attached, by means of an M-5 thread, the main brass staged rod on which a small-sized, light vane rotates on two ball bearings and on which are mounted 8 rods (pins) designed for the determination of the wind direction.

On the rod corresponding to the northern bearing is mounted a "KIM" type compass, and on the opposite side, a long rod acts as a stopping lever by means of which one can orient the vane according to the compass and fasten it on its axis. This instrument can be assembled and disassembled, and is therefore convenient for operation under field conditions. It is being successfully used in itinerary observations of atmospheric pollution in Baku.

The wind indicator proposed by G. M. Imam-Aliyev and Yu. V. Manukoyan differs advantageously from the 8-Yu-01-M wind gauge in that it is portable and accurately determines the wind velocity. It can be set up relatively fast and does not require a special support. It is mounted on the hood of an automobile. The wind gauge can be successfully used at stationary posts as well, but in this case a special stand is required to set it up at a given height.

The barothermohygrometer is an instrument measuring the pressure, temperature, and air humidity under field conditions. All three instruments are mounted on a single board. The pressure is measured with an MD-19 aneroid barometer, the air humidity with an MVK-hygrometer, and the temperature with a TP-1 type mercury thermometer. The housing of the instrument has ventilation holes on both sides, in the base, and in the back cover. The weight of the instrument is 5.4 kg.

In the course of operation of these instruments during itinerary observations in Baku, it was found desirable and possible to combine them into a single unit in the form of a field weather station.

The field weather station (Fig. 4) consists of a wind indicator and a barothermohygrometer. During the observations, it is set up on a special support. The weather station as a whole and its individual instruments were tested under laboratory and field conditions, and yielded satisfactory technical and performance data.

In organizing observations of the chemical composition of atmospheric air, it was found necessary to supply systematic information on the state of urban atmospheric pollution to interested organizations in order to take steps to reduce and eliminate noxious discharges into the atmcsphere. At the present time, all the offices of the hydrometeorological service are carrying out extensive work in this direction. According to data from regular observations, every month information bulletins on the state of atmospheric air pollution are issued and sent out to the consumers.

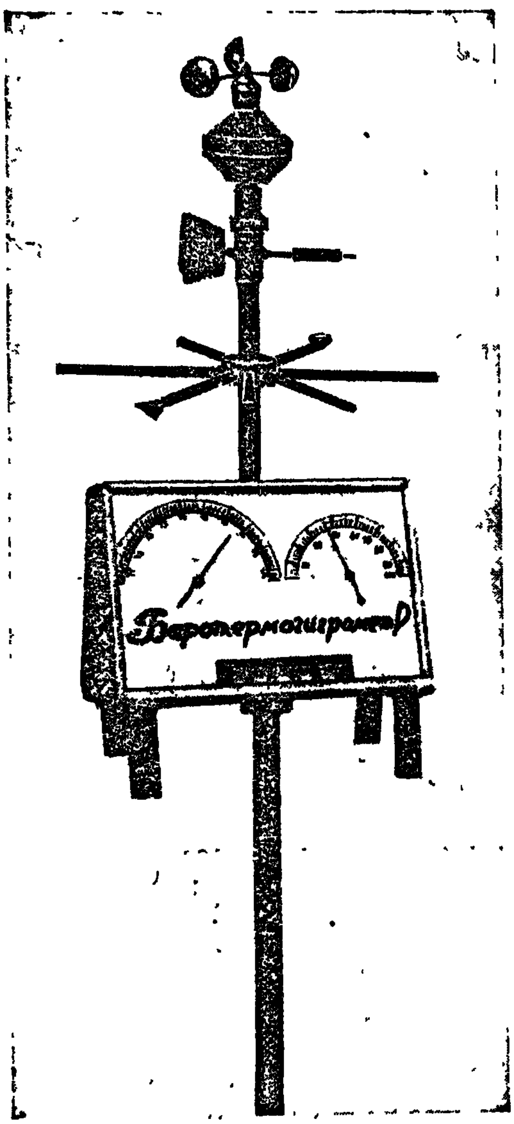

Fig. 4. Small sized field weather station.

The Volga OHMS has accumulated experience in issuing a daily report. The latter gives information on the concentration of noxious impurities in the atmosphere based on observations during the preceding day (for 2-3 periods). The observational data are plotted on a schematic map of the city, as a weather report is plotted on a synoptic map. In addition, on the basis of the predicted weather conditions, a qualitative assessment of the expected state of air pollution for the following day is given.

At the Upper Volga office of the hydrometeorological service, the enterprises of Dzerzhinsk are systematically informed on impending weather conditions that may give rise to dangerous pollution levels as a result of noxious discharges. On the basis of this information, the enterprises take appropriate measures to alter the operating schedule of the enterprises, primarily by decreasing random (unorganized) discharges into the atmosphere.

We should point out the efforts of the Ural OHMS toward improving information on the state of pollution. To this end, monthly information reports include a calendar (table) of air pollution in addition to the usual information. For each day and observation post and successively for each ingredient, this table lists the general characteristics of pollution levels, using certain conventional symbols.

The calendar provides a picture of air pollution in the different districts of the city for a month, and also reveals districts with high and with low pollution levels.

One of the main conditions for obtaining reliable data on the concentration of noxious substances in the atmosphere is an adequate organization of the collection of air samples for chemical analysis.

We shall consider, as an example, the organization of the operation of stationary posts in the city of Sverdlovsk.

As indicated elsewhere [1], stationary posts provided with stone pavilions are adequately heated in the wintertime. To ensure a smooth operation, two electric aspirators collecting samples for analysis of gaseous ingredients are set up in each pavilion. One of them is in operation, while the other is kept in reserve and is used only in case the first breaks down. The working aspirator is periodically checked and in case of any irregularity sent for repairs.

In this connection, we should mention the adequacy of the operation of instruments used at the posts and the efficiency with which the observers carry out their instructions.

In order to prevent errors in the collection of samples and in execution of meteorological observations, the operation of stationary posts is checked regularly. This checking is performed by the staff of the hydrochemical laboratory, and by meteorological engineers and other specialists of the OHMS.

In conclusion it should be noted that many territorial offices (northwestern, Krasnoyarsk, Irkutsk, Primor'ye, Murmansk and also the OHMS of the Kazakh, Kirgiz, Georgian, Turkmen SSR, etc.) have taken a number of major steps toward further extending the investigations of this problem. These offices of the hydrometeorological service have prepared comprehensive situation reports on the state of air pollution and have obtained the adoption of a special resolution concerning the protection of atmospheric air from pollution. Unfortunately, some OHMS are still giving insufficient attention to this problem.

The scope of the problems connected with the operation of stationary posts is much broader than discussed here. However, the contents of the article point to the unquestionable urgency and importance of these problems in stationary observations of atmospheric pollution.

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USE OF STATISTICAL METHODS FOR THE TREATMENT OF

OBSERVATIONAL DATA ON AIR POLLUTION

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From Trudy, Glavnaya Geofiz. Observat. im. A. I. Voeykova, No. 238, p. 42-47, (1969).

Stationary points for monitoring the pollution of the urban air reservoir yield information on the content of noxious impurities in air for individual areas and for the country as a whole. The organization of such posts and the classification and correlation of the enormous amount of data collected pose a number of questions: Are the measurement data sufficient and can they render the actual picture of the air pollution? How much more strictly should the material be treated and in what form should the results of the correlation be presented? Statistical methods can aid in the solution of these problems.

On the basis of some general considerations [3, 4, 5], the probability distribution of an impurity in air may be assumed to be described by the lognormal law

$$f(q) = \frac{1}{sq\sqrt{2\pi}} e^{-\frac{\ln^2 \frac{q}{m}}{2s^2}} \qquad (1)$$

where f(q) is the density function of the impurity concentration q and s and m are parameters of the lognormal distribution. To determine s and m, the measured values of the impurity concentration q are subdivided into gradations, and the accumulated frequencies p_k are determined for each gradation.

A graph is then plotted with the impurity concentrations laid off on the log scale along the ordinate axis and with values of the argument z_k of the integral function of the normal (Gaussian) distribution $\Phi(z_k)$, which coincides with our accumulated frequency $\Phi(z_k = p_k)$, laid off along the abscissa axis. Tables of the normal distribution are given in [1, 2].

If the impurity concentrations are distributed in accordance with the lognormal law, all the points are grouped near a straight line whose slope is equal to s and whose median value (corresponding to the argument $z_k = 0$) is equal to m. In the plotting of such a probability graph, instead of values of z_k, the abscissa axis usually carries values of the integral probability corresponding to them in the normal distribution. A detailed derivation of these relations is given in [1, 3].

An example of such a calculation for the concentrations of nitrogen oxides in Kursk in 1968 is shown in Table 1 and Fig. 1 (curve 1).

Table 1

Determination of z_k.

	Gradations, mg/m^3				
	0,41–0,50	0,31–0,40	0,21–0,30	0,11–0,20	0,00–0,10
Frequency, %	1	3	14	42	40
Accumulated frequency p_k, % . .	1	4	18	60	100
z_k	–2,37	–1,75	–0,92	–0,25	3,90

We carried out the treatment and plotted graphs for the distribution of the concentrations of sulfur dioxide, nitrogen dioxide, dust, carbon monoxide, and soot (104 distributions) for seven cities. In 75% of the cases, the points fall in the vicinity of a straight line on the probability graphs. This suggests that, as a rule, the impurity concentrations obtained by taking air samples at different times are distributed in accordance with the lognormal law.

Analysis of air pollution data by means of probability graphs leads to a number of essential conclusions with regard to the quality of the observations and the spreading of noxious impurities in cities.

In many cases, the points corresponding to low impurity concentrations deviate from the straight line on the probability graphs. Since low values are measured with a low accuracy, these deviations from the straight line may be assumed to be due to measurement errors. Analysis of the position of the points on graphs plotted on the basis of measurements of different impurities permits an evaluation of the limit to which the concentrations of noxious substances are measured with satisfactory accuracy. Thus, this will be 2-3 mg/m^3 for carbon monoxide, 0.2 mg/m^3 for dust, 0.1 mg/m^3 for sulfur dioxide and nitrogen dioxide, and 0.02 mg/m^3 for carbon disulfide.

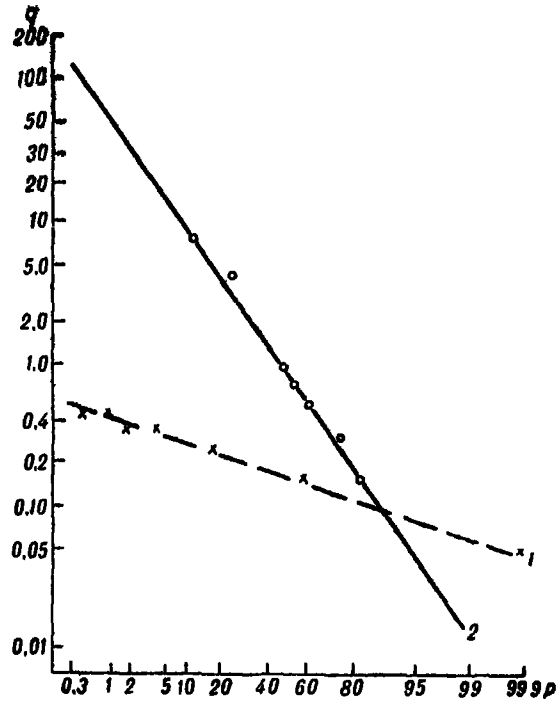

Fig. 1. Distribution of concentrations of nitrogen oxides and soot in winter.

The probability graph can be used as a vivid illustration of the manner in which a certain subjectivity is manifested in the determination of sulfur dioxide concentrations. For example, in cases where the chemical analysis of the air samples did not involve the use of a photoelectrocolorimeter, but of several scales - test tubes corresponding to a series of concentration values. As a result, the frequency of high impurity concentrations may be too low, and the frequency of low concentrations may be too high (or vice versa). The points on the graph will then deviate on both sides of the curve.

In cases where there is a great scatter of points, i.e., a deviation from the lognormal distribution is observed, it is necessary to explain the causes of this situation. The latter may be frequently related to a low quality of the selection or analysis of the samples, and sometimes to an abrupt change in the discharge parameters of one or several basic sources of air pollution.

According to the results of treatment of data on sulfur dioxide measurements at one of the points in the city of Kuybyshev in 1967, two independent distributions appeared to be present: one with high, and the other with low impurity concentrations. Analysis of the data and a determination of the causes have shown that the observational data for a certain period were unreliable in this case.

The distribution of soot concentrations in the city of Irkutsk was also studied. During the warm half of the year, when the air pollution is minimal, all the points satisfactorily fall on a straight line. During the winter, all the values above the maximum permissible concentration (MPC) are actually measured with a large error and, according to the above, urban distribution (Fig. 1, curve 2), very high values are probable. This indicates that the soot concentrations which we obtained in winter were too high.

Thus, the use of the method of analysis of the impurity concentration distribution on a probability graph permits the determination of reliable measurement data and range of the most reliable values. In observations carried out with sufficient precision, sharp changes in the nature of the discharges of the main sources can be revealed.

Another possible use of the method under consideration consists in evaluating the correctness of the choice of the area for setting up the points of sample collection. In selecting areas for urban points it is important that the climatic characteristics of the air pollution differ most substantially. At the same time, not only the average values, but also the distribution of the impurity concentrations obtained from data of observations at individual points should be sufficiently different. Hence, the statistical parameters m and s at the different points should also differ from each other. Therefore, in approaching the selection of areas for stationary posts, it is useful first to carry out itinerary observations at a number of urban points. On the basis of the data obtained, using a statistical treatment, it is necessary to determine the parameters s and m and to select points which permit an effective monitoring of the air pollution.

We have carried out such a treatment of observational data for expeditions in the areas of the Moldavskaya and Shchekino SREPP (State Regional Electric Power Plant) and the Krasnoyarsk and Cherkassk synthetic fiber plants. The data were used only in cases where there were 50 observations at each distance from the source of discharges (0.5, 1.0, 2.0 km etc.), i.e., the frequency of a single observation would be no less than 0.5%. For a smaller amount of data, the points of probability distribution of the different gradations of impurity concentrations may deviate considerably from a straight line. As a result, it was found that the distribution of impurity concentrations at different distances from the same source of air pollution also follows the lognormal law. An example is given in Fig. 2. The curve of distribution of the impurity concentration for each distance has a definite slope (value of s), which initially increases with the distance from the source and then begins to fall off after reaching a certain maximum.

If in observations at different distances from a plant the distance at which the highest impurity concentration was observed in a given period is recorded, then the probability of occurrence of the highest value is calculated for each distance, then by applying a suitable treatment, as shown in Table 1, the distribution of the maximum values as a function of the distance can be obtained. On the probability graph, the distance from the source of the discharges in this case is laid off on the log scale along the ordinate axis [4].

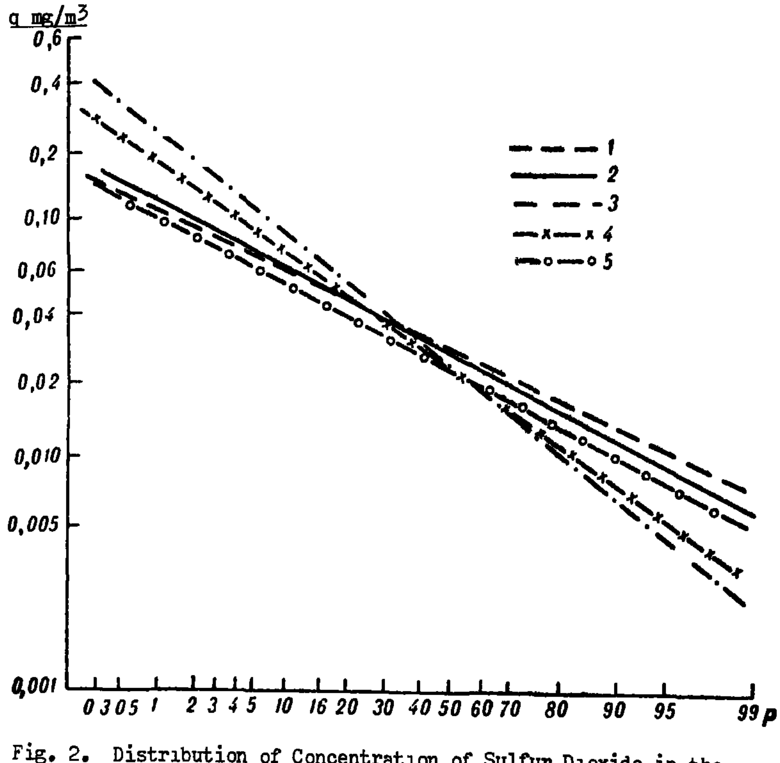

Fig. 2. Distribution of Concentration of Sulfur Dioxide in the Region of Moldavskaya SREPP

From the source at a distance: 1) 0.5 km; 2) 1 km; 3) 2 km; 4) 3 km; 5) 5 km.

In cases where the distribution of the values is lognormal, by using (1) one can obtain analytical expressions for the average value of the concentration q, its variance σ^2, the variation coefficient V, etc.:

$$\bar{q} = me^{\frac{s^2}{2}}, \tag{2}$$

$$\sigma^2 = m^2 e^{s^2} (e^{s^2} - 1), \tag{3}$$

$$V = \frac{\sigma}{\bar{q}} = \sqrt{e^{s^2} - 1}. \tag{4}$$

The probability of occurrence of a value of q above some value q_0 is

$$F(q > q_0) = \frac{1}{2}\left[1 - \mathrm{erf}\left(\frac{\ln \frac{q_0}{m}}{s\sqrt{2}}\right)\right]. \tag{5}$$

As was noted at the beginning of this article, low values of the impurity concentration are measured with large errors, which necessarily causes errors in the determination of the average values. The higher the frequency of low impurity concentrations, the larger the error. This may be avoided by calculating the average concentration $\bar{q}$ from formula (2). Such calculations were carried out for four cities for nitrogen dioxide, sulfur dioxide, carbon monoxide, and dust (Table 2). In Table 2, q_{av} is the average arithmetic value of the impurity concentration; V is the variation coefficient calculated from (4), and V_e is the variation coefficient obtained from observational data.

Table 2

Average Impurity Concentrations (mg/m³).

Year	Period	Impurity	q_{av}	$\bar{q}$	V	V_e
Minsk	1967	Nitrogen Dioxide	0,11	0,13	0,8	
Alma-Ata	1968	Dust	0,4	0,5	0,6	
	1967	Nitrogen Dioxide	0,19	0,29	1,3	
	1968	Sulfur Dioxide	0,15	0,24	1,4	
	1968	Carbon Monoxide	7	11	1,2	
Dushanbe	1967	Nitrogen Dioxide	0,20	0,27	0,9	
	1967	Carbon Monoxide	8	14	0,8	
Kursk	Winter 1967	Nitrogen Dioxide	0,05	0,09	0,5	0,8
	Summer 1968	" "	0,12	0,18	0,4	0,6
	Winter 1968	Sulfur Dioxide	0,07	0,13	0,8	0,9
	Summer 1968	" "	0,07	0,15	0,3	1,1
	1968	Carbon Monoxide	6	8	0,8	0,6
	Summer 1968	Dust	1,8	2,7	1,4	

As is evident from Table 2, in all cases the calculated averages are higher than the arithmetic mean values, although in some cases this excess is slight. Expression (5) was used to calculate the probabilities of concentrations of nitrogen dioxide and carbon monoxide above 10 MPC $F(q>10\ MPC)$. Comparison of the data obtained by direct treatment shows a good agreement (Table 3).

Of definite interest is the study of the variance of the different impurities. On the basis of observations in several cities for 1968, the mean square deviations were calculated for each month for dust, carbon monoxide, nitrogen dioxide, and sulfur dioxide. Fig. 3 shows the dependence of σ on q_{av}. The data indicate that the mean square deviation is close to the average, as also follows from the lognormal law. Formula (4) was also used to calculate V, the values of the variation coefficient (Table 2). The latter ranges from 0.4 to 1.9. The calculated and actual values of V_e are rather close. The calculated values of V show that they are lower during the warm half of the year than in winter, this being due to a greater influence of changes in the discharges and weather conditions during the cold half of the year.

At the present time, average (q_{av}) and maximum (q_m) concentrations are used as air pollution characteristics in the correlation of information. It follows from the above that the quantity $q_{av} + \sigma$ has some advantages over q_m, since σ is less dependent than q_m on the observation period treated.

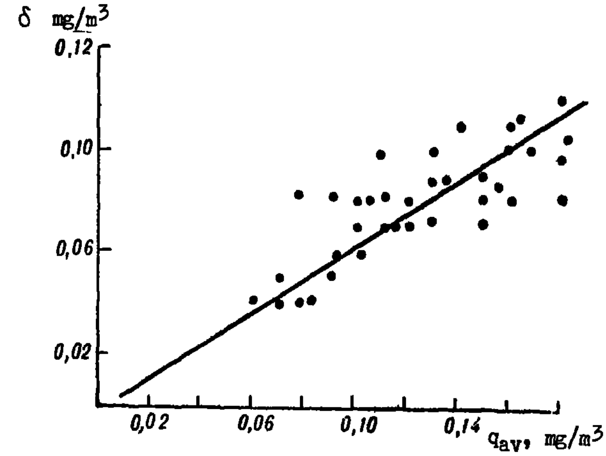

Fig. 3. Average (q_{av}) vs. mean square (σ) deviation of the impurity concentrations.

In each specific case, the error in the determination of maximum values is related to the number of observations of a given selection. Since this number varies in cities, the maximum values also frequently turn out to be incomparable. A maximum with any probability of being exceeded can be obtained by transforming expression (5). When $F(q>q_0) = 0.001$,

$$q_0 = me^{3s} \qquad (6)$$

Table 3 lists the maximum values from observational data on q_m and values obtained from (6).

The author expresses his sincere appreciation to Ye. L. Genikhovich for his useful comments.

Table 3

Probability of Impurity Concentration Above 10 MPC q_m.

Impurity	Point	$q\%$	F (q 10 MPC)%	$q_м$	q_o
		Alma-Ata			
Nitrogen Dioxide	2	5	6,5	1,50	1,50
" "	3	10	11	2,30	1,93
" "	4	4,5	5,5	3,40	4,07
Sulfur Dioxide	4	0,3	0,22	1,17	1,19
		Kursk			
Nitrogen Dioxide	2, 3, 4, 5	0,1	0,1	0,42	0,45
Carbon Monoxide	2, 3, 4, 5	0,9	1,6	22	27
Dust	2, 3, 4, 5	15	13	9,1	14,1

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STATISTICAL ANALYSIS OF DATA ON AIR POLLUTION IN CITIES BY MEANS OF NATURAL FUNCTIONS

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As a result of observations of atmospheric pollution in many cities, a considerable amount of information has now accumulated on actual concentrations of noxious impurities in the atmosphere and the accompanying meteorological conditions. Statistical analysis of this material aims primarily at obtaining a sufficiently complete picture of the atmospheric pollution existing in cities. In addition, as the factual data accumulate, it becomes possible to use them for the statistical forecasting of the level of atmospheric pollution in cities and industrial areas. An important stage in the solution of this major problem involves the statistical analysis of the initial information. For forecasting purposes it is essential that the statistical analysis filter out the noise, i.e., the reliability increases, and the volume of information processed in the forecasting decreases. At the same time, the statistical relationships established in such an analysis are of interest in themselves, since they reflect rules actually existing (although difficult to identify) and governing the processes of dispersal of impurities in cities and major industrial districts.

An essential part of the statistical analysis of initial data is the analysis of measured quantities of ground concentrations of various noxious impurities in air.

The concentration of each individual ingredient is a random function $q(x, t)$ of a point of space x and instant of observation t. At the present time, in analyzing this type of random fields, efficient use is made of the method of expansion in natural functions (in a statistically orthogonal system), which is one of the methods of the analysis of variance [1-6]. This method involves the plotting of a system of random orthogonal functions $\{\phi_K(\chi)\}$ such that a segment of the Fourier series $\Sigma\alpha_K(t)\phi^K(\chi)$ is the best approximation of the random function $q(\chi, t)$ in terms of the mean square error. In other words, the system of functions $\{\phi_K(\chi)\}$ is such that the approximate equality

$$q(x, t) = \sum_{l=1}^{M} \alpha_k(t)\varphi_k(x) \qquad (1)$$

with a given choice of coefficients $\alpha_K(t)$ describes the variability (variance) of the field $q(\chi, t)$ better than a linear combination of any other functions consisting of the same number of terms. The mathematical aspect of the problem has been discussed in specialized as well as meteorological literature [3-6].

Actually, observations of the air pollution level in a city are made at a number of fixed points, so that at each specific instant of time we have a set of N measured quantities $q_1, q_2, \ldots, q_N$ corresponding to the observation points with numbers from 1 to N. In this case, the natural function ϕ_K constitutes a vector with components $\phi_{K1}, \ldots, \phi_{KN}$, pertaining to the corresponding observation points. The natural functions ϕ_K are the eigenvectors of the correlation matrix $R = (r_{ij})$ of the concentration field, the elements of this matrix being found from the formula

$$r_{ij} = \overline{q_i q_j} - \overline{q_i}\,\overline{q_j} \qquad i, j = 1, 2, \ldots, N. \tag{2}$$

Here q_i is the concentration at the i-th point, the bar indicating averaging in time. In other words, the natural functions satisfy the equation

$$R\varphi_k = \lambda_k \varphi_k. \tag{3}$$

We shall assume hereinafter that the natural functions ϕ_K are numbered in decreasing order of the eigenvalues λ_K corresponding to them.

The expansion coefficients $\alpha_K(t)$ are found from the formula

$$a_k(t) = \sum_{i=1}^{N} \varphi_{ki} q_i(t), \tag{4}$$

where ϕ_{Ki} are components of vector ϕ_K. Let us note that the ratio of the variance described by expression (1) to the total variance of the process is

$$\frac{\sum_{k=1}^{M} \lambda_k}{\sum_{k=1}^{N} \lambda_k}.$$

Hence it is evident that if all the N natural functions are used in the expansion, a complete description of the concentration field will be obtained. More essential, however, is the fact that even if only a few of the first natural functions are used, the main part of the variability of the quantity studied will be identified. Discarding of the subsequent terms of the expansion (higher harmonics) will make it possible to filter out the noise and thus increase the reliability of the initial information. Thus, instead of a set of concentration values at the observation points, the impurity concentration field is described by the first few expansion coefficients. Also important is the fact that because of the orthogonality of the natural functions, the expansion coefficients are statistically independent, so that their forecasting is made independently of one another.

Let us examine the results of a statistical analysis of data on atmospheric pollution at seven points in the city of Sverdlovsk. The calculations, carried out on a "Ural-4" computer, utilized data on concentrations of nitrogen oxides and sulfur dioxide for the period from December 1966 to

February 1967. As follows from the results of calculation for nitrogen oxides, the first term of the expansion describes 70%, and the first two terms, 90% of the total variability; for sulfur dioxide, the first term of the expansion describes 48%, and the first two terms, 70% of the total variability. The fields of the first and second natural functions are shown in Fig. 1. Attention is drawn to the conformity of the fields of the first natural functions. Indeed, their maximum and minimum values are observed in the same parts of the city.

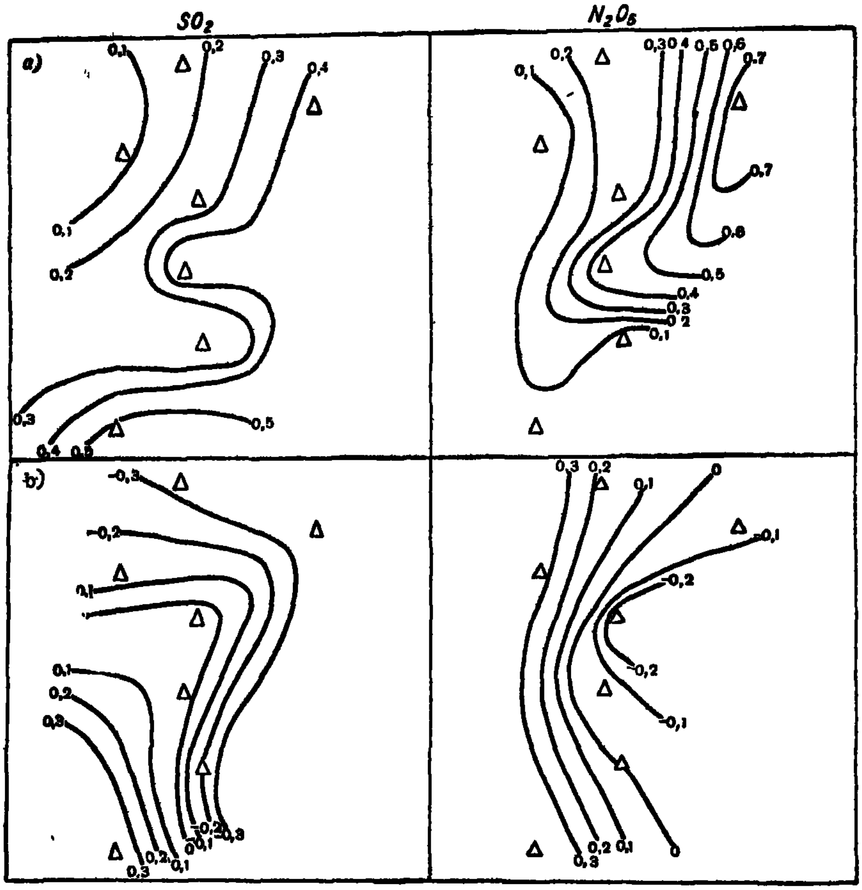

Fig. 1. Fields of the first (a) and second (b) natural functions.

The first natural function characterizes the basic characteristics of the spatial behavior of the impurity concentration field. Indeed, if in expansion (1) we confine ourselves only to one term, we obtain the approximate equality

$$q(x, t) \approx \alpha_1(t)\,\varphi_1(x), \qquad (5)$$

whose accuracy depends on which part of the total spatial variability is described by the first natural function. It follows from (5) that the first term of the expansion pertains to simultaneous changes of the concentration over the entire city. Here coefficient α_1 characterizes the level of total atmospheric pollution in the city, and its change with time shows by what factor this general air pollution has increased or decreased.

The proportions of the components of vector ϕ_1 show the relationships of the concentrations at different observation points during a simultaneous change of the general level of atmospheric pollution.

Thus, the closeness of the first natural functions for different ingredients signifies that as the level of the general atmospheric pollution of the city changes, the relationships between the concentrations of nitrogen oxides and sulfur dioxide at different points turn out to be relatively similar. This probably indicates a similarity in the spatial distribution of sources of pollution of the atmosphere with sulfur dioxide and nitrogen oxides.

The second natural functions given in Fig. 1 b characterize the tendencies of the spatial variability of that component of the concentration fields of these impurities which is associated with the basic deviations from simultaneous pollution of the city's atmosphere (for example, as a result of a directed transport of the impurity, etc.). As is evident from the figure, an increase of the concentration in one part of the city is associated with its decrease in another part.

Let us note that the first term of the expansion for sulfur dioxide contains less information than for nitrogen oxides. This could be explained by saying that in the atmospheric pollution of cities with impurities discharged from high sources (including SO_2), a more essential role is played by processes associated with a nonsimultaneous change of the atmospheric pollution in the city, which are largely determined by the second term of the expansion.

However, the SO_2 concentrations in cities are usually low, so that large errors are possible during their measurement. For this reason, the preceding conclusion requires further confirmation.

Fig. 2 shows the time dependence of the first and second expansion coefficients. As already noted, for the first expansion coefficient such a dependence describes the change of the total level of the city's pollution with time, i.e., the change of the concentrations at all the observation points simultaneously. It follows from Fig. 2 a that for different impurities there exists a common physical and meteorological mechanism causing a simultaneous change of the impurity concentration over the entire city, since the expansion coefficients for SO_2 and N_2O_5 change with time in similar fashion (the correlation factor between them is equal to 0.46).

Obviously, the values of α_1 characterizing the air pollution over the city as a whole contain less accidental information than single measurements of concentration at the observation points and should be more closely related to the meteorological situation. Thus, parameter α_1 is useful in the study of the relationship between impurity concentrations in air and weather conditions and, in the final analysis, in the statistical forecasting of air pollution. High values of coefficient α_1, corresponding to a heavier atmospheric pollution, should be reached under conditions most unfavorable for the dispersal of impurities. Indeed, the highest values of coefficients α_1 during the period under consideration were noted on 2-5 January 1967 (see Fig. 2 a). On these days, the city was situated in a slow-moving pressure crest. Definite conditions of air stagnation prevailed (average velocity at the surface of the ground was 0.1 m/sec, and at a height of 500 m, 3.8 m/sec). The average lapse rate in the layer up to 500 m was 9.2 deg/100 m, i.e., a strong inversion was observed in this layer.

The time dependence of coefficient α_2 is shown in Fig. 2 b. As is evident from the figure, most of the time the values of these coefficients for SO_2 and N_2O_5 are different (the correlation factor between them is equal to -0.36). Hence one can conclude that for different impurities there exists a single mechanism leading to deviations from a simultaneous change of the general level of atmospheric pollution (apparently related to certain wind directions). However, at fixed observation points, the sign of these deviations for sulfur dioxide and nitrogen oxide is different.

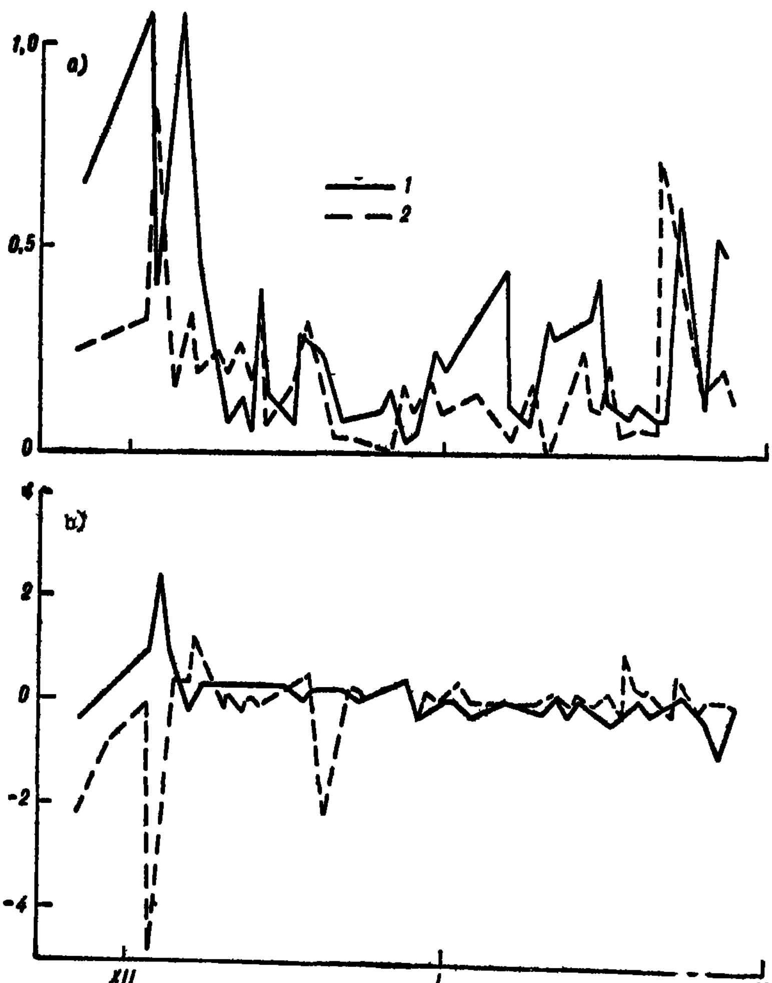

Fig. 2. Time dependence of the first (a) and second (b) expansion coefficients.
1 - for SO_2, 2 - for N_2O_5.

The present article gives the first results of an analysis of information on air pollution obtained by the method of expansion in natural components. In the future, the development of the research should take several directions. By obtaining natural functions for a number of cities, it will be possible to analyze the existing state of air pollution and the causes of its formation. The expansion coefficients of the first terms can be used in working out a prediction scheme. In addition, these quantities will further be used for the qualitative study of the relationship between air pollution and meteorological conditions.

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