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SCIENTIFIC REPORT NO. 1

SOME ASPECTS OF THE DISPERSION OF POLLENS AND INDUSTRIAL CONTAMINANTS IN RELATION TO MICROMETEOROLOGY

By

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TABLE OF CONTENTS

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ABSTRACT

Many micrometeorological aspects are involved in the dispersion and penetration of pollens and industrial contaminants. This report critically reviews some of the published research on the dispersion of pollens and industrial contaminants. The writer has been unable as yet to find any published material on penetration. The production of pollens and industrial contaminants, their introduction into, diffusion through, and removal from the atmosphere are discussed insofar as these processes are affected by micrometeorological or microclimatological conditions. Possible influences of pollen pollution and industrial contaminants on climate and on health are indicated.

1. POLLUTION AND CLIMATE

It has for years been thought by some that long-term fluctuations in the composition of the atmosphere have been major causes of the great ice ages and other manifestations of major climatic changes in the distant past. These earlier theories of climatic variations assumed that these changes in composition exerted their influence by modifying the amount of radiation reaching or leaving the lower atmosphere. More recently attention has been given to the possibility that cloud and precipitation regimes have been modified through the nucleating action of particulate matter introduced into the atmosphere.

A. Radiational Effects—Carbon Dioxide

The importance of absorption of terrestrial radiation by atmospheric carbon dioxide in relation to climate was pointed out by Tyndall (1861). The analysis was carried a substantial step farther by Arrhenius (1896) who computed for thirteen latitude belts and each of the four seasons the surface temperature change to be expected for five assumed values of the CO_2 content of the atmosphere. The assumed values ranged from two thirds of to three times the existing value: the corresponding surface temperature changes ranged from -3 to +8 C. Carbon dioxide is effectively transparent to solar radiation, but radiation in a portion of the far infrared is strongly absorbed by CO_2. An increase in CO_2 content thus decreases the heat loss to space by long-wave radiation, so that the temperature rises. Correspondingly, a decrease in CO_2 leads to a temperature drop. The probable causes of large fluctuations of atmospheric CO_2 content during geological time and the paleoclimatic conclusions to be drawn are considered both by Arrhenius and by Chamberlin (1897; 1899).

It was suggested by Callendar (1938) that the industrial emission of CO_2 to the atmosphere during the past half century has been a major factor in producing the observed increase in mean temperature during that period. Callendar's analysis has been revised, extended, and brought up to date by Plass (1953).

For present purposes there are three aspects of the problem which require consideration. (1) Are CO_2 changes due to atmospheric pollution? (2) How would changes in the amount of CO_2 affect climate? (3) Is there convincing evidence of such climatic changes? There seems to be no doubt that surface concentrations of CO_2 have increased significantly since the beginning of the present century (Callendar, 1940). The data as summarized by Callendar are given in Table I.

TABLE I

MEASURED CO_2 CONDENTRATIONS
IN PARTS PER MILLION BY VOLUME

Authority	Location	Date	No. obs.	Mean CO_2 p.p.m.
T. Thorpe	North Atlantic	1866	51	295
F. Schulze	Rostock	1868-71	1034	292
J. Reiset	Near Dieppe	1872-73	80 b	292 a
A. Levy	Montsouris, Observatory	1876-87	1000	292
G. Armstrong	Grasmere, England	1879	53 b	296
J. Reiset	Near Dieppe	1879-80	89 b	291 a
Muntz and Aubin	France (country)	1881	64	287 a
Petermann and Graftiau	Near Gembloux	1889-91	525	294
Letts and Blake	Near Belfast	1897	64	289 a
Brown and Escombe	Kew Gardens	1898-01	92	294 a
F. Benedict	Near Boston	1909-12	645	303
K. Buch	North Atlantic	1932	28	318
K. Buch	Petsamo, Finland	1934-35	95	321 a
K. Buch	North Atlantic	1935	53	320
J. Haldane	Near Perth, Scotland	1935	152	324

a thought to be the most accurate values
b excluding night values

The more difficult question is the origin of these changes. CO_2 is being continuously added to the atmosphere by the respiration and decay of animal and plant life and also being removed by assimilation in photosynthesis. There are other items in the carbon cycle (Rankama and Sahama, 1950). Goldschmidt (1934) evaluates the several items as shown in Table II. Other figures have been given which may or may not be more accurate, but the important point is the order of magnitude of the several components of the cycle. If one assumes that the loss by photosynthesis is exactly or very nearly equal to the gain by respiration and decay—a highly debatable assumption—then the contribution made by the combustion of coal and oil is indeed significant. The oceans are a reservoir of CO_2, containing much more than the atmosphere, and in the course of time tend to reduce atmospheric concentrations. However, turbulent mixing in the ocean appears to be too slow to allow any significant uptake of the surplus industrial CO_2 which has been produced during the past half century. The industrial production of CO_2 during this period would almost exactly account for the 10 per cent increase in measured concentration obtained by extrapolating to 1950 the values given in Table I. This agreement is suggestive, but may be purely fortuitous.

TABLE II

ANNUAL PRODUCTION AND CONSUMPTION OF CO_2

Process	CO_2 Added (mg cm^{-2})	CO_2 Removed (mg cm^{-2})
Volcanic emission	0.003-0.006	
Combustion of coal and oil	0.8	
Respiration and decay	$\simeq$ 40	
Photosynthesis		$\simeq$ 40
Weathering		0.003-0.004
Formation of caustobioliths		0.0003-0.002

A change in atmospheric CO_2 content might modify the climate in various ways. An increase leads to a reduced loss of heat by terrestrial

There is a distinct possibility, on the basis of the evidence summarized above, that industrial pollution of the atmosphere by CO_2 is a contributing factor to recent climatic changes. The agreement between theory and observation may, however, be partly coincidental. The fact that temperature rises have been substantially greater in northerly latitudes than elsewhere is not adequately accounted for on the CO_2 theory, and suggests that other causes are at work as well.

B. Radiational Effects—Dust and Smoke

Dust and smoke near the center of an industrial city deplete the solar radiation reaching the surface. Ultraviolet radiation is seriously depleted by smoke, especially in the winter when it is most needed, as shown by the Leicester survey (1945). Near the center of the city at least 30 per cent and at times 50 per cent of the ultraviolet solar radiation is cut off by smoke.

This fact leads naturally to the interesting question of whether there is a sufficient residue of industrial smoke in the atmosphere to influence the general pattern of climate. Humphreys (1913) deduced that the loss of short-wave radiation by the scattering produced by volcanic dust after major eruptions caused a cooling of 1 F. Wexler (1951) has carried the analysis farther. Extensive forest fire smoke may also cause local temperature decreases of short duration. It is estimated by Wexler (1950) that the great pall of forest fire smoke of 24-30 September 1950 reduced solar radiation so much that maximum temperatures were lower than the expected values by 10 F. Landsberg (1951) gives the estimated annual dust production of the major cities of the earth as no more than one fifth of that released by a major volcanic outburst of ash. On the basis of this comparison he believes that industrial smoke and dust are insufficient to affect world climate at the present time, but that climatic changes from this cause may develop in the future if industrial expansion continues and atmospheric pollution is not brought under control. Another point should be mentioned: increased pollution by industrial smoke and dust should lead to a large-scale temperature fall. But as mentioned in the discussion of CO_2 pollution, temperatures are rising, not falling. This suggests that smoke and dust are having no effect, unless one wishes to adopt the unsupported assumption that other processes are contributing to a large temperature rise which is being moderated by the cooling influence of industrial smoke. Such a possibility should not be entertained without strong supporting evidence, which is lacking.

C. Nucleating Effects

There is no doubt that atmospheric pollution affects the local microweather and microclimate. The evidence has been reviewed briefly by Landsberg (1951). It has been shown by Ashworth (1929, 1944) that at Rochdale, England both the average amount and average rate of rainfall are slightly smaller on Sunday than on other days of the week. These facts suggest that, since the factories were closed on Sunday, condensation on the nuclei produced by industrial processes leads to the increased rainfall on the other days of the week. According to Wiegel (1938), the Ruhr region of Germany gets measurable rain or drizzle on twenty more days per annum than do nearby less industrialized areas. Fog is also increased: a long series of observations for Prague, Czechoslovakia analyzed by Hrudička (1938) show that there were, on the average about 82 days with fog per year in the period 1800-1880, and that since that period the number has nearly doubled. Laboratory studies by Neuberger and Gutnick (1949) and by Neuberger (1951) indicate that fog duration is directly proportional to pollution. The relationship with fog density is more complicated. It is much more debatable whether industrial smoke and dust are influencing precipitation and fog occurrence over wide areas and far from industrial regions.

Wexler (1951) using experimental results of Schaefer (1949), suggests that some types of volcanic ash may act as nucleating agents to initiate cloud formation in initially cloudless strata which are supersaturated with respect to ice. The possibility exists that industrial smoke may act in the same manner, but the writer knows of no evidence that it does. Further light may be expected on this point as our knowledge of the physics of cloud and precipitation develops.

2. POLLUTION AND HEALTH

There is no doubt that pollution, under extreme circumstances, affects health and may even lead to death. During the period 1-5 December 1930, severe pollution occurred near Liege in the Meuse Valley in Belgium (Firket, 1936). Several hundred persons suffered from acute respiratory troubles and 63 died on December 4 and 5. A similar disaster occurred at Donora, Pennsylvania during the last few days of October, 1948 (Schrenk _et al_., 1949) when 20 persons died and hundreds were stricken. Severe smog in Great Britain took a large death toll late in 1952. The number of deaths in Greater London for the five weeks ending 3 January 1953 was 15,114; the number was 9,125 for the same period a year earlier. In 124 towns containing about half the population of England the comparable numbers of deaths were 34,764 against 25,821. In none of these cases have lethal contaminants been positively identified, but SO_2 is strongly suspected.

A fourth disaster has been less widely reported. On 24 November 1950 at Poza Rica, Mexico an accidental release of H_2S led to the hospitalization of 320 persons and the death of 22 (McCabe and Clayton, 1952).

The release occurred between 4:50 and 5:10 a.m. during a period characterized by a low level temperature inversion, light winds, and pronounced fog. These conditions are identical with those at Liege and Donora.

A. Smoke and Bronchitis and Pneumonia

If atmospheric pollution does cause or increase the incidence of disease, then respiratory diseases should show this influence. The evidence is not clear cut, but there are indications that there is a relation between the death rates of adults for pneumonia and bronchitis and the level of pollution. Russell (1924; 1926) has studied the influence of temperature and fog on mortality from respiratory diseases in two London boroughs. The amount of fog is taken as an indicator of pollution, an admittedly weak assumption. Over a period of time there is little relation with fog alone, but fog in association with low temperatures during the cold months of the year bring a substantial increase in mortality rates. Woods (1928) is in agreement with this conclusion. A study of death rates from respiratory diseases in Dublin during the early years of World War II when there was a coal shortage has been made by Leonard _et al_. (1942; 1943). Some of the data are shown by moving averages in Fig. 1. The coal shortage commenced in 1941 and continued for several years thereafter. The pollution both by suspended impurities and by SO_2 in 1941 was only half of the average value for the preceeding three years. The winter death rates for the period of low pollution were also about halved, as Fig. 1 indicates. These data are suggestive, but the low pollution years had warmer winter temperatures, which may have ameliorated the severity of respiratory diseases. No clear cut conclusion is to be drawn from these data.

B. Smoke and Asthma

It has been suggested (Cooke, 1934) that SO_2 is a cause of asthma in predisposed individuals. Three cases of prolonged bronchial

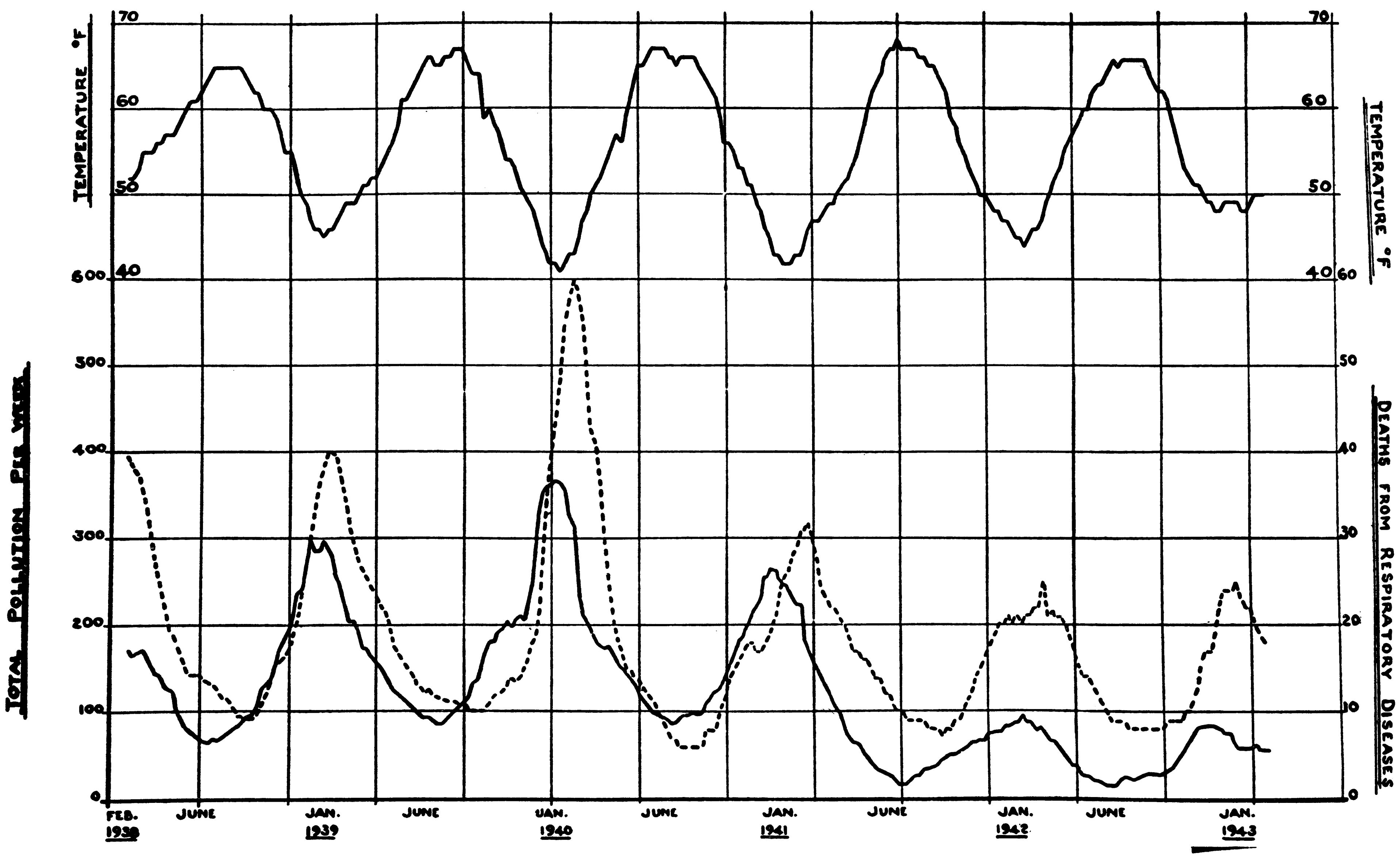

Fig. 1. Moving averages of death rates from respiratory diseases in Dublin as influenced by the coal shortage in 1941 (full curve: pollution by suspended matter; broken curve: deaths from respiratory diseases); corresponding temperature variations are shown above (after Leonard *et al.*).

asthma following exposure to SO_2 from leaking refrigerators were reported by Romanoff (1939). It is stated by Wittich (1950) that among a group of veterans of World War II with chronic asthma there were those whose attacks were precipitated by exposure to long range air pollution due to chemicals present in the air in the region in which the men happened to be. The attacks of many of these could be controlled by effective zoning.

C. Smoke and Cancer

The carcinogenic activity of soot, tar, and other products of the combustion and fractionation of coal and oil is well established. It is therefore natural to suspect such contaminants of being causative agents in respiratory cancer. Green (1914) suggested, as a result of investigations in Scotland and England, that atmospheric pollution by SO_2 was a contributory factor in the development of cancer. His analysis showed that death rates were small in cities situated on high or low areas which are comparatively flat; the mortality was large in rough terrain and valleys. The difference was attributed in part to accumulations of pollution in the rough terrain where atmospheric diffusion is at times reduced by the topography. It is no longer believed that SO_2 is a carcinogenic agent, but the diffusion considerations apply to any impurity. Meyers (1928, 1930) has taken the question up again. He asks why the death rate is 133.1 for San Francisco (hilly) and 92.7 for Oakland (flat). Why is that for Minneapolis (flat) 98.1 and 120.9 for St. Paul (hilly)? Meyers brings forth other data which suggest strongly that further study on this point is urgently required. Hueper (1950) tabulates industrial carcinogenic agents and states his suspicions in a forthright manner:

> "Cancerigenic agents polluting the air may enter the human body by inhalation, cutaneous contact or ingestion. Exposure of the population to cancerigenic air pollutants, especially those of stable nature, may result from their subsequent incorporation into and contamination of drinking water, foodstuffs and soil. Cancers caused by cancerigenic air pollutants may affect not only parts of the respiratory tract, such as the lung or the nasal sinuses, but, depending on the nature of the agent and the type of exposure, may affect other organs, such as skin, bones, bone marrow and bladder."

However, there are several contraindications. For example, Ingalls (1950) finds no evidence of increased susceptibility to cancer among 476 workers in the carbon black industry.

Finally, evidence is rapidly accumulating in both Great Britain and the United States that the recent and continuing increase in lung cancer is significantly correlated with increased tobacco smoking (Doll and Hill, 1950; Wynder and Graham, 1950). It seems clear at the present time that any carcinogenic effect of industrial smoke is negligible in comparison with that of tobacco smoking.

D. SO_2 and Disease

An interesting study of the possible long term effects of exposure to SO_2 has been made by Anderson (1950). Two groups of workers at the refinery of the Anglo-Iranian Oil Co., Ltd., Abadan, Iran were used. The contact groups consisted of men who had been exposed to SO_2 for varying periods from 1 to 19 years; the daily concentration varied from 0 to 25 p.p.m., and occasionally to 100 p.p.m. The control groups were men engaged in the same areas, but with no recorded exposure to SO_2. The study revealed no effect of SO_2 exposure on blood pressure, vital capacity (volume of air which can be exhaled from maximum inspiration to the end of maximum expiration) or the chest as shown by radiography.

This test may be taken as convincing evidence, unless the climatic conditions of Iran are such as to make the results inapplicable to areas with more moderate climates. SO_2 in solar radiation oxidizes to SO_3 which then unites with water to form H_2SO_4. The SO_2 in and near the plant has probably not oxidized by the time it has been breathed by the workers, and the atmosphere may be so dry as to inhibit the formation of sulphuric acid. There is evidence that H_2SO_4 mist is more toxic than SO_2 (McDonald et al., 1951) and this should be borne in mind when evaluating the above results. Incidentally, the above paper of McDonald et al. gives a very comprehensive survey of health in relation to atmospheric smoke pollution.

E. Aeroallergens and Health

Although there is doubt as to the nature and degree of the influence of smoke on health, there is no question of the adverse effects of pollution by pollens. The airborne spores of such fungi as molds, mildews, rusts and smuts also present a problem. These bodies are known as aeroallergens. Hay fever and asthma are considered rather as jokes by those who are not allergic to pollens or other aeroallergens. On a more objective evaluation, they do present serious medical problems. Sheldon et al. (1953) list the primary complications of bronchial asthma as follows:

1. Intractable asthma, which results in such impaired pulmonary function that the patient is incapacitated.
2. Pulmonary emphysema (dilatation of lungs), which also may cause the patient to be a pulmonary cripple.
3. Bronchiect sis due to plugging of distal bronchioles, with resulting infection (and often destruction of tube tissue).
4. Bronchitis and pneumonitis.
5. Atelectasis (collapse of lung due to plugging of bronchial tubes).
6. Pneumothorax (air between lung and chest wall, with lung collapse).
7. Mediastinal or subcutaneous emphysema (air in other parts of the upper body).

8. Cor pulmonale (excessive development and dilatation of the right hand portion of the heart).

Pathological details are given by Vaughn and Black (1948). Death from asthma with numerous case histories has been discussed by Rackemann (1944). It might be thought that simple hay fever presents less of a hazard to health. However, the records show that 30 to 40 per cent of hay fever patients will develop asthma if the disease runs unchecked (Sheldon *et al.*, 1953). It has been estimated that 5 per cent of the population of the United States find hay fever a definite health problem. Many more than these 8 millions are caused occasional discomfort.

F. Distribution and Incidence of Aeroallergens

In general there are three generic sources of allergenic pollens: trees, grasses, and weeds. Tree pollens are found in late winter and through the spring. The tree pollens do not appear before spring in regions with severe winters. In middle latitudes grass pollens begin in May and usually end in July or August; farther south they are prevalent throughout the year, except for December and January. Some weed pollens occur in late spring and early summer, but the most troublesome type in North America, ragweed, occurs in late summer (mid-August through September). There is very little ragweed in Great Britain (Freeman, 1950).

Ragweed presents the most serious problem in pollen allergy in the United States. It is widely distributed, as shown in Fig. 2. The annual ragweed deposition is very large in the triangular area whose corners lie in southeastern Texas, eastern North Dakota, and western Pennsylvania. It is more moderate to the east of this triangle and nearly negligible to the west of it.

Fungi are very widespread and numerous, there being about 80,000 different species. They produce spores in great variety and quantity. A very common mold is the *Alternaria*, and its spores are

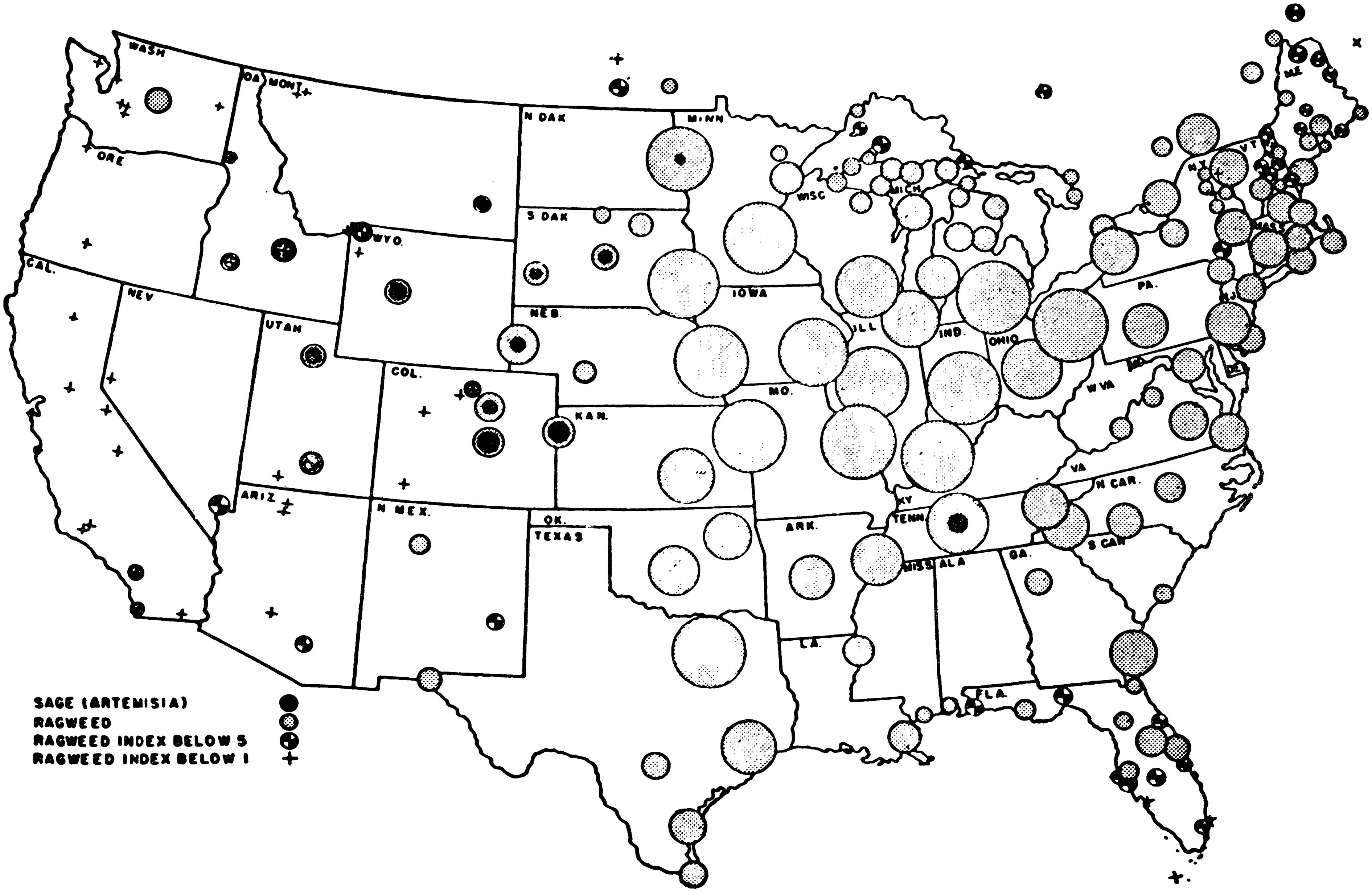

Fig. 2. Ragweed and sage (Artemisia) pollen counts for the continental United States and adjacent areas of Canada. Area of discs denotes comparative total annual fall of pollen in each locality (after Durham).

one of the foremost causes of respiratory allergy among the fungi. Alternaria has been reported from every state in the United States; conditions may be favorable for a peak release of spores anytime during the warm months, from May to November. Near canneries, the maximum spore production may coincide with the dumping of piles of waste by-products which are excellent culture media.

G. Meteorological Factors in the Dispersal of Aeroallergens

Prevailing weather conditions play a large part in the dispersion of pollens and spores. Excellent analyses of some of the meteorological factors in spore dispersal have been given by Gregory (1945, 1952a). A brief but provocative discussion of pollen dispersal has come from Dingle (1953). Possible control measures for ragweed based on an evaluation of the area of dispersal of the pollen have been proposed by Fletcher and Velz (1950). The need for such control measures is urgent, since the incidence of hay fever is steadily increasing from year to year. Wodehouse (1939) maintains that this increase is due primarily to the continuous increase of hay-fever plants, which have been given favorable environments by some of man's farming and urban land-use practices.

With Gregory (1952a) we may recognize two stages of dispersal: (1) take off or separation of the spore from the stratum where it was formed; and (2) transport of the spore to a distance. The kinetic energy of rain drops produces the take off of certain spores in two ways. Rain first loosens the spores from the sticky material in which they are embedded. The small droplets splashed upward by the rain drops carry the loosened spores with them the small droplets evaporate rapidly, leaving the spores to dry and be transported by the wind. Other fungi, such as puff-balls and earth-stars, have a bellows mechanism which ejects a jet of dry spores to a height of several centimeters when hit by a raindrop; thereafter the spores are diffused by turbulence.

Meteorological processes are also involved in the production and emission of pollen. Pollen production is reported to depend on meteorological conditions. Hyde (1950) found in the course of the study of the influence of situation and contemporary weather on pollen deposition in Great Britain that the production of tree pollens varies directly with the temperature. Jones (1952) reports that temperatures less than 60 F inhibited pollen shedding by some species in Nebraska and Oklahoma. Catches of grass pollen have a positive correlation with bright sunshine. There is some question whether these elements actually influence pollen production as Hyde assumes, or whether they act in facilitating or otherwise the transport of the pollen from plant to the collector—in this case as in most others a coated horizontal slide on which the aeroallergens are deposited.

Pollen is released when the anther containing it dehisces (breaks). The shedding, usually daily, is completed within several hours. Dingle (1953) suggests that low-level turbulence and gustiness are required to shake the pollen grains loose and to transport them upward into the air stream. Hyde and Williams (1946) report in a study of the pollen of the ribwort plantain (Plantago lanceolata L.) that at 07.15 and 07.30 hr on two May mornings, anthers which had dehisced remained stationary, and their pollen unshed, owing to the stillness of the air. Some investigations have shown that high humidity may prevent or at least delay dehiscence. Durham (1947) reports very great concentrations of ragweed measured just after the passage of a line squall. The observing station was near Highland Park, Illinois, in the middle of a country road that ran directly through a pure stand of about 30 acres of giant ragweed. Ideal ripening conditions without wind had prevailed earlier. The observations were made about 9 a.m. Durham computes that at the peak—just after the line squall had passed—he was breathing more than 100,000 granules of pollen per minute. This is more than a whole season's intake by the average city apartment dweller. No doubt the sudden onset of marked turbulence accompanying increased solar heating during the morning hours often serves to shake the pollens loose and to carry them away. Waldbott and Ascher (1937) have noted that the severity of symptoms of hay fever and asthma does not depend as much on the quantity of a certain pollen in the air as on the rapidity of the increase and decrease of its concentration. Micrometeorology must be very significant here, since the atmosphere must play a primary role in producing such rapid changes in the concentration of aeroallergens.

The height at which pollens are released is also micrometeorologically important. Tree pollens, being liberated at greater heights than grass pollens, where turbulence is more pronounced, get off to a better start, according to Hyde and Williams (1945).

Antecedent weather and climatic conditions also affect the production of pollen, either by a direct influence on production in the anther, or by providing growing conditions which foster ragweed growth and hinder other growth or vice versa. Hyde (1952) found in Great Britain that exceptionally severe weather between late January and the middle of March of 1947 halved the plantain pollen catch for the year; the pollen count of spring Juncaceae (Luzula) was less than 10 per cent of average. The pollen productivity of weeds is also influenced by spring rainfall, as indicated by Fig. 3. Hyde (1950) furthermore states that the main course of the incidence of pollen throughout Great Britain in 1943 had been to a large extent previously determined, in part presumably by the weather experienced during the late winter and spring or even during the preceding year. Hansel (1953) states that the severity of the ragweed season in the United States may be predicted on the basis of the amount

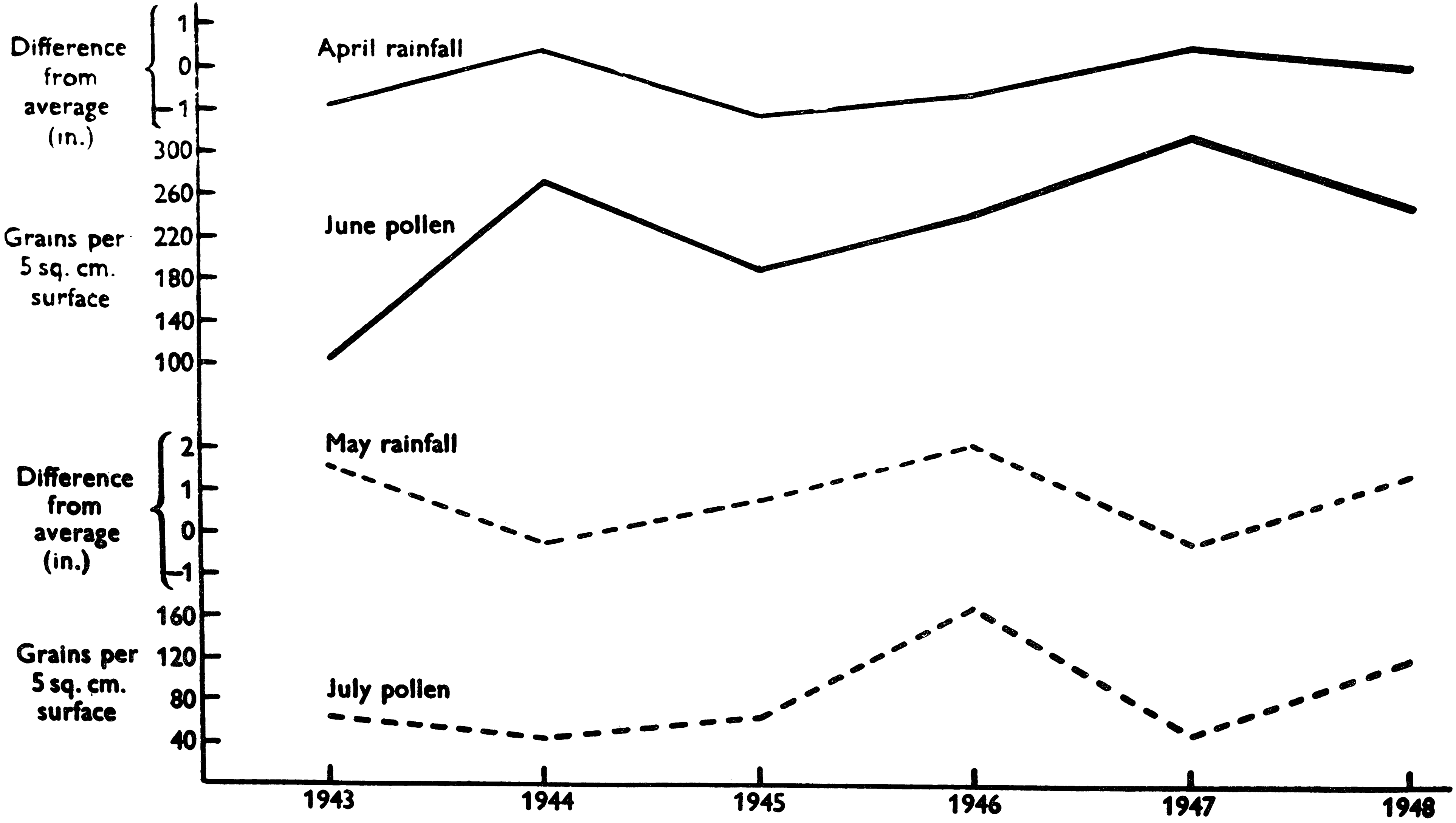

Fig. 3. Sorrel and dock (Rumex) pollen at Cardiff, Wales in the months of June and July 1943-48, as related to rainfall (inches above or below the 58-year monthly average) in April and May of the same years respectively (after Hyde).

of rainfall during June, July, and August. The greater the preseasonal rains are, the greater will be the pollen crop. This same statement is widely found in the literature, but without supporting documentation. Ragweed flourishes in bare soil, where it rapidly takes root and prospers; it does not readily wrest a root hold in already occupied soil. The result of antecedent weather conditions may therefore be more complex. For example, severe drought conditions in late spring and early summer may retard or kill less hardy plant growth, with the result that ragweed takes over the vacated soil. Hence, although individual plants may be less prolific in pollen production than when a rainy preseason occurs, there are so many more of them to pollinate that a severe hay-fever season results.

A detailed botanical-meteorological investigation would clarify these and many other points. After such a study it might be possible to issue by the middle of July regional forecasts of the severity of the hay-fever season on the basis of the weather of the preceding two months. Such forecasts would be most helpful to persons subject to hay fever and asthma in drawing up their vacation plans. Being based on antecedent weather, the forecasts should be highly reliable.

H. The Transport, Diffusion, and Deposition of Aeroallergens

The distances which aeroallergens will travel depends on a number of factors. Laboratory experiments at Iowa City have shown that the rate of fall of ragweed pollen varies directly with the humidity of the air (Shapiro and Rooks, 1951). At a relative humidity of 35 per cent, 2.9 per cent of the pollen remained airborne after 10 minutes; at a relative humidity of 98 per cent, the corresponding percentage of airborne pollen was only 0.5. In dry air, Crawford (1949) found that ragweed pollen (Ambrosia elatior) has a terminal velocity of 3 ft min^{-1}. The buoyancy of pollen grains usually increases after the anther dehisces and the pollen leaves the plant, owing to the drying of the initially moist particle.

The rate of fall also depends on the size of the pollen. A very useful classification of 45 species of pollen giving mean diameters, time of day of pollen shedding, and general season of pollen shedding has been published by Jones (1952). The smallest pollen classified is that of giant ragweed (Ambrosia trifida), with a diameter of 20μ; the largest is pollen of one of the corns (Zea mays), with a diameter of 100μ. Jones found that rye pollen (Secale cereale) of diameter 55μ is prevalent at breathing level only on windy days. With light winds, horizontal coated slides on the ground caught about four times as much pollen as similar slides at plant level.

It is doubtful, however, that variations in rate of fall in still air are of much significance in atmospheric dispersal. Stepanov (1935) liberated in a meadow near Leningrad a mixture of spores of Tilletia caries (17μ) and Bovista plumbea (5.6μ) and trapped the spores at the ground at various distances from the point of release. Despite the fact that in still air Tilletia falls six times as rapidly as Bovista, there was no significant difference in the downwind catch of the two sizes of spores.

There are two conceivable means by which concentrations of pollens might decrease with distance downwind from a source. The first is by sedimentation, i.e., fall under gravity. If gravitational fall is primary, as assumed by McCubbin (1944) and many others, then sedimentation will control the rate at which concentrations decrease downwind. There is no doubt that sedimentation will be very important with large pollen grains, i.e., those over 40μ in diameter. With spores and the smaller pollens sedimentation should be a secondary effect. That eddy diffusion is the primary process is strongly suggested by Gregory's

(1945) use of Stepanov's (1935) data on spore dispersal to show that Sutton's (1932) equation

$$\sigma^2 = \frac{1}{2} C^2 x^m \qquad (1)$$

is applicable. The quantity σ is the standard deviation of the cross-wind positions of the spores from their mean position, at a specified distance x from the source; C is a diffusion coefficient; and $m = 2 - n$, where n is obtained by fitting the theoretical profile $u = u_1 z^{n/(2-n)}$ to the observed change of wind with height. According to Sutton, m ranges from 1.50 for a large inversion, 1.75 for a neutral lapse rate, to 1.80 for a large lapse. With $C = 0.64$ and $m = 1.76$—values in good agreement with other experimental data—a very good fit with Stepanov's observations is obtained, as shown in Fig. 4. Gregory (1945) gives an expression for the deposition of spores on the ground, the pollen being from an instantaneous point source. The development is based on one of Sutton's expressions, with the additional postulate that the deposition is directly proportional to the concentration of spores in the air above the surface on which deposition occurs. With these is obtained

$$Q_x = Q_o \exp \left[- \frac{2px^{[1-(1/2)m]}}{(\pi)^{1/2}\, C\, (1 - \frac{1}{2} m)} \right] \qquad (2)$$

where Q_o is the original quantity of spores released, Q_x is the total quantity of spores remaining in the cloud when its center has moved a distance x, and p is a deposition coefficient. For the spores used by Stepanov (1935), the appropriate value of p is 0.05.

Dingle (1953) suggests that although Sutton's expressions are appropriate for small particles (1μ or less), they are not adequate for larger particles. From dimensional considerations Dingle deduces that the rate of dispersion is inversely related to the diameter of the pollen grains. This approach deserves further development.

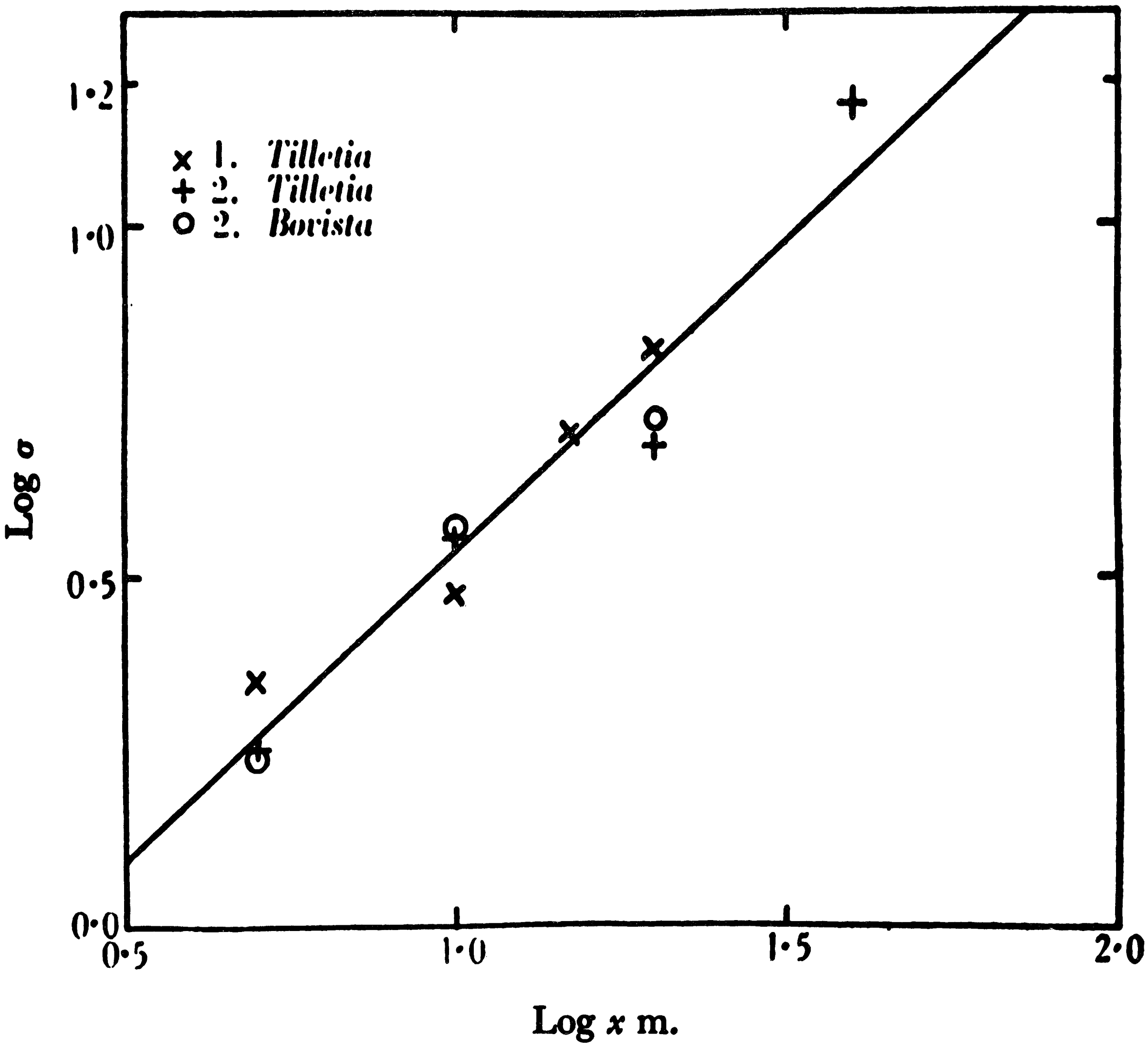

Fig. 4. Analysis of Stepanov's experiments on releasing spores at a point, showing relation between standard deviation of spores deposited at each distance from their mean positions, and the distance from the source. The straight line is the linear regression corresponding to $\sigma^2 = (1/2)\ C^2 x^m$, with $C = 0.64$ and $m = 1.76$ (after Gregory).

It has been widely held that pollens and spores frequently travel for hundreds of miles from their place of origin before being deposited. This view is based on the supposition that fall under gravity is the primary agent in deposition. Spores and pollens have been measured up to considerable heights by aircraft, as by Rempe (1937). He found maximum numbers as high as 500 m above the surface. The analysis on the basis of sedimentation runs as follows. High concentrations are found as high as 500 m, or 1800 ft to use a convenient number. Crawford's (1949) rate of settling for ragweed pollen was 3 ft min^{-1} or 180 ft hr^{-1}. Hence it takes 10 hr for ragweed pollen to settle from 1800 ft to the ground. But with a wind of 20 mi hr^{-1}, the horizontal transport in this time is 200 mi. With smaller spores or greater heights, the distances would be correspondingly greater. Rempe's observations show that only under the most stable atmospheric conditions, when turbulent mixing would be small, is there any marked sorting of particles according to size. This fact merely confirms that for pollens and spores of small to moderate size, sedimentation as a means of vertical motion is secondary except perhaps at night. The prime means of vertical transport is atmospheric turbulence. Night sedimentation may have significance in hay fever and asthma: if pollens or spores are carried up to considerable heights by convective action during the day, they may fall through the nocturnal inversion by sedimentation and reach the earth's surface late at night or during the early morning. The arrival of pollen in this way may in part account for the hay fever or asthmatic attacks which occur at night or in the early morning.

The evidence is clear that most of the time, the airborne trajectory of pollens and spores is relatively short. Hyde and Williams (1944) conclude, on the basis of a daily census of pollen deposition at Cardiff, Wales during 1942, that under ordinary atmospheric conditions a considerable proportion of the pollen caught had come from distances of 500 m or less; all but a very few types had traveled no farther than 1 km. The point of origin of these few was no farther than 10 km; there is no evidence that any pollen came from a greater distance. A later paper by Hyde (1950) concedes that some may come from 5 to 10 mi, and that there is a very small distant component nearly always present. Gregory (1952a) is most emphatic on this point. His statement is as follows.

> "It might be expected that once in the air, dry spores would mostly be carried far from their source, but under ordinary conditions this proves not to be so, and the bearing of this fact on plant pathology, fungus ecology, population genetics, and allergy is profound. Observations and theory agree that for spores or pollen liberated near the ground under normal conditions of turbulence, 99.9 per cent of the spores will be deposited within 100 m of the source. This is not to say that a very small proportion will not travel vast distances, but it is clear that most spores do not."

This conclusion is reinforced by the following investigations, as well as those of Hyde and Williams: the experiments of Stepanov (1935); the work of Parker-Rhodes (1951) on the basidiomycetes of Skokholm Island; and by the studies of Bateman (1947) in connection with vegetable seed production.

Fletcher and Velz (1950) have strongly supported this view, and have pointed out that these facts show that pollinosis as an environmental public health problem in cities may be controlled by programs of spraying stands of ragweed in vacant lots and elsewhere with 2,4-D. Several programs of spraying have been initiated, but the benefits of the results have not been adequately assessed. Micrometeorological studies during the ragweed season would be valuable in a number of ways, and especially so in tracing concentrations of pollution back to their sources, which may be sprayed, both immediately and in successive years. Such studies should also be effective in locating sources outside the city limits as well as those within.

I. The Limitations of Pollen Measurements

The prevailing methods of measuring the prevalence of aeroallergens in the United States have been fully described by Durham (1948), who has pioneered in developing methods of measurement and fostering their employment in the United States. The gravity slide sampler is very widely used. This is essentially a coated horizontal slide on which pollens and spores impinge and to which they presumably adhere. The number of pollens per square centimeter is then determined with the aid of a microscope. The number of pollen particles per cubic yard is obtained by multiplying the count for 1 cm^2 on the slide by a conversion factor—3.6 in the case of short ragweed (*Ambrosia elatior*).

The apparatus is shown in Fig. 5. It consists of two circular plates of polished stainless steel, 9 inches in diameter, with a holder which supports the coated slide at a height of 1 inch above the lower plate. The plates are supported by a 30-inch metal rod on a tripod stand. It was initially thought that gravity produced the impaction of particles. Studies by Durham (1948) and others using slides with various orientations with respect to the wind have shown that gravity impingement is secondary to wind impingement.

The gross inaccuracy of the results obtained is widely recognized, but no substitute which is sufficiently simple yet accurate to recommend itself for routine use has appeared. The outstanding need in the field of aeroallergen research at the present time is for a simple yet accurate device for measuring concentrations on a routine basis. Substantial advances may be expected when precise concentration measurements become widely available. Durham (1948) gives the data by which the conversion factor of 3.6 for short ragweed was obtained. The comparison was made with the readings obtained with the impinger developed by Hawes *et al.* (1942). In a series of seventeen tests, the factor

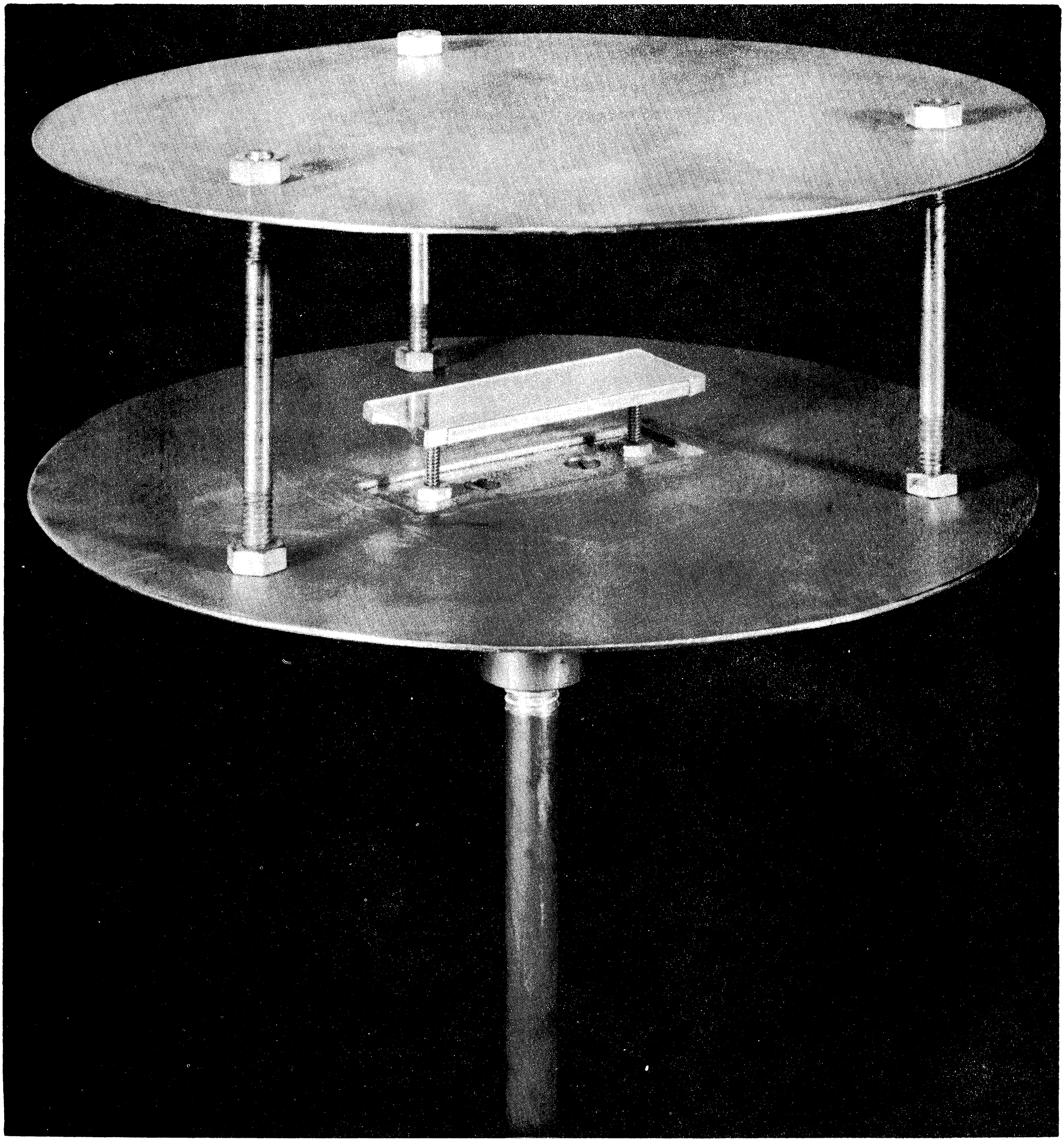

Fig. 5. Standard sampling apparatus for aeroallergens as developed by Durham (1946).

actually varied from 1.1 to 7.0, with a mean for the series of 3.6. It seems clear that the impaction results from a centrifugal action as the air flows around the coated slide. The number of particles which are impacted per unit time on the slide must be a complex function of their size and of the contemporary atmospheric turbulence; the impaction rate will vary with the fluctuating wind speed and angle of attack on the coated slide. A more accurate conversion factor which is a function of gustiness might be specified, but the gustiness itself would then have to be measured, which introduces a complication. A direct, simple, and accurate measuring technique is greatly to be preferred.

A similar slide technique, but with modifications, has been used in Great Britain by Hyde and by Hyde and Williams. Gregory (1952b) has used the cascade impactor developed by May (1945), and with the modifications made by Hirst (1952). With care and in skilled hands this apparatus will provide satisfactory data.

3. THE EFFICIENCY OF NATURAL CLEANSING PROCESSES

The crux of the problem of air sanitation is the ability of the atmosphere to eliminate the contaminants introduced into it. The elimination of the substances discussed earlier in this paper will be considered.

A. The Natural Cleansing of CO_2 from the Atmosphere

The evidence is clear on geochemical grounds that CO_2 can be removed from the atmosphere only very slowly (Rankama and Sahama, 1950). The oceans act as a regulator of CO_2, since they hold some sixty times as much of the gas as the atmosphere does. The regulating action is, however, relatively slow. CO_2 is carried into the oceans by rainwater, in which about 3 per cent by volume of the dissolved gases is CO_2. It also diffuses directly into the ocean water, but both these processes are slow. Considering diffusion alone, turbulent mixing in the oceans is so sluggish that it will reduce atmospheric CO_2 at a very slow rate. The prospect is, therefore, that CO_2 in the atmosphere will continue to increase owing to industrial activity until such time as the partial pressure difference of CO_2 between atmosphere and ocean has risen sufficiently to produce equilibrium. In this state CO_2 will be absorbed as fast as it is produced. At the present time, however, the excess CO_2 partial pressure is only 0.02 mb. Equilibrium will be attained only when the difference has grown to 0.3 mb. Any subsequent increase will be slow, since nearly all the CO_2 will be absorbed into the oceans. It is estimated that several thousands of years are required to establish any such equilibrium between atmosphere and ocean. Thus, if the recent CO_2 increases are mainly due to industrial activity, and if the corresponding warming of the climate is due to increased CO_2, then we may anticipate continued warming concurrent with industrial release of this gas. Induced changes in atmospheric circulation might, however, lead to different climatic manifestations.

B. The Natural Cleansing of SO_2 from the Atmosphere

Since SO_2 readily oxidizes in the atmosphere to SO_3 in the presence of sunlight, and since SO_3 unites readily with water to form H_2SO_4, it would appear that the principal mode of removal of SO_2 would be in rain water. According to Conway (1942), most of the sulphate in rain water comes from H_2S generated in shallow water on the continental shelves. Industrial centers are important local sources. Thus an analysis of rainfall in Tennessee by MacIntire and Young (1923) shows a large sulphate content of Knoxville rain water, but only one-fifth as much 7 mi from the city. Amounts in the city are also substantially greater in winter, when the consumption of soft coal is high. Similar results are found in Alabama by Volk *et al.* (1945). The observations of Wilson (1921, 1923, 1926) indicate increasing atmospheric pollution at Ithaca, New York, but little change is shown at other locations, such as Stillwater, Oklahoma (Harper and College, 1943). The yearly amounts are shown in Fig. 6. Ogiwara and Okita (1952) conclude from electron microscope studies that the condensation nuclei of cloud and fogs are not pure H_2SO_4. A very complete listing of references to sulphur in atmospheric precipitation is given by Eriksson (1952). Meetham (1950) has made a comparison of the amounts of contaminants emitted over Great Britain with the amounts deposited, in the course of a study of the natural removal of pollution from the atmosphere. He concludes that of the 5 million tons of SO_2 emitted each year, 1 million tons are blown out to sea. The remaining 4 million tons are deposited on land, and if this deposit occurs exponentially, the average life in the air of a molecule of SO_2 is 10 1/2 hr.

All the above evidence points to a rapid removal of SO_2 from the atmosphere, so that no long term accumulation is likely.

C. The Natural Cleansing of Smoke from the Air

The removal of larger smoke particles from the atmosphere is readily understood. These are carried downward under the joint action of turbulence and gravitational settling, and deposited by impaction due to centrifugal action as the particles are transported in the swirling eddies. Some are washed out by rain. Bosanquet *et al.* (1950) find that in a turbulent wind the maximum deposition of small particles with a negligible settling speed occurs at a distance of ten plume heights from the stack. With larger particles maximum deposition occurs nearer the source. Baron *et al.* (1949) give somewhat greater distances for the maximum

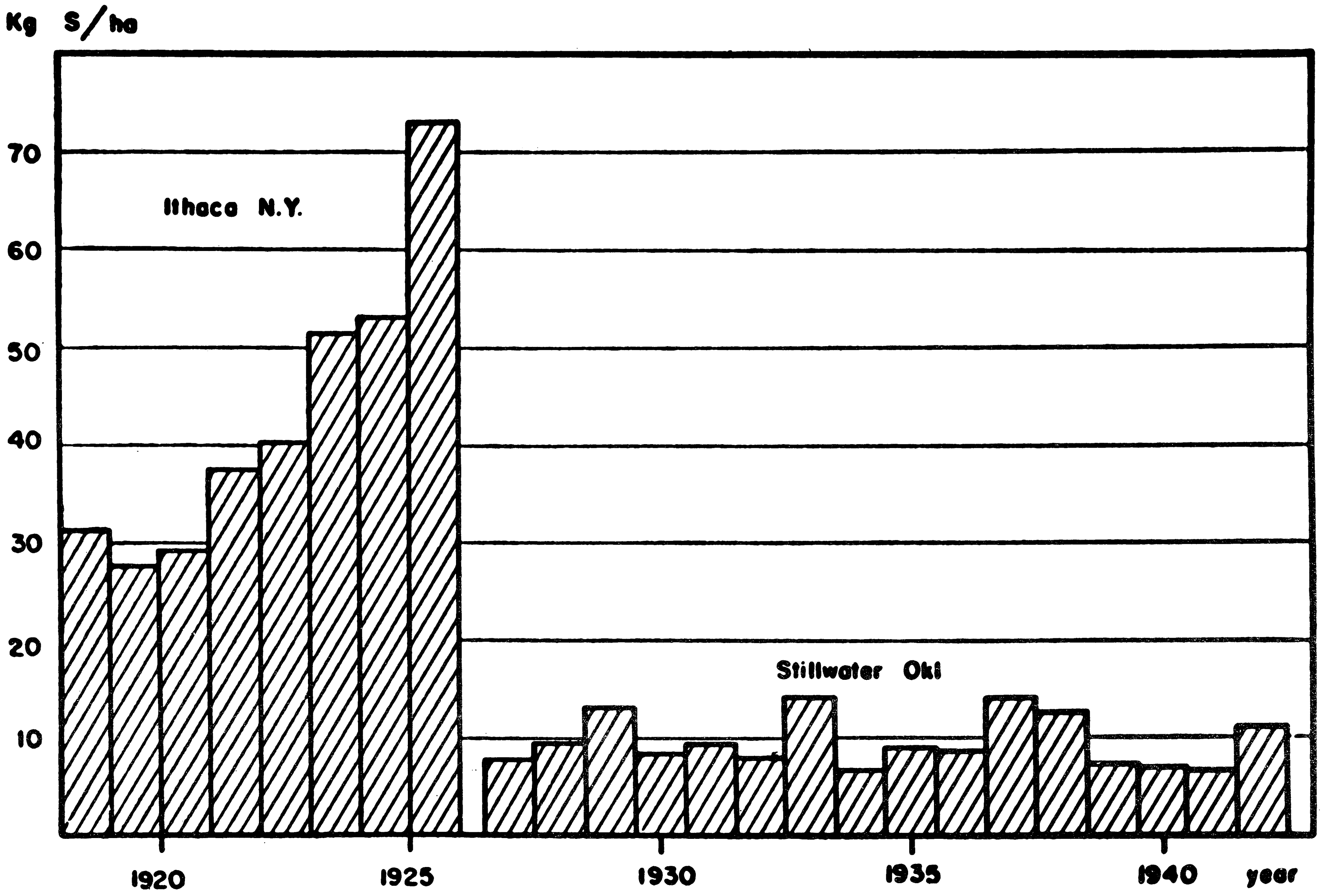

Fig. 6. The yearly amounts of sulphur (kg per hectare) in precipitation at Ithaca, New York (after Wilson) and at Stillwater, Oklahoma (after Harper and College).

deposition, but the differences are not large. The terminal velocities of the larger particles are important in the cleansing process; Bosanquet *et al.* (1950) give in their Fig. 10 falling speeds in air of particles of diameter from 10µ to 800µ.

The larger smoke particles present no problem in natural cleansing since they are quickly deposited so near their source. The natural removal of the very small particles is a very different matter. Lowell (1945) states that the foreign particles in the atmosphere, such as those resulting from combustion, range in size from 10µ to 0.001µ in radius. Meetham (1950) shows electron photomicrographs of samples of smoke taken in the open air at Teddington, near London in 1943. From the various samples it was found that particles less than 0.075µ in diameter constitute half the total number; only about 200 particles in a million were larger than 1µ and only 10 particles in a million were larger than 2µ in diameter. Meetham goes on to say that it is by no means obvious how such very small particles are removed from the air: he calculates that it would take 46 days for a spherical particle of diameter 0.1µ and density 2 to fall to the ground from a height of 10 m.

Many of these small particles may act as nuclei for condensation, and thus be removed by rain. Lettau (1939) has estimated that about 20 per cent of the condensation nuclei in the atmosphere have been produced by man's combustion processes. Electron microscope studies of snow crystal growth in Japan in areas far from cities have been made by Kumai (1951). He finds that a relatively large solid nucleus always exists at the center of the crystal, and that there are innumerable minute nuclei in the remainder of the crystal. Kumai refers to the former as the "center nucleus", and to the latter as "condensation nuclei". The center nucleus ranges in size from 0.5µ to 8µ. The diameter of the condensation nuclei varies from 0.01µ to 1µ; two sizes predominated, the smaller ones having a diameter of 0.05μ and the larger ones a diameter of 0.15μ. The smaller nuclei (0.05μ) were about eight times as prevalent as the larger ones. It is calculated that a dendritic plane crystal with a diameter of 1.6 mm and a thickness of 10μ contains 10^7 such nuclei. Precipitation of such crystals, either as snow or after melting, as rain, may be an important way in which natural cleansing of very small smoke particles from the atmosphere occurs.

A similar study of sea-fog nuclei has been made by Kuroiwa (1951). A few of the nuclei appear to be carbon particles produced by combustion; they are about 1μ in diameter. The water vapor seems to condense preferably on large nonhygroscopic particles rather than on hygroscopic particles of very small size. Natural removal of such very small particles by the precipitation of sea-fog droplets would therefore appear to be negligible. Ogiwara and Okita (1952) find with the electron microscope that the greater part of cloud and fog nuclei are composed of hygroscopic and nonhygroscopic smoke particles which originate in combustion. These nuclei range in diameter from 0.3μ to 1.2μ. Smoke particles in this range will therefore be removed by rain, but not those in the smaller ranges.

There is no doubt that some large smoke particles are collected and washed out by rain drops during their descent. Langmuir (1948) deduces, however, that particles smaller than 1μ are not picked up by falling rain. Cleansing by this type of rain action is limited then to removal of the larger particles.

Coagulation of smoke particles leads to increased size, which means more rapid deposition. Laboratory studies of coagulation have been made: a recent example is an investigation by Richardson (1952). The smallest particles studied, however, had a diameter of 0.5μ. Both theoretical and experimental field studies of the coagulation of smoke particles near the earth's surface have been made by Teverovsky (1948). By means of ultramicroscopes the change in the size of smoke particles in a plume was investigated: it was found that with 10^4 to 10^6 particles cm^{-3} the average radius increased from 0.2μ to 0.4μ while the smoke traveled a distance of 1 km. Teverovsky attributed this coagulation to microeddies, much smaller than those revealed by present-day micrometeorological instrumentation, which cause neighboring particles to converge. The diffusion coefficient appropriate for such eddies is given as 10^{-3} cm^2 sec^{-1}, in contrast to that for the large eddies with which micrometeorology has been mostly concerned, which is about 10^4 cm^2 sec^{-1}. Coagulation may thus lead to cleansing, especially near the source of smokes where the concentration is high; coagulation is ineffective elsewhere.

Impaction on natural surfaces is probably an important means of removal of smoke particles. As the air flows in a curved path around objects such as vegetation, stones, etc. the larger particles are impacted onto the objects by centrifugal action. If microeddies such as Teverovsky postulates do exist, then the microeddies which are adjacent to objects such as blades of grass will hurl small particles onto them in the same way that the centrifuge removes particles. It is possible that even the extremely small smoke particles mentioned earlier, with diameters 0.01μ or even 0.001μ, may be impacted on the surface of the earth by even smaller eddies than Teverovsky postulated. It would make little difference whether the microeddy centrifuge threw the particles onto the object itself or into a laminar sublayer. The latter, if it exists at all, is very thin. Poppendiek and Vehrencamp (1952) found some evidence for a laminar sublayer 0.01 cm thick over a very flat and uniform desert dry lake area. Such a layer will be much thinner over the ordinary surfaces of grass, bushes, etc., so that centrifugal impaction would be facilitated.

Even very small particles at great heights could be removed in this way. The particles would be carried down first by large eddies, of the scale of the major convective cells, and then by progressively smaller eddies of the atmospheric spectrum, until they were impacted on the surface from microeddies. Very small eddies have so far received little attention in micrometeorological investigations: they have been considered as near the end of the train by which energy is passed from the largest eddies down through the spectrum to the smallest, to be finally dissipated as heat. The above discussion suggests that microeddies may also play a fundamental part in the cleansing mechanism by which very small smoke particles are removed from the atmosphere.

We have some direct evidence as to how long dust in the stratosphere remains. Wexler (1951) marshals the evidence that volcanic dust thrown into the high atmosphere by major volcanic outbreaks has been observed to diminish solar radiation at the surface by as much as 10 per cent for as long as 3 years. Pernter (1889) estimated from optical observations that the average diameter of the particles of volcanic dust which were thrown into the high atmosphere by the eruption of Krakatoa was about 1.8μ. The same size of particles has been produced by later eruptions. We can say, then, that the time of deposition of particles of size 1.8μ in the high atmosphere is greater than 3 years. We still know nothing of the time of deposition of combustion particles of diameter 0.01μ.

Further study of the very small particles would be very desirable. The fine structure of atmospheric turbulence, especially near the earth's surface, should be studied by very sensitive and fast-response instrumentation, such as the hot-wire anemometers developed for wind-tunnel investigations. It might be possible by using existing or specially designed high speed centrifuges to study in the laboratory the mechanism of impaction of smokes by centrifugal action.

D. The Natural Cleansing of Aeroallergens from the Air

The natural removal of aeroallergens presents no special problems such as those provided by CO_2 and very small smoke particles since they are all relatively large. The pollens are from 20µ to 100µ in diameter, and even the smallest spores are several microns in diameter. The spores of *Lycoperdon giganteum*, for example, are about 4µ in diameter. Deposition occurs by turbulence and sedimentation in combination, often accelerated by coagulation and clumping, by impaction, and by rain washing. Durham (1938) points out that *Hormodendrum* spores float in masses. When the spores are most plentiful in the air the clumps are usually small, averaging five or six spores in the clump. At other times the clumps are infrequent but very large—40 to 80 spores per clump. The presence or absence of such large clumps probably depends in part on the intensity and structure of the turbulence at the time of release of the spores.

Rempe (1937) found indications of rain washing of pollen from the air. The following deposits on an area of 1 cm^2 for 4-minute periods before, during, and after a thunder shower were obtained: 0.31 grain; 1.90 grains; and 0.15 grain, respectively. During one period of rainy weather the number of grains caught decreased steadily to one tenth of its initial value in the course of 2 days. Rain washing in the thunder shower would appear to be established, but the second example is inconclusive unless it is established that rates of pollen production, of dehiscing and ejection, and of turbulent diffusion, as well as wind direction, are all effectively constant during the 2-day period. Gregory (1952a) gives values of the collection efficiency of rain drops for spores of various sizes based on Langmuir's (1948) theory. According to Langmuir's figures, collection efficiency is at a maximum for all spore sizes with drops 2 mm in diameter; it is then about 25 per cent for 4μ spheres, and 80 to 90 per cent for spores 20 to 30μ in diameter. At Rothamsted on 22 June 1951 it was found by Gregory that 2 mm of rain falling during 2 hours brought down 200 times as many spores of Ustilago perennans (8-9μ) as were deposited during the whole day on a similar area exposed to wind but sheltered from the rain.

Impaction of spores on vegetation has also been discussed in detail by Gregory (1952a). Medium sized spores are impacted on blades of grass and stems, and larger spores on large stems and leaves. The impaction of the smallest spores is probably aided by the centrifugal action of microeddies, but this mechanism is not discussed by Gregory.

E. A Meteorological Observatory for the Study of Standards of Atmospheric Purity and Their Maintenance

It is evident from the foregoing that long-term changes in the composition and concentrations of the impurities in the atmosphere are a distinct possibility. In the case of CO_2 the changes are already apparent. Such changes, actual or potential, are of the utmost importance, and should be the subject of continuing study. There are a number of other impurities in the atmosphere which have not been mentioned in this survey, and growing accumulations of these may be affecting human life in ways as yet unsuspected.

It is therefore suggested that a meteorological observatory whose prime function is the measurement and analysis of atmospheric impurities be established at some suitable location far from local sources of pollution. A site on the windward side of one of the isolated islands of the Pacific would be ideal. Such an observatory should be maintained on a permanent basis, or at least until it is certain that no man-made pollution is significantly changing the composition of the atmosphere.

4. SOME SPECIFIC PROBLEMS

A number of questions and problems emerge as a result of the considerations raised in this paper. Some of these questions and problems are listed below.

A. Problems of Pollution in Relation to Climatic Change

1. Are CO_2 changes due to atmospheric pollution?
2. Are climatic changes during the past half century such as would be expected from the increase in CO_2?
3. Are CO_2 concentrations continuing to increase at the present time, and at a rate that corresponds with industrial output?
4. What is the time scale of CO_2 exchange between atmosphere and ocean?
5. Do the small combustion particles which are dispersed far from industrial centers act as nucleating agents so as to increase cloud formation?

B. Problems of Pollution in Relation to Health

1. Is atmospheric pollution or is low temperature of greater importance in the mortality from respiratory diseases in winter?
2. To what extent are the development and incidence of asthmatic attacks by certain individuals due to atmosphere pollution by SO_2?
3. To what extent is the development of lung cancer in nonsmokers due to carcinogenic agents in atmospheric pollution? If it appears that lung cancer is promoted by tar and soot, the possibility of synergistic action of these with tobacco smoke should be investigated.
4. Are atmospheric diffusion conditions sufficiently different over hilly and flat regions to account for the observed difference in cancer death rates?
5. Do climatic differences vary the susceptibility to pathological conditions caused by atmospheric pollution?
6. To what extent is pollen production by individual plants dependent on current weather conditions? On previous weather conditions?

7. To what extent do current weather conditions influence the dehiscence of the anther?

8. Is atmospheric turbulence required to shake pollen loose from the anther after dehiscence?

9. How is dispersion influenced by the time of day at which pollen shedding generally occurs?

10. To what extent is the number of ragweed plants governed by antecedent weather conditions?

11. Do sudden increases in pollen concentration arising from atmospheric influences produce more severe allergic symptoms than a steady high concentration?

12. Can a system of accurate forecasting of the prevalence of aeroallergens be developed for periods of a month or more in advance?

13. Can meteorological observations in conjunction with concentration data be used to locate centers of ragweed growth for eradiction programs?

14. Can a simple but accurate method of measuring the concentration of aeroallergens be devised?

15. Is atmospheric dispersal of particles a function of their size?

C. Problems of the Natural Removal of Pollution

1. Is SO_2 removed in rain as pure H_2SO_4 or as sulphate salts?

2. How are very small smoke particles (0.001μ to 1μ) removed from the atmosphere?

3. Are very small smoke particles precipitated in large numbers in a single rain drop or ice crystal?

4. Do microeddies exist in the atmosphere? If so do they serve to deposit very small smoke particles by centrifugal impaction?

5. Is rain washing or direct impaction on surface objects more important in removing pollens and spores from the atmosphere?

5. CONCLUSIONS

Industrial pollution of the atmosphere by CO_2 may be modifying world climate, causing a temperature rise.

There is no evidence that industrial dust and smoke are modifying climate, either through radiational or nucleating effects.

Pollution in extreme cases may be lethal. Mortality from respiratory diseases may be increased by smoke pollution. Asthma may be precipitated in susceptible individuals by smoke, perhaps SO_2. There is no evidence that cancer is induced by industrial smoke pollution.

Atmospheric pollution by aeroallergens such as pollens and spores causes hay fever and a substantial amount of asthma. The latter, if unchecked, may lead to pulmonary crippling, total disability, or even death. Micrometeorology can aid in controlling pollution by aeroallergens by assisting in eradication programs; it can also provide much valuable basic information on the conditions of production, release, dispersion, and deposition of aeroallergens. A simple but accurate sampler is required for widespread use.

Natural cleansing processes are not removing CO_2 from the air as rapidly as it is being produced by our industrial society. SO_2 is removed from the atmosphere and there is no long-term accumulation. The larger smoke particles and aeroallergens are removed rapidly by turbulence and gravity settling in combination and by rain washing; the very small smoke particles may be deposited in ice crystals or onto surface objects by centrifugal impaction by microeddies. The smoke particles of moderate size also act as condensation nuclei and are precipitated in rain. Coagulation of smoke particles may be important near a source, but not elsewhere.

A meteorological observatory for the study of standards of atmospheric purity and their maintenance should be established.

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