Interaction of Air Pollution and Weather in Their Effects on Health

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THE interaction of meteorologic variables with air pollution and their effects on health, especially as measured by morbidity and mortality statistics, are being examined critically by many epidemiologists. The high degree of correlation between weather and air pollution, in particular in urban centers, and the independent effect of weather on health, are of special interest. For example, air pollution has been indicted as a cause or an exacerbating factor in many diseases, including lung cancer, chronic bronchitis, and asthma.

The numerous studies that have tried to show causal relationships between normally occurring levels of air pollution and disease, however, have met with little success. The research strategies employed in the study of such relationships can be divided roughly into two main approaches.

1. Temporal comparison—in a given location, the variation of pollution with time has been correlated with the variation of morbidity or mortality with time (*1–4*).

2. Spatial comparison—in a given period of time, the variation of pollution with geographic area has been correlated with the variation of morbidity or mortality statistics in those locations (*5–9*).

In both types of studies, attempts to control confounding

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variables have been made with varying degrees of rigor. Although not all workers have controlled social variables such as social class or ethnicity, those that have often took into account several separate measures of social status. In contrast, few workers have paid attention to physical variables such as weather. Those that have done so have generally used a single measure such as temperature.

Weather and Health

That meteorologic variables might confound the relationship between pollutants and health has been recognized in statements from various authors. For example, Goldsmith (*10*) in 1969 stated:

> Sufficiently severe cold can both increase morbidity and mortality and also require greater fuel consumption for domestic heating, thus increasing atmospheric pollution. In other parts of the world a heat wave can both increase morbidity and mortality directly and increase the volatilization and reaction rates of hydrocarbons into and within the atmosphere, and if, as is often the case in Southern California, the heat wave is associated with very light winds, there is a substantial associated increase in the photochemical pollution.

Anderson and Ferris (*11*) said:

> It is also clear that climate as well as air qualities might have to be considered as an independent variable when the prevalence of respiratory symptoms in two different areas is compared. Rainfall and temperature may by themselves affect the distribution of respiratory symptoms as well as alter the estimation of air quality. Unless these factors are taken into account, it becomes very difficult to interpret the magnitude of the air pollution differential between communities.

McCarroll and co-workers in 1966 (*12*) noted:

> The biologic activity of air pollutants is undoubtedly greatly influenced by co-existing meteorologic variables, which in themselves have some biologic activity.

Burrows and co-workers (*13*) also stated that temperature and air pollution levels were related. In their words:

> However, it is difficult to separate the acute effects of air pollution from those secondary to concomitant changes in meteorological conditions. Indeed, cough, pulmonary function, and hospital admission rates have been shown to be closely related to environmental temperature as well as to air pollution levels.

The evidence that weather can affect health is hardly less voluminous and reliable than the evidence that air pollution affects health. Tromp (*14*) cited 129 references in a review of the influence of local and regional meteorologic environments on the development and spread of communicable diseases and on short- and long-term changes in the physicochemical state of the body. The influence of thermal stress on the thermoregulatory system has been examined by various authors. Mach (*15*) observed as early as 1934 that weather alters the response of human beings to drugs including digitalis and tuberculin and affects the action of drugs on infectious agents in the body.

In another paper on asthma, Tromp (*16*) separated the effects of weather and pollution (allergens in this study) and showed that meteorologic factors seemed to trigger attacks in the asthmatic patients.

In the Encyclopedia of Atmospheric Sciences and Astrogeology (*17*), studies on the effect of the passage of cold fronts on heart disease, the autonomic nervous system, and hormonal functions are discussed.

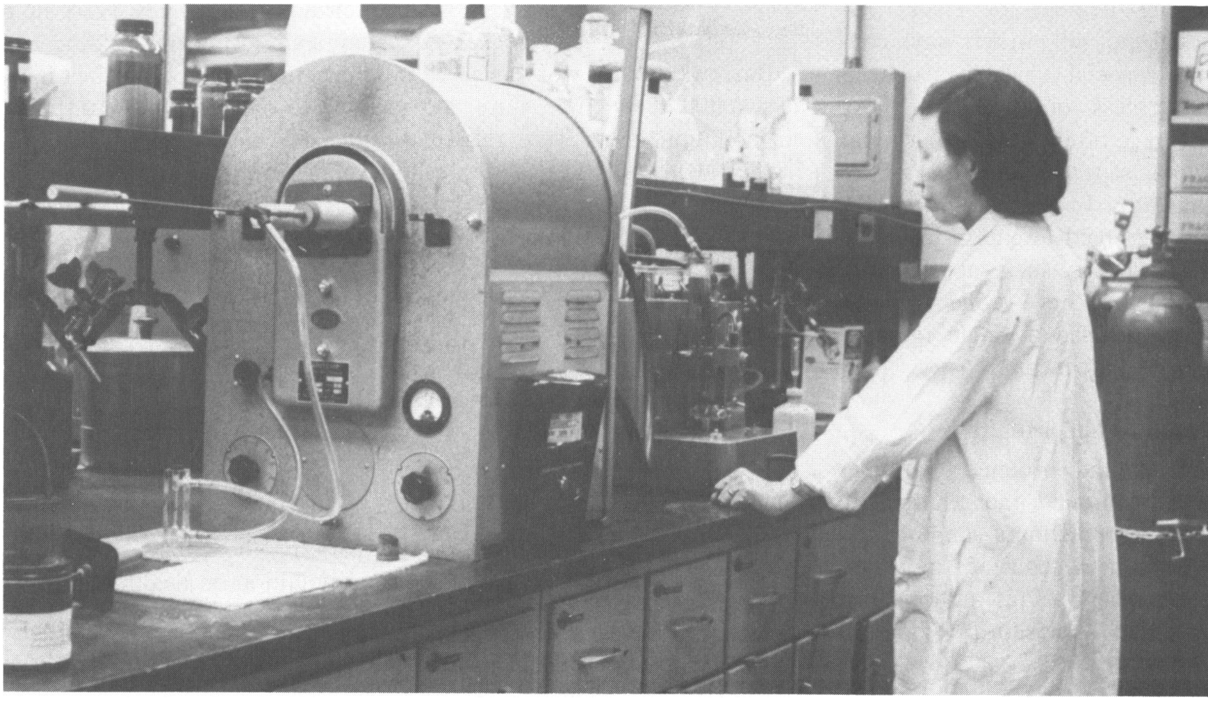
That periods of hot weather can have a marked effect on mortality has been demonstrated by Oechsli and Buechley (*18*) in a study carried out in Los Angeles. The periods of hot weather happened to coincide with days with sufficient ventilation so that the level of air pollution was low.

Interaction of Two Factors

The aforementioned studies in which the independent effect of weather on health is observed are only the beginning of what promises to be a fertile field of investigation. They are cited to strengthen the statement that the problem posed by the difficulty of separating the effects of weather and pollution on health has to be looked at more rigorously. To study either the independent effect or possibly a synergistic effect of both weather and pollution, these two variables must be separated.

The association between meteorologic variables and air pollution is reciprocal. Weather influences pollution, but pollution, in turn, influences weather. Peterson's following description illustrates this point (*19*).

> In addition to the two seasonal primary causes of heat islands, other factors are important year round. The "blanket" of pollutants over a city, including particulates, water vapor, and carbon dioxide, absorbs parts of the upward-directed thermal radiation emitted at the surface. Part of this radiation is re-emitted downward and retained by the ground; another part warms the ambient air, a process that tends to increase the low-level stability over the city, enhancing the probability of higher pollutant concentrations. Thus airborne pollutants not only cause a more intense heat island, but alter the vertical temperature structure in a way that hinders their dispersion. Reduced wind speed within an urban area, a result of the surface roughness of the city, also affects the heat island. The lower wind speed decreases the city's ventilation inhibit-



UNICO smokeshade analyzer

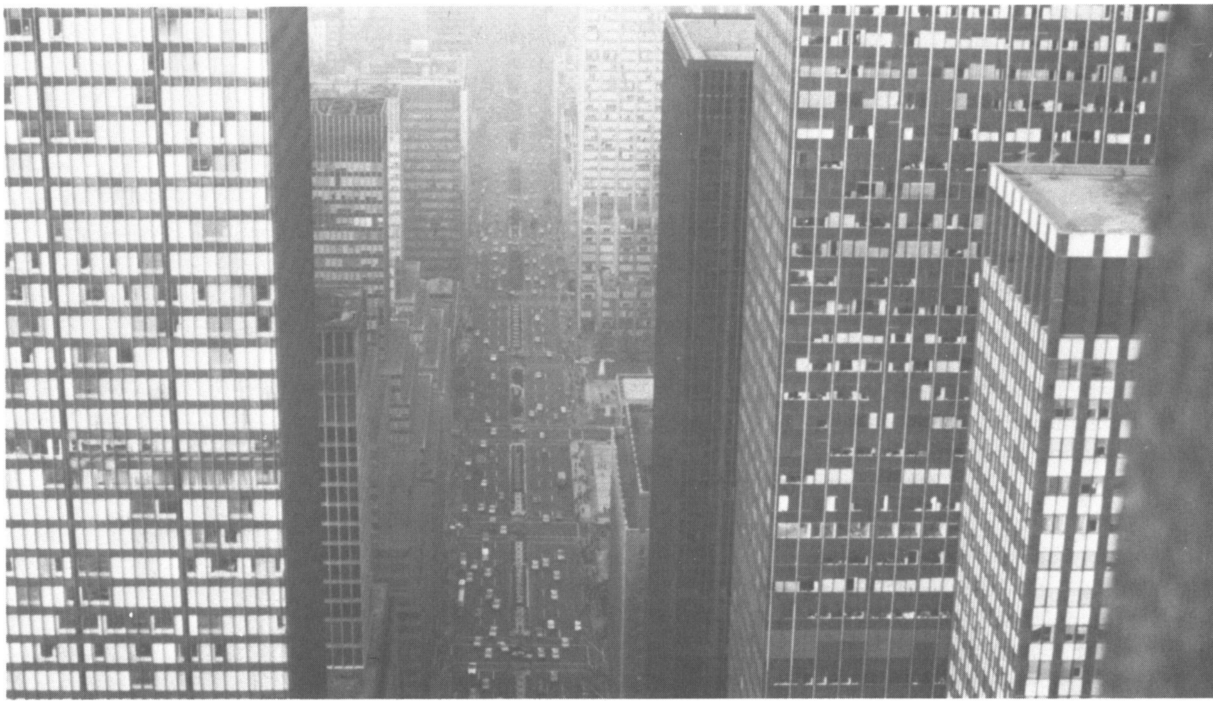
ing both the movement of cooler outside air over the city center and the evaporation process within the city.

The correlation of some pollutants and weather has been substantiated by a number of studies. Kaplin and co-workers (*20*) demonstrated a close correlation between weather and air pollution on the lower east side of Manhattan. They developed an equation for the prediction of the level of pollution (as measured by sulfur dioxide and suspended particulates) in the ambient air from meteorologic variables alone, as measured on the lower east side of Manhattan. They showed that by considering six meteorologic variables—wind velocity, pressure, surface temperature, humidity, precipitation, and atmospheric stability—they could predict the level of the aforementioned pollutants at the measuring station.

Kaplin and co-workers' results make clear the dependence of pollution on these six weather variables, and the need to use all six to predict levels of pollution with reasonable accuracy. Any attempt to separate the effects of weather variables from the effects of pollution variables on a population in a single location must find a means to take into account the intercorrelation between weather and pollution. For example, some authors have concluded that pollution correlates more highly with disease than does temperature; yet in the area of the lower east side of Manhattan at least, where the weather variables, including temperature, together closely predict the levels of some pollutants, the question of whether any or all of these six parameters have independent or synergistic effects on health must be considered unresolved.

Various safeguards have been used to insure that correlation between measured pollution and mortality or morbidity are not artifacts. Thus, statistical corrections have been introduced to eliminate seasonal effect (*2*) and the effect of the day of the week (*21*) because both air pollution and utilization of medical facilities vary with the day of the week. No study that has analyzed weather, pollution, and health jointly, however, has done full justice to the complexity of their interrelationships.

Holland and co-workers (*22*) investigated the effects of meteorologic factors on the incidence of respiratory and heart diseases; the authors used a statistical technique described by Snedecor (*23*) in 1956 which involved the fit of a mathematical formula expressing the incidence of the disease under consideration in terms of the meteorologic variables. Data for the occurrence of disease were derived from the



Smog from traffic in New York City

Emergency Bed Service of the King Edward Hospital Fund for London and from records of admission to sick quarters in the Royal Air Force. The authors concluded that they had not succeeded in separating the effects of pollution and weather. A correlation between the incidence of respiratory disease and temperature and atmospheric pollution was found for those aged 15 years and older.

Greenburg and co-workers (*1*) made an attempt to separate weather from pollution effects during a period of intense air pollution from January 29 to February 12, 1963, in New York City. During that period 809 deaths were noted in excess of the overall 15-day average number of deaths for the same periods in the 4 years, 1961, 1962, 1964, and 1965. During the 1963 episode both cold weather and influenza were prevalent as well as high levels of air pollution. To correct for the aforementioned factors, data were collected for a similar period of 15 days during 1958 when cold weather and influenza prevailed but air pollution did not.

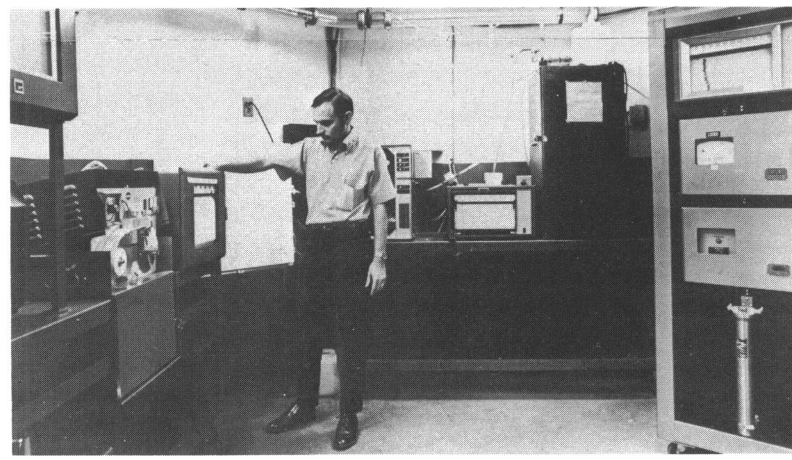
The authors calculated that the effect of air pollution could account for approximately 200 to 400 excess deaths during the critical period January 29–February 12, 1963. Temperature was the only meteorologic variable that was taken into account in this study. From Kaplin and co-workers' study (*20*), we suspect that for pollution conditions in New York City to have differed greatly under the same temperature conditions during the two periods in 1958 and 1963 compared by Greenburg and co-workers, other meteorologic variables, such as windspeed and wind direction, must have differed too; however, their independent effect on mortality was not considered.

Hodgson (*3*) used multiple regression to obtain a quantitative estimate of the relationship between mortality and certain environmental factors for November 1962–May 1965 in New York City. Mortality from heart and respiratory diseases was significantly related to environmental conditions over time, especially air pollution (particulate matter) and temperature (degree days). (The number of degree days Q is defined as the magnitude of difference between mean daily temperature Tm and 65° when the daily temperature is below 65° F. (*24*); that is, $Q = 65 - Tm$.) Seventy-three percent of the variation in mortality from heart and respiratory diseases could be accounted for by the concurrent variation in air pollution and temperature, with pollution being more useful in predicting mortality. Only one of the meteorologic variables that might affect health was weighed.

In summary, in a city like New York, whose pollution (in terms of SO_2, particulates, and smokeshade) comes mainly from domestic sources and powerplants serving them, one would expect that the main temporal variables affecting the concentration of these pollutants in the ambient air are the meteorologic forces determining the rate and amount of dissemination and emission of these pollutants.

The level of pollution in the atmosphere depends mainly on two factors: (*a*) the amount of emission of pollutants from their various sources and (*b*) the rate of dissemination of these pollutants from the atmosphere into which they are emitted.

Both these factors are heavily dependent on weather conditions, especially in nonindustrial urban environments such as New York City. The amount of power and fuel that is consumed depends on temperature in a complex way. For example, in the winter the lower temperatures require more fuel for heating, and in the summer the higher temperatures require more fuel for air conditioning. The rate of dissemination of the emitted pollutants again depends on weather factors such as windspeed and temperature.



All photos from New York City Department of Air Resources

Above, pollutants darken New York City's atmosphere. Below, instruments record smokeshade, sulfur dioxide, and carbon monoxide

The Temporospatial Strategy

The previous discussion and quotations from the literature reinforce Goldsmith's (*10*) statement in 1969:

> When pollution factors are confounded by weather or other trends, the comparison of the experience in two different areas differing in their pollution experience over time through the period in which the trend phenomena are likely to occur is the only reasonably valid way to draw an epidemiologic conclusion. This we call the temporospatial strategy; a two-dimensioned approach. To make comparisons between two areas at the same time and one area over different times is increasingly recognized as unsatisfactory.

The necessity for using multiple sites to measure the pollution in a large city that the population is exposed to and the inadequacy of many of the current methods used at this time were described by Corn (*25*).

That air pollution in New York City, as an example, is not distributed uniformly can be seen by studying the data on air pollution. These data are obtained by monitoring various pollutants through a network of 40 stations. To consider New York City as a candidate for the temporospatial strategy, two areas of the city similar in their demographic and social makeup and with similar weather conditions, but differing in their levels of air pollution, can be compared to monitor the separate effects of air pollution and weather on health.

Such a comparison between Harlem in Manhattan and Bedford-Stuyvesant in Brooklyn is now being undertaken by the Air Pollution Epidemiologic Research Unit at the Columbia University School of Public Health and Administrative Medicine. Data are being gathered on the daily frequency of emergency room visits of persons whose diagnosed ailments are assumed to be affected by air pollution. This information is being collected at five major hospitals in the Harlem and Bedford-Stuyvesant areas for a 3-year period, and it will be correlated with daily levels of air pollution measured in these areas and with several weather variables.

Conclusion

The evidence that weather affects health seems to be as reliable and voluminous as the evidence that air pollution affects health. The effect of weather on health has not been effectively separated from that of air pollution, and the effects are unlikely to be separated by many of the approaches previously used, in particular, by a study restricted to a single area. Further, one cannot study the independent effect on health of either air pollution or weather in two areas unless one hypothetical causal variable varies and the other can be controlled.

In the temporospatial approach, areas within cities with similar weather conditions and with similar social and demographic characteristics but different exposures to air pollution are compared. This comparison is seen as the most promising approach to the problem of answering these basic questions:

1. Does air pollution affect health?
2. Does weather affect health?
3. Do weather and air pollution have a synergistic action on health?

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