# Meteorological Aspects of Large Scale Air Pollution

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THE practicing weather forecaster cares very little about the composition of the air aside from its water vapor content. But we are beginning to realize that there is more to meteorology than advising the public whether or not it will rain tomorrow. We live in the atmosphere and it is important that we keep it as clean as possible. Man's dispersal of wastes into the air has become so enormous that in certain areas, particularly urban ones like Los Angeles, the atmosphere is at times incapable of providing adequate local dilution.

Though pollution by cities of their own immediate locality is a major concern, we should keep in mind that most pollutants are not destroyed by disposing of them downwind of a city. Under some circumstances, the pollutants of many cities combine and affect areas far removed from the sources of pollution. Ultimately, if the exponential growth of industry with its waste disposal problems continues, contamination may become global, making further dilution impossible. When pollution becomes a worldwide problem, the allowable releases will depend on the atmosphere's cleansing ability.

The consequences of air pollution reach beyond immediate effects such as damage to health and agriculture. They affect the weather as well. There is strong evidence that increased atmospheric contamination reduces visibility and modifies electrical conductivity, precipitation, and the radiation balance. What subtle and far-reaching effects will result from these and other phenomena are now unknown.

Our present aims in studying the meteorology of air pollution are measurement, understanding, and prediction. Unfortunately, none of these reduces the amount of pollutant put into the atmosphere. But through the proper selection of industrial sites, local contamination can be minimized; through meteorological detective work, an offending culprit can be uncovered; and through forecasting, pollutants can, in principle, be withheld pending a return to conditions more conducive to dilution.

The major effort in meteorological research of air pollution is on a microscale—citywide contamination. At present, a meteorological analysis is considered successful if a way is found for the pollutants to be vented into the atmosphere without local difficulties. By the time the effluent reaches the next city, diffusion is expected to reduce concentrations to a satisfactory level. But there are exceptions even today. For example, Dr. C. D. Keeling of the Scripps Institution of Oceanography at La Jolla, Calif., almost 100 miles south of Los Angeles, says that he has often watched the carbon dioxide concentration rise from 310 to 340 ppm as a brown cloud from the north descends on his observation post. Similarly, it has been estimated that 15 percent of the organic partic-

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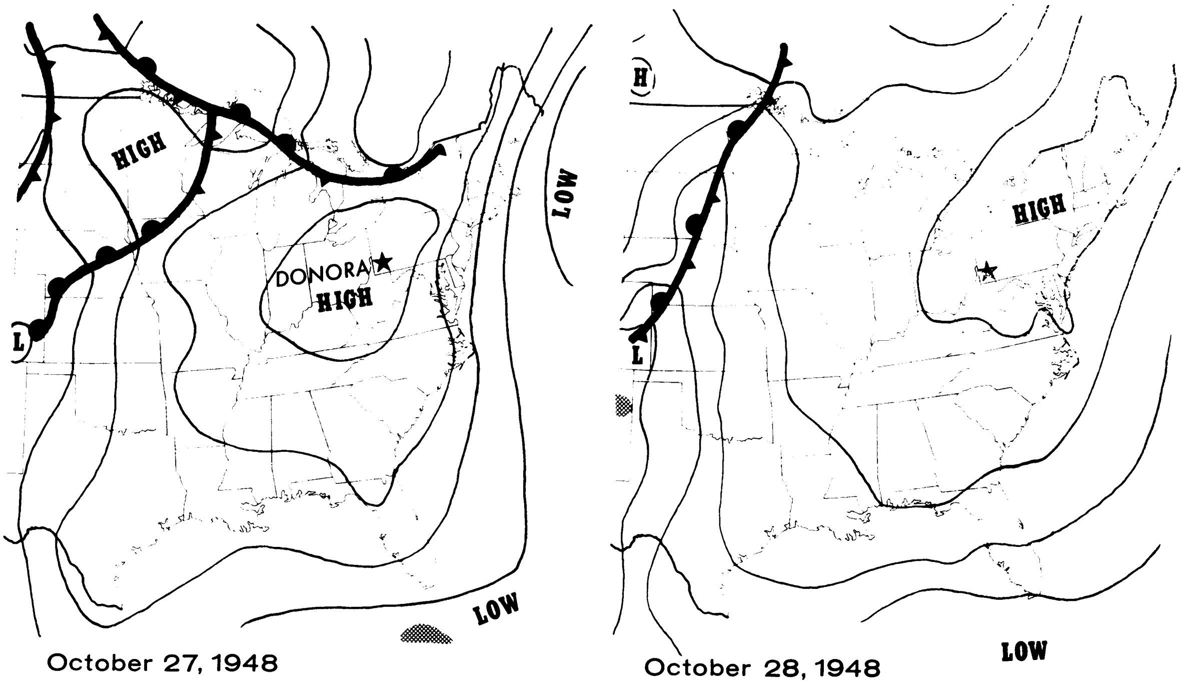
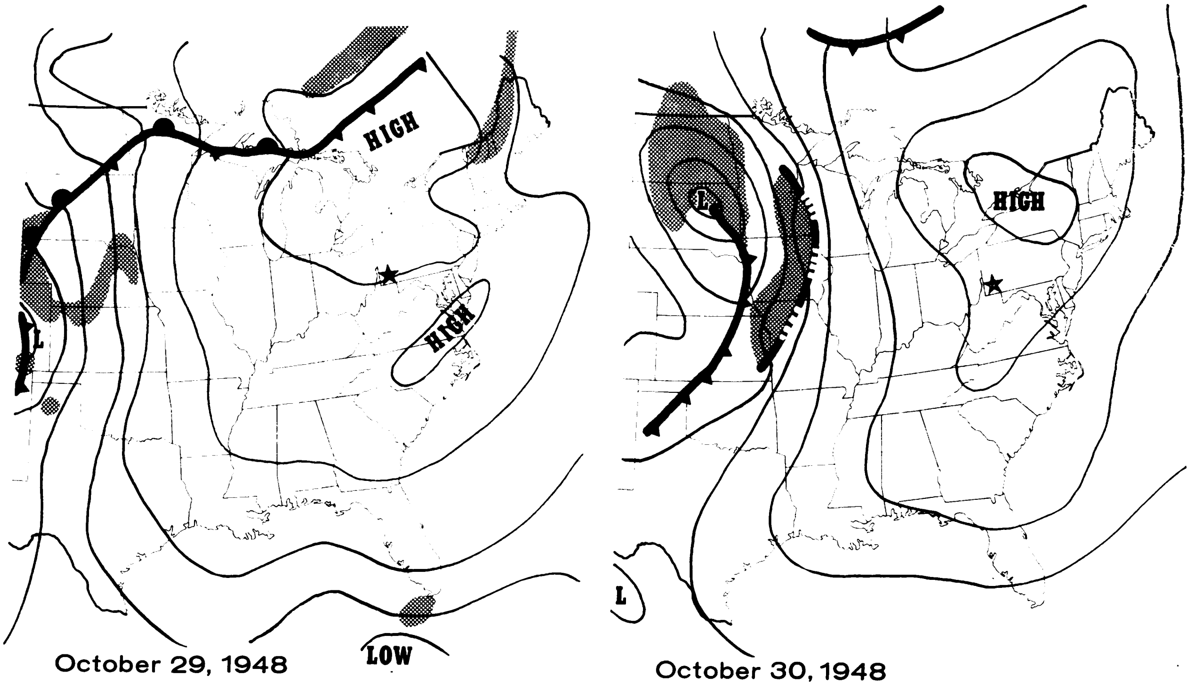
**Figure 1. Surface weather charts for October 27–30, 1948, during the air pollution episode at Donora, Pa.**



October 27, 1948

October 28, 1948



October 29, 1948

October 30, 1948

ulates measured at Louisville, Ky., originate outside the area of Greater Louisville.

The areawide air pollution problem will be with us in the near future, if it is not here today. Meteorological study of this larger problem has so far succeeded in identifying the weather conditions conducive to large-scale air pollution episodes and confirming the relation between these conditions and high concentrations of pollutants.

## The Warm High

We think there are three weather factors which favor air pollution episodes on a broad scale: first, small dilution due to light winds and a low altitude thermal inversion which inhibits upward mixing; second, the absence of rain scavenging; and third, the persistence of this weather for several days, permitting pollutants to accumulate.

This weather fits the description of a warm high-pressure system. It is entitled a "warm" high because, unlike a polar mound of high pressure, the air within it is warm in comparison to the surrounding atmosphere. Insofar as I am aware, every important air pollution episode, Donora, London, and Meuse Valley has occurred during the passage of a warm high-pressure system. In Los Angeles, episodes coincide with this weather system, but other meteorological and topographical factors are also important. Orographic features and sources of pollutants determine where and when an episode will occur during the presence of a warm high-pressure system.

We can illustrate the significant factors with surface weather maps which are typical of a slow-moving warm high. Figure 1 shows the surface weather charts during 4 successive days of the well-known episode at Donora, Pa., in October 1948. The thin lines are isobars. The heavy lines mark the separation between warm and cool air masses. Shaded areas show regions of rain. A center of high pressure on the first day of the series is in southern Ohio. On successive days it moves erratically over the eastern United States, a typical situation.

The speed of wind at ground level and in the first few thousand feet of air is more or less inversely proportional to the spacing of the isobars. From these maps it is evident, first, that the weak pressure gradient associated with the wide spacing of the isobars in the region around the center of high pressure results in very light winds. Local ventilation is severely restricted by this condition. Second, the air mass making up the high pressure is sinking. The result is a low-level thermal inversion, with a base at about 3,000 feet in the afternoon and lower at other times. This inversion acts like a lid, preventing upward mixing. Because of clear skies the nocturnal outgoing radiation is intense, building up a very strong nighttime ground thermal inversion which likewise inhibits vertical mixing. In the London and Donora episodes, the air cooled enough to produce fogs which could not be burned off by the daytime solar heating.

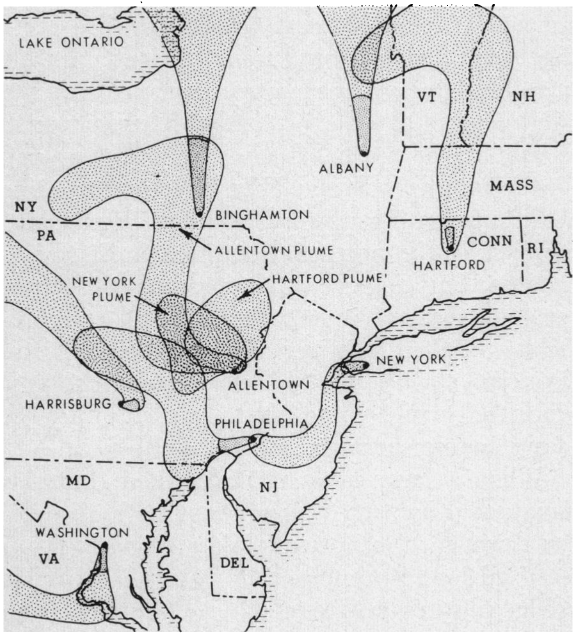
When a large area of the United States is dominated by such a slowly moving high-pressure system, the normal, fairly rapid west-to-east airflow is replaced by air which drifts about slowly and irregularly. Pollutants from one city are more likely to be added to those of another in appreciable concentrations. The absence of vertical mixing confines all of the contamination to the layer of air near the ground.

In a study of potential atmospheric contamination from nuclear reactors, Pack and Hosler (*1*) have analyzed the effects of a stagnant meteorological pattern upon atmospheric dilution over the densely populated and industrialized Middle Atlantic States. To do so, they determined the spread of effluents if they were released continuously for a 36-hour period from eight hypothetical locations during an actual stagnant weather system.

They selected a slowly moving weather system that occurred October 11–16, 1956. During all 5 days of this weather pattern, a warm high-pressure system was quasi-stationary over the Middle Atlantic States. The system was attended by light winds at the surface and the first few thousand feet above the ground. An intensifying subsidence inversion, based at about 3,000 feet, accompanied the high-pressure cell, while ground thermal inversions prevailed during nocturnal hours.

Pack and Hosler's analysis, illustrated in figure 2, is based on the following assumptions:

**Figure 2. Plumes of effluents which would be created by 36 hours' continuous release from 8 locations under the weather conditions of October 12–13, 1956**



(*a*) effluent is carried at the speed and direction of the surface wind; (*b*) the plume diffuses 11° laterally in each 6 hours of movement; (*c*) vertical spreading of the plume is limited to within the mixing layer, that is, the estimated depth of the well-stirred lower atmosphere at the time of maximum afternoon temperature; and (*d*) effluent is uniformly distributed within the volume defined by the first three assumptions, except for the material dispersed during the most recent 6-hour period, which maintains a separate and distinct geometry of distribution.

In figure 2, the shading for the most recent 6-hour plume traverse is more intense to distinguish it from the older, more dilute cloud of effluent. The irregular paths are apparent; more important, this diagram illustrates the reinforcement of several plumes from many sources as a result of time and space variations. For instance, effluents from New York, Hartford, Philadelphia, and Allentown all contribute to pollution of the area just west of Allentown, Pa.

It is possible to compute average concentrations of pollutants for this model, since the volume of air in the plumes can be readily estimated. By Pack and Hosler's calculations, $5\times10^{12}$ cubic meters is the minimum volume of air into which the effluent in a single plume would be released in a 36-hour period. If 10,000 tons of carbon monoxide—the amount released in Los Angeles in 2 days—were diffused in a 48-hour plume, an average concentration of 1 ppm would blanket the area over which the plume extended.

Finally, the hypothetical situation depicted by Pack and Hosler accounts for the movement and overlapping of effluents from only eight locations in the Middle Atlantic States. It underestimates the actual cases of overlap, since there are many additional sources of pollution in this heavily industrialized area.

## Forecasting Episodes

In 1957, an experimental program was established to associate predictions of stagnant warm high-pressure systems with measurements of pollutant concentrations. One objective of the program is to make sure that the stagnant warm high-pressure system is the one to which meteorologists should direct their attention.

Techniques developed under the program were applied to the eastern United States in a study covering the period September 1 through November 15, 1958. The weather criteria which had to be met in order to predict a potential for above-normal accumulation of pollutant were:

1. Surface winds of less than 8 knots.
2. Windspeeds no greater than 25 knots at any level below 20,000 feet.
3. Evidence of sinking motion at levels below 15,000 feet.
4. Continuation of the preceding three conditions for at least 36 hours.

Air quality data were collected from the study area by stations of the National Air Sampling Network. Niemeyer (*2*) showed from examination of the data that, with few exceptions, highest dust loadings occurred during the five periods when warm high-pressure systems were predicted to, and subsequently did, overlay the area. This experiment demonstrated that it is feasible to use forecasts of large-scale weather features to delineate periods of high air pollution potential over large areas.

### Radon

Radon is a naturally occurring radioactive gas which is emitted from the ground. It has been amply demonstrated that ground-level radon concentration increases remarkably when atmospheric vertical mixing becomes weak. For example, nighttime ground-level concentrations are higher than daytime concentrations.

We have also studied radon concentration during the passage of a slow-moving warm high-pressure system. The system we selected occurred in Washington, D.C., in late October 1954. Through the courtesy of Dr. Luther Lockhart of the Naval Research Laboratory, the measurements of radon concentration in Washington recorded for that time were made available to us.

Figure 3 shows the average diurnal cycles of radon concentration in Washington before, during, and after passage of the warm high, or stagnation period, of late October 1954. Average windspeed during the 89 hours of stagnation was only 4.7 knots. It is apparent from the figure that significantly higher radon concentration occurred while the warm, stagnant high lay over Washington than either before or after its passage. The shaded area identified by "poor data" corresponds to the period of the daily filter changes when the radon decay products were not yet in equilibrium.

**Figure 3. Average diurnal cycles of radon concentration in Washington, D.C., before, during, and after passage of a stagnant warm high-pressure system, October 1954**

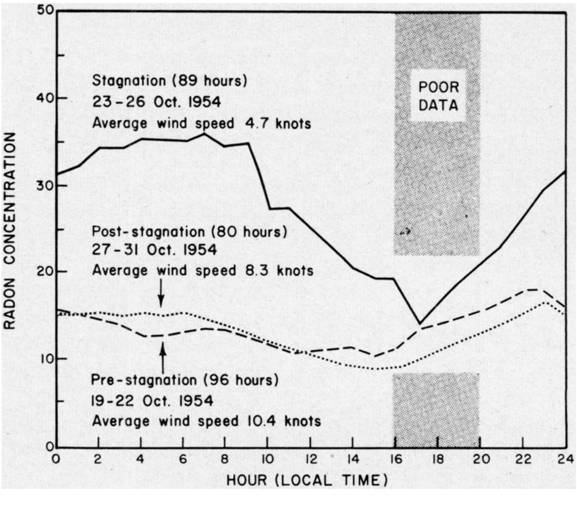
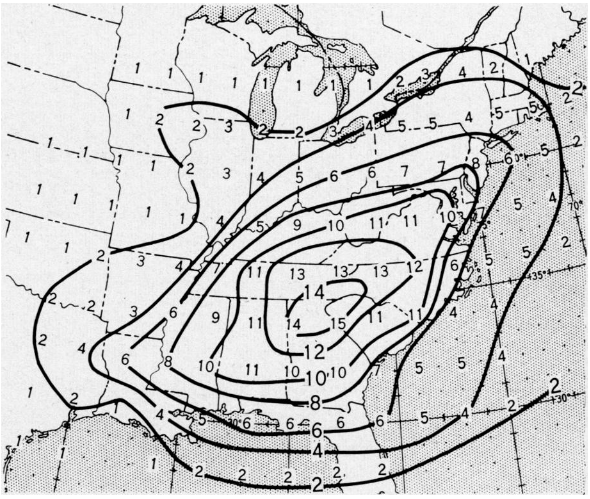


**Figure 4. Occurrences of stagnant warm high-pressure systems during the month of October, 1936–1956**



Further study of radon observations may reveal other applications for this type of data to air pollution problems.

### Geographic Frequency Distribution

Korshover (*3*) has studied the spatial and temporal frequency distribution of stagnant warm high-pressure systems for the United States east of the Rockies. The maximum frequency occurs in the southern Appalachian Mountains and decreases radially from this area. Analysis of cases by months reveals a pronounced maximum frequency in the month of October.

Geographic distribution of the frequency of October stagnant warm highs is shown in figure 4. The numbers on the figure denote the frequency during a 21-year period of cases with 4 or more successive days of light winds (under 8 miles an hour). The heavy lines indicate equal frequency of occurrence. This October weather coincides with pleasurable memories of Indian summer, a period of unusually fine weather after the heat of real summer has waned.

It may be surprising to note the high frequency of cases, even in winter, when warm high-pressure systems cover the southeastern United States. Some of these instances result from extension of the Bermuda high-pressure cell onshore, much farther west than its normal position. It seems probable that with equal industrialization, air pollution complaints would be more numerous in the Southeast than, say, in New England with its stormier weather.

### Conclusion

I have described some meteorological aspects of large-scale air pollution, a problem almost certain to become aggravated in the future. The best way of avoiding air pollution episodes is by preventing dispersion of wastes into the atmosphere. Failing that, there are two ways the meteorologist can assist: first, along with health officials, he can monitor the atmosphere's cleanliness. Second, he can continue his efforts to devise adequate methods for predicting the dilution, transport, and removal properties of the atmosphere in case meteorological control becomes necessary—that is, permitting the release of pollutants only at times when weather conditions favorable to dilution have been forecast.

I suspect that in many ways the meteorologist is ahead of others in working on problems in this broader scale of air pollution.

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