6.7 AN AIR POLLUTION EPISODE: DONORA, 1948

Factors of meso- and micrometeorology have on occasion hindered atmospheric mixing to such an extent that episodes of severe air pollution have been experienced. An episode in Donora, Pennsylvania, in 1948 is an example. A five-day period of near-stagnation brought on such aggravated conditions that 17 deaths occurred within a 14-hour period, when only one death might have been expected under ordinary circumstances. This was the first clear instance in the United States of air pollution exacting a toll in epidemic proportions.

The episode at Donora began on Tuesday, October 26, when an east coast storm was replaced by a cold anticyclone advancing from the southwest. A cold ground intensified the elevated inversion of the anticyclone as it moved in. And then the high-pressure region stagnated over western Pennsylvania for five days until Sunday, October 31, at which time it took up its movement toward the northeast and the episode ended. During the period of stagnation, the anticyclone moved only a few hundred kilometers, and the elevated inversion layer extended over a large portion of Pennsylvania and neighboring states, as shown on the weather map in Fig. 6.8. Winds were gentle, as indicated by the wide spacing between the isobars.

Yet only the inhabitants in the immediate area of Donora experienced an abnormally high rate of morbidity and mortality. None of the other cities in western Pennsylvania, many of which were in approximately similar geographical

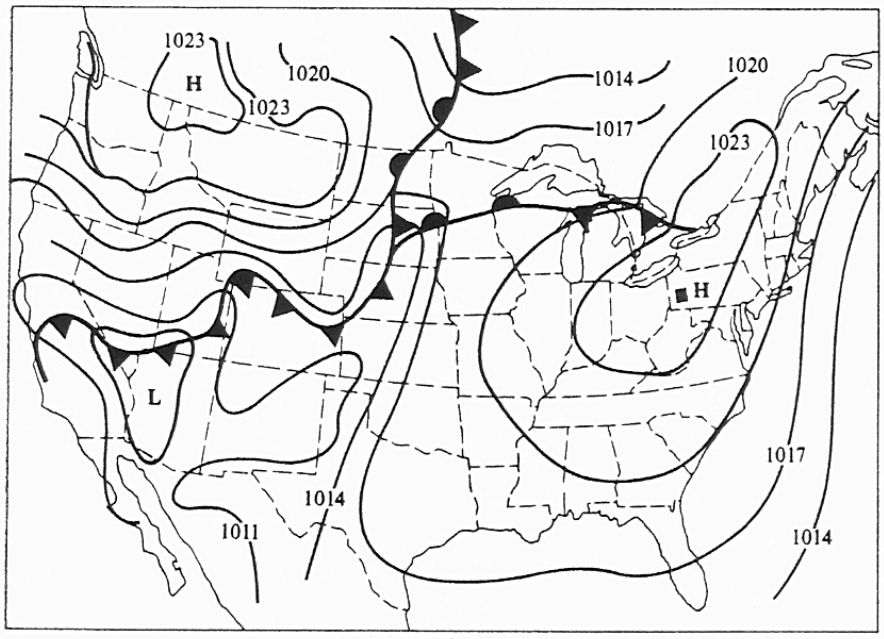

Fig. 6.8 Anticyclone stagnating over northeastern United States on October 26, 1948. The location of Donora is marked by the square. Pressures along the isobars are given in millibars.

locations, suffered similar fates. Clearly the poor ventilation was aggravated by local conditions of meteorology and pollutant emissions. Yet the 1948 episode was an unusual situation, because on at least two previous occasions Donora had been subjected to stagnating anticyclones for longer than a week, with no remarkable toll of life.

Perhaps the best way to convey a sense of what happened is to quote a portion of the description by Berton Roueché[11] based on eye-witness accounts:

> The fog closed over Donora on the morning of Tuesday, October 26. The weather was raw, cloudy and dead calm, and it stayed that way as the fog piled up all that day and the next. By Thursday, it had stiffened adhesively into a motionless clot of smoke. That afternoon it was just possible to see across the street, and except for the stacks, the mills had vanished. The air began to have a sickening smell, almost a taste. It was the bittersweet reek of sulfur dioxide. Everyone who was out that day remarked on it, but no one was much concerned. The smell of sulfur dioxide, a scratchy gas given off by burning coal and melting ore, is a normal concomitant of any durable fog in Donora. This time it merely seemed more penetrating than usual.

And the fog with its burden of pollutants did not lift for many days. The extreme persistence of conditions and atmospheric stability were largely results of the peculiar terrain and micrometeorology.

The city of Donora is located in the valley of the Monongahela River some 50 km south of Pittsburgh. About 14,000 people lived on the west bank, inside a horseshoe bend of the river. Another 1000 people lived in the village of Webster on the opposite bank, on the outside of the bend. The slopes of the valley rise sharply upward to a height of about 100 m to the east of Webster; on the west of Donora, the rise is more gentle and leads on to rolling hills. The bottom land thus forms a drainage basin for cold downslope winds at night. At the time of the episode, the ground-based inversions were strengthened by radiational cooling of the valley floor, and together they could produce a strong temperature inversion with a temperature gradient as high as 33°C/km, as has been measured on subsequent occasions.[12]

As night fell on October 25 and the ground cooled, the high relative humidity resulting from the previous storms quickly led to a saturated condition within the lower region of the cold anticyclone. The subsequent condensation caused extensive fog over western Pennsylvania. This condition was especially pronounced in the river valleys like that at Donora, where evaporation sustained the high humidity and a high aerosol concentration in the polluted air encouraged the formation of numerous water droplets. The fog was held close to the ground by the stability of the elevated inversion layer.

Under these circumstances, the fog absorbed all of the earth's thermal radiation close to the ground and prohibited further development of a ground-based radiational inversion. However, the upper layers of the fog continued to radiate their energy into the air and thus continued to cool. Such cooling is observed also in the upper layers of elevated stratus clouds; as a result one finds there

additional condensation and a higher content of water, amounting to as much as 0.5 g/m^3.[13] In elevated clouds the distribution of droplet sizes peaks at about 7 microns radius, which is similar to the size found in many fogs. As the top layer of a fog cools, the temperature profile below changes toward a more unstable condition. Since the air is saturated, an unstable lapse rate will exist if the decrease in temperature with height is greater than the wet adiabatic lapse rate of about 6°C/km. Thus at night there may be general mixing of pollutants within a fog as the cold, denser upper layers subside and are replaced with warmer air from below. But because the upper layer of the fog is cooling with respect to the overlying clear air, an elevated inversion is formed, as illustrated in Fig. 6.9(a). This stable layer acts as a blanket to confine the fog and its burden of pollutants.

Usually the fog lifts after sunrise when solar radiation penetrates to warm the ground, and the upward convection of sensible heat breaks the inversion. However this did not occur on October 26, because the fog was too dense and deep; the upper layers reflected most of the solar energy. The albedo of a stratus cloud such as fog depends upon its thickness, and some measurements indicate it may vary from 40% for a 150 m thickness to 80% for a 500 m thickness. In elevated clouds, very little radiation is absorbed, perhaps as little as 7% for thick clouds.[13] And most of this is absorbed in the upper layers. Thus if there is any appreciable warming it occurs in the upper layers of the fog, with the result that the stability of the air within the fog is increased. This is illustrated in Fig. 6.9(b). The delay in heating the ground, accompanied by stable lapse rate, discourages upward convection of energy which would otherwise serve to warm the air and evaporate fog droplets. Thus the fog is perpetuated if it is sufficiently dense and thick, as occurred in Donora. Furthermore, the daytime stability within the fog led to an accumulation of air pollutants.

Within the interior of the fog-bound valley, pollutants continued to be emitted. The economic life of the communities was centered around employment

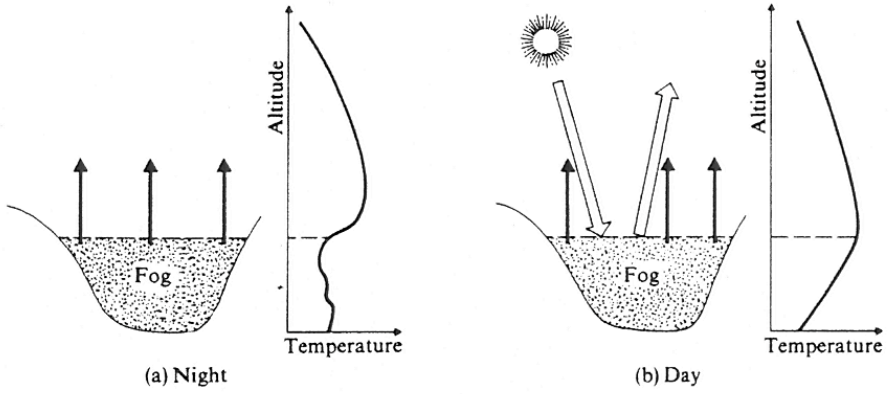

Fig. 6.9 Representative temperature profiles for a fog-filled valley (a) at night and (b) in the daytime. Broad arrows indicate solar radiation, and thin arrows thermal radiation from the upper layer of the fog.

at a large steel and wire mill, a zinc plant, and an accompanying sulfuric acid plant. Approximately 3000 people worked at these river-front establishments. The bulk of the fumes and particles from these plants was released from exhaust stacks of various heights, none exceeding 40 m. The zinc plant processed zinc sulfide ores by roasting in order to replace the sulfur by oxygen. Sulfur dioxide is a byproduct of the process and some of it was collected and further oxidized to form sulfuric acid for commercial sale. Great quantities of sulfur dioxide and particulate matter were emitted as pollutants, including substantial quantities of zinc, lead, and cadmium. Emissions from the steel mill, especially from the blast furnaces and open hearth furnaces, consisted mainly of sulfur dioxide and particulate matter. Domestic use of soft coal for space heating added to the atmospheric burden of carbon monoxide, particulate matter, and sulfur dioxide, although the daily amount of the latter was only about a quarter of the amount emitted by the zinc plant.

During the third and fourth days of the episode, as ambient concentrations of pollutants escalated, a large fraction of the population became ill. No measurements of ambient levels of pollution were taken during the episode, but a lower limit is suggested by levels monitored during a brief period of stagnation from April 20 to 21, 1949, during which however no marked increase in mortality occurred. During this latter period the mass concentration of particulate matter reached 4 mg/m^3 and the sulfur dioxide concentration 0.5 ppm.

The climax of the episode came on Saturday, October 30 when the atmospheric stability intensified. Seventeen deaths were recorded that day and two more the next. These were exclusively people over 52 years of age, many of whom had a history of cardiac or respiratory disease. During the entire episode, some 43% of the population experienced some effects from the smog. Others seemed hardly to be bothered, and a few were even unaware of the extent of the illness among the population. Of the sufferers, 17% of the population were moderately affected and 10% severely affected. The susceptibility of older people is indicated by the fact that of the group 60 years and older, a much larger percentage of about 29% suffered severely. Also, of the 50 persons who were hospitalized, more than two-thirds were over 55 years old. Most of the affected, some 90%, complained of upper respiratory symptoms such as nasal discharge, constriction of the throat, or sore throat. Some 87% reported symptoms that affected the lung.

Subsequent epidemiologic studies have shown that the incidence of illness, especially severe illness, was highest in Webster to the east and across the river from the steel mill and zinc plant. Furthermore the death rate in Webster was 6.6 per thousand, whereas for Donora it was only 0.9 per thousand, a discrepancy which can be accounted for by neither age nor state of health. The reason for this is not known with certainty. Perhaps it resulted from the prevailing northwest winds each morning, blowing at about 5 km/hr, which carried the effluent from the zinc plant over the river and directly into the town. Early mornings were a period of especially pronounced stability, a result of the nighttime drainage winds from the hillsides. Furthermore a portion of the town of Webster is on the