Photochemical Air Pollution: Transport from the New York City Area into Connecticut and Massachusetts

Abstract. *Photochemical air pollution resulting from primary emissions in the New York City metropolitan area is transported by prevailing winds on a 300-kilometer northeast trajectory through Connecticut and as far as northeastern Massachusetts. As a result, southwestern Connecticut has the highest ozone concentrations in the region and there is a substantial increase in ozone concentrations in Massachusetts. The ozone concentrations of air entering the New York City metropolitan area are often already above the federal standard of 0.08 part per million, but the concentration distribution is well below concentration distributions at downwind sites in Connecticut.*

We conducted a study of the transport of photochemical air pollution in the region of the northeastern United States covering eastern New York, northern New Jersey, Connecticut, and Massachusetts between 1 May 1974 and 30 September 1974. This study was conducted by means of an analysis of ground-level ozone measurements at 32 sites along a corridor from New York City to Boston and the following meteorological information: surface wind speed and direction from six sites, wind speed and direction at eight heights from ground level to 700 mbar at two sites, and forward trajectories every 6 hours from New York City based on the use of wind velocities between 0 and 1500 m. The ozone data (monitoring sites are shown in Fig. 1) were provided by the air pollution agencies of the four states and the Boyce Thompson Institute, Yonkers, New York (*1*). The meteorological measurements were provided by the National Weather Service, National Oceanic and Atmospheric Administration. The air parcel trajectories were calculated with the use of the trajectory model of the Air Resources Laboratory, Environmental Research Laboratories, National Oceanic and Atmospheric Administration (*2*).

An inventory (*3*) of the emissions of hydrocarbons and oxides of nitrogen in each state's portion of the various air quality control regions shows a very high level of emissions in the New York and New Jersey portion of the New York City metropolitan area, which is 16 percent of the total area of eastern New York, northern New Jersey, Connecticut, and Massachusetts, but which accounts for 59 percent of the emissions of hydrocarbons and 50 percent of the emissions of oxides of nitrogen. An important question thus concerns the direction of movement of air from the New York City area with this high concentration of primary pollutants. For the months June through August 1974 we investigated this direction of movement through analyses of the forward air parcel trajectories calculated from the trajectory model. These calculations show that 60 percent of the flows from the New York area are in the directions northeast, east, and southeast, and 25 percent of the flows are in the northeast direction. Cleveland *et al.* have shown (*1*) that the highest ozone concentrations in New Jersey, New York, Connecticut, and Massachusetts are in the Greenwich-Stamford area of southwestern Connecticut, 43 km northeast of New York City. Thus the data on emissions, prevailing wind, and ozone concentrations strongly suggest that emissions in the New York City metropolitan area are responsible for the high concentrations of ozone in southwestern Connecticut. This delay in the photochemical generation of ozone is wholly in keeping with results in the Los Angeles Basin, where ozone concentrations increase with the movement of the air mass from areas of strong source emissions (*4, 5*).

To substantiate this claim of transport from the New York City region and to investigate its scope, we plotted daily maximum ozone concentrations from 0800 to 2400 hours for each of the 32 sites against wind directions (the direction from which the wind is blowing, with 0° as north and 180° as south) for a subset of days from May to September 1974. Four of these plots are shown in Fig. 2. Since days with low temperatures have conditions that are not conducive to photochemical production of ozone in this region (*6*), only those days are included for which the daily maximum temperature in Hartford, Connecticut (approximately in the center of the region), is above 21°C. In order to eliminate days with highly variable winds, days for which the ratio of the resultant wind speed to the average wind speed at the designated hours is below 0.9 have been discarded. As an aid in summarizing the dependence of the ozone concentrations on wind direction, curves of moving statistics have been superimposed according to the method of Cleveland and Kleiner (*7*). For a given wind direction the value of the middle curve in Fig. 2 summarizes the middle of the ozone concentration distribution; the upper curve summarizes the upper tail of the distribution, and the lower curve, the lower tail. In addition, three vertical lines have been drawn on each plot in Fig. 2 to indicate the direction of the New York City metropolitan area from each site. The two outer lines on each plot show the directions of the two tangent lines from the site to a convex polygon covering the major portion of the New York City metropolitan area. The middle line shows the direction from the site to Central Park, New York City.

The resultant directions of the surface wind velocities for 1000 and 1300 hours at Newark Airport are used in the four plots in Fig. 2, since Newark is an inland site which does not display persistent local anomalies and which appears to perform quite well in characterizing general air flow. The times of day of the wind measurements were chosen to be commensurate with the times of day of photochemical activity.

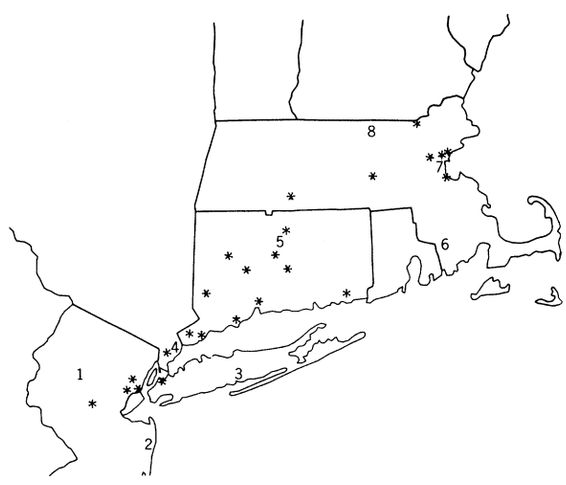

Fig. 1. Location of ozone monitoring sites are identified either by numbers or by stars. Specific sites are as follows: *1*, Chester; *2*, Asbury Park; *3*, Babylon; *4*, Mamaroneck; *5*, Hartford; *6*, Fall River; *7*, Boston; and *8*, Fitchburg.

The general conclusions from all of the ozone–wind direction plots are that those sites which lie in locations that are outside the New York City metropolitan area and that prevailing winds would reach after crossing the New York City area show a clearly defined increase in ozone concentrations when the air is flowing from the New York City area to the sites. With southwest winds, a

very substantial increase in ozone occurs in Connecticut and a moderate increase occurs in eastern and central Massachusetts. Asbury Park, New Jersey, which lies to the south and southeast of the New York City metropolitan area, and Babylon, New York, which lies to the east, are quite interesting since these locations also are frequently downwind of the New York City area but in directions different from the large number of sites to the northeast. The plots for Babylon and Asbury Park in Fig. 2 show clearly defined peaks when the air is flowing from the New York City area to the sites.

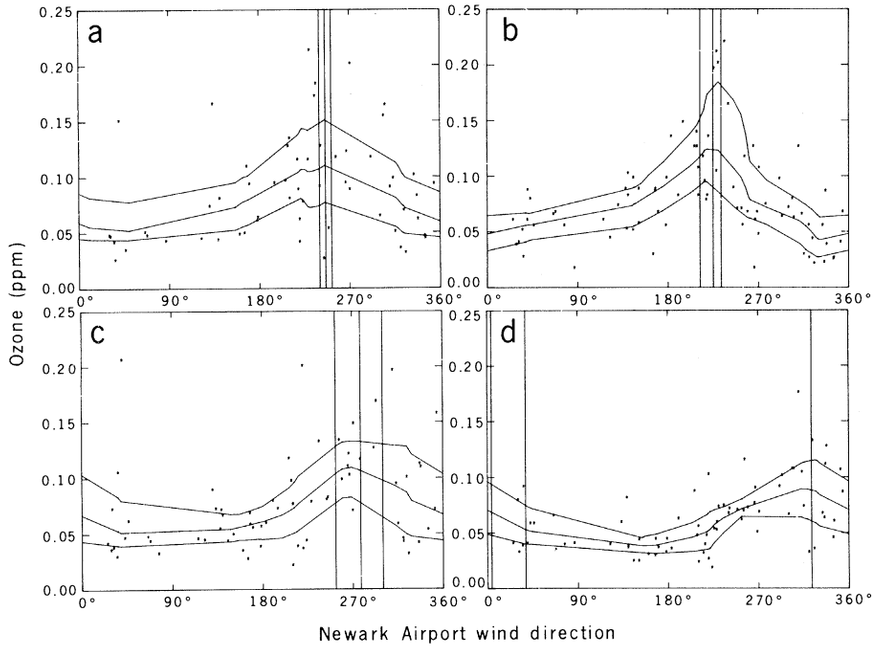

Fig. 2. Daily maximum ozone concentrations (in parts per million) for (a) Fall River, (b) Hartford, (c) Babylon, and (d) Asbury Park are plotted against wind direction (the direction from which the wind is blowing, with 0° denoting north and 180° denoting south). Curves of moving statistics are superimposed to summarize the dependence of the ozone concentrations on wind direction. The upper curve summarizes the upper tail of the distribution of ozone given wind direction, the middle curve summarizes the location of the distribution, and the lower tail summarizes the lower tail of the distribution. The three vertical lines on each plot show the direction from the site to the New York City metropolitan area.

The ozone concentrations at sites within the New York City metropolitan area and those to the southwest and west show some dependence on wind direction with a small rise with southwest winds, a phenomenon that has been pointed out by Jacobson and Salottolo (*8*). The results for the Chester site, which lies in an area of New Jersey with low primary emissions and which is infrequently downwind of the New York City area, present important information about the ozone content of air entering the New York City area. On days with southwest winds the ozone daily maxima at Chester are frequently above the federal standard of 0.08 part per million (ppm) but are considerably lower than the daily maxima at Connecticut sites. Thus, on these days the ozone content of the air entering the New York City metropolitan region is frequently above the standard but is considerably less than the ozone content of the air leaving the region and entering Connecticut.

For a large number of individual days during the sampling period the movement of photochemical air pollution from one geographical region to another was quite evident. We examine one such day here in detail. On 2 July 1974, the highest ozone concentrations at sites in the New York City area and southwestern Connecticut

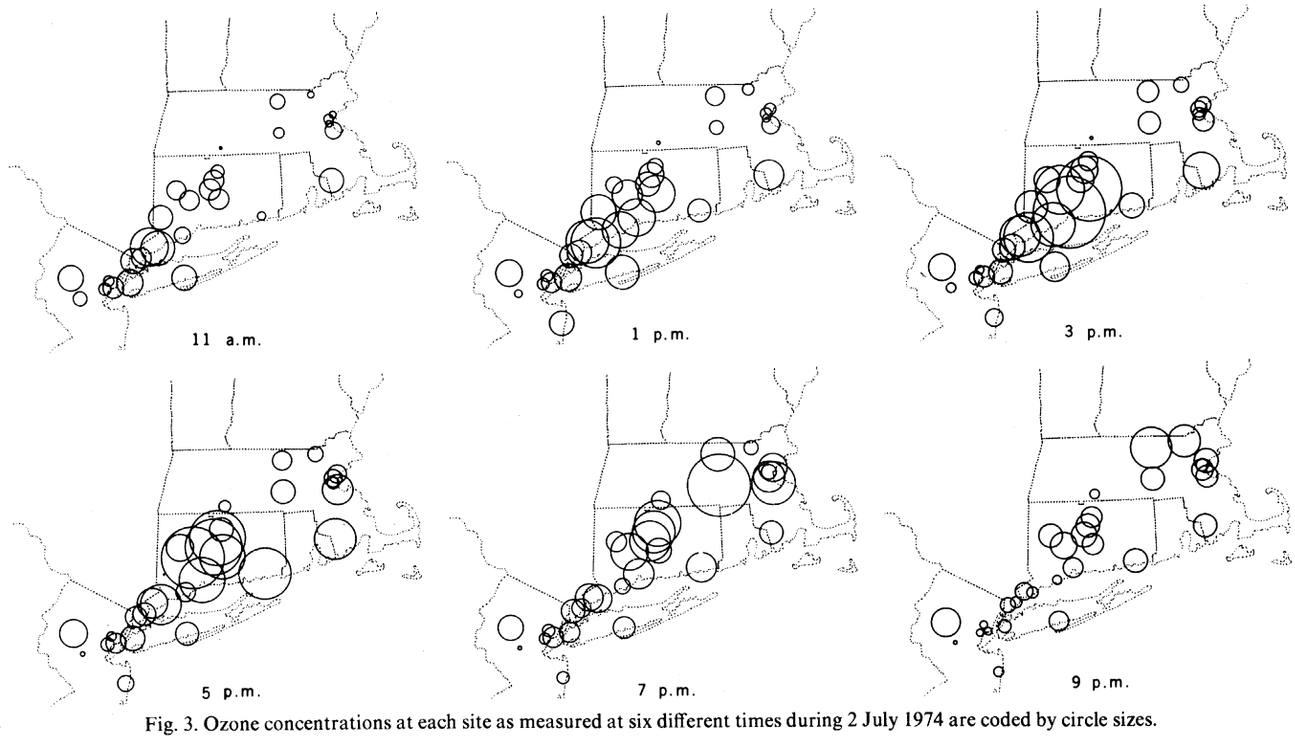

Fig. 3. Ozone concentrations at each site as measured at six different times during 2 July 1974 are coded by circle sizes.

occurred in early afternoon. The peak activity in the Hartford area was observed in the late afternoon, and the peak in Massachusetts occurred in the evening. This movement is shown in Fig. 3 where the concentrations, shown for every 2 hours from 1100 to 2100 hours, are plotted at their geographical locations with the values proportional to the diameters of the circles shown. This movement of photochemical activity is consistent with the meteorological data. The wind directions show a clearly defined air flow from southwest to northeast. The average surface wind speeds at Newark Airport and Worcester Airport from 0700 to 2200 hours were 20 and 19 km/hour, respectively. At this speed, transport from the New York area to the Boston area (approximately 300 km) would take 15 hours. However, since surface wind speeds are lower than those aloft as a result of ground friction, the transport time aloft would be less. On 2 July the wind speed aloft (950 mbar and above) at Fort Totten, New York, was 40 to 47 km/hour at 0700 hours and 36 to 43 km/hour at 1900 hours. For speeds in this range the transport time would be approximately 6 to 8 hours. These calculations are thus quite consistent with the movement of a photochemical plume starting in the morning or early afternoon in the New York City area, arriving in Hartford in the late afternoon and in the Boston area in the evening.

Additional demonstrations of the transport mechanism are discussed in detail elsewhere (*9*). In particular it is shown that there is a shift of photochemical activity to later hours of the day with increasing distance from the New York City area. With increasing distance the ozone concentrations are generally higher at night relative to those during the day, daily ozone peak values tend to occur later in the day, and the centers of gravity of ozone diurnal curves tend to show greater dependence on wind direction, shifting to later times of day in northern Connecticut and eastern Massachusetts with southwest winds.

Thus it is clear that primary emissions in the New York City metropolitan area have a substantial effect on ozone concentrations at downwind areas of Connecticut and Massachusetts. The highest ozone concentrations in the region studied are in the Greenwich-Stamford area of Connecticut, 43 km northeast of the center of the New York City metropolitan area, and the next highest are in a region to the east and northeast of Greenwich-Stamford (*1*). Values of the ozone concentration in excess of the federal standard of 0.08 ppm for hourly averages at Fitchburg and Fall River, the two sites with the highest ozone concentrations in Massachusetts (that is, the highest upper quartile of daily maxima), are frequently a result of the transport of photochemical air pollution into Massachusetts. At the Fitchburg site 66 percent of all values of the ozone concentration that are above the federal standard occurred when the wind at Worcester Airport was within 35° of the direction from Fitchburg to the New York City metropolitan region. At the Fall River site the corresponding value is also 66 percent.

On the days with southwest winds and high ozone concentrations in Connecticut, the concentration distribution at the Chester site, which lies to the west of the New York City metropolitan area and thus serves as an indicator of the ozone content of air entering the New York City area, is considerably less than those in Connecticut. However, the Chester site frequently has ozone concentrations above the federal standard. Thus, although the New York City area is substantially adding to the ozone burden of the air entering the region, it is adding to an air mass that is frequently already in excess of the federal standard.

The transport of ozone from urban areas has been discussed in a number of other publications. Cleveland and Kleiner (*10*) have demonstrated transport from the Camden-Philadelphia urban complex at distances up to 49 km. Fankhauser (*11*) has argued ozone transport from four metropolitan areas at distances up to 16 km. High ozone concentrations have been observed in rural Maryland and West Virginia, and the possibility of transport from midwestern cities has been raised (*12*). Ozone transport has been demonstrated to the Mineral King Valley of California (*13*) and out over the Pacific Ocean (*14*). In a general discussion of transport, Martinez (*15*) reports that it has been difficult in the past to substantiate ozone transport from urban areas for distances greater than 75 miles (120 km). In a recent publication Altshuller (*4*) has reported that the Los Angeles ozone plume extends at least 100 miles downwind and conjectures that "if plumes of other cities have similar dimensions, the spacing of cities in the Eastern and Mid-western U.S. is such that the plume of an upwind city could overlap a downwind urban area." The results presented here provide the strongest evidence yet in support of the validity of this conjecture.

W. S. CLEVELAND, B. KLEINER
J. E. MCRAE, J. L. WARNER
Bell Laboratories,
Murray Hill, New Jersey 07574

References and Notes

1. W. S. Cleveland, B. Kleiner, J. E. McRae, R. E. Pasceri, J. L. Warner, paper 75-51.6 presented at the annual meeting of the Air Pollution Control Association, Boston, Mass., 14 June 1975.
2. J. L. Heffter and A. D. Taylor, *Natl. Oceanic Atmos. Admin. Tech. Mem. ERL-ARL-50* (1975).
3. "1972 National Emissions Report" (Publication EPA-450/2-74-012, Environmental Protection Agency, Washington, D.C., 1974).
4. A. P. Altshuller, *J. Air Pollut. Control Assoc.* **25**, 19 (1975).
5. G. C. Tiao, G. E. P. Box, W. J. Hamming, *ibid.*, p. 260.
6. S. M. Bruntz, W. S. Cleveland, B. Kleiner, J. L. Warner, in *Symposium on Atmospheric Diffusion and Air Pollution* (American Meteorological Society, Boston, Mass., 1974), pp. 125–128.
7. W. S. Cleveland and B. Kleiner, *Technometrics* **17**, 447 (1975).
8. J. S. Jacobson and G. D. Salottolo, *Atmos. Environ.* **9**, 321 (1975).
9. W. S. Cleveland, B. Kleiner, J. E. McRae, J. L. Warner, "The analysis of ground-level ozone data from New Jersey, New York, Connecticut, and Massachusetts: Transport from the New York City metropolitan area" (Bell Laboratories technical memorandum, Murray Hill, N.J., 1975).
10. W. S. Cleveland and B. Kleiner, *Environ. Sci. Technol.* **9**, 869 (1975).
11. R. K. Fankhauser, "Ozone levels in the vicinity of 33 cities" (Environmental Protection Agency report, Research Triangle Park, N.C., 1972).
12. W. D. Bach, C. E. Decker, H. L. Hamilton, L. K. Matus, L. A. Ripperton, T. M. Royal, J. J. B. Worth, "Investigation of high ozone concentration in the vicinity of Garnett County, West Virginia" (Report of Project 410-764, Environmental Studies Center, Research Triangle Institute, Research Triangle Park, N.C., 1973).
13. R. P. Miller, M. H. McCutchan, H. P. Milligan, *Atmos. Environ.* **6**, 623 (1972).
14. H. R. Gloria *et al.*, *J. Air Pollut. Control Assoc.* **24**, 645 (1974).
15. E. L. Martinez, paper presented at the conference on Air Quality Measurements sponsored by the Southwest Section of the Air Pollution Control Association, Austin, Texas, 10–11 March 1975.
16. We are greatly indebted to R. E. Pasceri of the New Jersey Department of Environmental Protection for his advice and assistance in carrying out the research reported here and to R. Draxler and J. L. Heffter for their assistance in obtaining the air parcel trajectories.

23 July 1975; revised 3 November 1975

Plant Desiccation: Polysome Loss Not Due to Ribonuclease

Abstract. *During desiccation of the drought-tolerant moss* Tortula ruralis *polysome levels decline substantially before any increase in ribonuclease activity is observed. Furthermore, ribosomes in the desiccated moss are not complexed with messenger RNA fragments. It is concluded that ribosome runoff and failure to re-form an initiation complex mediate polysome loss during desiccation.*

Plant tissues subjected to drought or water stress lose polysomes (*1, 2*). The mechanism underlying this loss is little understood. However, increased activity of ribonuclease observed in tissues under prolonged water stress has been suggested as a potential cause of polysome loss (*3*). This suggestion has been questioned because polysomes can be conserved under certain conditions (for example, in the presence of