Air Pollution and Urban Climatology at Norfolk, Virginia

by W. MAURICE PRITCHARD *and* KULDIP P. CHOPRA, *Department of Physics and Geophysical Sciences, Old Dominion University, Norfolk, Va. 23508.*

ABSTRACT.—The atmosphere at Norfolk is usually stable, with no strongly prevailing wind direction. Linear regression analyses of visibility data indicate a generally decreasing visibility trend between 1960 and 1972, with a possible trend reversal in later years. A 44 percent increase in the annual frequency of 0-4-mile visibility occurred in 1960-72. Similar analyses of precipitation data for 1960-74 show a slight increase in the annual number of days with precipitation exceeding 0.01 inch. The correlation coefficient between the annual frequencies of low (0-4-mile) visibility and days with precipitation greater than 0.01 inch was rather small and negative.

NORFOLK IS ONE OF FOUR contiguous cities in the Hampton Roads area in the southeastern corner of Virginia. This area is urban and coastal in character, bordering on the Atlantic Ocean. It has no significant concentrations of heavy industry and is generally well ventilated. However, an analysis of weather data for recent years has shown that local variations in certain meteorological parameters may be associated with the effects of particulate air pollutants.

Air pollution influences urban climatologies in a variety of ways. Among these is a decrease in visibility. A low surface visibility due to air pollutants is now a common occurrence in many urban areas. In other areas where air pollution is not a serious problem, decreasing visibility may serve as an indication of an increasing concentration of air pollutants.

The analysis of visibility data is complicated by the fact that visibility is affected by several meteorological factors as well as by air pollutants. The reduction in visibility due to air pollution is almost always associated with particulate matter in the atmosphere. This reduction is due to scattering and absorption of light by airborne particles. Gaseous pollutants are usually either invisible or present in concentrations too low to affect visibility. However, in sufficiently large concentrations, some gases may produce changes in sky color. A high concentration of NO_2, for example, causes a characteristic brownish discoloration of the sky.

As far as precipitation is concerned, particulate air pollutants may furnish additional condensation nuclei. Significant changes in precipitation patterns have been observed at several cities in studies made as a part of Project METROMEX (Metropolitan Meteorological Experiment).

The influence of a particular type of pollutant depends on the size, concentration, and physical properties of the particles. The particle concentration is related to the air volume occupied. This mixing volume can be estimated by using as a vertical dimension the height of the base of a low-lying temperature inversion. Winds serve to dilute the concentration of atmospheric particulate matter by increasing the mixing volume. Low-level atmospheric turbulence also has a diluting effect.

VISIBILITY

In recent years, declining visibility attributed to air pollution has been reported at or near a number of urban areas. These include: Tucson, Arizona *(Green and Battan 1967)*; Point Mugu, California, near Los Angeles *(Lea 1970)*; Los Angeles, *(Chass and Keith 1971)*; Akron, Ohio, Lexington, Kentucky, and Memphis, Tennessee, *(Miller et al. 1972)*; and Norfolk, Virginia, *(Pritchard and Chopra 1972)*. The periods considered were 1949-65 by Green and Battan, 1949-69 by Lea, 1933-69 by Chass and Keith, 1962-69 by Miller et al., and 1960-70 by Pritchard and Chopra. The most pronounced effect observed by all these investigators was a generally increasing trend in the frequency of low visibility. The earlier visibility study by Pritchard and Chopra *(1972)* has now been extended by 4 years and expanded to include consideration of atmospheric stability, wind conditions, and precipitation.

The visibility data analyzed were recorded at the Norfolk Regional Airport in Norfolk, Va. In particular, visibilities measured at noon EST on weekdays were examined for the 15-year period 1960-74. This choice of data is the same as that made by Chass and Keith *(1971)* for the Los Angeles study.

The mean annual visibilities from 1960 to 1972 (fig. 1) show a slight trend toward reduced visibility. The solid line is the linear regression line given by

$$\bar{V} = 8.20 - 0.0275\ N \qquad [1]$$

where V is the mean annual visibility in miles and N = 1, 2, 3, . . . 13 is the year index beginning with N = 1 for 1960. The regression line indicates a slight decreasing trend over the 13-year period. However, a reversal of this trend may have occurred, possibly beginning in 1972. The mean annual visibilities for 1973 and 1974 were 9.17 and 9.57 miles respectively. These values

Figure 1.—Mean annual visibility, 1960-72.

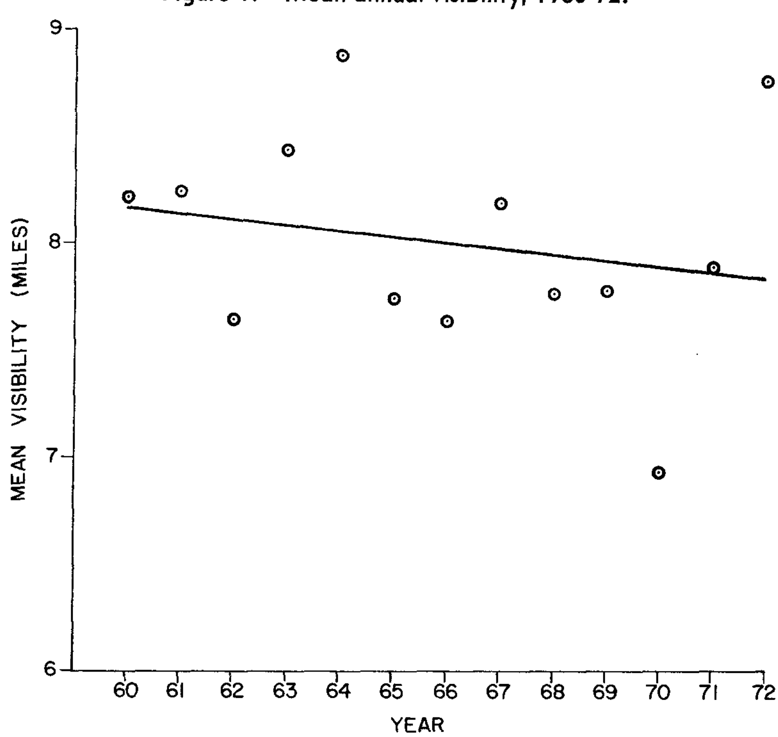


Figure 2.—Annual frequency of 0-4-mile visibility, 1960-72.

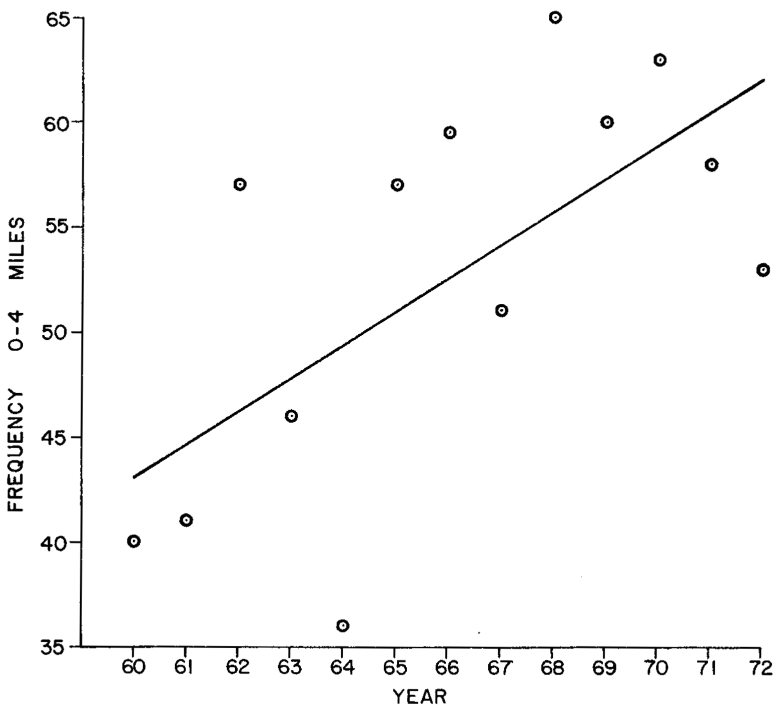
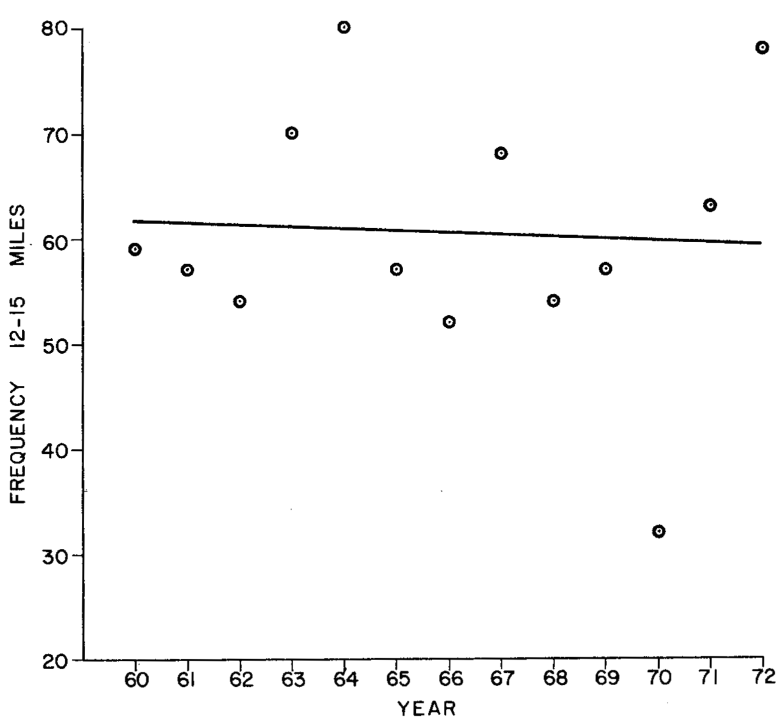


Figure 3.—Annual frequency of 12-15-mile visibility, 1960-72.



are considerably higher than the values given by the regression line.

The annual frequencies of occurrence of visibilities in the 0-4-mile range (fig. 2) for the period 1960-72 fit the regression line

$$F=41.5+1.58\ N \qquad [2]$$

where F is the annual frequency. In this case, a significant increasing trend is observed. The frequence of occurrence of low visibilities, as given by the regression line, increased by 44 percent between 1960 and 1972. A possible trend reversal after 1972 was observed here also. The frequencies of occurrence of visibilities in the 0-4 mile range decreased to 48 in 1973 and to 41 in 1974.

An increase in low visibilities might be expected to indicate a concurrent decrease in high visibilities. The annual frequencies of occurrence of visibilities in the 12-15-mile range (fig. 3) from 1960 to 1972 bear this out. The regression line for these high visibilities is given by

$$F=61.0-0.132\ N \qquad [3]$$

This equation indicates a slight decreasing trend for high visibilities. The data for 1973 and 1974 do not follow this trend. The annual frequencies of occurrence for visibilities in the 12-15-mile range were 102 in 1973 and 205 in 1974. Both of these frequencies are far above the regression line.

PRECIPITATION

The availability of condensation nuclei from anthropogenic sources may lead to increased precipitation patterns in and around urban areas. To investigate this effect, we examined precipitation data from the Norfolk Regional Airport weather station. Data on total annual precipitation, P, (fig. 4) and

Figure 4.—Total annual precipitation, 1960-74.

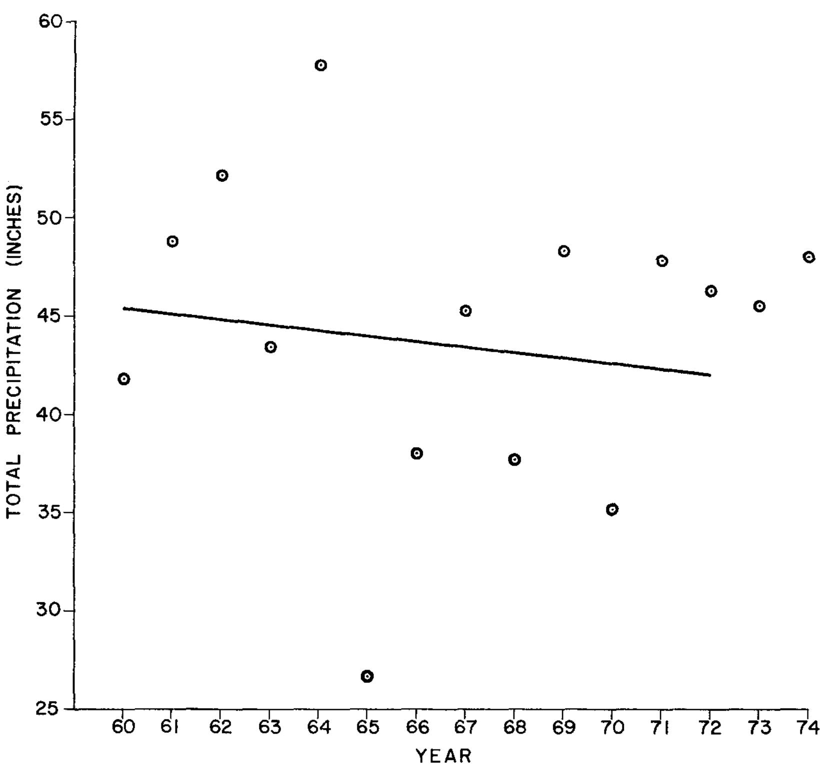
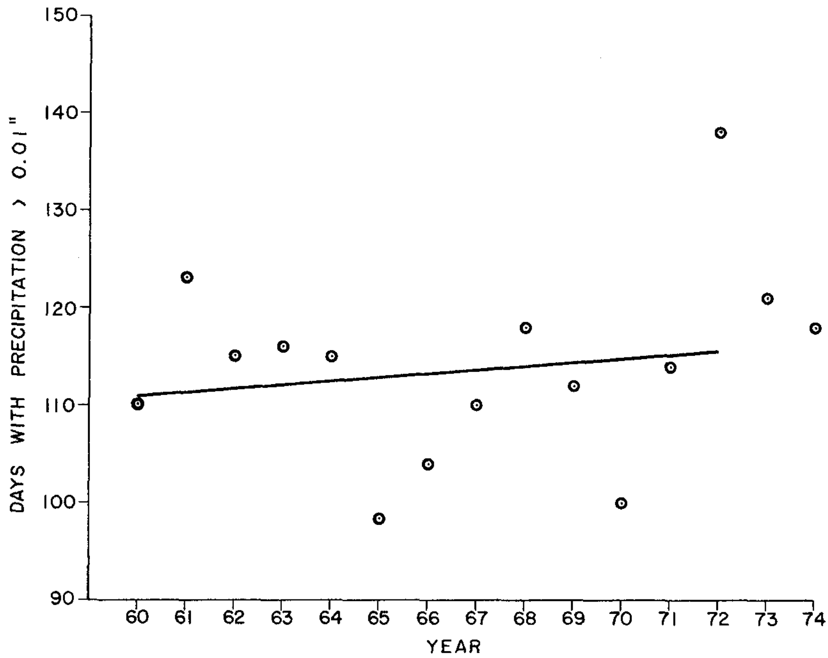


Figure 5.—Annual frequency of days with precipitation greater than 0.01 inch, 1960-74.



annual number of days, F_P, with precipitation greater than 0.01 inch (fig. 5) were considered for the period 1960-74. The regression lines for the data through 1972 are described by

$$P = 45.7 - 0.284\ N \text{ inches} \qquad [4]$$

and

$$F_P = 110.7 + 0.379\ N \text{ days} \qquad [5]$$

A slight decreasing trend in P and a slight increasing trend in F_P is apparent. The value of F_P computed from the regression equation increased by 4 percent between 1960 and 1974. An examination of the precipitation data (figs. 4 and 5) shows that the data points for 1973 and 1974 follow the trends of the regression lines based on data for the period 1960-72.

AIR FLOW CHARACTERISTICS

The atmospheric flow characteristics of a region have an important bearing on the rate of dispersal of pollutants. These characteristics can be classified as wind speeds and directions and atmospheric stability. The extent of vertical air motion is related to the atmospheric lapse rate, which determines whether vertical motion is enhanced or diminished.

The annual distribution of wind directions (table 1) and frequency of Pasquill stability classes (table 2) were

Table 1.—Annual distribution of wind directions

Wind direction	Distribution
	Percent
N	9.1
NNE	7.1
NE	5.6
ENE	6.6
E	7.1
ESE	3.0
SE	3.9
SSE	5.8
S	9.1
SSW	10.5
SW	6.2
WSW	5.7
W	7.5
WNW	4.0
NW	3.7
NNW	5.1

Table 2.—Annual frequency of Pasquill stability classes

Stability class	Frequency
	Percent
A. Extremely unstable	3
B. Unstable	7
C. Slightly unstable	12
D. Neutral	47
E. Stable	32

determined from data recorded at the Norfolk Naval Air Station between December 1966 and November 1971. The data for this weather station are considered representative of the area, and hourly measurements are made. It appears that, on an annual basis, there is no pronounced prevailing wind direction.

The regional atmosphere at Norfolk displays a generally high stability, which is not usual for an urban area. Normally Pasquill stability class C (slightly unstable) would prevail in an urban environment. This is due to the greater surface roughness and higher temperature environment of cities as compared with rural areas. It is significant that, at Norfolk, stability classes D (neutral) and E (stable) account for 79 percent of all occurrences.

The reasons for the high stability in Norfolk are to some extent geographical. The Norfolk metropolitan area is on a peninsula, and the surrounding water, with low surface roughness, increases the stability of the air passing over it and thus reduces the urban effect. In general, high atmospheric stability is not conducive to the dispersion of air pollutants.

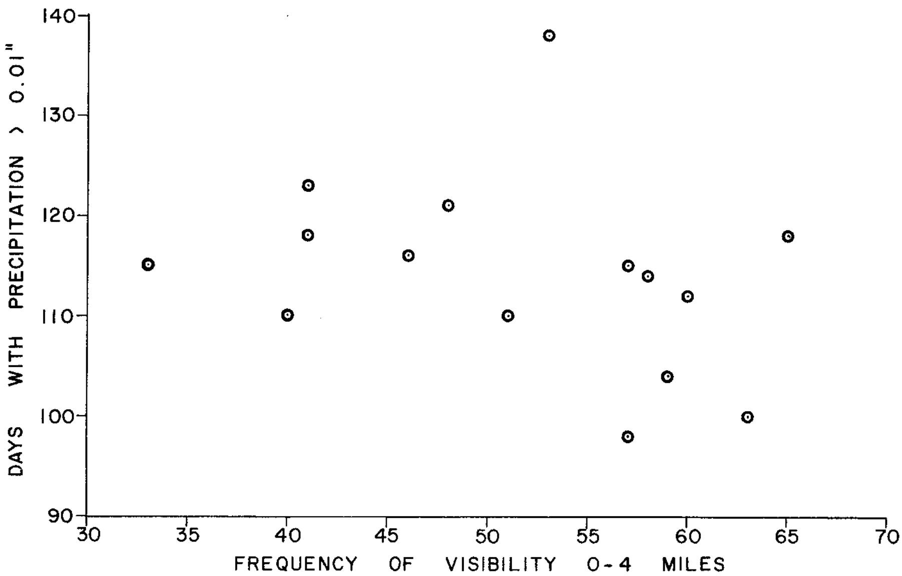
DISCUSSION

A significant decrease in visibility at Norfolk occurred during the 13-year period 1960-72. This decrease may be related to an increasing atmospheric concentration of particulate air pollutants. The most pronounced effect was a substantial increase in the annual frequency of occurrence of low (0-4 mile) visibilities. This result is in agreement with the findings of other investigators for time intervals ending in the late 1960s. For example, Chass and Keith *(1971)* observed that the noon weekday visibility at Los Angeles showed a marked increase in the annual frequency of visibilities in the 3-6-mile range for the 37-year period 1933-69. The declining visibility at Norfolk was associated primarily with sharply lower visibilities during the summer months. This can be attributed to the combined effects of increasing air pollution and a seasonal high in relative humidity. Hygroscopic particles in the atmosphere absorb water and increase in size when the relative humidity is high but the air is unsaturated. Larger particles are more effective in reducing visibility. The same seasonal effect has been observed by Miller et al. *(1972)*.

The extremely high visibilities observed at Norfolk during 1973 and 1974 are somewhat difficult to account for. Some reduction in the generation of particulate air pollutants has occurred. The Virginia Air Pollution Control Board began in 1972 to enforce regulations designed to reduce air pollution from point sources. In the Norfolk Area, the principal point sources of particulate air pollutants were incinerators and businesses engaged in the production of asphalt and fertilizers. Since 1972, particulate emissions from these sources have substantially decreased. However, the extent of the reduction in particulate emissions from heating systems and automobile engines is uncertain.

Precipitation data for the entire 1960-74 period show a slightly increasing trend in the annual frequency of days with precipitation greater than 0.01 inch. This effect may also be due to particulate air pollutants. In addition, some correlation between visibility and precipitation data might be expected. A cross-correlation plot of the annual frequency of days with precipitation ex-

Figure 6.—Correlation between visibility and precipitation, 1960-74.



ceeding 0.01 inch versus the annual frequency of visibility in the 0-4 mile range is shown in figure 6. The correlation coefficient in this case, for the entire 1960-74 period is

$$\rho = \frac{\sum_{i=1}^{15} (F_{vi} - \overline{F}_v)(F_{Pi} - \overline{F}_P)}{\left[\sum_{i=1}^{15} (F_{vi} - \overline{F}_v)^2 \sum_{i=1}^{15} (F_{Pi} - \overline{F}_P)^2\right]^{1/2}} = -0.296 \qquad [6]$$

Here F_{vi} and F_{Pi} are the annual frequencies for visibility and precipitation respectively, and $\overline{F}_v$ and $\overline{F}_P$ are the 15-year averages of the F_{vi} and F_{Pi} values. The correlation coefficient, although rather small, is negative and is consistent with the hypothesis that the effect of precipitation is to increase visibility by washing particulate matter out of the atmosphere.

REFERENCES

Chass, R. L., and R. W. Keith.
1971. DOWNTOWN LOS ANGELES NOON VISIBILITY TRENDS. Preprint of Paper Presented at Conference on Air Pollution Meteorology at Raleigh, NC. Am. Meteorol. Soc., Boston.

Green, Charlotte R., and Louis J. Battan.
1967. A STUDY OF VISIBILITY VERSUS POPULATION GROWTH IN ARIZONA. J. Ariz. Acad. Sci. 9: 226-228.

Lea, Duane A.
1970. A PRELIMINARY ANALYSIS OF VISIBILITY TRENDS AT POINT MUGU, 1949-1969. U.S. Navy Pacific Missile Range Geophys. Div. Atmos. Sci. Tech. Note 22a.

Miller, Marvin E., Norman L. Canfield, Terry A. Ritter, and C. Richard Weaver.
1972. VISIBILITY CHANGES IN OHIO, KENTUCKY, AND TENNESSEE FROM 1962 TO 1969. Mon. Weather Rev. 100: 67-71.

Pritchard, W. M., and K. P. Chopra.
1972. EFFECT OF AIR POLLUTION ON URBAN VISIBILITY STATISTICS. Preprint of Paper Presented at Conference on Urban Environment and Second Conference on Biometeorology at Philadelphia. Am. Meteorol. Soc., Boston.