ACID DEPOSITION Long-Term Trends

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Uncertainties in Trends in Acid Deposition: The Role of Climatic Fluctuations

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INTRODUCTION

Acid deposition is the end product of a series of complex processes involving emission of precursors, chemical transformations in the atmosphere, physical transport of the pollutants through the atmosphere, and eventual dry or wet deposition. Day-to-day changes in weather play an important role in this sequence of events, since meteorological conditions at the time the pollutants are emitted determine the direction and the rate of both horizontal and vertical dispersal. Subsequent changes in these conditions determine whether precipitation will occur and to what extent the atmosphere will be cleansed of its pollutant load.

Considerable attention has focused on the influence of meteorological processes on acid deposition, with particular emphasis on source-receptor relationships to determine the origin and the route of transport of deposited materials (National Research Council 1983). In assessing changes in acid deposition over time scales longer than seasons, however, short-term *meteorological* variability is less significant than longer-term *climatic* variability. Climate is a statistical expression of daily weather events; but, over time periods of years and decades, changes in climate do occur, and these may be of considerable importance when evaluating long-term records of acid deposition. Clearly, temporal and spatial variations in atmospheric circulation over extended periods may directly influence patterns of deposition. Climatic fluctuations may also bring about changes in ecological conditions that could either accentuate or mask the effects of acid deposition. Indeed, climatic fluctuations could induce changes that might be confused with the effects of acid deposition.

Climatic variability is thus a pervasive factor in all aspects of the problem of detecting long-term trends in acid deposition. Consequently, any long-term records of acid deposition, whether they be direct or surrogate measures, must be evaluated in the context of climatic fluctuations over the same period. To this end, this chapter summarizes certain aspects of climatic variability in the eastern United States over the past 50 to 100 years that may be relevant to evaluating trends in acid deposition and its effects.

CYCLONE TRACKS

The occurrence of precipitation and precipitation-bearing weather systems is of prime interest to those studying acid deposition, particularly wet deposition. Much attention has centered on meteorological conditions preceding acid rain events, generally in an attempt to understand source-receptor relationships. This chapter focuses not on this aspect but rather on the general synoptic weather conditions that produce precipitation in the eastern United States.

Besides summertime convective storms, which are often dispersed spatially, the primary sources of precipitation in the eastern United States are organized frontal system associated with low-pressure centers (cyclones) traveling eastward across the region. Airflow into these systems carries polluted emissions far from the source area. It is the flow of air from different directions into the storm systems that carries polluted emissions away from the source area. Large interannual changes in the primar tracks that precipitation-producing systems follow, and hence changes in the flow of air into these systems, will affect interannual deposition patterns. Similarly, longer-term changes in the tracks of low-pressure systems and in the total number of cyclones per year will affect long-term airflow patterns and acid-deposition trends.

By studying the movement of cyclones over long periods of time, the primary tracks that they follow can be mappe (Figure 3.1). These maps, however, provide statistical summaries only and obscure the marked variability in storm tracks that characterize any one year. Not only may the actual tracks followed by individual storms and the associated airflows vary markedly from month to month, but the total number of storms affecting the region per year may vary over time (Figure 3.2).

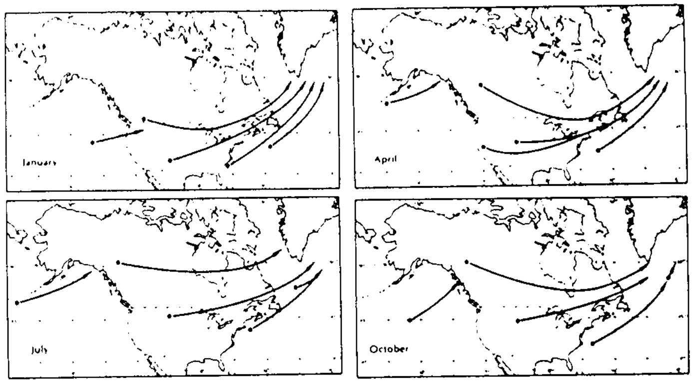


FIGURE 3.1 Primary depression tracks for four months of the year based on synoptic weather charts for 1951-1970. SOURCE: Reitan (1974).

What is the significance of these changes for acid deposition? The processes by which material passes from source to receptor are complex and not fully understood. Every weather situation is unique and must be interpreted individually. Nevertheless, changes in airflow over a region that accompany long-term changes in cyclone tracks and associated frontal systems must play a fundamental role in producing temporal and spatial variations in acid deposition. This aspect of climatic variability deserves further study to quantify its potential significance in assessing trends in acid deposition.

PRECIPITATION AND DROUGHT

Since acid deposition results from both wet and dry processes, variations in the amount of precipitation and in the frequency and the size of precipitation events must play an important role in long-term trends in acid deposition. However, there has been surprisingly little research on this matter.

Precipitation records for the eastern United States are characterized by fairly large year-to-year variations of precipitation superimposed on long-term trends. In the Adirondack Mountains, for example, precipitation in some years is approximately 50 percent higher than in

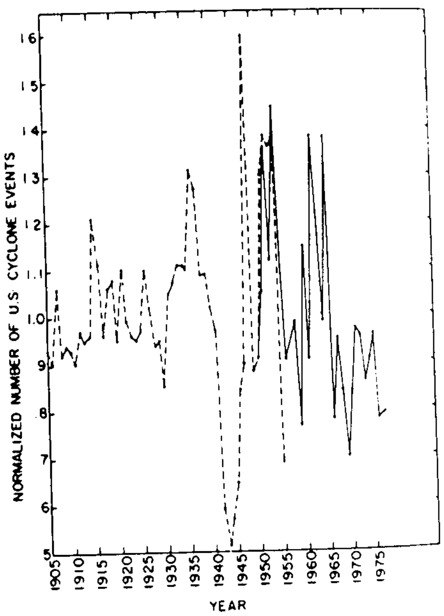


FIGURE 3.2 Normalized number of U.S. depression events, 1905-1977 (after Hosler and Gamage (1956) and Zishka and Smith (1980)).

others, and precipitation may be above or below the long-term average for several consecutive years (Figure 3.3). Furthermore, the type of precipitation event may be significant to total acid deposition. In some areas, the frequency of days with heavy rain has increased markedly over the past 20 to 30 years with associated changes in cloudiness (Changnon 1983). Large precipitation events (greater than 1 in. (25 mm)) tend to have higher pH than smaller precipitation events but greater impact on total acid deposition (Likens et al. 1984). Thus, even if total annual precipitation were identical in any two years, differences in wet deposition could arise from differences in the size and the frequency of precipitation events. Unfortunately, little is known about the extent to which year-to-year variations in the number and size of precipitation events affect total acid deposition, principally because reliable long-term precipitation chemistry data sets are not available.

Changes in cloud cover (cloud type and extent) have not yet been studied in any detail. However, the frequency of convective clouds may be important in redistributing pollutants from low to high altitudes, thereby promoting their long-range transport. Further study of this aspect of climatic variability is warranted.

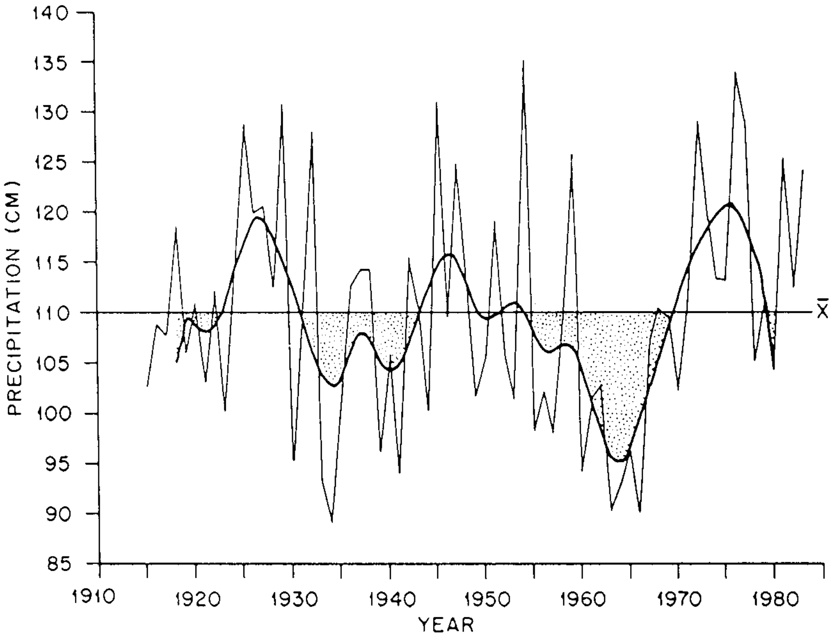


FIGURE 3.3 Annual precipitation in the Adirondack Mountains, New York. Horizontal line (X̄) is the long-term average. Darker line shows low-frequency trends in the record (based on an 11-point binomial filter). Shaded areas indicate years of lower than average precipitation.

The occurrence of individual precipitation events with respect to the timing of sample collection may be of considerable importance in comparing historical data sets, particularly of stream-water chemistry. The acid shock phenomenon--low-pH water at the start of snowmelt--is fairly well known (National Research Council of Canada 1981), but even individual precipitation events during summer months can produce sharp reductions in pH similar to spring snowmelt changes (Kurtz et al. 1984). Thus, it is important to take into account the recent precipitation history of a site (i.e., the period before sampling) in comparing discrete stream-water samples.

Just as the amount of precipitation is important in evaluating trends in acid deposition, so is the absence of precipitation. Drought conditions, defined as periods of anomalously low precipitation (generally coupled with above average temperatures) are relatively common occurrences in some areas of the country, such as in the upper Midwest; in other areas, New England and New York for example, drought is a relatively uncommon event.

Wet deposition is reduced during droughts, but dry deposition may increase. In assessing trends in acid deposition and its effects, the ecological consequences of drought may be most significant. In those areas where droughts are relatively common, ecosystems capable of withstanding periodic water shortages have evolved. In areas where droughts are relatively rare, the ecological effects of drought are likely to be more profound and may result in changes and readjustments within ecosystems long after droughts per se have ended. Such changes may complicate attempts to assess the effects of acid deposition on ecosystems. In particular, studies of annual tree growth increments as a surrogate measure of the effects of acid deposition on biomass production may not differentiate unequivocally the long-term effects of periodic droughts from the effects of acid deposition.

Also, drought may affect precipitation chemistry directly. Early monitoring of precipitation chemistry in the eastern United States (Junge 1956, Junge and Werby 1958) provides an important data set with which to compare recent measurements. A direct comparison reveals significantly lower pH values over most of the East in the late 1970s compared with those approximately 25 years earlier. However, drought in the Midwest during the mid-1950s and consequent windblown dispersal of aerosols rich in calcium and magnesium may have resulted in overestimating pH values for this interval (Figures 3.4(a) and 3.4(b)). By adjusting the calculated pH values to take "excess" calcium and magnesium into account, changes in pH between the 1950s and late 1970s appear to be less than reported previously for most of the eastern United States (compare Figures 3.4(b) and 3.4(c)). Although one could take issue with the methods employed in making such adjustments and with the many assumptions necessary (Butler et al. 1984, Stensland and Semonin 1984), it is nevertheless clear that climatic variations over years and decades may have consequences that preclude directly comparing data for different time periods.

The severity of a drought is commonly expressed in terms of the Palmer Index (P.I.) (Palmer 1965). The occurrence of drought for at least two consecutive months with a P.I. of less than 3 is considered a severe event. The frequency of such events in the eastern United States

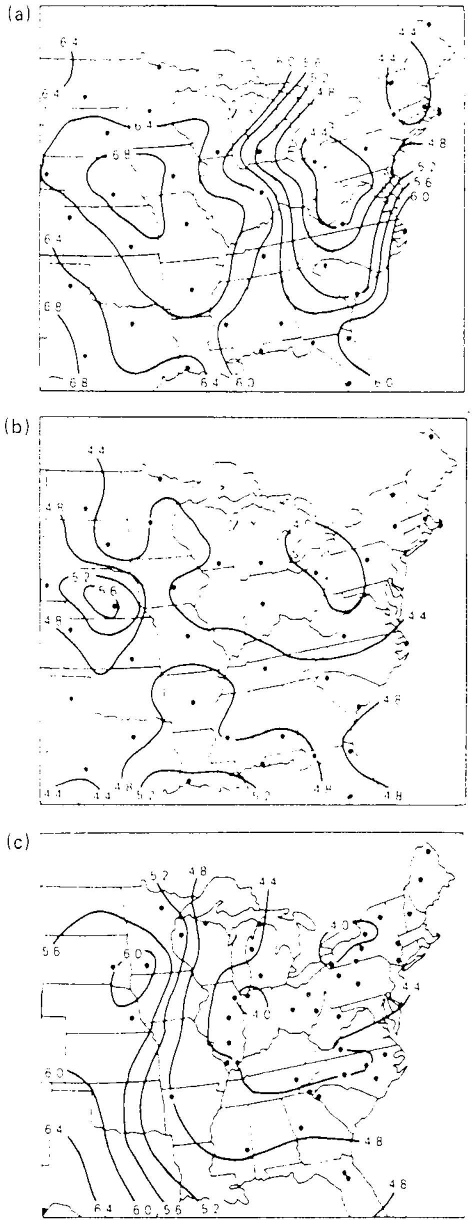


FIGURE 3.4 1955-56 pH distribution; (a) based on adjusted Junge data; (b) after correcting for assumed anomalously high concentrations of calcium and magnesium; and (c) September 1980 median pH distribution from National Acid Deposition Program network. See Chapter 5 for a detailed discussion of these data (Stensland and Semonin 1982).

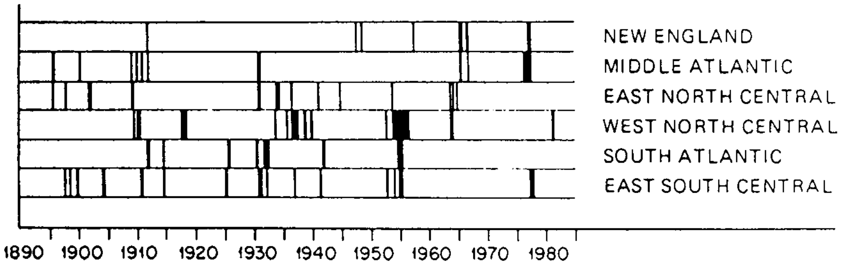


FIGURE 3.5 P.I.s (<3) for regions of the eastern United States, 1895-1981 (after Diaz 1983). New England comprises Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, and Connecticut. The Middle Atlantic region comprises New York, Pennsylvania, and New Jersey. The East North Central region comprises Wisconsin, Michigan, Ohio, Indiana, and Illinois. The West North Central region comprises Minnesota, North Dakota, South Dakota, Iowa, Nebraska, Missouri, and Kansas. The South Atlantic region comprises Delaware, Maryland, West Virginia, Virginia, North Carolina, South Carolina, Georgia, and Florida. The East South Central region comprises Kentucky, Tennessee, Alabama, and Mississippi. These climatological regions do not correspond exactly to the regions that we have defined in this report to characterize trends in acid deposition (see Chapter 1, Figure 1.2). However, the regions denoted here are somewhat analogous; i.e., New England plus the Middle Atlantic States are nearly equivalent to our Region B, the South Atlantic plus the East South Central States are nearly equivalent to our Region C, and the East North Central States are somewhat similar to our Region D.

is shown in Figure 3.5. Over the past 90 years droughts have occurred in all areas of the eastern United States at some time. Most significant was the drought of the 1930s, which began to affect the area east of the Mississippi River, except New England, around 1930. The drought later became centered over the North Central States, lasting until the end of the decade in the West North Central region (see Figure 3.5). In the 1950s, a major but less severe drought affected an area from the South Atlantic seaboard to the upper Midwest; once again New England for the most part escaped its effects, as did the two other regions of the North (the Middle Atlantic and East North Central States). In the mid-1960s, however, an exceptionally severe drought affected New England and the Middle Atlantic States. Dendroclimatic studies have reconstructed drought severity in the Hudson River Valley since the seventeenth century (Figure 3.6), and from this work it appears that the 1960s drought was one of the most severe in the past 300 years (Cook and Jacoby 1979). Interestingly, this was a cool drought accompanied by below-average temperatures and anomalous northwesterly airflow. The most recent drought (1976-1977) also affected New England and the Middle Atlantic States but was not so extreme as the 1960s drought.

AIR STAGNATION EPISODES

It is well known that high air pollution levels are often associated with certain weather conditions, the most noteworthy of which are slow-moving anticyclones (high-pressure systems). Anticyclones are generally associated with subsiding air motion, clear skies, and strong nighttime radiative cooling, giving rise to pronounced temperature inversions that limit vertical dispersal of pollutants. Since pollutants are not readily dispersed during air stagnation episodes, relatively high levels of major contaminants, such as ozone, may occur for extended periods during these events. Thus, in evaluating the relationship between ecological indicators and acid deposition one should account for long-term changes in the frequency of air stagnation events in each region under study.

In addition, changes in air stagnation trends may play a role in changes in regional visibility over time. Visibility is also affected by variations in temperature and relative humidity, since hygroscopic sulfate aerosols, a primary ingredient in reducing visibility, absorb water from the air. Comparisons of long-term visibility data should thus account for variations in these parameters (Sloane 1983, 1984). This is discussed further in Chapter 4.

The frequency of air stagnation episodes in the eastern United States has been studied by Korshover (1976), who found the maximum frequency of such cases to be centered over Georgia and South Carolina (Figure 3.7). Seasonally, the fall (August-October) has the maximum number of air stagnation cases. An analysis of the number of stagnation cases each year in the eastern United States over the past 50 years reveals an increase

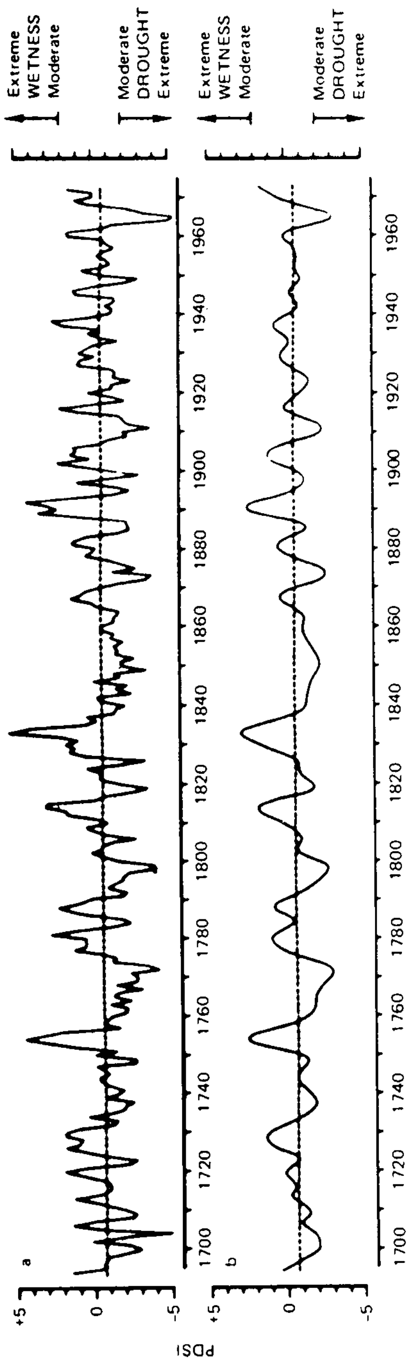


FIGURE 3.6 Dendroclimatic reconstruction of P.I.s for the Hudson River Valley area. The more negative the index the more severe the drought event; (a) raw data, (b) smoothed data. PDSI, means Palmer Drought Severity Index. SOURCE: Cook and Jacoby (1979).

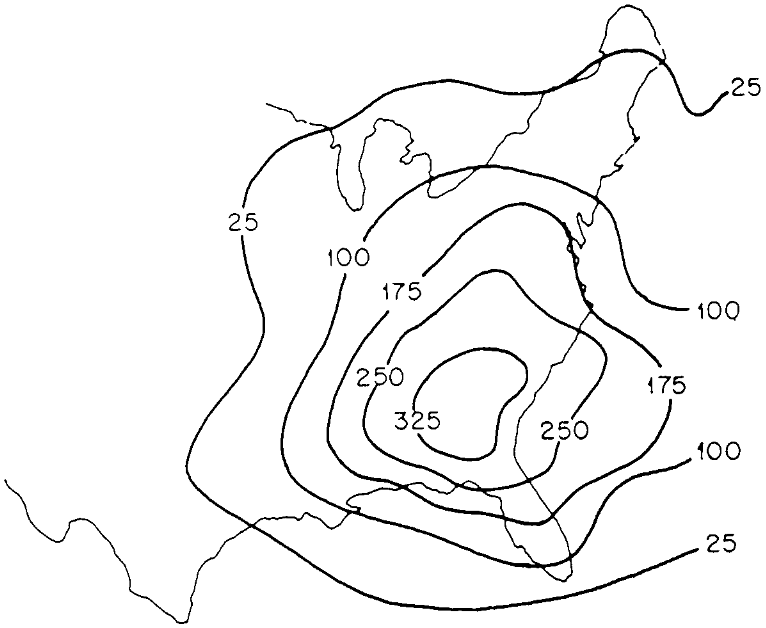


FIGURE 3.7 Geographical distribution of number of air stagnation days in the eastern United States over the period from 1936 to 1970 (after Korshover 1976).

from a low of 30 days/yr in 1936 to 1940 to a high of 57 days/yr in 1979 to 1983 (Figure 3.8). This does not imply that all parts of the country experienced an increase in stagnation days over the 50 years, but it does mean that the total number of cases within the entire eastern United States has increased. Nevertheless, it is clear that air stagnation conditions are variable in time and space and thus play a role in evaluating spatial and temporal trends in acid deposition and its effects.

TEMPERATURE

Changes in temperature over time are not of direct significance for trends in acid deposition. Nevertheless, they may affect a biological indicator, such as tree growth, and thereby confound efforts to isolate unequivocally any acid deposition signal in the tree ring records. (See Chapter 6.)

An analysis of long-term temperature data for the United States shows that the record since 1895 divides into three periods (Diaz and Quayle 1980) (Figure 3.9). The first period (1895 to 1920) was characterized by relatively low temperatures, the second period (1921 to 1954) by a warming trend, and the third period (1955 to 1979 or later) by a return to cooler conditions. When the changes in temperature between these periods are examined by region, it becomes clear that over the past 60 years the most pronounced changes in temperature have occurred in the eastern half of the United States (Figure 3.10). In particular, since the early 1920s summer (June-August) temperatures have decreased 1.5°F (0.8°C) or more in a zone centered on Tennessee and Kentucky. During the same period winter temperatures declined in this region by 3°F (1.7°C) or more. The decade of the 1960s in particular was notable for a succession of cold winters, which may have contributed to the onset of forest decline in the eastern United States. This point is discussed in more detail in Chapter 6. Such changes are quite significant and may be of particular ecological importance near the normal geographical range limit of a species or at higher elevations. It is also in these areas, where vegetation is under environmental stress, that increases in acid deposition might have the greatest impact. Thus, separating the climatic and acid deposition signals in vegetation can be complex and may produce equivocal results.

The changes in mean monthly or seasonal temperature that have been observed are only one isolated measure of climate. It is probable that these temperature changes reflect adjustments in large-scale circulation patterns of the eastern United States involving a multitude of other, more subtle changes in climate, such as length of the growing season, frequency of frosts, growing degree days, type and amount of cloudiness, vapor pressure, net radiation, and wind direction. Such changes may be significant ecologically, yet they are rarely subjected to careful long-term analysis because adequate data sets are lacking. Even with good long-term data and reliable models of the important interactions, it would be extremely difficult to isolate the multiplicity of effects that such changes could have on ecosystems from the additional influence of acid deposition. As it is, both data and models are generally inadequate as a means of resolving the unique effects of any particular factor.

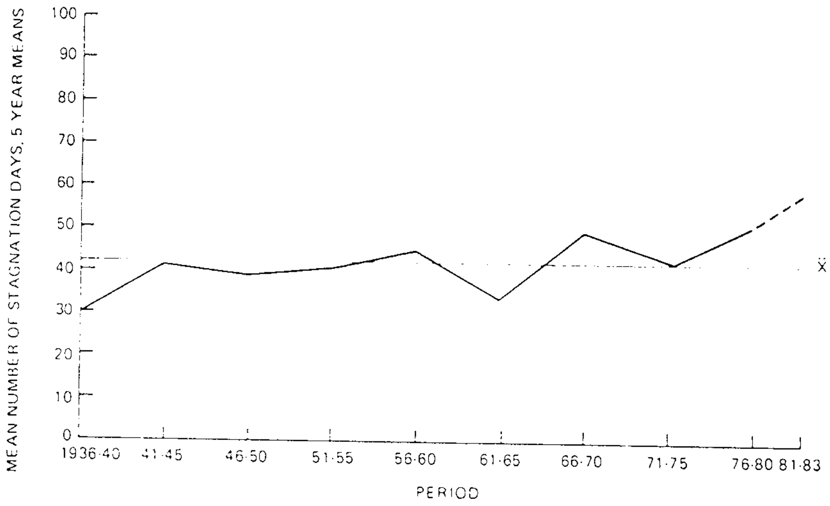


FIGURE 3.8 Air stagnation days in the eastern U.S., 1936-1983. Horizontal line (X̄) is the long-term average. Dashed line signifies the 3-year mean from 1980 to 1983 (data courtesy of J. Korshover, Air Resources Laboratory, NOAA, Silver Spring, Md.).

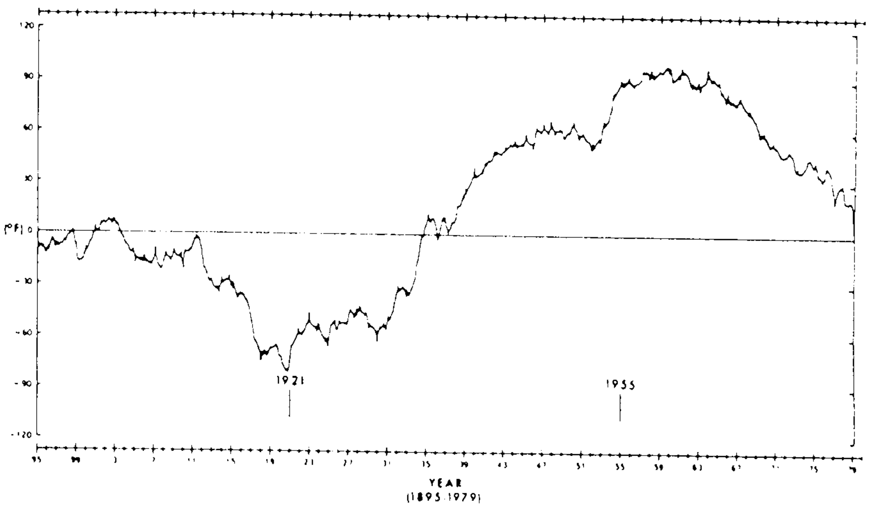
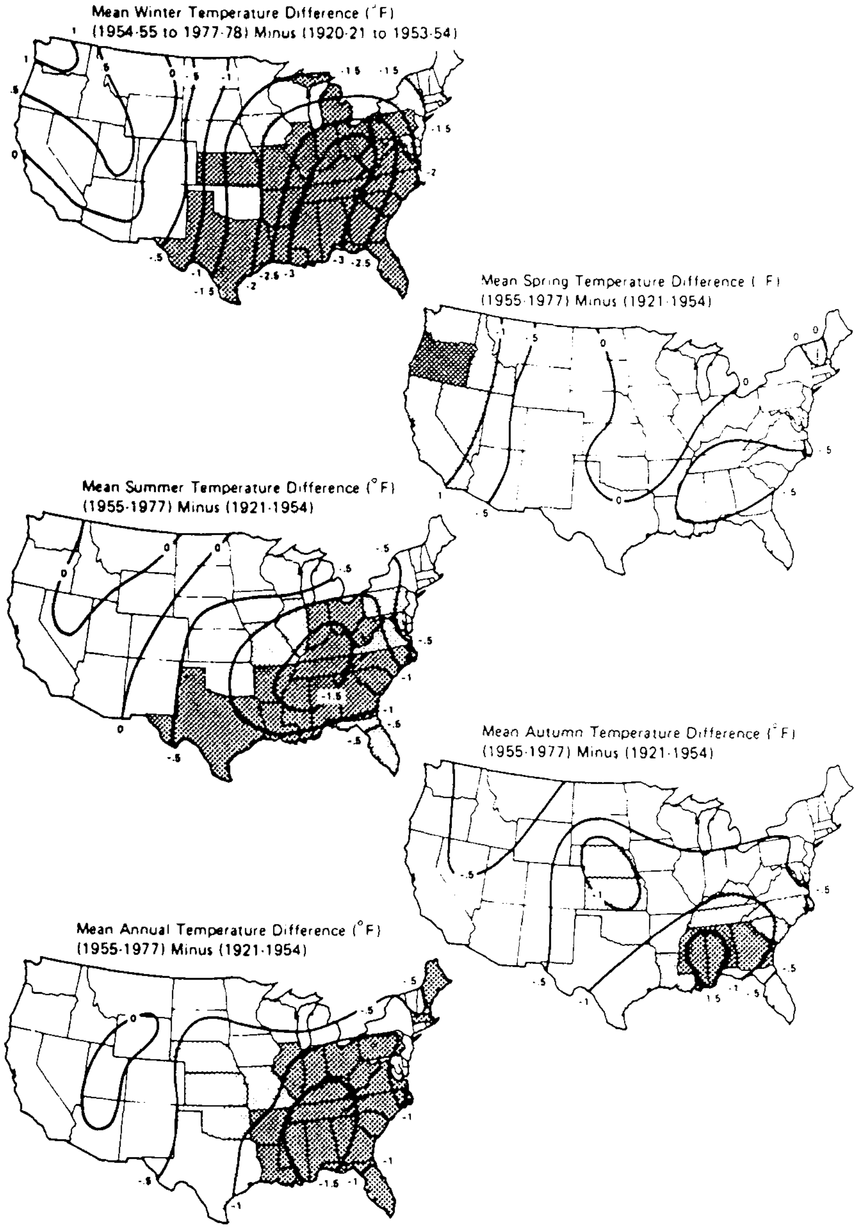


FIGURE 3.9 Cumulative departures of long-term mean monthly temperature in the contiguous United States; monthly means compiled from January 1895 to March 1979. SOURCE: Diaz and Quayle (1980).



Mean Winter Temperature Difference (°F) (1954-55 to 1977-78) Minus (1920-21 to 1953-54)

Mean Spring Temperature Difference (°F) (1955-1977) Minus (1921-1954)

Mean Summer Temperature Difference (°F) (1955-1977) Minus (1921-1954)

Mean Autumn Temperature Difference (°F) (1955-1977) Minus (1921-1954)

Mean Annual Temperature Difference (°F) (1955-1977) Minus (1921-1954)

FIGURE 3.10 **Mean seasonal and annual temperature differences (°F) for (1955-1977) minus (1921-1954). Shading indicates significance at the 99%** (dark) and 95% **(light) levels, respectively** (after Diaz and Quayle 1980).

SUMMARY

Acid deposition is a consequence of atmospheric processes acting on air pollutants. As such, the phenomenon is subject to the variability of the atmospheric system on both short (meteorological) and long (climatological) time scales. In assessing trends in acid deposition, climatic trends must be an implicit part of the assessment. Furthermore, in trying to understand the effect that acid deposition may have had on various ecosystems it is equally important to have a clear understanding of the effects of climatic variations on the ecosystems. Because this type of analysis has rarely been carried out, research should focus on the following topics:

1. The effects that climatic variability may have on those systems thought to be affected by acid deposition, such as aquatic and forest ecosystems.
2. The implications of long-term climatic changes for trends in acid deposition both in the past and in the future.

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