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Association Between Meteorological Conditions and High Ozone and Sulfate Concentrations

A 1974 Episode in the Eastern United States

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ASSOCIATION BETWEEN METEOROLOGICAL CONDITIONS AND HIGH OZONE AND SULFATE CONCENTRATIONS
A 1974 Episode in the Eastern United States

by

Gerard A. DeMarrais
Meteorology and Assessment Division
Environmental Sciences Research Laboratory
Research Triangle Park, N.C. 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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Mr. DeMarrais is a meteorologist in the Meteorology and Assessment Division, Environmental Sciences Research Laboratory, Environmental Research Center, Research Triangle Park, N.C. 27711. He is on assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

ABSTRACT

A 1,000,000 km^2 area of the Eastern United States had sulfate concentrations exceeding 10 $\mu g/m^3$ on July 10, 1974, and there were indications that parts of the area had high concentrations on prior days. The meteorology associated with the high concentrations and correlations of high ozone and sulfate concentrations are discussed. It appeared that slow moving and subsiding air contributed to the high concentrations of both pollutants. Long range transport, as shown by trajectory analyses, was a factor in the problems in most areas, but the worst situations with regards to sulfates were associated with emissions from nearby, upwind sources. While high ozone concentrations were observed immediately prior to high sulfate concentrations in many areas, there were high sulfate concentrations that were not associated with high ozone concentrations. In the latter situation, the high sulfate concentrations were associated with air which had earlier movement over areas with high SO_2 emission.

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POSTSCRIPT

After the final draft of this report was completed, a technical article examining the same sulfate episode was published. This article, Spatial and Temporal Distributions of Airborne Sulfate in Parts of the United States in Atmospheric Environment, V.12, 735-752, (1978), by G. Hidy et al., briefly discusses with isoplethed maps the high sulfate concentrations of July 8-11, 1974.

This EPA report differs from the technical article in that major emphasis is given to the coexistence of high ozone and high sulfate concentrations. In addition, more consideration is given to details. These details show that isoplething masks out discrepancies and on occasion does not show a significant feature; for example, the isoplethed map for July 10 indicates a concentration of approximately 10 $\mu g/m^3$ in the vicinity of West Virginia whereas two stations in the area showed concentrations four and five times as great.

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SECTION 1

INTRODUCTION

Sulfate concentrations are frequently above average when ozone concentrations are relatively high[1]. In a southern California investigation[2], it was shown that an 8-d sulfate episode coincided with an ozone episode. To further test the cofrequency hypothesis, a period was sought during which high ozone concentrations occurred in that 16-state area* that has consistently shown higher sulfate concentrations than the rest of the nation[3]. Such an ozone event occurred over the area during July 6-10, 1974, and a preliminary correlation of the ozone concentrations and meteorological conditions was previously noted[4]. In this report the available sulfate data (they are not as abundant as ozone data), ozone concentrations, and meteorological conditions for the period are discussed.

* This 16-state area is east of the Mississippi River, and is roughly bounded by Illinois and Massachusetts to the north and Tennessee and North Carolina to the south.

SECTION 2

CONCLUSIONS

On the basis of the analysis of the daily ozone, sulfate, and meteorological data, the following conclusions are drawn:

1. A large-scale ozone episode occurred over the Northeastern United States from July 6 to 10, 1974, and midway through the episode sulfate concentrations became high and eventually spread over a 1,000,000 km^2 area of the Eastern United States.

2. The ozone episode was initially associated with only the air behind a cold front that pushed southeastward over the area on July 6. The air mass eventually became the warmest of the year (most locations in the ozone episode area had the highest temperatures of the year during this 5-d period) and was characterized by slow movement at the surface and aloft (stagnation) and subsidence. The high sulfate concentrations each day were not restricted to the high temperature areas but were associated with the slow moving and subsiding air.

3. The areas of high ozone concentrations on each day did not correspond to the areas with restricted visibility or precipitation. The areas of high sulfate concentrations on each day corresponded somewhat to the areas with restricted visibility during several days when the sulfate data were limited and on the one day (July 10) with abundant sulfate data. The area with high sulfate concentrations on July 10 corresponded to the area with rainfall. After the passage of a front toward the end of the period, the ozone concentrations were reduced, and the restrictions to visibility eliminated, but the sulfate concentrations remained high.

4. The trajectory analysis frequently showed that air with a high ozone or sulfate concentration at a receptor had had a high concentration

at an earlier time in an upwind location; long-range transport, although limited by stagnation, did occur. However, at times air arrived from areas that did not show a high ozone or sulfate concentration, but at these times the air usually came from an area that was a large emitter of precursors.

SECTION 3

BACKGROUND AND METHODS

SULFATES, REACTIONS PRODUCING SULFATES, AND MEASURING OF SULFATES

Most sulfur in the atmosphere, land surface, and water exists as the hexavalent oxidized sulfate ion ($SO_4^{=}$) in such diverse forms as sulfuric acid; amonium bisulfates; calcium sulfate (the major component of gypsum); magnesium sulfate (epsom salts); sodium and potassium sulfates (in seawater); and other metal salts, such as copper, nickel, iron, lead, and zinc sulfates[1].

On a global scale, natural sources contribute about two-thirds of the sulfur compounds in the atmosphere by weight, and human activities the remainder. In the continental United States, probably 90% of the atmospheric sulfur is the result of anthropogenic emissions in the form of sulfur dioxide (SO_2)[1]. Most of the SO_2 is oxidized to the sulfate form within a few days, and, while this oxidation is taking place, the pollutants in the air can be transported long distances; the sulfate receptors may be hundreds of km from the sources of primary emissions[5].

The important mechanisms by which SO_2 is converted to sulfuric acid and sulfate salts[3,6] are: 1) direct photooxidation; 2) indirect photooxidation; 3) air oxidation in liquid droplets; 4) catalyzed oxidation in liquid droplets; and 5) catalyzed oxidation on dry surfaces.

A substantial fraction of the man-made sulfate problem is believed to be associated with SO_2 emitted by large power plants[1]. The 16-state area with the higher sulfate concentrations correlates spatially with high SO_2 emission density, high rainfall acidity patterns, and a high density of power plant locations[3].

The majority of sulfate data evaluated in this report were supplied by the National Aerometric Data Bank (NADB) and the CHESS (Community Health and Environmental Surveillance System) program of the U.S. Environmental Protection

Agency (EPA). The sulfate data in the NADB came from State and local air pollution control agencies and were generally collected every 12th day in accord with a preset schedule (in July 1974 nearly all stations had data for the 10th and 22nd); some stations sampled on additional days at random times. The stations in the CHESS program were operated every day. Sulfate data from stations in a network operated by the electric power industry[7] and 49 stations in a Tennessee Valley Authority (TVA) network are also considered in the analyses. Each sulfate measurement is made from a small strip of filter on which suspended particulate had been collected in a high volume air sampler. Each sampling period is 24-h, and the filters are changed at midnight (local standard time). The filter strip is extracted with water, and a portion of the aqueous extract is analyzed for sulfate by the methyl thymol blue method.

At the present time no National Ambient Air Quality Standard (NAAQS) exists for sulfates. In an EPA position paper[3] on the regulation of atmospheric sulfates the highest concentration tentatively associated with adverse health effects was reported to be 10 $\mu g/m^3$ (24-h average) and in this report concentrations greater than 10 $\mu g/m^3$ are labeled high.

THE OZONE EPISODE

The investigation of the ozone episode[4] examined data from approximately 100 stations in the Eastern United States extending from Ohio and Massachusetts in the north to Tennessee and North Carolina in the south. In the report[4] data for 50 representative stations in 11 states are presented (no ozone data were available for West Virginia and South Carolina). Ozone monitoring stations are usually operated by State and local agencies, with the State agency being responsible for providing the Federal Government with a near-complete and accurate record. More than two dozen agencies collected the analyzed data. One station in Richmond, Virginia, used an ultraviolet Dasibi instrument, but all others employed a chemiluminescence instrument.

The current NAAQS (hourly value) for ozone*, not to be exceeded more than once a year, is 160 g/m^3 or 80 ppb[8]; in this report, when the NAAQS is violated, a concentration is called high. The ozone data presented came from the NADB.

*It has been proposed that the NAAQS be revised upward to 200 $\mu g/m^3$.

THE SO_2 TO SULFATE CONVERSION AND LONG-RANGE TRANSPORT

The conversion of SO_2 to sulfate in the air and the possibility of long-range transport of the sulfate have been reported extensively[9-16]; there are many observations and findings but the agreement is not universal. One group of investigators[9] found no clear evidence of long-range transport, another investigator[10] reported obvious transport out to 1000 km, and others[11] found transport readily occurred but was limited to several hundred km. An incomplete knowledge of the meteorology, chemistry, and timing of processes in the conversion of man-made SO_2 to sulfates and of the eventual return to the surface by uptake and precipitation is the cause of the disagreement about the long-range transport of sulfates. Various investigators have hypothesized about features of the processes. Georgii[12], basing his hypothesis on observations over Central Europe, noted three important features. First, the vertical SO_2 concentration decreases rapidly with altitude, reaching half the ground concentration at 800 to 1200 m above the surface. Second, seasonal variations of the SO_2 concentration are limited to the 2000 m immediately above the surface. Third, inversions prevent, and convection accelerates the transport of SO_2 into higher layers; above the inversion and haze layers, the SO_2 concentration decreased markedly, whereas the sulfate concentration is not much influenced by the thermal structure of the atmosphere. The difference between the gas phase and liquid phase conversion of SO_2 to sulfate was noted by Kellogg et al.[13]. They reported the gas phase conversion showed a half-life for SO_2 of 12 d while, when SO_2 was dissolved in fog or cloud droplets, particularly where metal salts were present to serve as catalysts, the SO_2 rapidly (within hours) oxidized. Weber[14] estimated that 50% of the SO_2 emitted by power plants and the space heating chimneys in the Frankfurt area was oxidized in the first 20 min to 1 hr of travel time during the winter (in relatively moist air). Atkins et al.[15] in discussing sulfate concentrations over Britain, stated that the concentrations were indicative of the history of the air mass several days earlier and showed air in which oxidation of SO_2 occurred at distances up to 1000 km upwind over Central Europe. The authors[15] further stated that the sulfate was removed from the atmosphere almost solely by rainfall.

Nisbet[16] stated that after transport and oxidation, sulfur is returned to earth by four principal routes:

1. absorption of gaseous SO_2 by the soil or vegetation;
2. deposition of SO_2 in rain or snow;
3. deposition of sulfates in rain or snow; and
4. dry deposition of particles containing sulfates.

DIURNAL VARIATIONS OF SULFATES

Since many meteorological phenomena (e.g., wind speeds, temperature, relative humidity) usually show marked diurnal variations, a knowledge of the diurnal variations of sulfates could indicate which meteorological phenomena might account for sulfate variations. Unfortunately, investigators of the diurnal variations of sulfate concentrations have produced inconsistent and conflicting results[15,17-20].

METEOROLOGICAL CONDITIONS ASSOCIATED WITH HIGH CONCENTRATIONS OF OZONE AND SULFATES

Considerable documentation of the meteorology associated with high oxidant concentrations has accumulated. Middleton et al.[24], in 1950 reported that high ozone concentrations occurred with weak winds and stagnant air. Other early, comprehensive investigations of the Los Angeles ozone concentrations[22-24] related variations in concentrations to variations in the following: intensity and duration of solar radiation; surface temperature; the depth of the polluted layer (the top coincided with the base of the subsidence inversion); and wind speed and direction. Following the report[25] that winds aloft in the Los Angeles area are important in transporting that which the author describes as "second-hand ozone" to unsuspecting downwind areas, investigators examined the three dimensional air movements and transport in the 200-km long Basin. Evidence[26-28] confirms that high ozone concentrations are frequently in the air aloft, even within the subsidence layer, and that these ozone-laden layers move with the winds aloft. Eventually, some of the ozone is brought to the surface in daytime mixing. In recent years the long-range transport of ozone has been reported in many areas of the nation[29-33]

As previously noted, direct and indirect photochemical processes are important in the production of sulfates, so intense solar radiation and abundant sunshine are conducive to high concentrations. Whenever there is good vertical motion in the daytime and ozone is carried aloft, SO_2 in the presence of this ozone aloft is oxidized at appreciable rates at night as well as in the daytime[34]. The heterogeneous rate of oxidation of SO_2 to sulfate is dependent on relative humidity[35,36]. In a laboratory study[36], no oxidation was detected when the relative humidity was less than 70%, while at higher humidities the oxidation rates were considerable (possibly because catalyst particles changed from solid form into solution drop form). Low speeds tend to keep sulfates near the sulfur sources; Bushtuveva[37] found that concentrations of sulfuric acid aerosol during "calm days" were 4.5 times greater than during days with winds averaging over 5 m/s. Sulfate concentrations will also vary with rainfall[18,38]. Early investigators[38] found that the sulfate concentration of rainwater decreased with an increased rate of rainfall; they suggested that there was a limited quantity of sulfate in the lower atmosphere, which is removed in each period of precipitation. In the other study[18] it was reported that the sulfate concentra- declined sharply as a result of rainfall and increased rapidly after the rainfall ended. Sulfate concentrations in urban areas tend to peak in the third quarter of the year (July, August, September) but occasionally peak in the second quarter[39].

POTENTIAL SOURCE AREAS OF OZONE AND SULFATE PRECURSORS

Since ozone and sulfates are seldom emitted directly to the atmosphere, their presence is dependent on the emission of precursors--pollutants that after being emitted into the atmosphere react and become ozone and sulfates. Hydrocarbon emissions are considered important forerunners of ozone, and SO_2 is the primary precursor of sulfates. Because differences in the observed spatial patterns of concentrations of ozone and sulfates could be due to differences in the emission patterns of the precursors, data on the emission patterns were sought.

Figure 1 shows the annual emissions of hydrocarbons in tons for 1973 (the most recent year available) for each state in the study area. The large tonnages in Illinois, New York, Ohio, Michigan, and Pennsylvania show that those states are major sources of ozone precursors. When emission density (emissions per km^2) is considered, a number of smaller states also have to be designated as large emitters--Massachusetts, Connecticut, New Jersey, and Maryland. Thus, the large emitters are primarily in the northern part of the Eastern United States.

Figure 2 shows the annual SO_2 emissions from power plants for 1974. The states with large emissions were Michigan, Illinois, Indiana, Ohio, Pennsylvania, New York, West Virginia, Kentucky, Tennessee and Alabama. The states of Massachusetts, Connecticut, Rhode Island, New Jersey, Delaware, Maryland and Virginia and the District of Columbia on an emissions per km^2 basis have to be considered small emitters.

METEOROLOGICAL RESOURCES

Daily weather data contained in the Local Climatological Data[40] for 86 National Weather Service (NWS) stations in the Eastern United States were evaluated. Major emphasis was given to maximum temperatures, visibilities, and the occurrences of precipitation at these stations. Daily Weather Maps[41] were reviewed; this publication has maps for the United States showing the conditions that prevailed at the surface and at 500 mb, about 5500 m above the surface, at 7 a.m., Eastern Standard Time each day. These maps were used to locate fronts, centers of high and low pressure, and areas of precipitation and to relate the wind speeds and directions to high concentrations.

Trajectory analyses[42] were used to supplement the data from the Daily Weather Maps by showing the likely paths of the layer of air prior to arrival in the area. The trajectory analyses are based on the wind data from the rawinsonde observations scheduled at 7 a.m. and 7 p.m. and the winds aloft observations at 1 a.m. and 1 p.m. each day. In the basic calculation, a point along the trajectory is determined every 3 h and data within a radius of 300 nautical miles (556 km) are evaluated. The model includes a

distance weighting factor (the closest observations receive the greatest weight), an alignment weighting factor (observations upwind and downwind receive the greatest weight), and a height weighting factor (the thicker the subpart of the trajectory layer that the wind represents, the greater the weight). Trajectory segments are linked together to produce a complete trajectory for the desired period of time. Trajectories are usually started from a source or receptor four times daily, 1 and 7 a.m. and 1 and 7 p.m. In this report, trajectories are used to show the backward movement of the surface-to 1000 m layer in 12-h segments for a number of designated cities. These trajectories are approximations and thus become progressively less reliable with each added segment. In this report the trajectories are limited to 48 h. A point on a trajectory indicates the general area and not a specific location where a layer of air was located at an earlier time.

SECTION 4

RESULTS

BACKGROUND

Whereas the air quality data collection program throughout the nation provides continuous hourly data for ozone concentrations, sulfate date are gathered only every 12th day and for a 24-h period. During early July 1974 the sulfate monitoring network, operated by the State and local agencies, collected samples on the 10th. Since this was only 1 d during the ozone episode, an ozone-sulfate correlation could be misleading unless the sulfate concentrations were shown to be representative of the period. Accordingly, the basic sulfate data were supplemented by: 1) Norfolk data in the NADB for July 8 and 9; 2) data from a four-station network operated daily by the CHESS program in the New York City area; 3) data from nine stations in a network[7] operated daily by the electric power industry in the Northeastern United States; and 4) data from 49 monitoring stations at 18 locations in a TVA network (this network collected samples on every sixth day).

The number of State and local sulfate monitoring stations in the Eastern United States that operated on July 10 was 83. Although much more numerous in the north, there were enough stations in the south to delineate the area with high concentrations. The ozone stations were so numerous in the Northeast that all could not be conveniently plotted on a map, so a number are not on the ozone figures that follow. In contrast to the Northeast, there was no ozone data for West Virginia, South Carolina, Georgia, and Alabama and a very limited amount of data for Michigan and Indiana.

SULFATE DATA

The locations of the State and local sulfate monitoring stations are shown in Figure 3, and the names of the stations are shown in Table 1. The sulfate data for the 83 stations on July 10 are shown in Figure 4. High

concentrations prevailed in an area from Boston to Atlanta to Chicago to Boston, an area of 1,000,000 km^2. The concentrations ranged from 63 $\mu g/m^3$ in southern Pennsylvania to 4 in northern Indiana with approximately three-fourths of the stations showing concentrations exceeding 10 $\mu g/m^3$. Not to be overlooked are the numerous areas reporting extremes in concentrations within short distances, for example: 1) southern Michigan, 42 (Lansing) vs 9 (Flint); 2) northern Indiana 25 (East Chicago) vs 4 (South Bend); 3) southeastern Pennsylvania, 63 (York) vs 7 (Lancaster); and 4) northeastern New Jersey, 29 (Elizabeth) vs 7 (Newark). These contrasts indicate that individual observations are representative of limited areas and that judgments about regional conditions should be based on observations from several locations. With more than 60 stations in the million km^2 area showing concentrations in excess of 10 $\mu g/m^3$, it is concluded that an episode of at least a 1-d duration existed in the region.

The data for Norfolk showed that the sulfate concentrations for July 8, 9, and 10 were respectively 5.0, 12.7, and 14.7 $\mu g/m^3$. These limited data indicate that Norfolk's relatively high concentrations extended back to the 9th, but not to the 8th.

The data for the four CHESS stations in the New York City area for July 6 to 11 are shown in Table 2. In the New York City area the sulfate concentrations were markedly higher on the 10th than on the 5 other days. The concentrations were relatively low on the 8th, increased on the 9th, then increased two or three fold on the 10th.

The data for the nine electric power company stations[7] which gave coverage from Illinois to New York, are shown in Table 3. The overall indication is that most of the area had concentrations in excess of 10 $\mu g/m^3$ most of the time. Three Indiana stations (and the fourth for 2 d) had high values on all 6 d and the values were comparable to those at the NADB stations on July 10 (see Figure 4). The only places and times at which low values were recorded were Huntington on the 6th and 7th, Scranton on all days but the 9th, and Albany on the 6th, 7th, and 11th. Tong et al[22] evaluating the concentrations at each of these stations, showed the following monthly average concentrations ($\mu g/m^3$) for July 1974; about 22 at the four Indiana stations

and at Huntington, 27 at Wheeling, 16 at Collins, 13 at Scranton, and 9 at Albany. Concentration levels twice the average values occurred at only one of the four stations in Indiana and then on the 11th, on the 8th and 9th at Huntington, on the 7th, 8th, and 9th at Wheeling, and on the 9th at Scranton and Albany.

The 18 locations from which the TVA obtained sulfate data are shown in Figure 5, and Table 4 lists the names of the locations. The 6-d sampling schedule provided large amounts of data for July 3 and 9 and a few data points for July 6, 7, and 8. The observed concentrations on these days and the average concentration observed during the July sampling days are shown in Table 5. The data for the 3rd indicate that the area had many locations exceeding 10 g/m^3, but the limited data for the 6th, 7th, and 8th indicate that concentrations were relatively low; most were less than 10 g/m^3, and all showed concentrations that were about half or less than the July average. On July 9, a majority of locations had concentrations exceeding 10 g/m^3 (again most stations had concentrations below the July average). In a number of areas there were sharp contrasts in concentrations within short distances; for example, in northeast Alabama between Widows Creek (13) and Hytop (15), in northwest Alabama between Colbert (3) and Muscle Shoals (9), and in western Kentucky between Paradise (10) and Land Between the Lakes (16).

The indication of the TVA data is that the concentrations on July 9 over the Southeastern United States were similar to those in the State and local network on July 10 (Figure 4), but on the 2 prior days they were lower.

The composite picture drawn from the sulfate data from the four sources is: 1) a 1,000,000 km^2 area in the eastern United States had high sulfate concentrations on July 10; 2) whereas some places had concentrations exceeding 10 g/m^3 on earlier days, the period of markedly high concentrations over an extensive area appeared to be July 8 to 10; 3) there was an apparent movement from west to east of a peak concentration with the peak passing through West Virginia on the 8th and 9th, Pennsylvania and New York on the 9th, and the New York City-Long Island area (and possibly Norfolk) on the 10th; and 4) although no peak moved through the southern part of the affected area, the area of high concentrations appeared to spread southward

from July 8 to 9.

THE OZONE DATA

The extent of the high concentrations of ozone on each day from July 6 through 11 is shown in Figures 6 to 11. On July 5 only a half-dozen locations had NAAQS violations while on July 6 (Figure 6) slightly more than one-third of the stations had violations. The high concentrations, on this date, were restricted to the northern areas and extended from Chicago to eastern Connecticut in three separate areas. On July 7 (Figure 7), a Sunday, almost two-thirds of the stations recorded violations of the standard, and the higher concentrations were observed farther south than they had been on the 6th. There were only two separate areas of high concentrations (the area of low concentration on July 6 in central New York and Pennsylvania was eliminated); they were separated by an area of low concentrations oriented north-south through western Ohio and eastern Kentucky and Tennessee. On July 8 (Figure 8) about three-fourths of the locations had NAAQS violations, and again the two separate areas with high concentrations were seen. This was the day that the majority of stations recorded their highest concentrations. July 9 (Figure 9) was the day with the greatest number of locations showing violations as more than three-fourths had concentrations exceeding 80 ppb. There were still indications of eastern and western areas with high concentrations, but the problem was moderating in the latter. On July 10 (Figure 10) less than half of the stations had violations, since the high concentrations were concentrated in the Richmond-to-New York corridor and Pennsylvania and Ohio. On July 11 (Figure 11) only five locations had violations, while 57 did not show violations; the regional ozone episode had ended by July 11.

The overall picture is that a large area in the Northeastern United States had high ozone concentrations from July 6 to 10. The concentrations and the number of stations with high concentrations were greatest on July 8 and 9. There was no gradual spreading of the area with high concentrations nor an apparent movement of a peak concentration across the area, as there had been with the sulfate concentrations.

TEMPERATURE DATA

The initial high ozone concentrations occurred on July 6, so the analysis of the temperature data start with that day. Figure 12, shows the maximum temperatures reported at 86 NWS stations in the Eastern United States. In order to locate the relatively warm areas, each station that observed a maximum temperature 2.7°C (5°F) or more warmer than its July average is marked in bolder print. Only three small warm areas are shown on July 6, indicating that high temperatures were not associated with the initial occurrence of high ozone concentrations. The overall comparison of July 6 maximum temperatures and the July average indicated that this was a relatively cool day over the whole area.

On July 7 (Figure 13) a large area across the northern section of the Eastern United States and two separate stations had relatively high temperatures. Many stations with high ozone concentrations (Figure 7) were within the area that observed high temperatures, but a large number were south of the area. Although a few of the Electric Power Industry stations showed high sulfate concentrations in the high temperature area, most stations in the area (Tables 2 and 3) had low concentrations.

On July 8 (Figure 14) the area with high temperatures included all of the northernmost stations, and the southern boundary was farther south than it was on July 7. It is interesting that temperatures in the north were on the average about 2.7°C (5°F) warmer than those in the south. The areas with high ozone concentrations (Figure 8) were for the most part in the same area as those with high temperatures; the stations with high ozone concentrations extended a little farther south. Comparison of the limited sulfate data with the temperature pattern showed no consistent agreement; monitoring stations (Tables 2 and 3) within the area of high temperatures showed a wide variation in concentrations.

On July 9 (Figure 15) the area with relatively high temperatures covered the greatest area that it was to cover during this period, and 17 stations had the highest temperature of the month on this date. The area with high ozone concentrations (Figure 9) was approximately the same as that with high temperatures. Although many stations in the high temperature area had high

sulfate concentrations, some stations outside the area had high sulfate concentrations (Tables 3 and 5).

On July 10 (Figure 16) two large separate areas and a station in West Virginia had high temperatures. The high-temperature eastern area had many locations with high ozone concentrations, but many locations with high concentrations were not in the areas with high temperatures. The area with high sulfate concentrations on this day (Figure 4) was practically the entire area; the areas of high sulfate and relatively high temperature were not similar.

Overall, the indication is that the initial high ozone concentrations occurred before the high temperatures, but through the worst of the ozone episode the area of high ozone concentrations was almost the same as the area with high temperatures. However, in the case of the sulfates there did not appear to be a good spatial agreement with regard to the areas of high temperature and high sulfates. Even if one were to consider a lag between the high temperatures and high sulfates, and compare the area of high temperatures of July 9 with the area of high sulfates of July 10, there did not appear to be agreement.

VISIBILITY

The NWS records always note the visibility restriction (fog, haze, smoke, precipitation, etc) whenever the visibility is less than 11.25 km (7 mi). The visibility observations that are presented are for 1 p.m. Eastern Standard Time, a time in the day when relative humidities are usually low and fog is reported infrequently. In the figures to follow the visibilities and obstructions to visibility are shown for the 86 NWS stations in the east, and areas with obstructions to visibility, other than rain, are delineated. In the text that follows, poor and restricted visibility are used interchangeably.

On July 6 (Figure 17) the first day with high ozone concentrations, the restricted visibility area was a 350-km wide band, running from just below New York City to near Richmond and extending 1300 km to southern Indiana in the west. Outside the restricted visibility area, 16 km (10 mi) or greater visibility was recorded at most stations. The majority of stations with high ozone concentrations (Figure 6) were to the north of the restricted visibility

area, and the majority of the ozone monitoring stations in the poor visibility area did not have NAAQS violations. With regard to the limited sulfate data (Tables 2, 3, and 5), most of the stations with low concentrations were outside the restricted visibility area, and most with high concentrations were inside the area.

On July 7 (Figure 18) the restricted visibility area extended from southern Michigan to northern Kentucky, then eastward to the Washington, D. C., area. Most of the ozone stations (Figure 7) in the poor visibility areas did not have violations of the NAAQS. To the northeast of the restricted visibility area, the ozone concentrations were high, and visibilities generally 16 km (10 mi) or more: to the west of the poor visibility area, all but one NWS station had a visibility of 12.9 km (8 mi) or more, while all five ozone monitoring stations showed violations. The EPRI sulfate monitoring stations (Table 3) with high concentrations were generally in the restricted visibility area, while the relatively clean EPRI stations (Scranton, Albany), CHESS stations (Table 2), and TVA stations (Table 5) were outside the area.

On July 8 (Figure 19) the area of poor visibility covered the Midwest and extended into northern Virginia, Georgia, and southwestern Tennessee. Although many of the ozone monitoring stations (Figure 9) in the poor visibility area did have NAAQS violations, a much greater proportion of stations had violations in the relatively good visibility area along the east coast. The sulfate data for Norfolk, and from the EPRI (Table 3) and CHESS (Table 2) networks, although limited, indicate that the stations with high concentrations were generally in the area with restricted visibility and those with low concentrations outside the area. The one TVA station reporting on this day, Loves Mill in southwest Virginia (Table 5), had a low concentration and was in an area with good visibility.

On July 9 (Figure 20) most of the Northeastern United States had poor visibility, and a large majority of the ozone monitoring stations (Figure 9) in the area had NAAQS violations. The sulfate data from Norfolk, and from the EPRI (Table 3) and CHESS stations (Table 2), indicate that stations with concentrations in excess of 10 $\mu g/m^3$ were generally in the restricted visibility area, but the TVA data (Table 5) indicate that a large area with high concentrations did not have restricted visibility.

On July 10 (Figure 21) the area of restricted visibility was smaller than it was on July 9, but still covered a large portion of the Eastern United States. Most stations with high ozone concentrations (Figure 10) were in the restricted visibility area. The sulfate data for July 10 were abundant (Figure 4) and show that the area of high sulfate concentrations was larger than the area with obstructions to visibility.

Overall, the indication is that the area of restricted visibility was not similar to the area with high ozone concentrations, except during the height of the ozone alert, July 9 and possibly July 10. On the days with limited sulfate data, the areas of restricted visibility and high sulfate concentrations were similar, but on the day with the most abundant sulfate data, the area with high concentrations was a little larger than the restricted visibility area.

SYNOPTIC WEATHER SITUATION

The broad scale weather conditions or synoptic weather data of July 6 to 10 are documented in the Daily Weather Maps[41]. The conditions on the first day, July 6, are shown in Figure 22; maps for the period July 7 to 10 were also examined, but were omitted because there were only small or gradual changes after July 6.

The main features of the surface weather map were: 1) a stationary front extending from below New England, west southwestward to northwest Tennessee; 2) a high pressure area centered over Lake Erie; and 3) the western extension of the Bermuda high pressure area over the Southeastern United States. The location of the front practically coincided with the southern boundary of the area of high ozone concentrations (Figure 6); the high ozone concentrations were restricted to the air mass north of the front. The area of reduced visibility (Figure 17) included locations on both sides of the front and was practically centered on the front. The sulfate data from the CHESS stations (Table 2) showed that the air immediately north of the front was relatively clean, whereas the EPRI data (Table 3) showed that most stations north of the front had high concentrations.

On July 7 there was just a remnant of the stationary front immediately south of Pennsylvania and a weak high over the east was the only feature on the surface maps on July 8 and 9. The July 10 map showed a cold front was over southern Michigan, New York, and New England. Throughout the period the areas with high ozone concentrations (Figures 7-10) and poor visibility (Figures 18-21) expanded as the two high pressure areas of July 6 amalgamated. High sulfate concentrations also gradually spread over the entire area as the weak high pressure dominated the weather. Behind the cold front of July 10 the ozone concentrations were reduced and the visibility improved, but the sulfate concentrations (Figure 4) appeared to be unaffected.

The 500-mb map for July 6 (Figure 22b) was typical of July 6 to 10. High pressure with subsiding air over the Eastern United States was the dominant feature of the maps for the period. The strong flow out of the extreme Southeastern United States feeding the flow over the northern tier of states in the east was a feature of the maps from July 6 to 8. Warm air was being transported into the high over the east by this flow.

Overall, the synoptic situation was one that showed stagnation at the surface and aloft and subsiding air over a large part of the Eastern United States. This stagnation coupled with the subsidence appeared to have marked effect on the observed ozone and sulfate concentrations and visibility. The high ozone concentrations were restricted to one air mass in which the number of stations with high concentrations increased with time as the air moved slowly and became progressively warmer due to an influx of air from warmer areas and the subsidence. In addition, the high ozone concentrations were not restricted to the western side of the surface high pressure area, as reported by Lyons and Cole[43], but were observed throughout the high pressure area. The sulfate concentrations when the data were limited were highest near the center of the surface high pressure area, but on the one day with abundant data, high concentrations were widespread and extended beyond the area of poor visibility at the surface. The visibilities were restricted in the vicinity of the slow-moving front early in the period, and then the obstructions spread throughout the slow-moving air mass. Next, the obstructions were eliminated as the rapidly moving front passed through the area toward the end of the period. The passage of the front was associated with an improvement

in visibility and with a reduction in the ozone concentrations, but did not simultaneously reduce the high sulfate concentrations.

OTHER METEOROLOGICAL OBSERVTIONS

Meteorological parameters other than those previously summarized were also examined. These included minimum temperatures, visibility at 7 a.m., relative humidity at 6 a.m. and noon, percent of possible sunshine, and precipitation for 24-h periods. The minimum temperatures, like the maximum temperatures, were relatively high. None of the other parameters showed a pattern that was considered noteworthy except precipitation. During the period of July 6 to 9, the rainfall was usually in the form of afternoon or evening showers and these occurred over widely separated areas. The rainfall on these 4 d did not appear to be associated with the ozone concentrations; some areas with high concentrations had rainfall while most had no precipitation. The spatial distribution of sulfate monitoring stations during these 4 d was inadequate for making comparisons with rainfall patterns.

On July 10 (Figure 23) the rainfall was extensive. The rainfall again occurred over both areas with high ozone and low ozone concentrations. With regard to sulfate concentrations (Figure 4) the area with high sulfate concentrations was about the same as the area that recorded rainfall. There appeared to be no correlation between the 24-h rainfall and restricted visibility (at 1 p.m.) patterns, although there was a rather consistent relationship for 5 d (July 6-10); the southern part of the area with poor visibility generally had rainfall, while the areas to the north and west did not.

TRAJECTORIES OF THE SURFACE-TO-1000-m LAYER

Backward trajectories indicate the general area from which air has come to designated locations. The trajectories may be used in conjunction with air quality data to show that air came from an area that already had a pollution burden. The upper limit of the layer for which trajectories are determined is the conservative height of 1000 m; the bulk of the pollution in the atmosphere would be contained in the layer between the surface and 1000 m. Trajectories on occasion show that air from one area may be moved in a period of 48 h to more than one downwind location. During periods of weak winds, July 6-10, 1974, for example, trajectories readily crossed one

another, and on some occasions air arrived in various areas by circuitous routes.

Backward trajectories for 48-h periods for selected stations, mostly state capitals, for July 6 to 10, 1974, are shown in Figures 24 to 28. Although four trajectories were determined for each day, only that for the ending time of 1 p.m. is shown. This ending time is close to the time when maximum hourly ozone concentrations generally occur, and the trajectories for this ending time were considered representative of the four daily trajectories. The station coverage is dense in order to show the various areas from which air moved into almost every state and the fact that air from over one area reached widely separated receptors.

Figure 24 shows the trajectories for July 6. These trajectories indicate that the high ozone concentrations (Figure 6) in the northeast were associated with rapid flows from the west and northwest, while the high concentrations in the northwest were associated with circuitous trajectories. The limited sulfate data (Tables 2, 3, and 5) showed that the lower concentrations occurred in areas that had long and direct trajectories, while the high concentrations occurred in the area where the air traveled a circuitous path. The area of poor visibility (Figure 17) occurred in the boundary area between the flows with the component from the north (in the northern third of the area) and the flows with the component from the south. Comparison of individual trajectories also showed interesting results. The trajectories ending in central Connecticut (which had high ozone concentrations) and eastern Massachusetts (which had low ozone concentrations) traversed locations that were generally much closer than the terminal points (about 150 km apart; although the air came to the two locations from the same general source areas these downwind receptors observed different concentrations. The flows ending in southeast New York and south-central Pennsylvania (both areas had high ozone concentrations) traversed common areas in eastern Ohio and western Pennsylvania. A point that was common to three plotted trajectories, those ending in central and northeast Illinois and central Indiana, was 150 km south of Chicago (not shown is a trajectory for central Ohio which also crossed the area). The cities at the end of these trajectories had high ozone concentrations.

On July 7 (Figure 25) the trajectories were markedly shorter than those

for July 6 indicating that the air movement on July 7 was considerably less than that on July 5. Most of the flow into the southern stations was from the south, and the area did not have high ozone (Figure 7) or sulfate (Table 5) concentrations. The flows into the northern stations were from the west and northwest, and the stations in this area were those that had high ozone and sulfate (Table 3) concentrations and restricted visibility (Figure 18). The areas with high ozone concentrations in the north were downwind of areas that had air with an ozone burden on July 6 (Figure 6). The unpolluted areas in the south had flows from relatively clean areas. If the ozone burden in the air was no more than 2 d old, the high contratrations at the individual stations must have been caused by emissions within a state or from a state immediately adjacent to it; most of the trajectories originated in one state and terminated in an adjacent state. The sulfate data in Table 3 show that Wheeling had a markedly high concentration, and the trajectory ending in West Virginia indicated that that area had the least air movement; the high sulfate concentration was associated with emissions from areas very close to Wheeling.

On July 8 (Figure 26) in all areas except the extreme northeast, the trajectories were short. In the west and southeast the movement was from the south, and in the northeast it was from the northwest. High ozone concentrations were observed in practically all areas (Figure 8). Most of the southerly flows brought air from areas that had relatively low concentrations on July 6 and 7 and normally emitted a small amount of ozone precursors (Figure 1) yet the downwind stations observed high ozone concentrations. The high ozone concentrations were not always associated with flows from areas having high ozone concentrations on earlier days. The limited sulfate data in Tables 2, 3, and 5 indicate that the area with the highest sulfate concentrations, West Virginia, had the trajectory with the shortest travel distance; the observed high concentrations at Huntington and Wheeling were associated with emissions from nearby sources.

On July 9 (Figure 27) the trajectories were about as long or slightly longer than those on July 8. In the northeast the flows were mostly from the west, the ozone concentrations were high (Figure 9), and on prior days the air was over areas with high ozone concentrations (Figures 8 and 9).

In the northwest and south, where ozone concentrations were declining (Figure 10 vs Figure 9), the flow during the most recent 12 h was from the west or southwest, while earlier it was from the south; the upwind areas had relatively low concentrations on July 8. It is interesting that the area of high ozone concentrations is associated more with flows from the areas of large emissions of ozone precursors (Figure 1) than the area with the shortest trajectories (i.e., the weakest winds). The limited sulfate data (Tables 2, 3, and 5) showed high sulfate concentrations at Wheeling, Huntington, and the one Lawrenceburg (near Cincinnati) station. The movement of air over West Virginia was so slow that the polluted air could not have come from a great distance; at the Lawrenceburg site for the most recent 12-h flow, the flow was along the Ohio River Valley.

On July 10 (Figure 28) the lengths of the trajectories were generally longer than they had been on July 9. The trajectories show that areas with high ozone concentrations (Figure 10) were downwind of areas that also had high concentrations on the prior days and are normally expected to have large emissions of ozone precursors. The NADB sulfate data (Figure 4) show that high concentrations occurred throughout the area. The most recent of the 12-h trajectory segments show that many of the high concentrations in the north and east were associated with a flow out of the northwest. Earlier, however, all trajectories were generally of shorter length and showed movements over all areas normally associated with large emissions of SO_2 (Figure 2); the high concentrations were likely more affected by earlier slow movement over source areas than by the most recent 12-h flow.

Overall, the trajectory analyses showed that the high concentrations of ozone were associated with flows across the northern tier of states--the area where the sources of ozone precursors are most numerous. The indication was that air having an ozone violation on one day frequently had shown a violation on an earlier day at an upwind location. Although the trajectories indicated that interstate transport of ozone occurred, 48-h movements were frequently restricted to flows between adjacent states; long-range transport was limited due to the stagnation conditions. The highest sulfate concentrations were generally associated with the shortest

trajectories; local emissions appeared to be the major cause of the worst sulfate conditions. On the day when the sulfates were an area-wide problem, practically all of the high concentrations could be traced back to slow movement over source areas.

SECTION 5

SUMMARY

1. On July 10 a 1,000,000 km^2 area of the Eastern United States observed high sulfate concentrations. The concentrations appeared to be high over a large area from July 8 to 10, and the peak in concentration appeared to move eastward during the period. On July 6 and 7 a few stations in the north had high concentrations.

2. The ozone episode covered the Northeastern United States from July 6 to 10. Although the concentrations and number of stations with high concentrations was greatest on July 8 and 9, the ozone problem was fairly widespread and severe on all 5 d. There was no apparent movement of a peak concentration across the area.

3. The maximum temperature data analysis showed that: a) there were high concentrations of ozone over a large area before there were high surface temperatures; b) during the worst of the ozone episode, the area with high ozone concentrations was almost the same as the area with high temperatures; and c) during the worst of the sulfate episode, the area with high concentrations covered a much larger area than that with high temperatures.

4. The visibility data analyses showed that: a) the area with high ozone concentrations did not correspond day by day to the area with restricted visibility; and b) there did appear to be considerable similarity in areas with poor visibility and high sulfate concentrations on those days when the data were limited, and to a lesser degree on the day when the sulfate data were abundant. Areas with low sulfate concentrations were generally outside the areas with restricted visibility.

5. The synoptic weather analysis showed that: a) large-scale stagnation occurred at the surface and aloft; b) the high ozone concentrations were not

restricted to the western side of the air mass but spread throughout it; d) the sulfate concentrations were initially high near the center of the surface high pressure area (based on a limited amount of sulfate data), but eventually the whole area had high sulfate concentrations; e) the restrictions to visibility were initially associated with a front (obstructions were present on both sides) but after July 6 the high sulfate concentrations generally occurred in the areas of restricted visibility and low sulfate concentrations occurred outside the poor visibility areas; and f) a frontal passage toward the end of the period was associated with a lowering of the ozone concentrations and the elimination of restrictions to visibility but did not affect sulfate concentration.

6. The rainfall analyses showed that: a) there was no correlation between rainfall and ozone concentrations; and b) the area of rainfall on July 10 had boundaries corresponding to the area with high sulfate concentrations.

7. The trajectory analysis showed that: a) high ozone concentrations were usually associated with flows over the area of highest emissions of ozone precursors and air that had an ozone burden before it arrived in the area where the high concentration was detected; b) long-range transport was involved in moving the ozone-laden layers, but the transport was limited by the stagnation conditions prevailing; c) the highest sulfate concentrations were associated with the shortest trajectories; and d) on the day with the area-wide problem with sulfates, the high concentrations were traced back to slow-moving air over the area with high precursor emissions.

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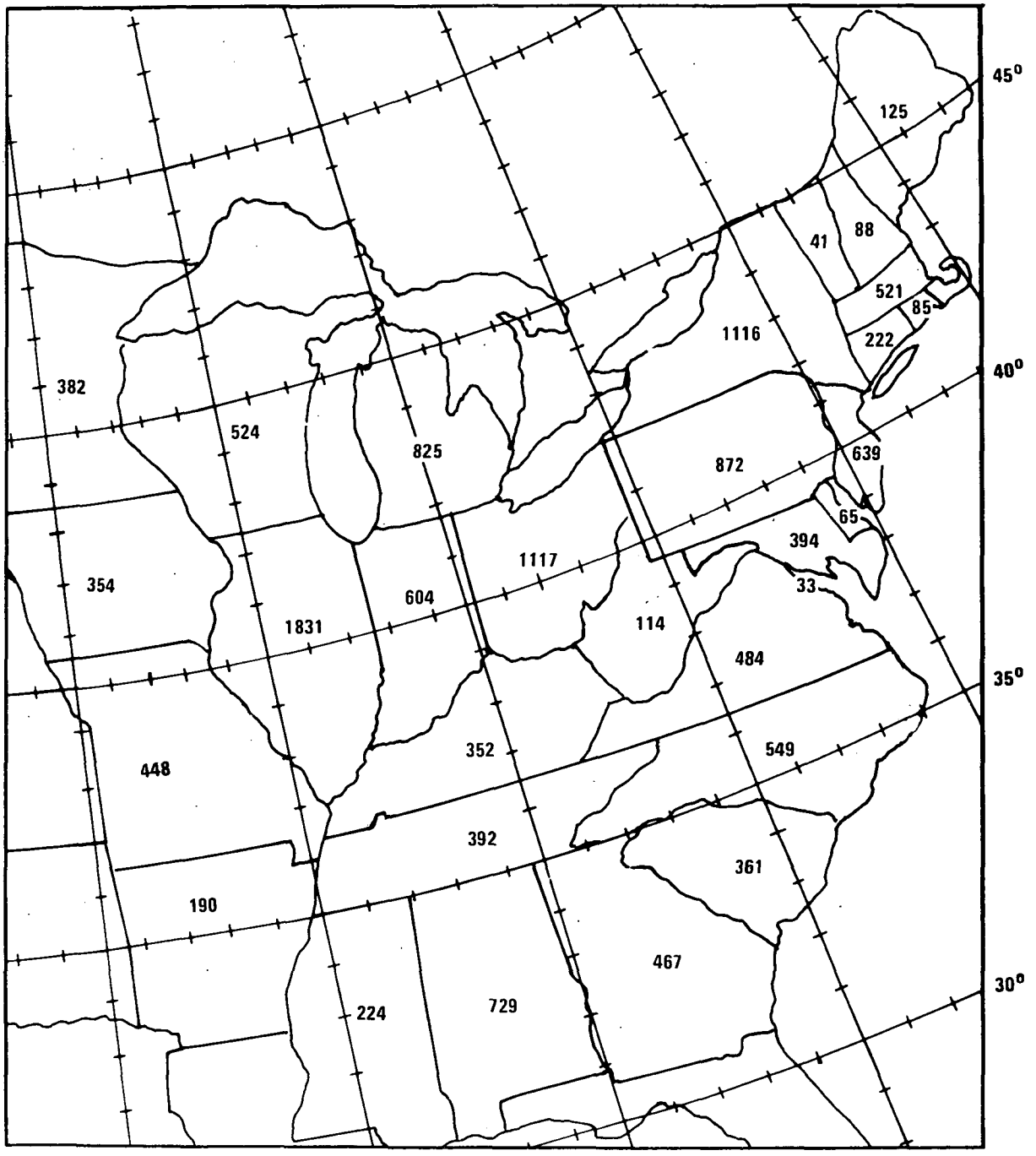


Figure 1. Annual hydrocarbon emissions by state in 1973 (1000 tons).

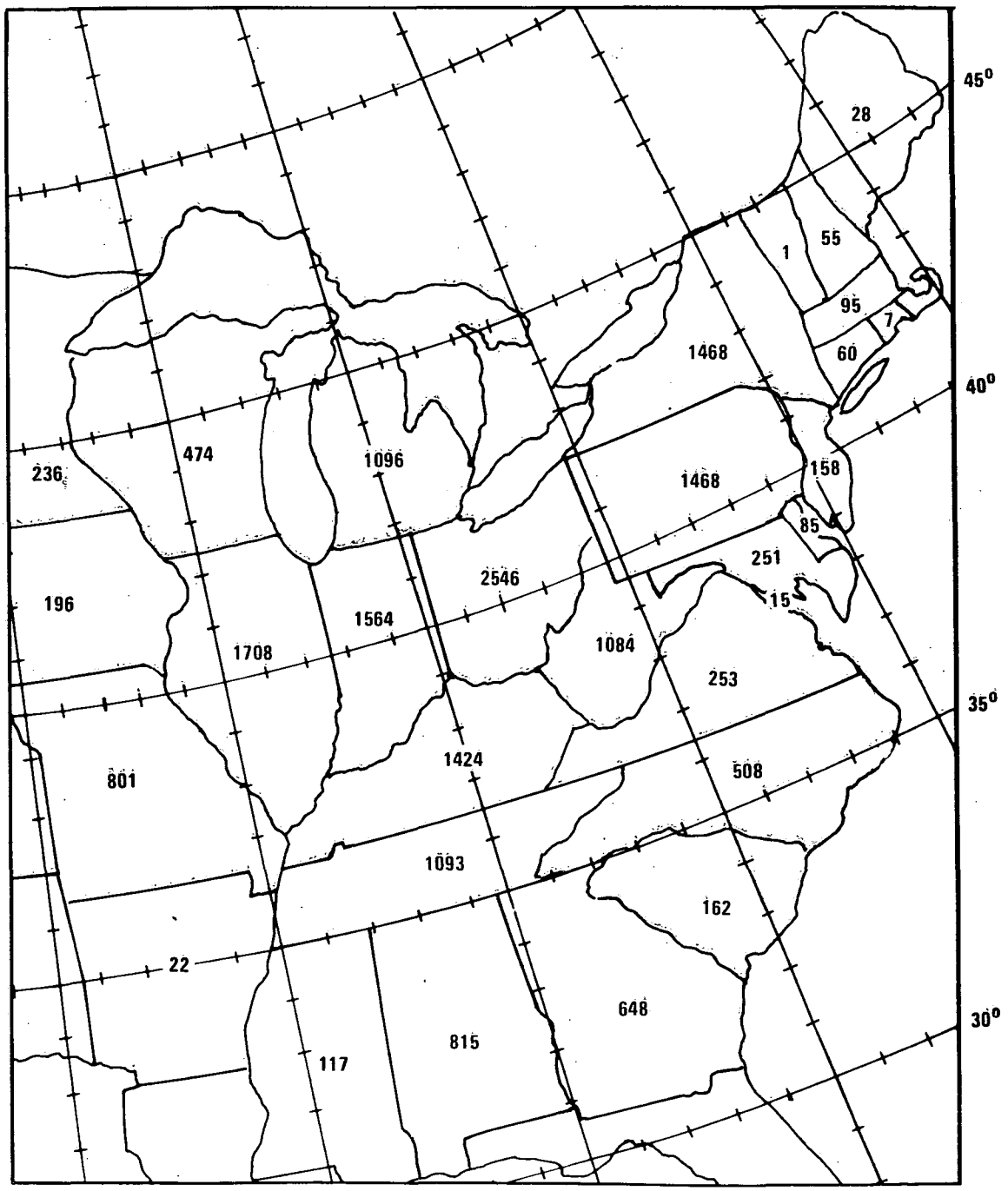


Figure 2. Annual SO_2 emissions from power plants by state in 1974 (1000 tons).

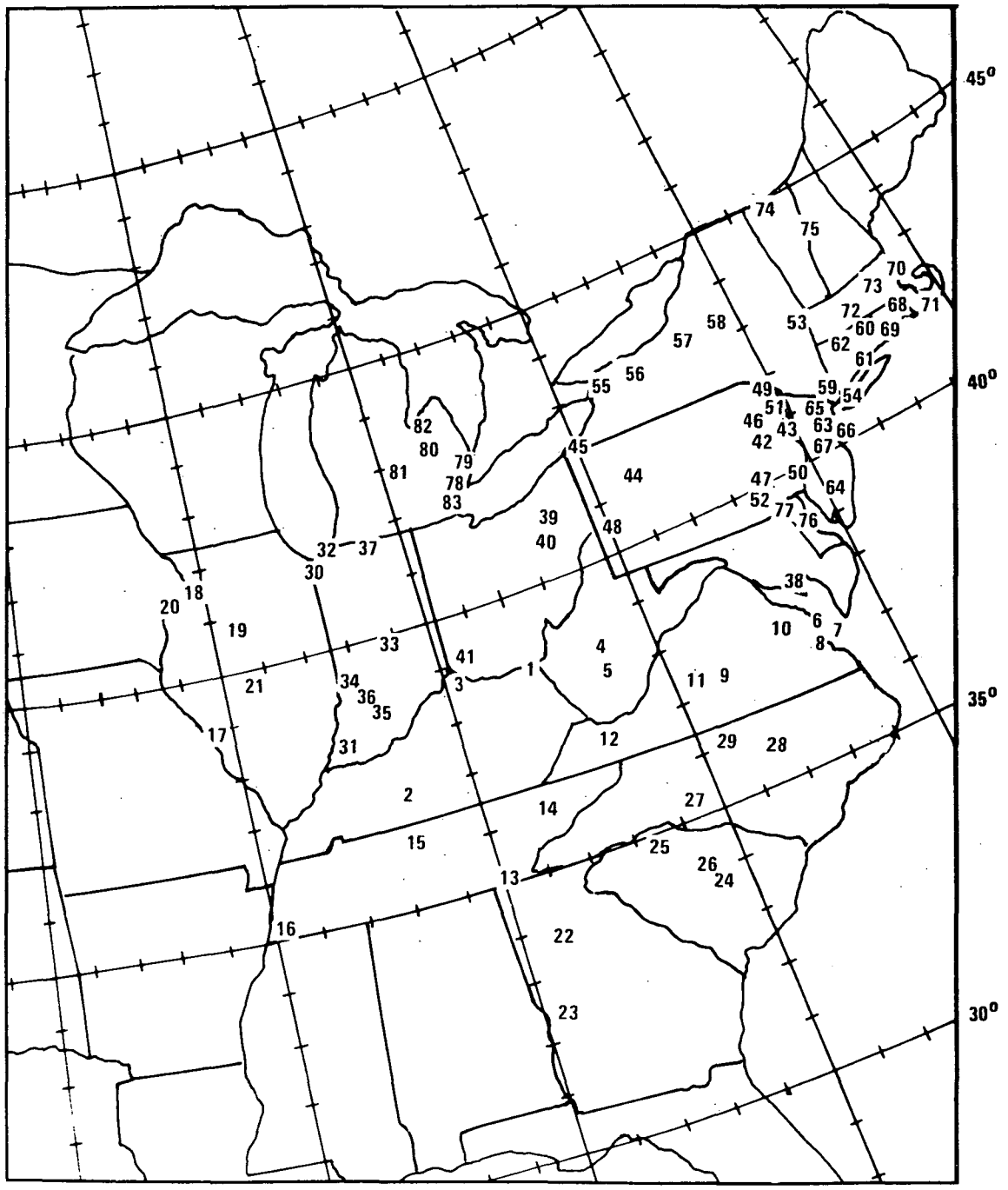


Figure 3. Locations of sulfate monitoring stations of state and local agencies (see Table 1 for station names).

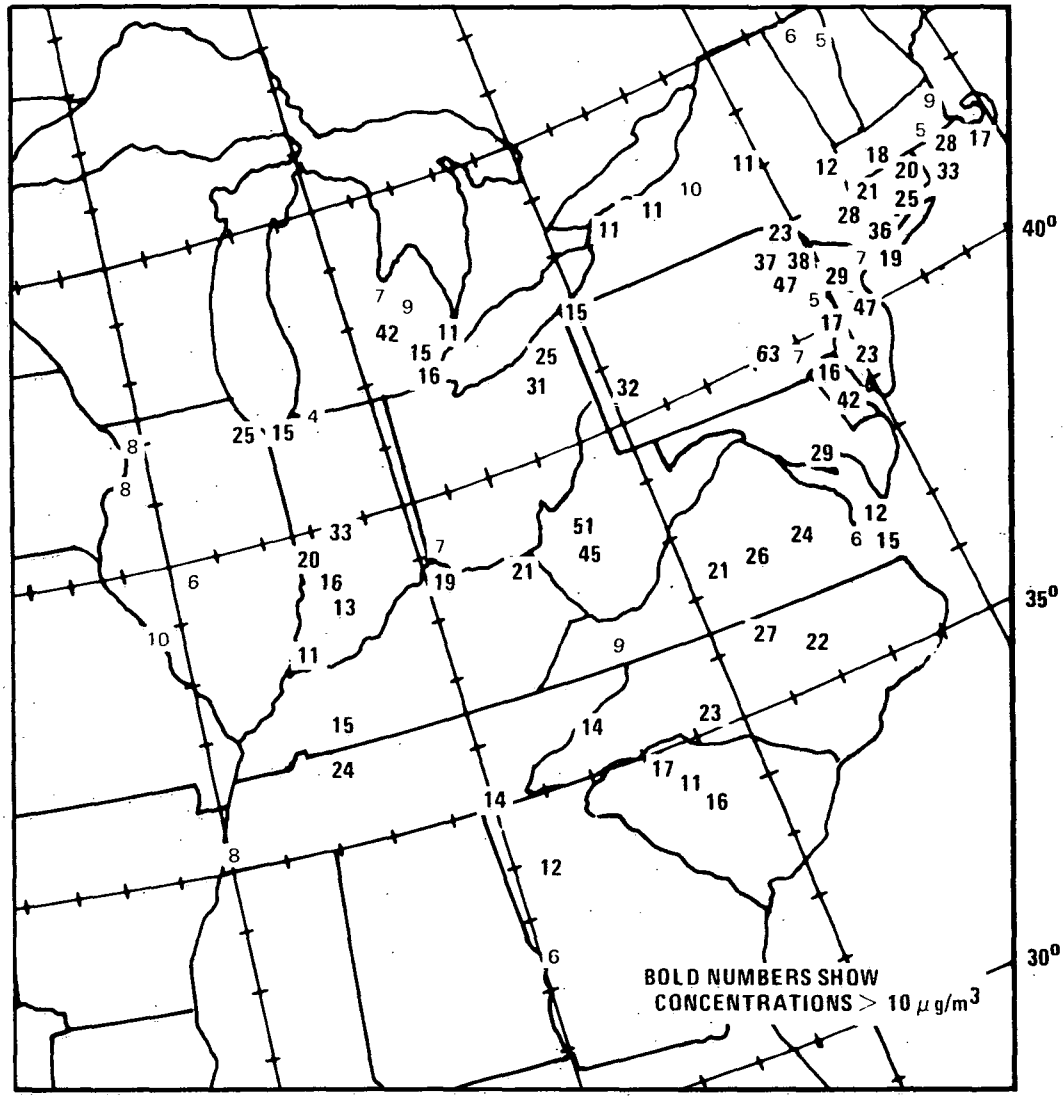


Figure 4. Sulfate concentrations ($\mu g/m^3$) July 10, 1974.

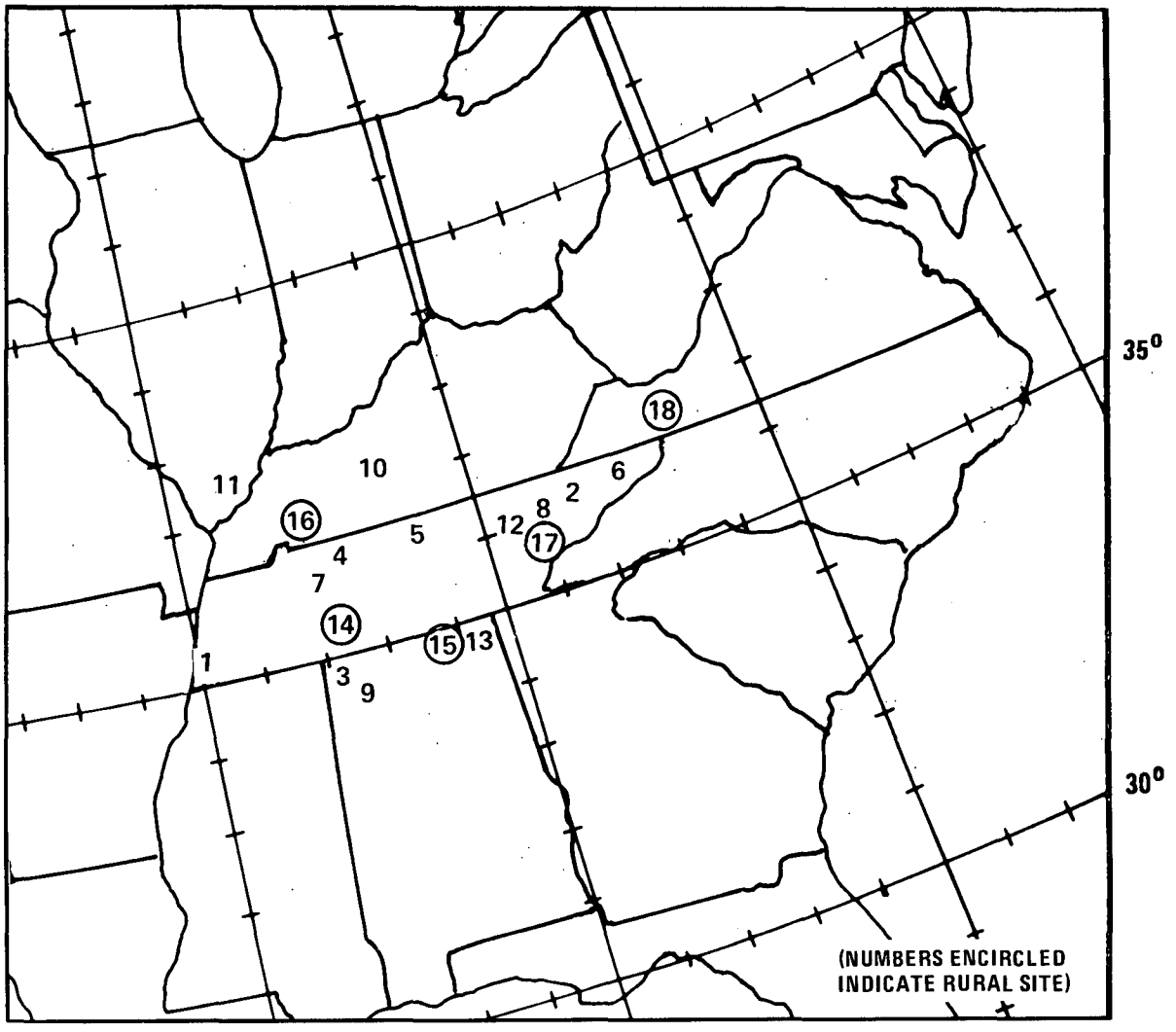


Figure 5. Station locations (see Table 4 for station names) TVA network.

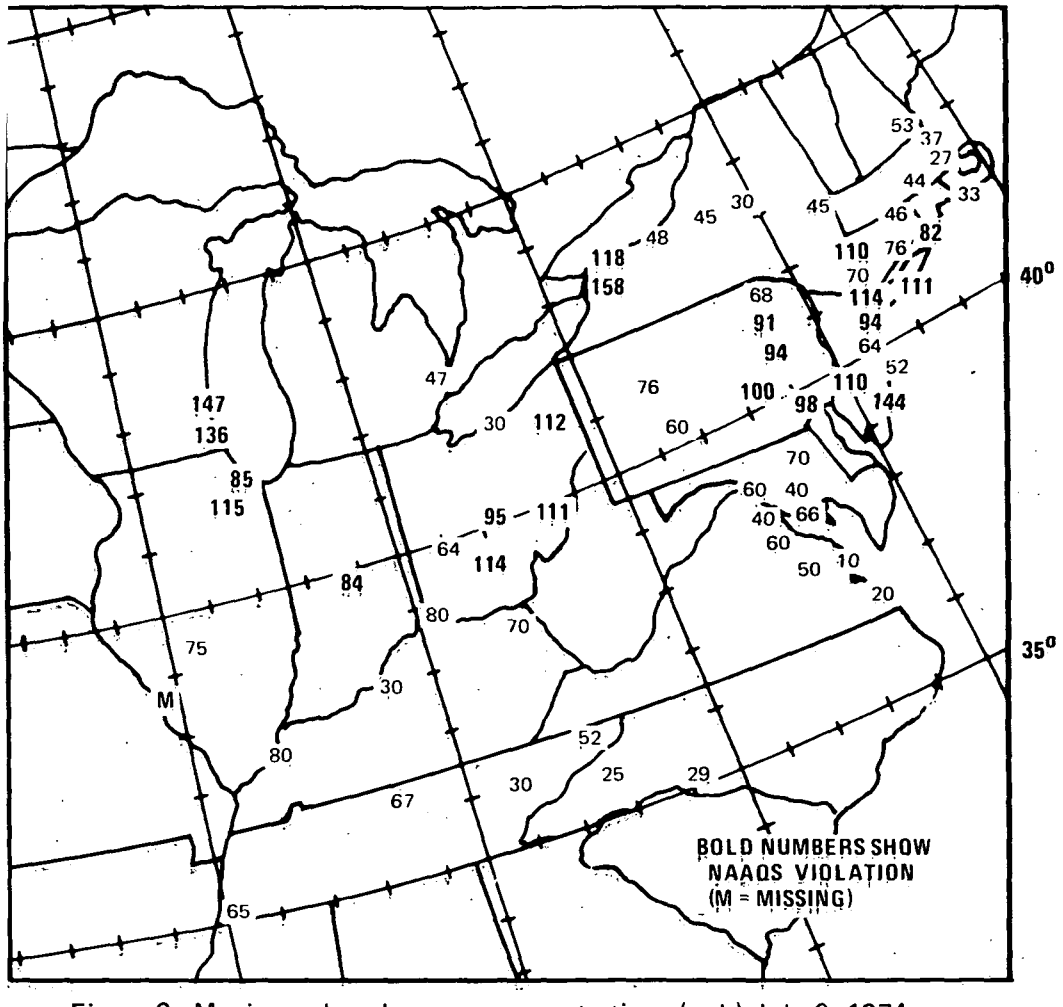


Figure 6. Maximum hourly ozone concentrations (ppb) July 6, 1974.

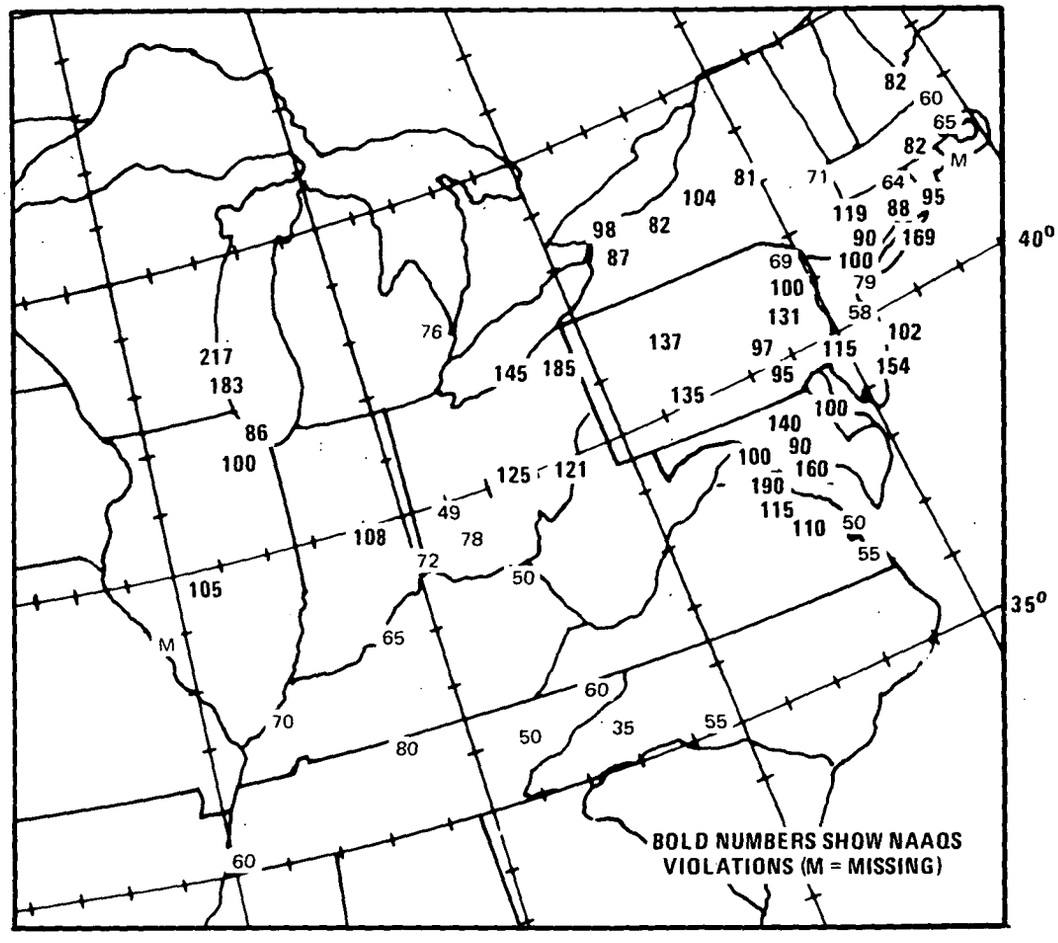


Figure 7. Maximum hourly ozone concentration (ppb) July 7, 1974.

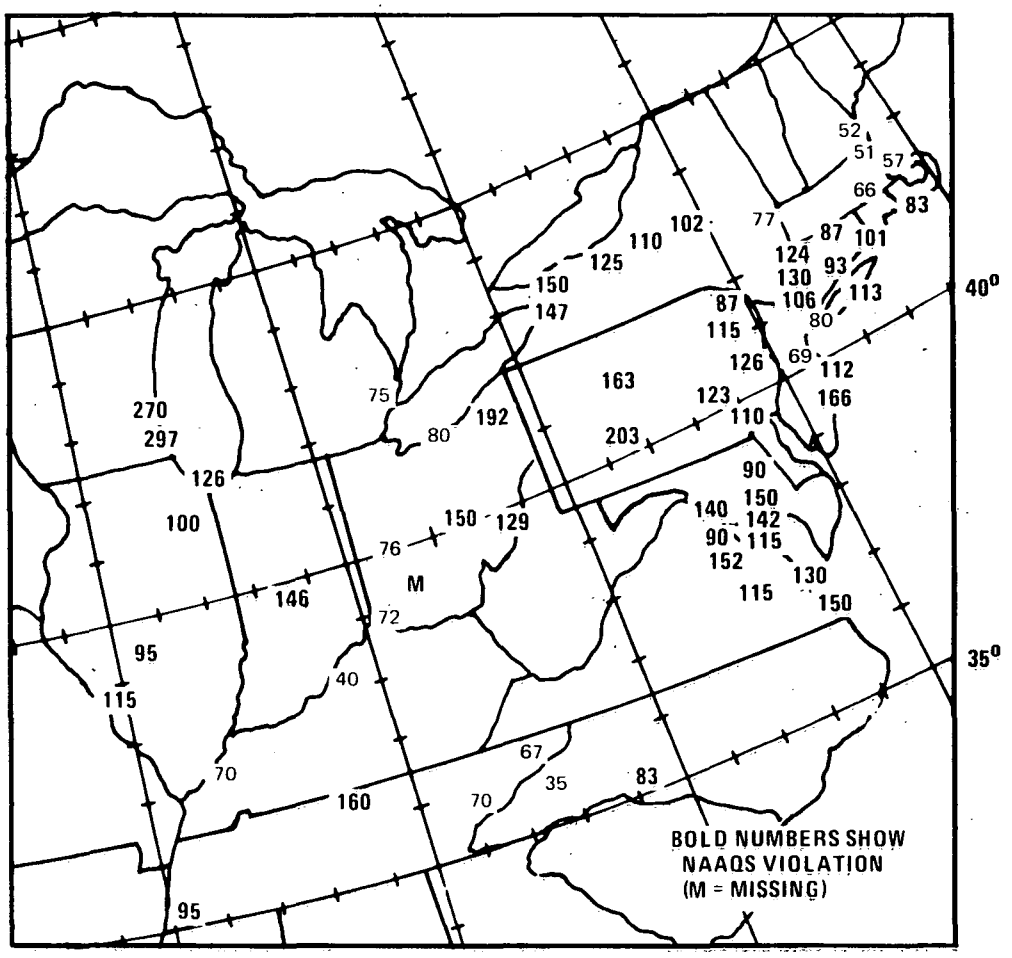


Figure 8. Maximum hourly ozone concentration (ppb) July 8, 1974.

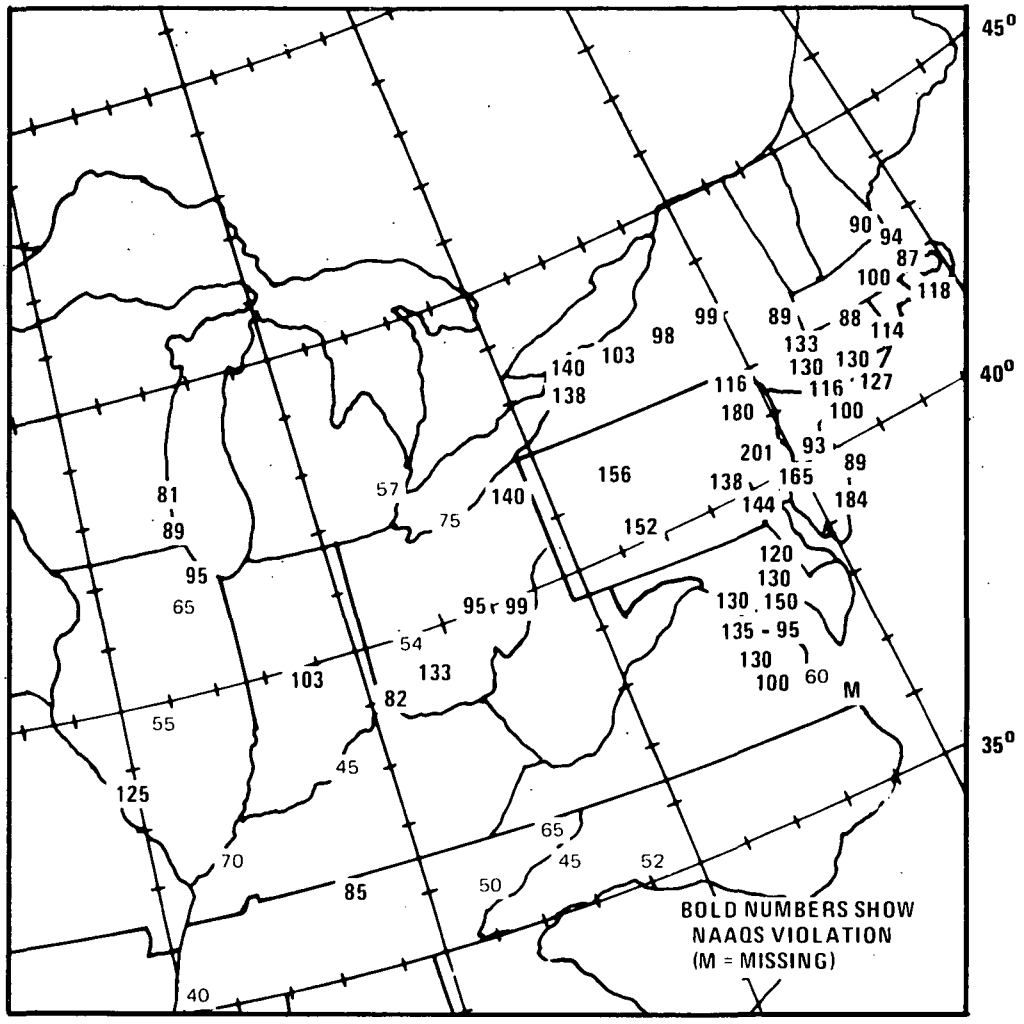


Figure 9. Maximum hourly ozone concentration (ppb) July 9, 1974.

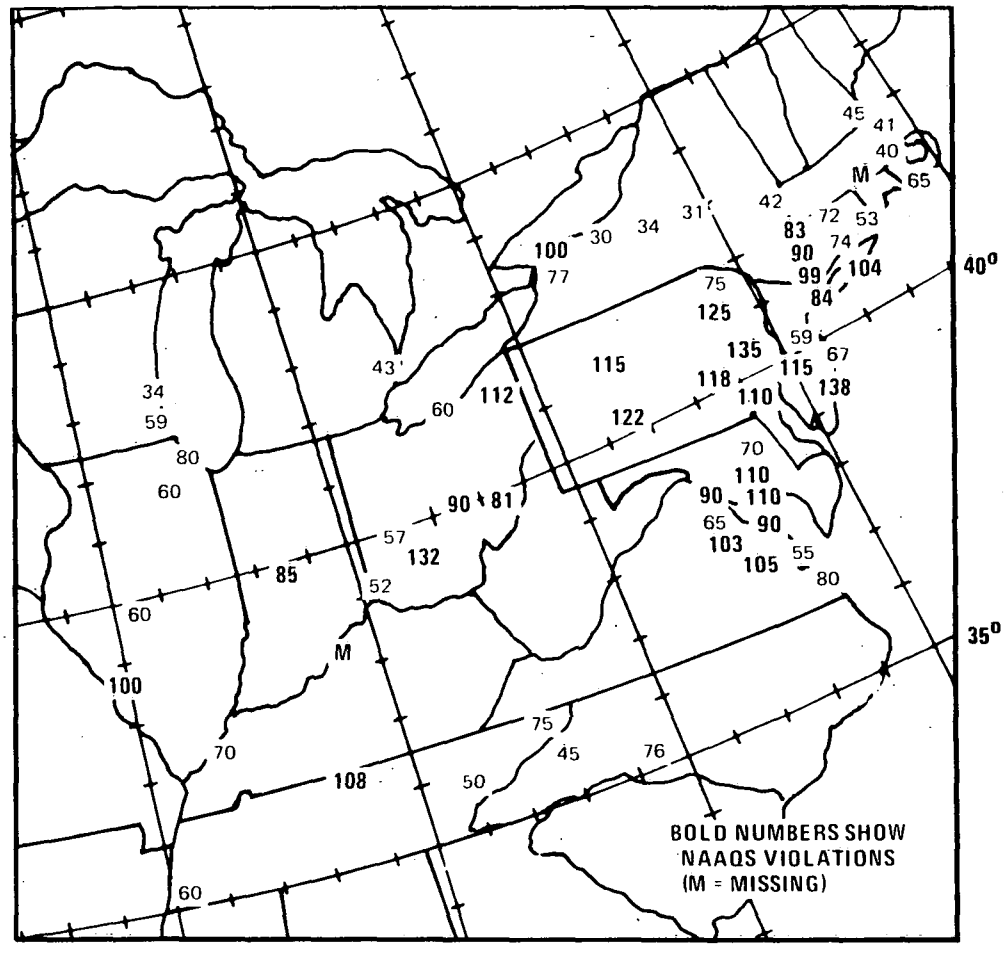


Figure 10. Maximum hourly ozone concentrations (ppb) July 10, 1974.

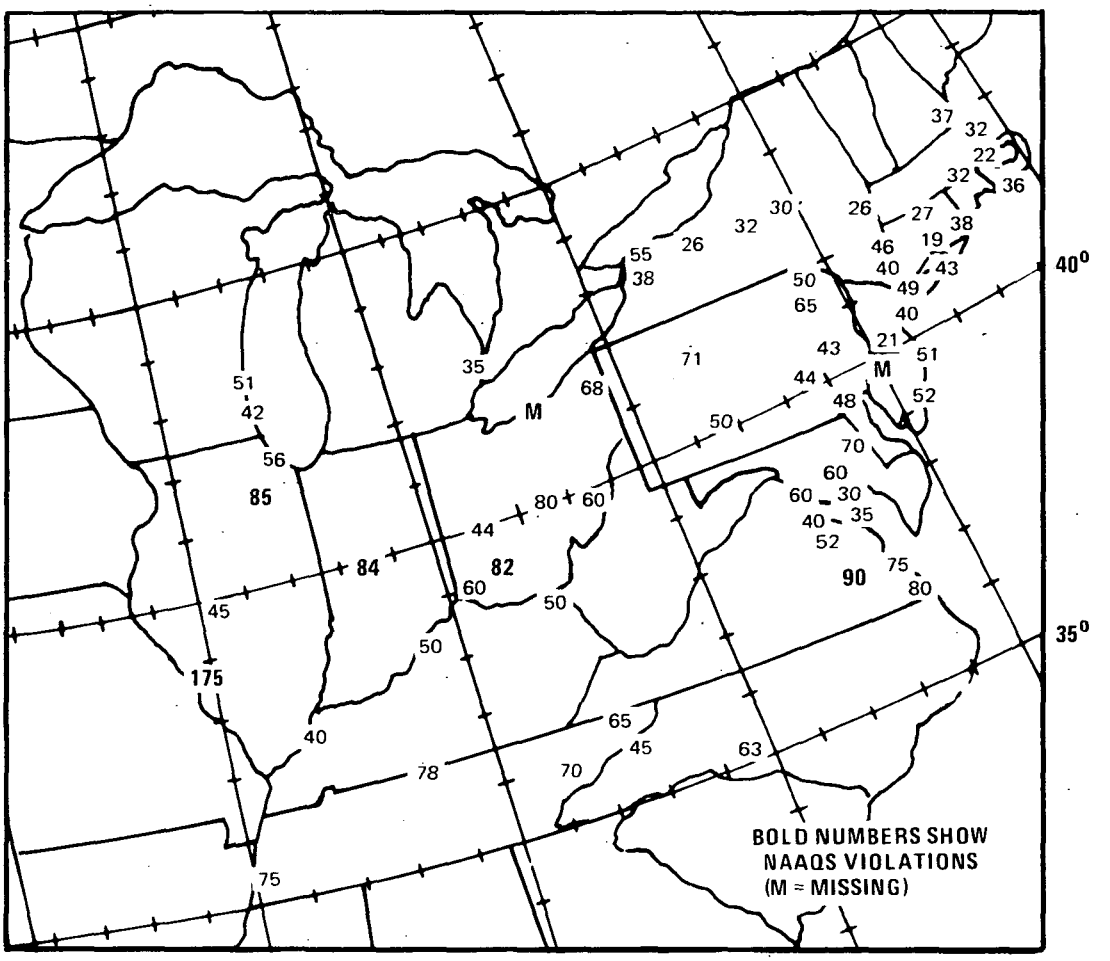


Figure 11. Maximum hourly ozone concentration (ppb) July 11, 1974.

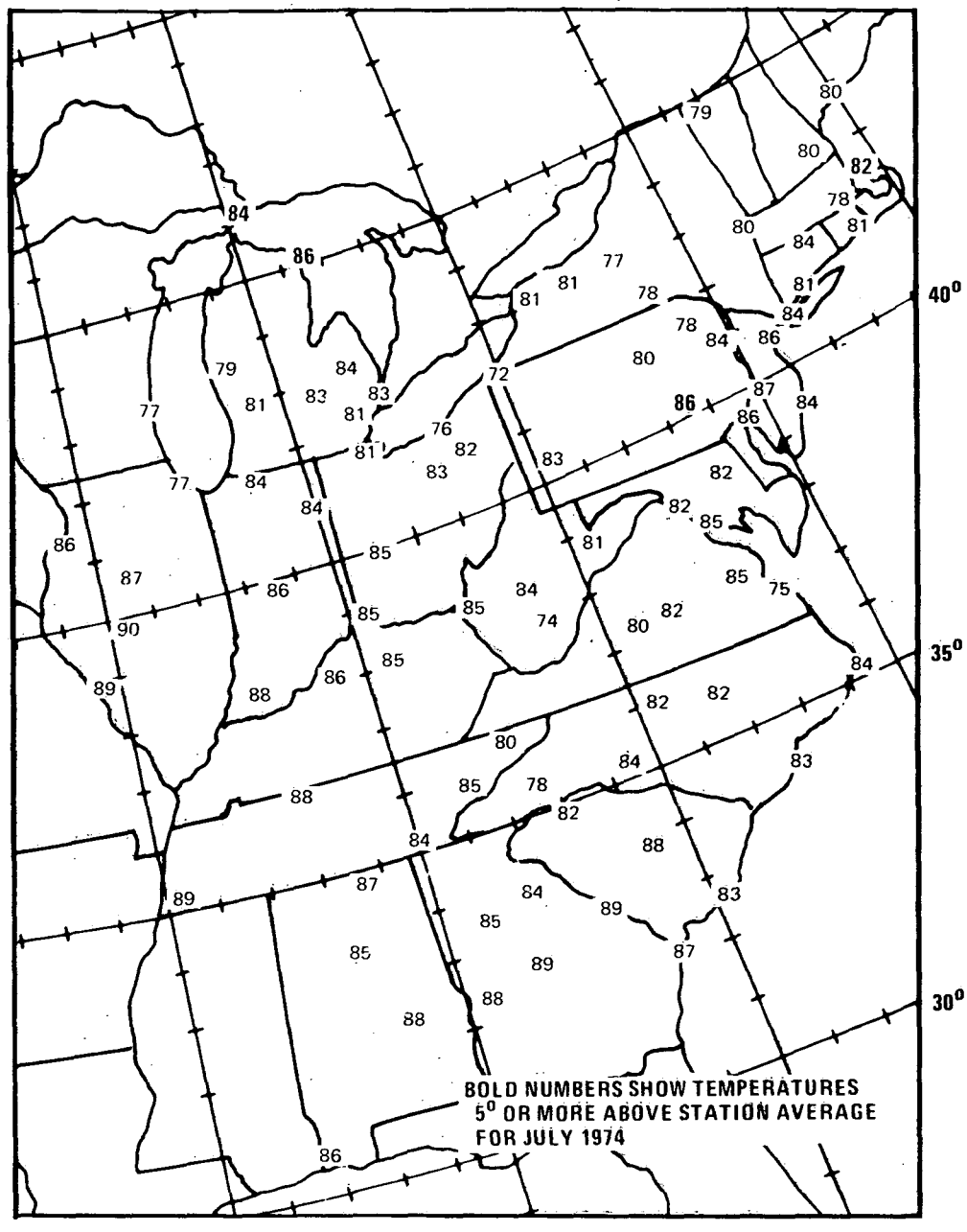


Figure 12. Maximum temperatures (°F) July 6, 1974.

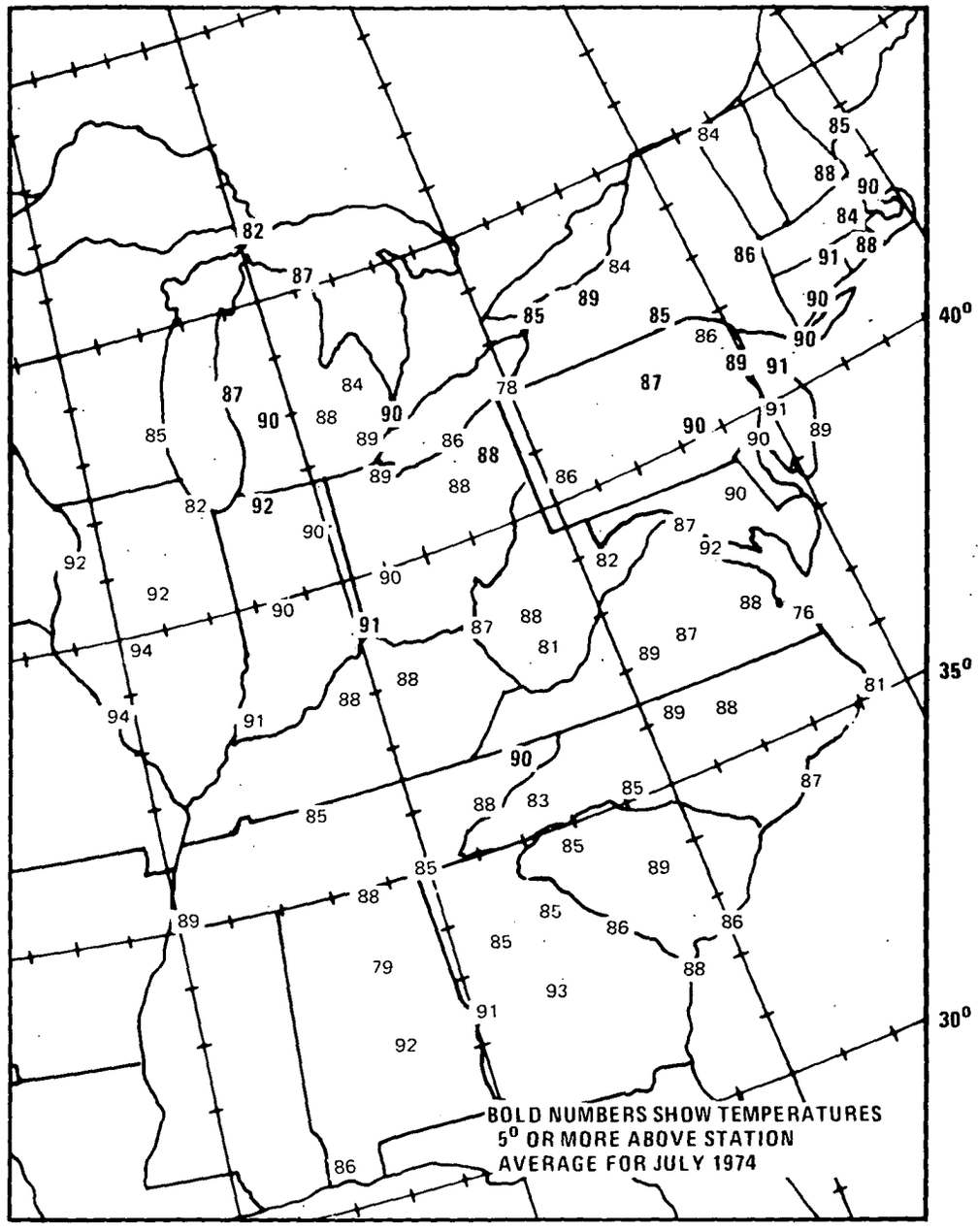


Figure 13. Maximum temperatures (°F) July 7, 1974.

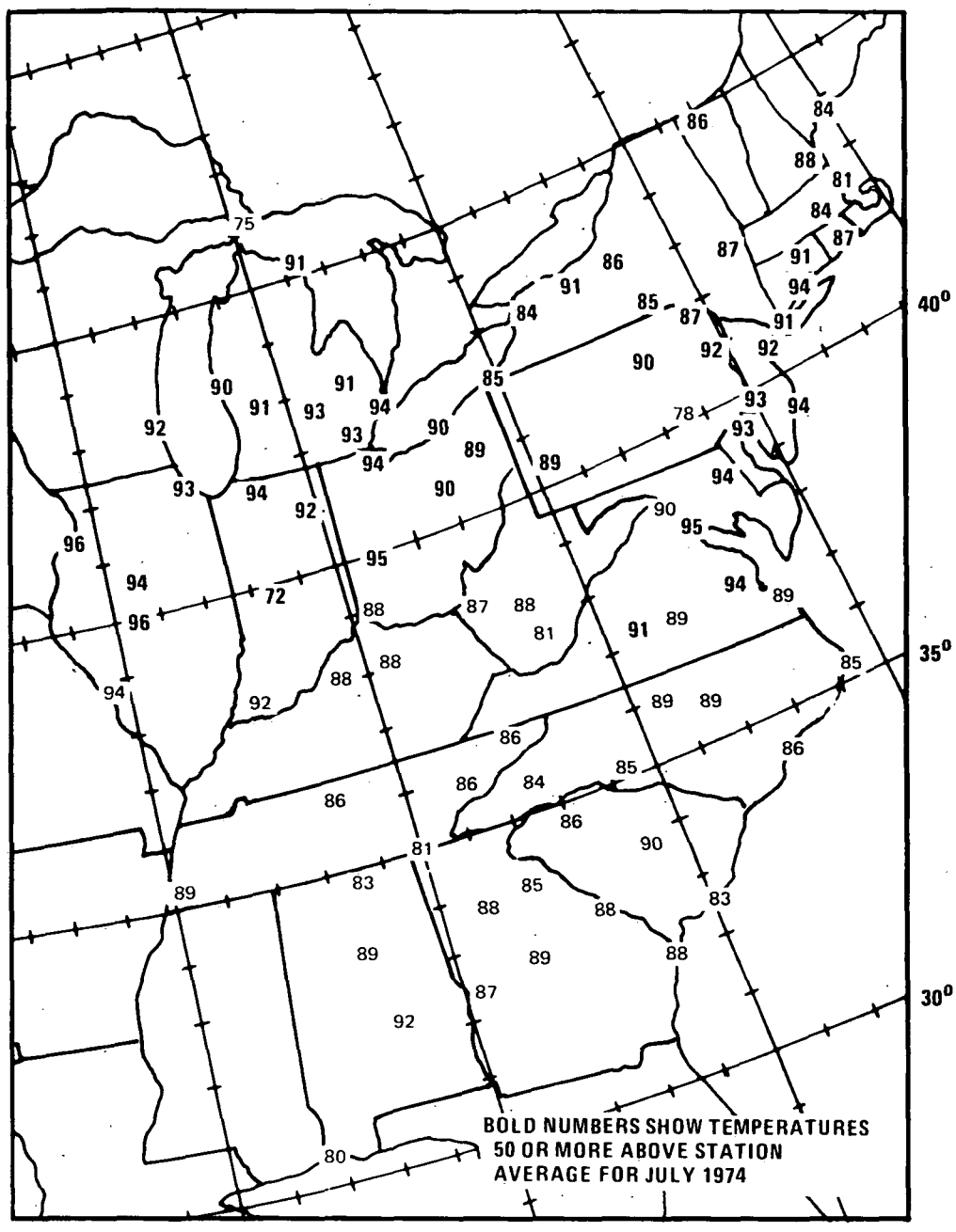


Figure 14. Maximum temperatures (°F) July 8, 1974.

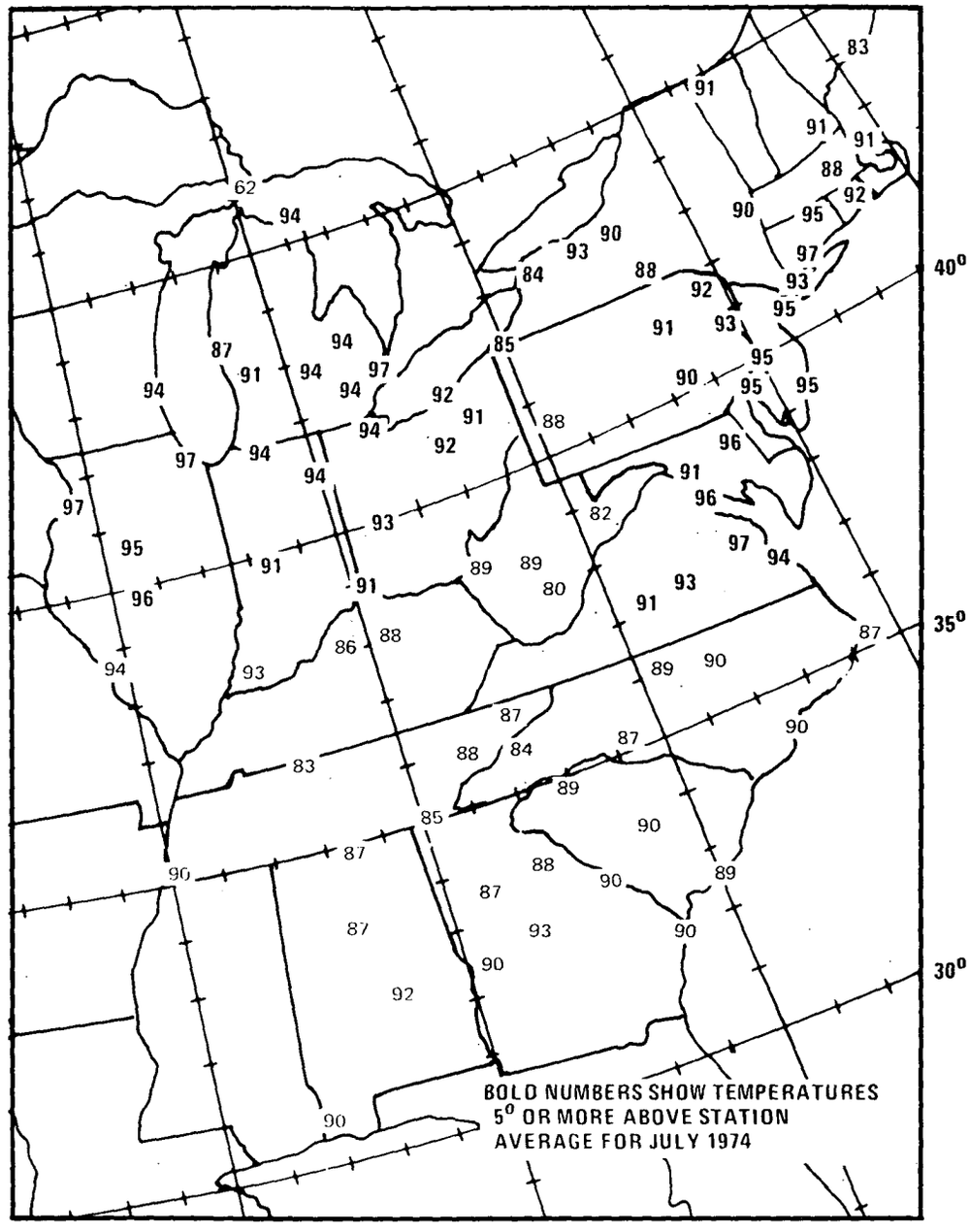


Figure 15. Maximum temperatures (°F) July 9, 1974.

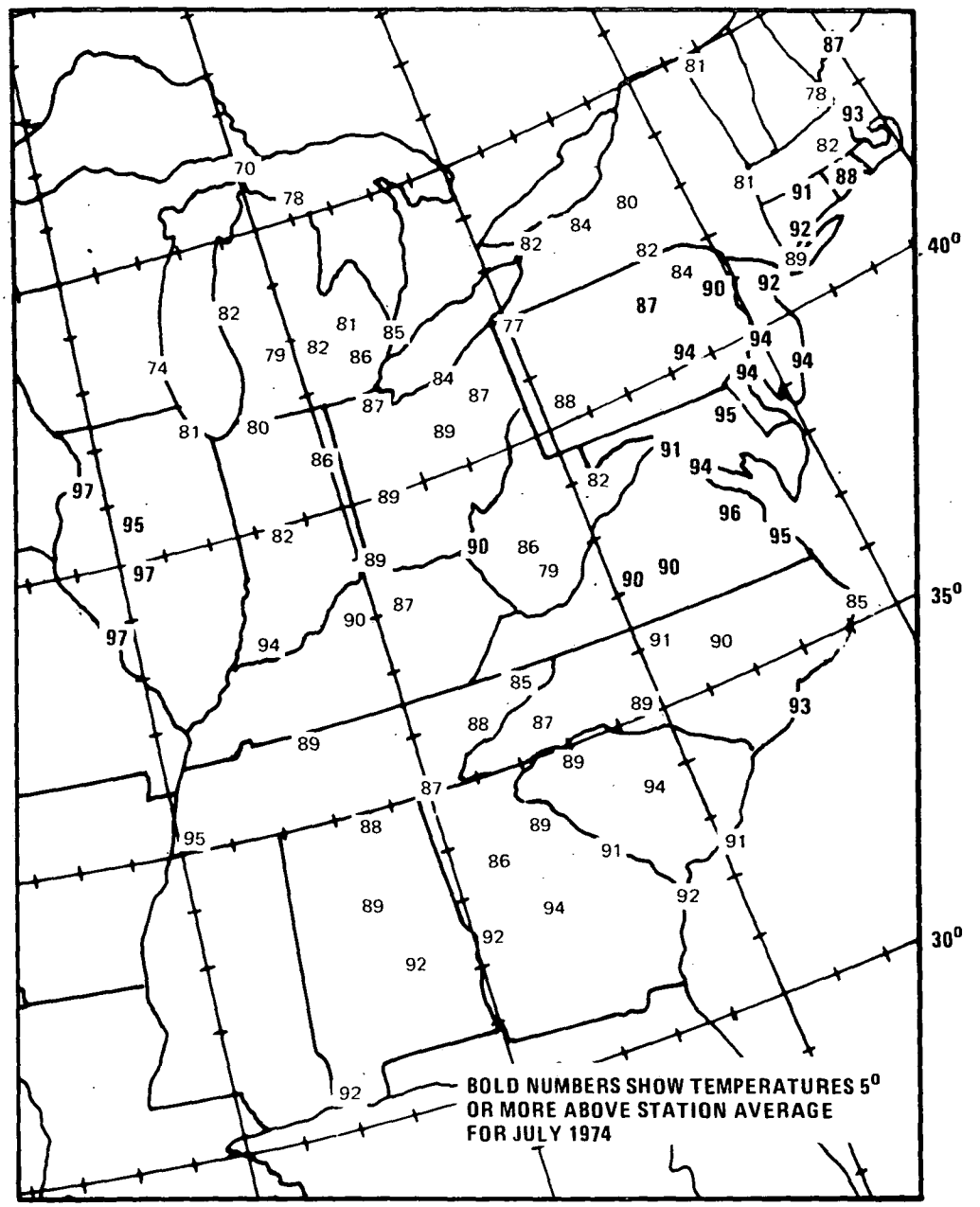


Figure 16. Maximum temperatures (°F) July 10, 1974.

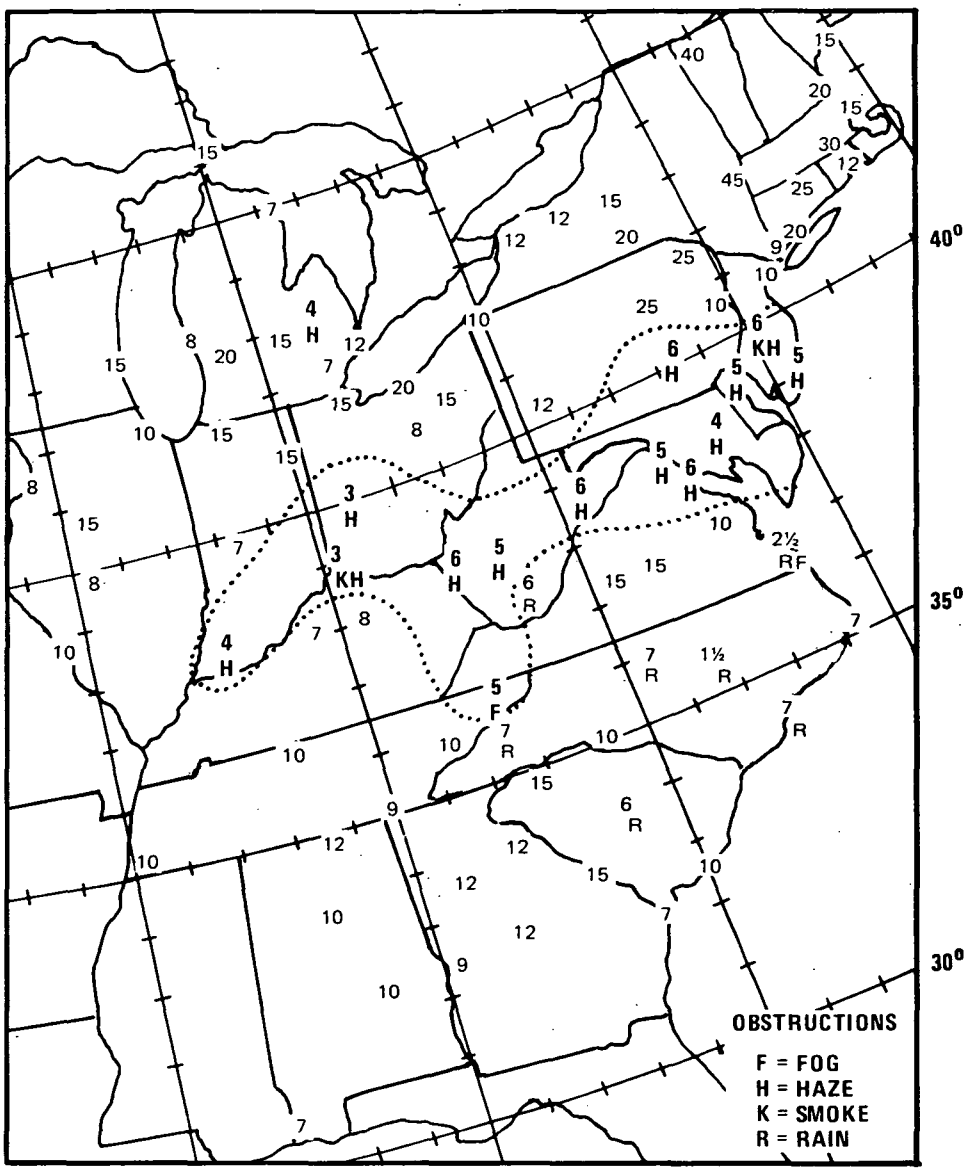


Figure 17. Visibility (miles) July 6, 1974, 1300 EST.

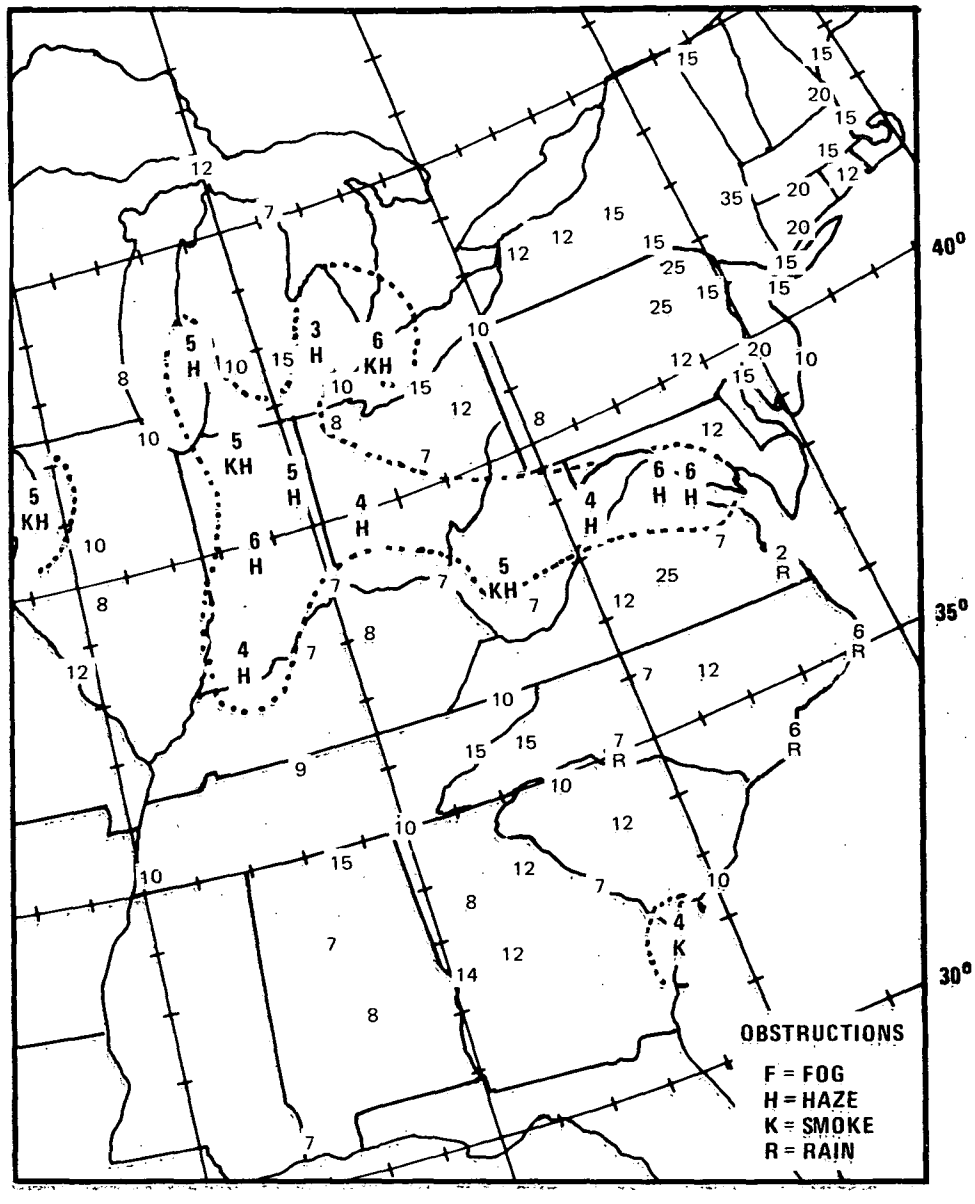


Figure 18. Visibility (miles) July 7, 1974, 1300 EST.

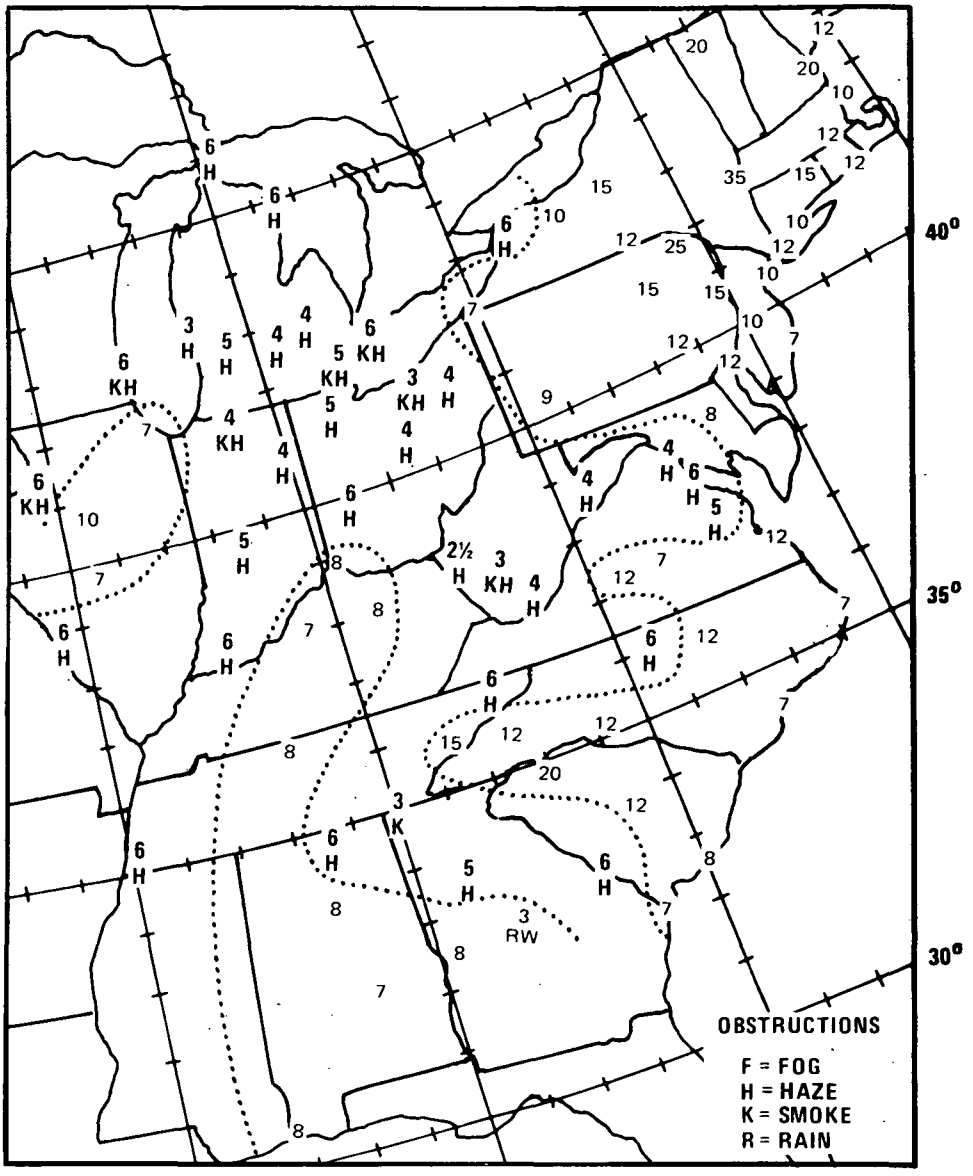


Figure 19. Visibility (miles) July 8, 1974, 1300 EST.

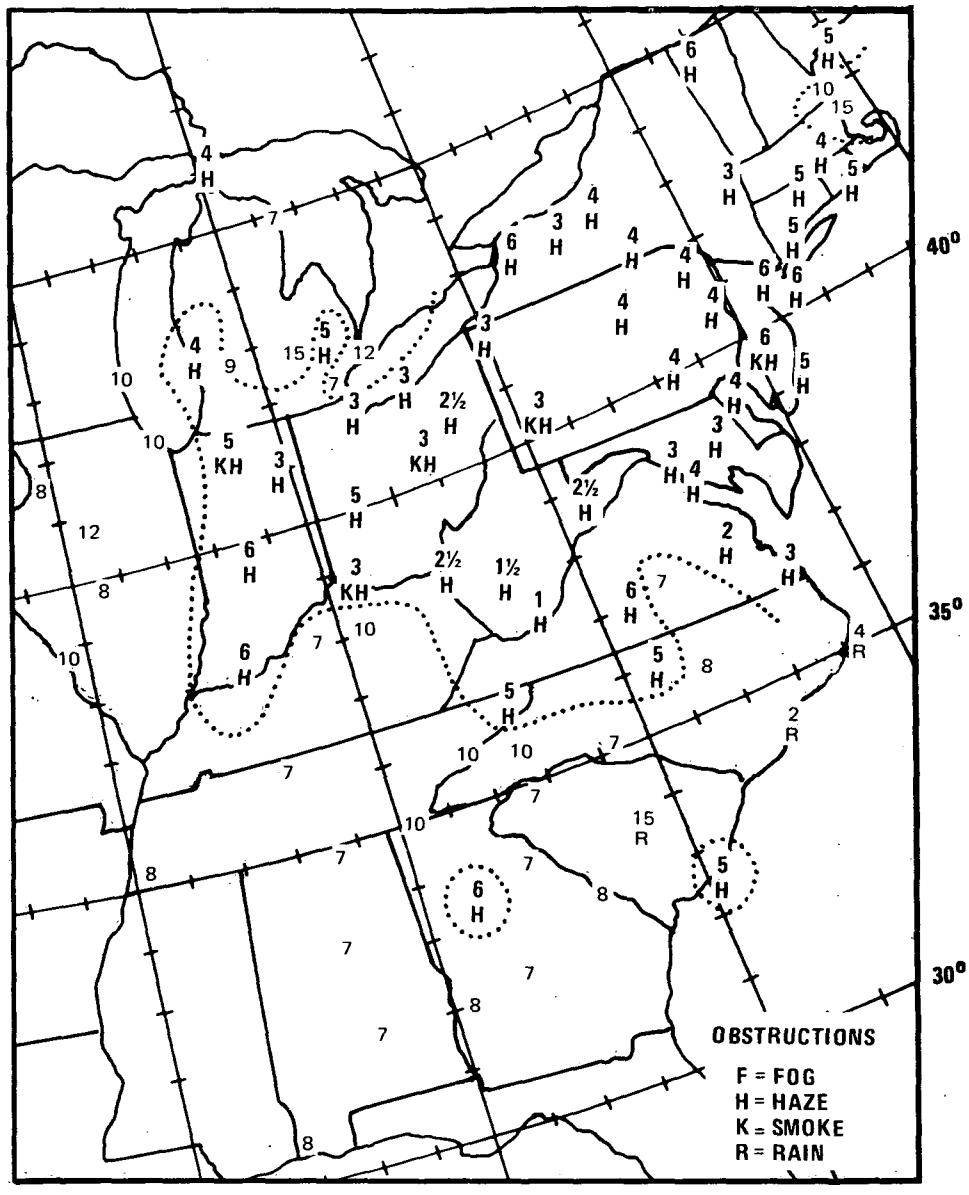


Figure 20. Visibility (miles) July 9, 1974, 1300 EST.

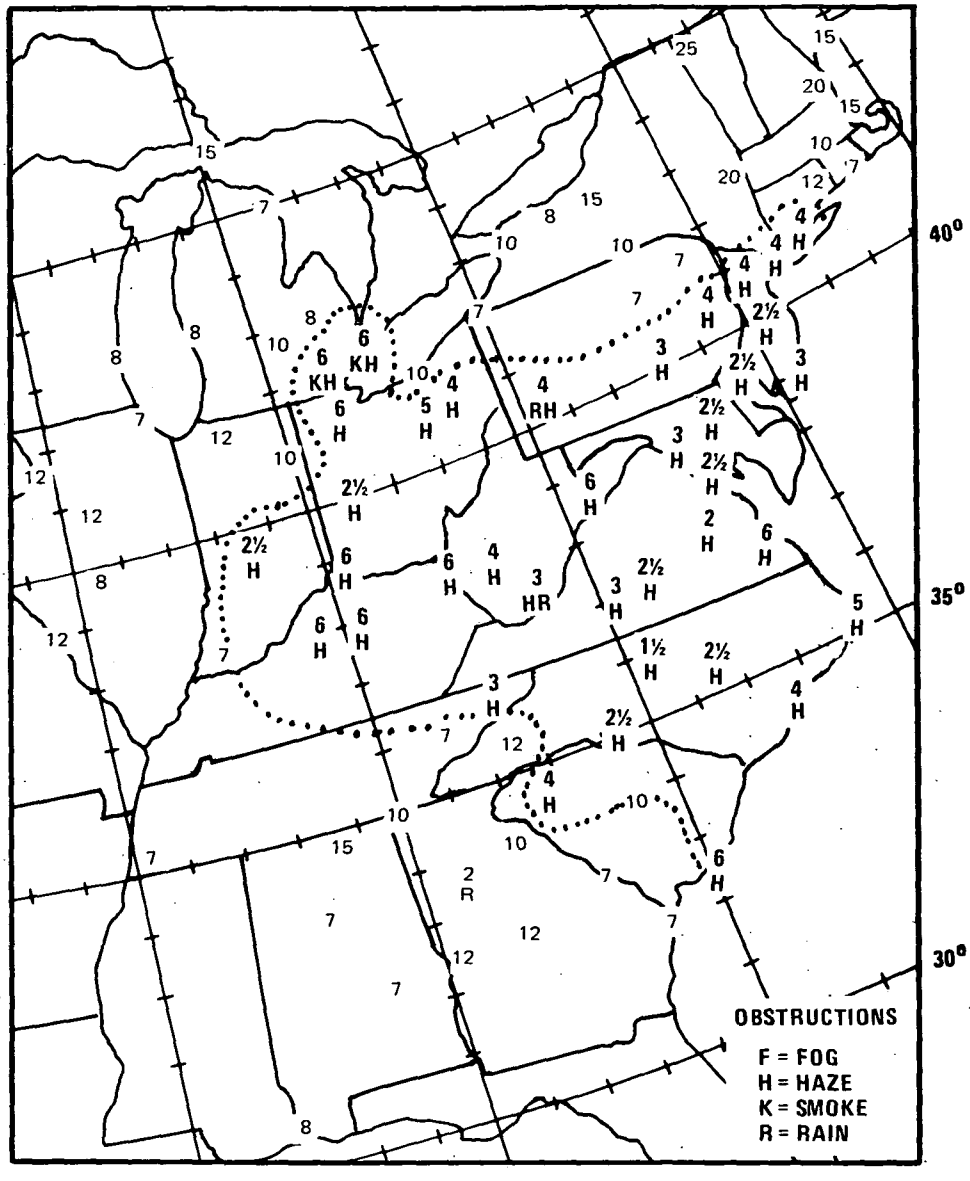
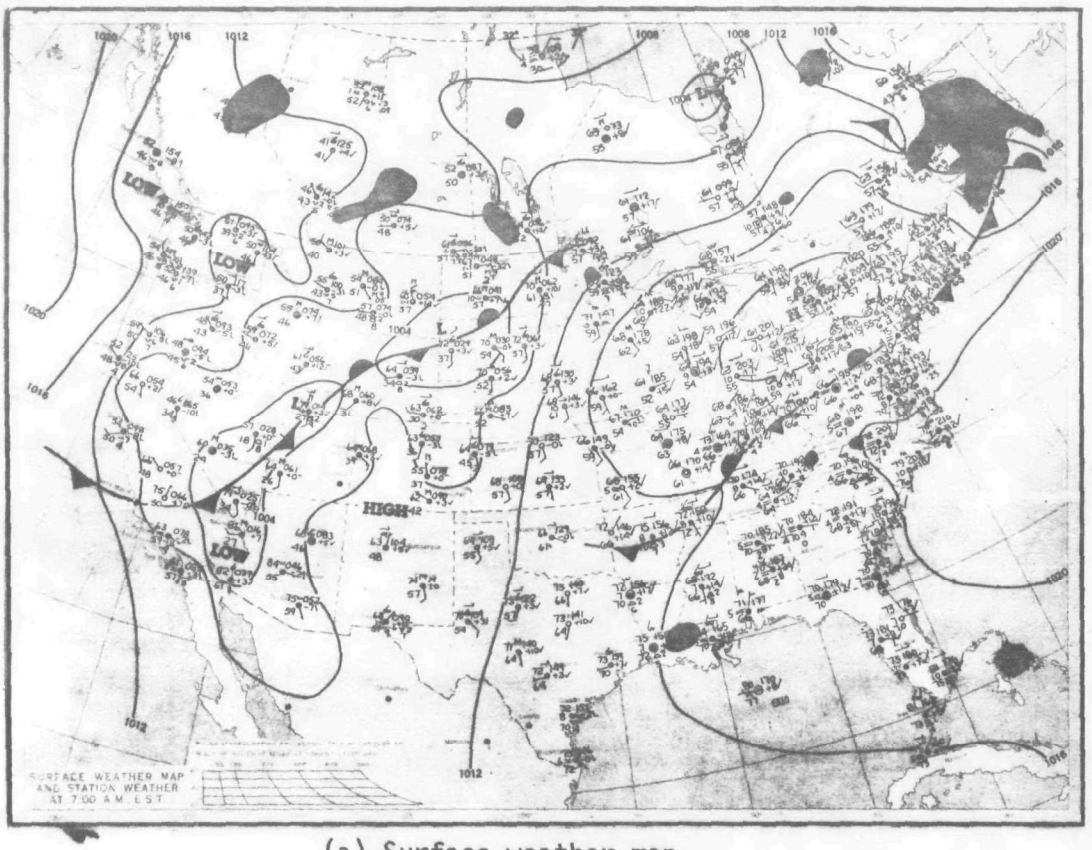
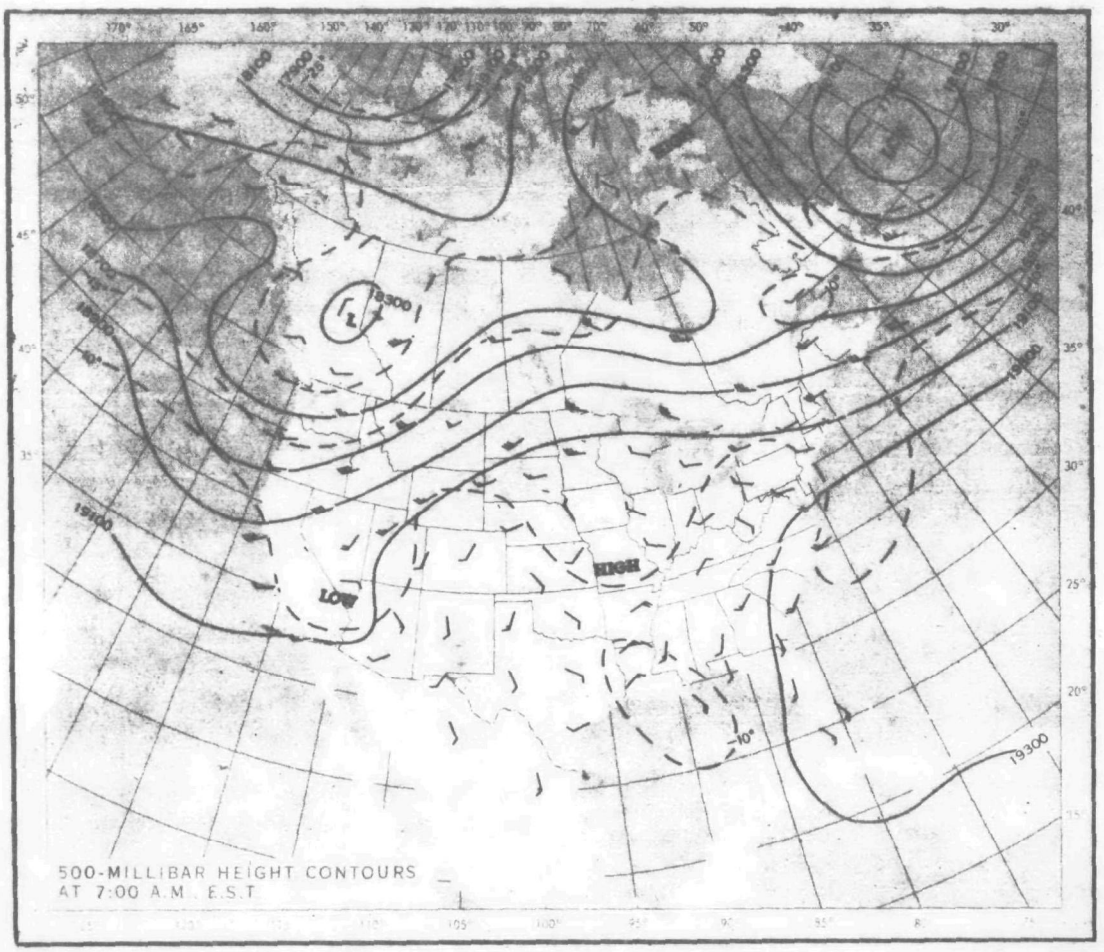


Figure 21. Visibility (miles) July 10, 1974, 1300 EST.



(a) Surface weather map



(b) 500-mb map

Figure 22. Daily weather maps for July 6, 1974

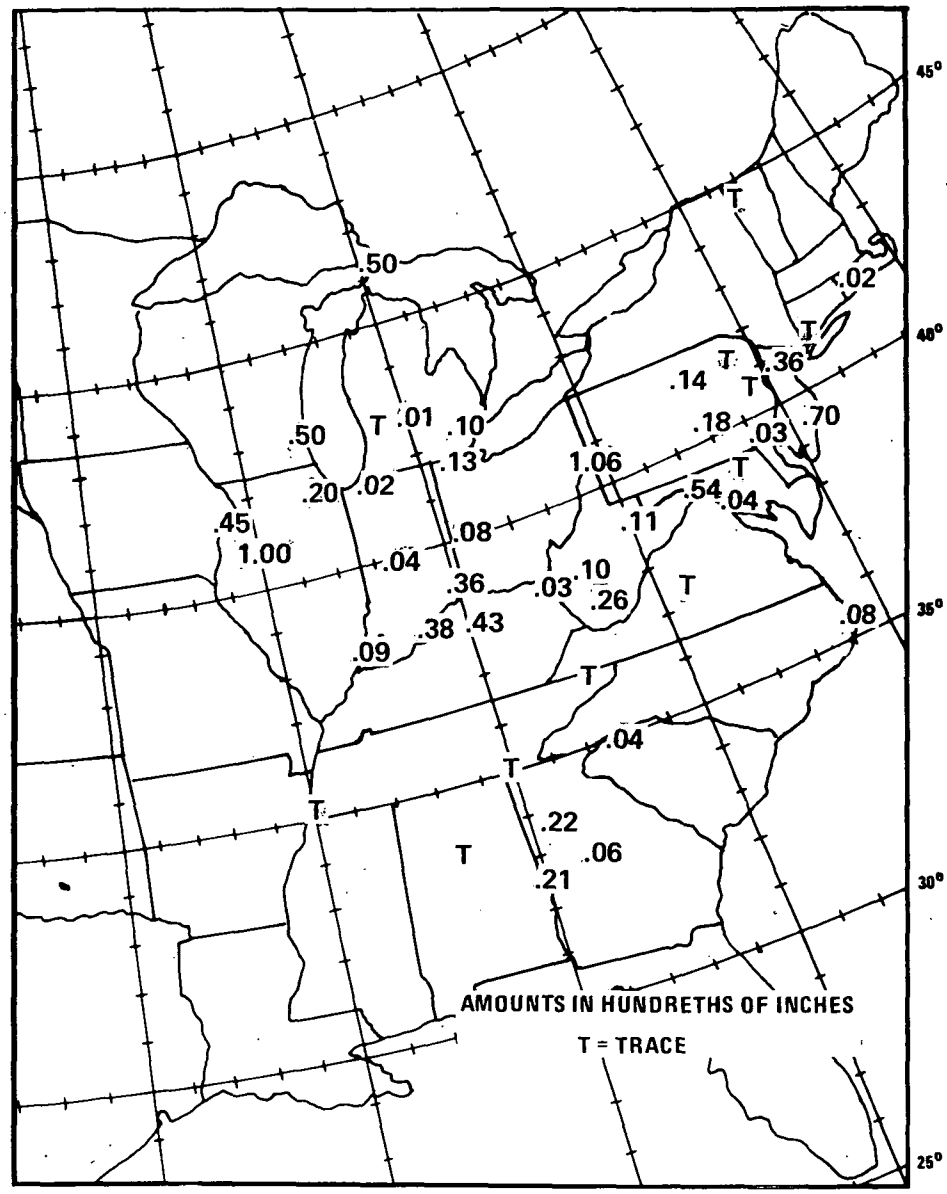


Figure 23. Rainfall during sulfate sampling period of July 10, 1974.

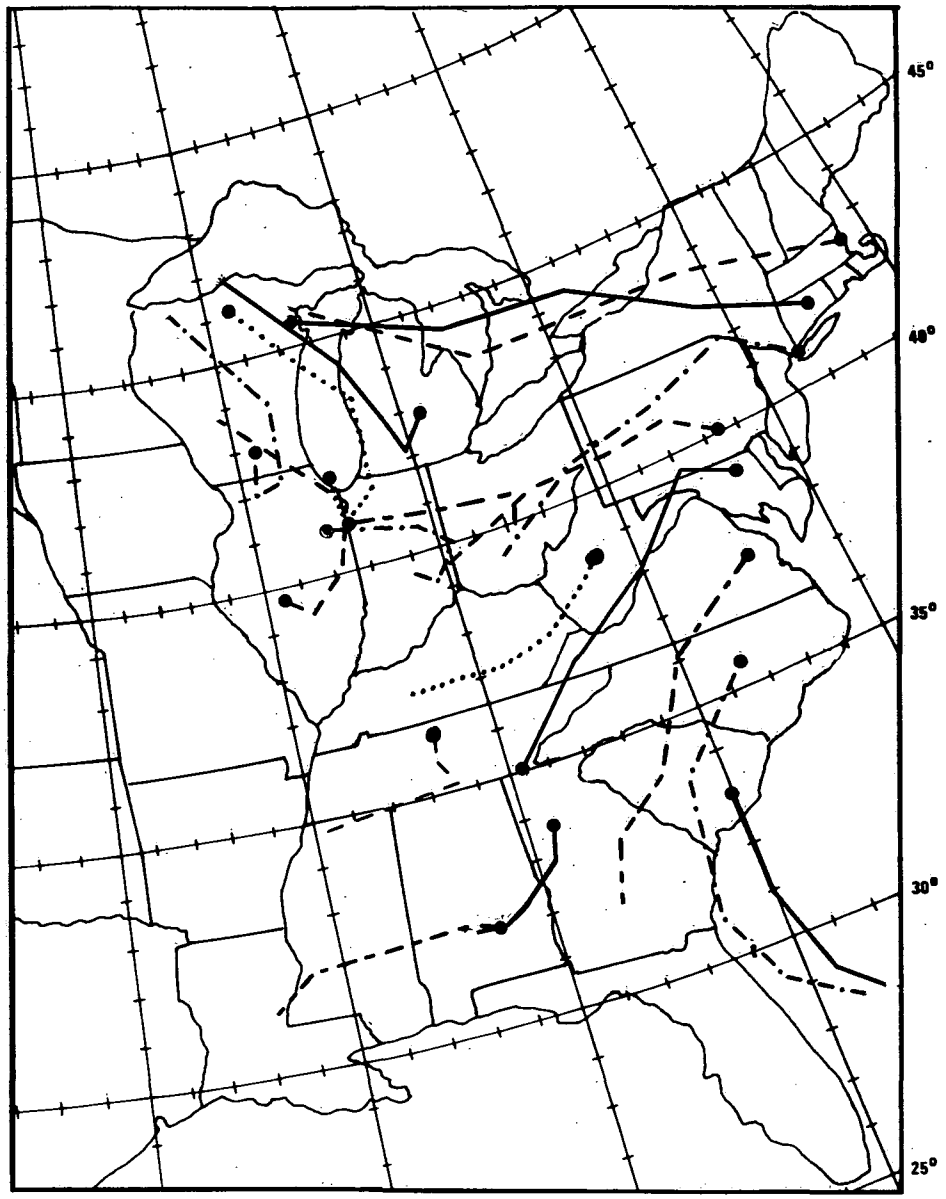


Figure 24. 48-h trajectories (12-h segments) of layers of air between the surface and 1000 m for selected cities, July 6, 1974 (arrival time 1 p.m., e.s.t.).

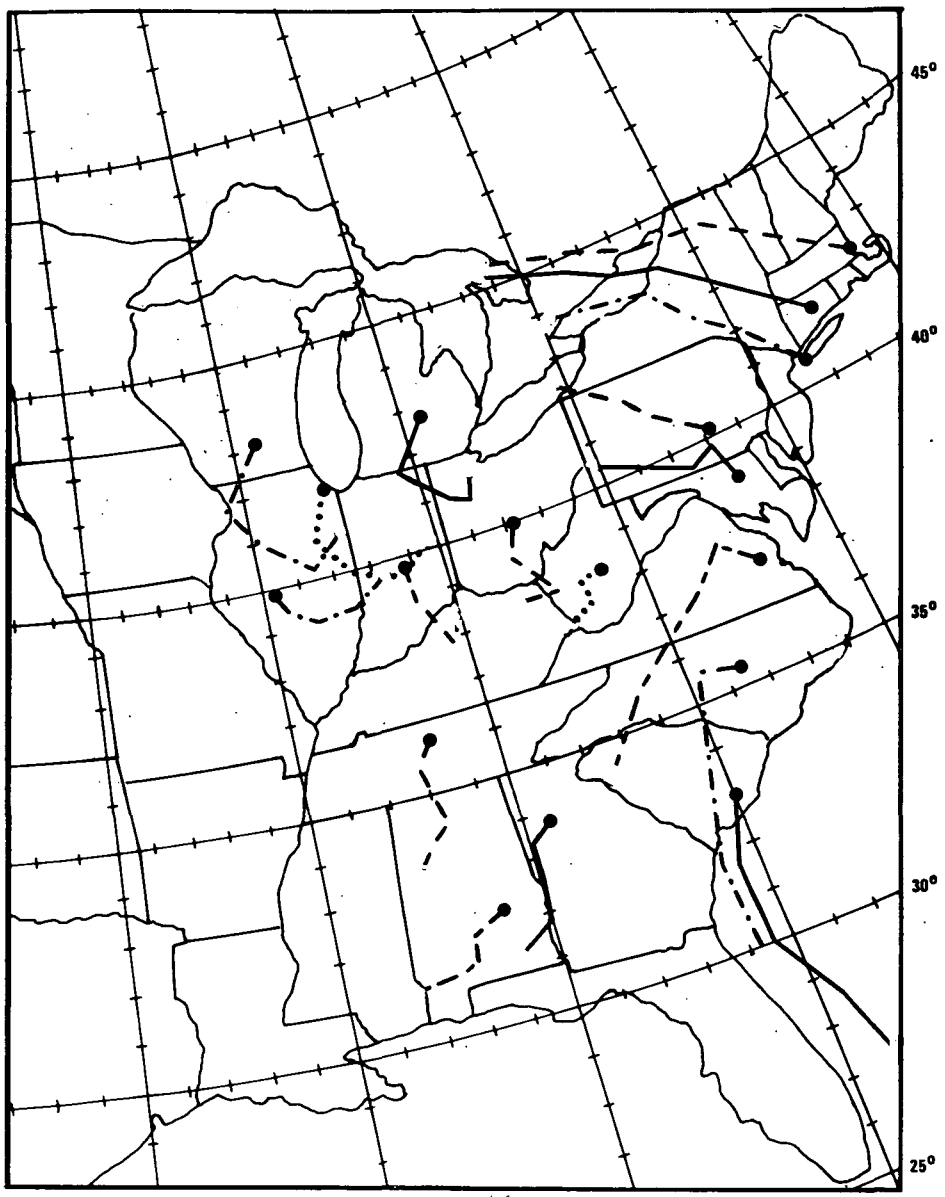


Figure 25. 48-h trajectories (12-h segments) of layers of air between the surface and 1000 m for selected cities, July 7, 1974 (arrival time 1 p.m., e.s.t.).

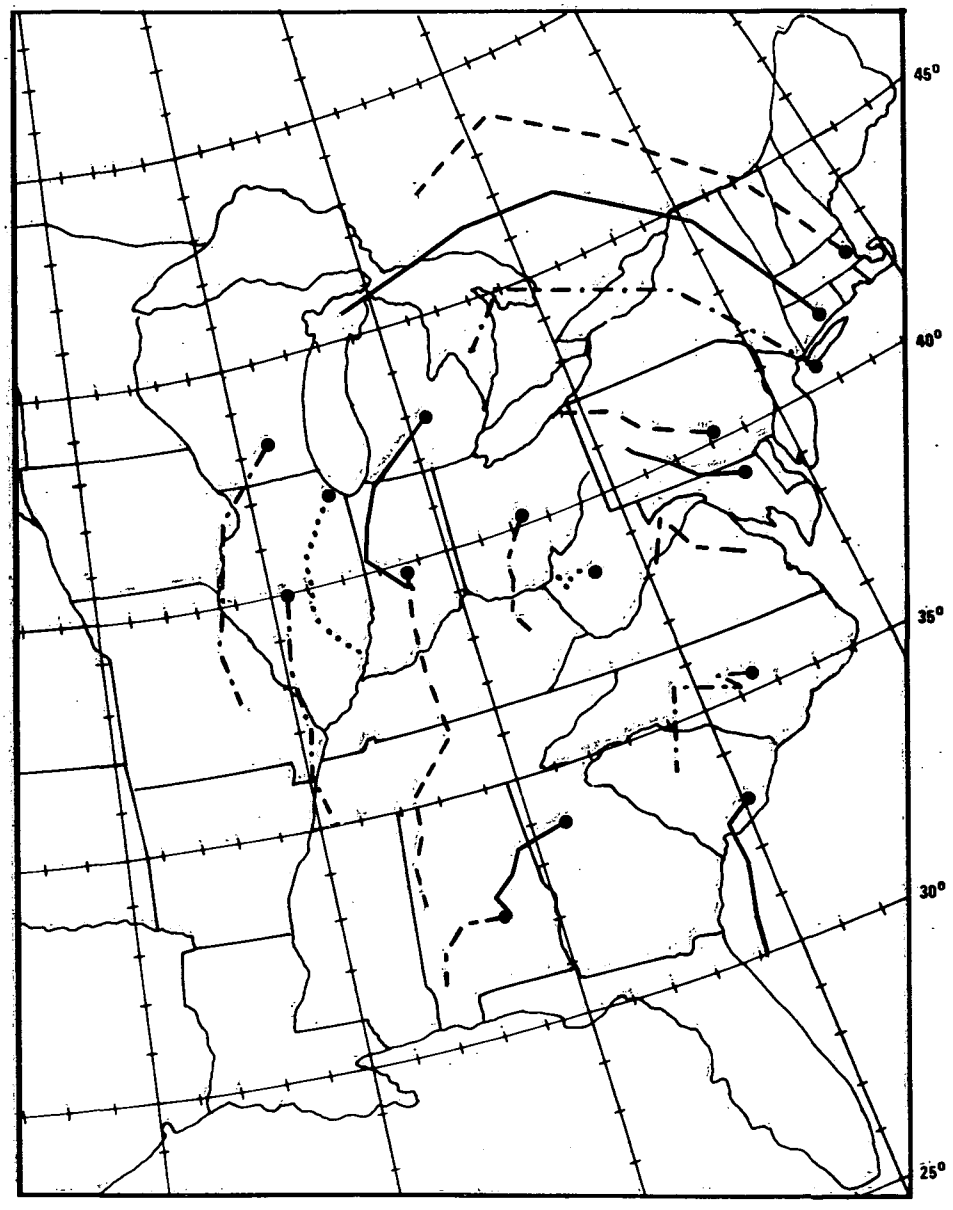


Figure 26. 48-h trajectories (12-h segments) of layers of air between the surface and 1000 m for selected cities, July 8, 1974 (arrival time 1 p.m., e.s.t.).

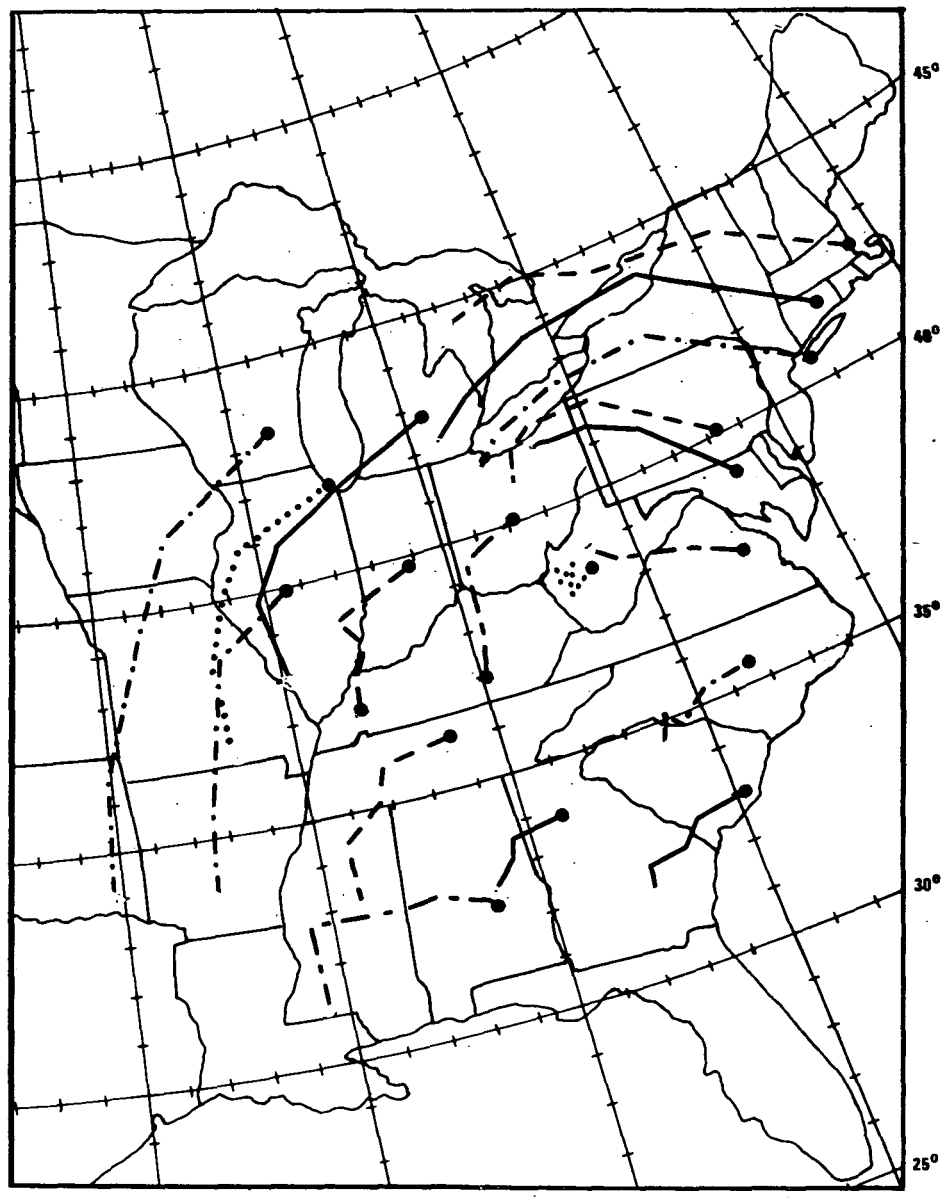


Figure 27. 48-h trajectories (12-h segments) of layers of air between the surface and 1000 m for selected cities, July 9, 1974 (arrival time 1 p.m., e.s.t.).

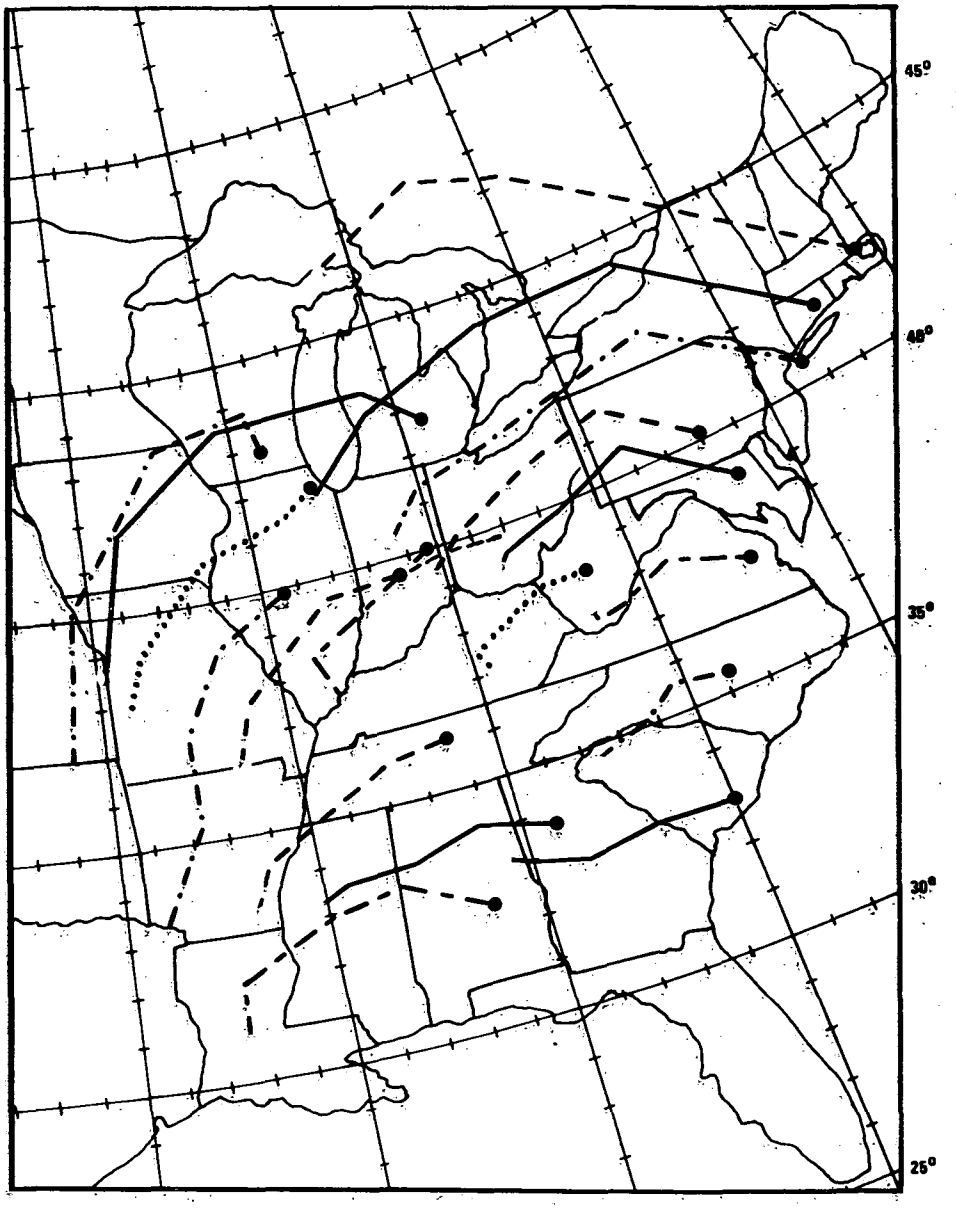


Figure 28. 48-h trajectories (12-h segments) of layers of air between the surface and 1000 m for selected cities, July 10, 1974 (arrival time 1 p.m., e.s.t.).

TABLE 1. NAMES OF STATIONS IN SULFATE MONITORING NETWORK (see Figure 3 for station locations)

1. Ashland, KY
2. Bowling Green, KY
3. Covington, KY
4. Charleston, WV
5. South Charleston, WV
6. Hampton, VA
7. Norfolk, VA
8. Portsmouth, VA
9. Lynchburg, VA
10. Richmond, VA
11. Roanoke, VA
12. Wythe Cnty, VA
13. Chattanooga, TN
14. Knoxville, TN
15. Memphis, TN
16. Nashville, TN
17. East St. Louis, IL
18. Moline, IL
19. Peoria, IL
20. Rock Island, IL
21. Springfield, IL
22. Atlanta, GA
23. Columbus, GA
24. Columbia, SC
25. Union Cnty., SC
26. Richland Cnty., SC
27. Charlotte, NC
28. Durham, NC
29. Greensboro, NC
30. East Chicago, IN
31. Evansville, IN
32. Gary, IN
33. Indianapolis, IN
34. Terre Haute, IN
35. Monroe Cnty., IN
36. Parke Cnty., IN
37. South Bend, IN
38. Solomons Island, MD
39. Akron, OH
40. Canton, OH
41. Cincinnati, OH
42. Allentown, PA
43. Bethlehem, PA
44. Clarion, PA
45. Erie, PA
46. Hazelton, PA
47. Lancaster, PA
48. Pittsburgh, PA
49. Scranton, PA
50. Warminster, PA
51. Wilkes Barre, PA
52. York, PA
53. Albany, NY
54. New York City, NY
55. Niagara Falls, NY
56. Rochester, NY
57. Syracuse, NY
58. Utica, NY
59. Yonkers, NY
60. Hartford, CT
61. New Haven, CT
62. Waterbury, CT
63. Elizabeth, NJ
64. Glassboro, NJ
65. Newark, NJ
66. Perth Amboy, NJ
67. Trenton, NJ
68. Providence, RI
69. Washington Cnty., RI
70. Cambridge, MA
71. Fall River, MA
72. Springfield, MA
73. Worcester, MA
74. Burlington, VT
75. Orange Cnty., VT
76. Smyrna, DE
77. Newark, DE
78. Dearborn, MI
79. Detroit, MI
80. Flint, MI
81. Lansing, MI
82. Saginaw, MI
83. Trenton, MI

TABLE 2. SULFATE CONCENTRATIONS ($\mu g/m^3$) AT CHESS STATIONS IN THE NEW YORK CITY AREA, JULY 6-11, 1974

STATION \ Date	July 6	July 7	July 8	July 9	July 10	July 11
Riverhead	4.9	7.1	6.2	12.5	27.2	11.0
Queens	6.8	12.6	7.9	15.6	38.5	11.2
Brooklyn	M	M	12.2	16.2	54.1	M
Bronx	9.3	10.6	6.0	M	M	M

M = Missing

TABLE 3. SULFATE CONCENTRATIONS ($\mu g/m^3$) AT ELECTRIC POWER INDUSTRY SITES IN NORTHERN UNITED STATES, JULY 6-11, 1974

Station \ Date	July 6	July 7	July 8	July 9	July 10	July 11
Collins, IL	M	M	26.1	13.1	M	M
Rockport, ID	15.9	10.8	M	M	M	M
Madison, ID	18.5	12.3	13.4	19.1	20.8	14.2
Lawrenburg I, ID	31.6	23.4	22.2	36.0	25.9	27.6
Lawrenburg II, ID	19.4	18.9	21.5	16.7	22.8	46.6
Huntington, WV	8.9	4.9	45.7	48.7	21.0	28.2
Wheeling, WV	34.7	53.7	83.0	75.7	M	M
Scranton, PA	5.7	5.0	7.3	27.0	M	3.5
Albany, NY	4.0	7.3	13.2	25.3	10.6	2.7

M = Missing

Source = Environmental Research and Technology[7]

TABLE 4. STATION NAMES, TVA NETWORK
(See Figure 5 for station locations)

1. Allen	10. Paradise
2. Bull Run	11. Shawnee
3. Colbert	12. Watts Bar
4. Cumberland	13. Widows Creek
5. Gallatin	(14.) Giles County
6. John Sevier	(15.) Hytop
7. Johnsonville	(16.) Land Between Lakes
8. Kingston	(17.) Loudon
9. DCAD (Muscle Shoals)	(18.) Loves Mill

( ) = Rural sampling site

TABLE 5. SULFATE CONCENTRATIONS ($\mu g/m^3$) TVA NETWORK, JULY 3-11, 1974

Station	Monitoring Site Data: Distance[1] (Mi.)	Bearing (°)	Elevation (Ft.)	July: 3	6	7	8	9	July 1974 Average
Allen	4.2	68	230	-				8.9	11.2
Allen	2.9	54	240	10.9				6.5	16.8
Allen	3.2	32	217	9.6				6.0	14.9
Bull Run	2.6	61	880		9.5				19.0
Bull Run	4.9	56	910		7.9				13.5
Bull Run	4.3	273	900		8.0				17.6
Colbert	1.8	23	495	11.2				2.8	9.7
Colbert	2.3	259	470	13.4				4.7	13.1
Colbert	2.4	263	510	12.6				5.7	15.7
Cumberland	4.3	39	590	8.9				9.3	20.3
Cumberland	6.2	37	725	15.2				10.6	23.0
Cumberland	1.1	163	470	15.9				6.8	18.9
Cumberland	4.6	130	590	13.2				15.2	18.3
Cumberland	19.2	58	440	19.7				4.6	21.0
Gallatin	1.8	4	470	16.2				13.4	16.0
Gallatin	4.2	13	570	14.6				11.0	17.3
Gallatin	4.8	340	575	14.6				12.5	17.9
John Sevier	1.9	63	1220		11.2				20.2
John Sevier	1.0	229	1140		9.7				14.7
Johnsonville	2.6	187	385	11.5				10.1	25.0
Johnsonville	2.8	42	380	14.5				18.7	20.6
Johnsonville	2.6	339	380	14.2				14.3	23.9
Johnsonville	2.1	134	470	13.4				12.3	21.5
Kingston	3.6	243	800		9.1				21.2
Kingston	2.9	328	900		-				24.8
Kingston	1.3	143	750		12.6				25.7

[1] - Distances and bearings from power plant

(continued)

TABLE 5. (Continued)

Station	Monitoring Site Data: Distance[1] (Mi.)	Bearing (°)	Elevation (Ft.)	July: 3	6	7	8	9	July 1974 Average
DCAD	1.5	224	530	13.1				11.2	18.2
DCAD	1.2	168	510	22.3				15.8	19.8
DCAD	2.4	26	550	19.5				13.0	31.5
Paradise	2.6	41	420	17.1				17.0	24.8
Paradise	2.9	31	490	20.0				17.7	25.5
Paradise	7.9	284	460	18.2				15.0	26.7
Paradise	5.3	126	398	16.2				16.7	20.0
Paradise	21.0	301	475	17.3				20.4	28.8
Shawnee	2.6	158	375	13.6				14.5	29.5
Shawnee	2.6	256	360	14.7				13.5	27.7
Shawnee	2.7	35	385	16.3				15.5	27.7
Shawnee	2.1	84	350	14.6				10.2	25.9
Watts Bar	0.8	3	845			12.1			24.1
Widows Creek	2.5	135	1450	20.4				19.0	23.0
Widows Creek	4.8	27	680	31.8				M	24.0
Widows Creek	2.0	102	1500	30.1				31.1	33.2
Widows Creek	2.0	167	1570	28.6				26.5	29.7
Widows Creek	2.3	30	640	31.4				24.9	26.4
Giles County	10.0	(NE)	800	15.6				17.0	16.0
Hytop	19.3	271	1785	16.1				10.2	15.5
Land Between the Lakes	35.8	320	580	12.7				10.9	21.1
Loudon	6.5	(SSE)	880			9.7			23.2
Loves Mill							5.9		14.8

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/4-79-009	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE ASSOCIATION BETWEEN METEOROLOGICAL CONDITIONS AND HIGH OZONE AND SULFATE CONCENTRATIONS A 1974 Episode in the Eastern United States		5. REPORT DATE February 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Gerard A. DeMarrais		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS (Same as Box 12)		10. PROGRAM ELEMENT NO. 1AA603 (FY-78)
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory - RTP, NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Inhouse 2/78-10/78
		14. SPONSORING AGENCY CODE EPA/600/9

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A 1,000,000 km^2 area of the Eastern United States had sulfate concentrations exceeding 10 $\mu g/m^3$ on July 10, 1974, and there were indications that parts of the area had high concentrations on prior days. The meteorology associated with the high concentrations and correlations of high ozone and sulfate concentrations are discussed. It appeared that slow moving and subsiding air contributed to the high concentrations of both pollutants. Long range transport, as shown by trajectory analyses, was a factor in the problems in most areas, but the worst situations with regards to sulfates were associated with emissions from nearby, upwind sources. While high ozone concentrations were observed immediately prior to high sulfate concentrations in many areas, there were high sulfate concentrations that were not associated with high ozone concentrations. In the latter situation, the high sulfate concentrations were associated with air which had earlier movement over areas with high SO_2 emission.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Air pollution *Ozone *Sulfates *Meteorological data	Eastern United States 1974 episode	13B 07B 04B

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