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Project Summary

1987 Wet Deposition Temporal and Spatial Patterns in North America

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The purpose of this research project is to determine the spatial pattern of wet deposition in North America during 1987 and to investigate trends in wet deposition in North America from 1979 through 1987. The project considers precipitation-weighted average concentration and deposition for nine ion species: hydrogen ion, sulfate, nitrate, ammonium, calcium, chloride, sodium, potassium, and magnesium. To accomplish the research an Acid Deposition System (ADS) data base has been established that integrates wet deposition monitoring data from several regional and national monitoring networks. Networks included are the National Atmospheric Deposition Program/National Trends Network (NADP/NTN), the MAP3S precipitation chemistry network, the Utility Acid Precipitation Study Program (UAPSP) network, the Canadian Precipitation Monitoring Network (CAPMoN), and the daily and 4-weekly Acidic Precipitation Monitoring in Ontario Study networks (APIOS-D and APIOS-C). The ADS data base and statistical summaries are available to others to conduct additional research studies.

This Project Summary was developed by EPA's Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Data Preparation and Methodology

The spatial and temporal pattern analyses include data from the six networks identified above. These networks operated 69 sites in 1979 and increased the number of sites to 315 in 1987. During this period, each network applied specific protocols for selecting site locations, field operation procedures, laboratory analysis procedures, and data quality procedures. In addition, they participated in the development of unified data screening and summary procedures through the Unified Deposition Database Committee (UDDC) (Olsen et al. 1989). This project applied the UDDC procedures in selecting sites and preparing data summaries for statistical analysis. The number of sites that meet the UDDC criteria for annual summaries increased from 39 in 1979 to 154 in 1987. In 1987, approximately 50% of the sites operating met the UDDC criteria. This is a reflection of the strictness of the criteria. The 1987 spatial analyses, 1979-1987 trend analyses, and 1982-1987 trend analyses use specific subsets of these sites.

The report presents 30 mosaic maps of 1987 annual and seasonal wet deposition spatial patterns. For each map (ion species and summary period), the sites used are selected so that the sites meet the UDDC criteria for that ion species and summary period. The number of sites

used range from 154 to 240. For example, the number of sites for the 1987 annual sulfate maps is 154.

A primary consideration in selecting a site for temporal pattern analysis is the continuous operation of the site for the entire period of interest. Preferably, the site would also meet the UDDC criteria for each year during the period. Applying these criteria severely restricts the number of sites. A slightly relaxed criteria was developed that applied to multiple years of data and still met the objective of identifying sites with good quality data throughout the period. The criteria resulted in 39 sites being selected for the 1979-1987 trend analyses and 148 sites for the 1982-1987 trend analyses. The 1979-1987 sites have six sites located west of the Mississippi river, two sites in Canada, two sites south of North Carolina, and the rest in eastern United States. The geographic pattern of sites for 1982-1987 trend sites is similar but Ontario Province has 42 sites.

Mosaic maps display the 1987 spatial patterns. The procedure for developing the maps is to estimate the spatial patterns by using a kriging spatial estimation procedure that includes measurement error. A separate kriging analysis was applied to eastern and western North America, since the regions have distinctively different spatial structure. The surface is estimated for approximately 3700 hexagons with an area of 2000 square kilometers. The gray scale map presentation is based on the percentiles from the frequency distribution of the estimates for the eastern and western United States.

The project used two approaches for trend analysis: graphical displays of annual summaries and statistical trend analysis of four-weekly summaries. Qualitative assessment of trend patterns relies on time trend graphical displays of percentiles of annual summaries for each year in the sites associated with either the 1979-1987 or the 1982-1987 trend period. Quantitative trend assessment relies on the modified Kendall seasonal tau trend statistical test and Sen's median slope estimation procedure applied to four-weekly summary data at each site. The results of the trend analyses are qualitatively summarized across sites.

Spatial Patterns for 1987

Thirty mosaic maps summarize and display the estimated spatial patterns in 1987 for five ion species concentration and deposition on annual, winter and summer basis. The five ion species are hydrogen ion (pH), sulfate, nitrate, ammonium, and calcium. Simpson and Olsen (1990) contains the maps and extensive descriptions of the patterns.

Areas of maximal sulfate and nitrate deposition vary slightly from year to year, but have generally remained within the area bounded by Indiana on the west, southern Ontario on the north, Pennsylvania and New York on the east, and northern Kentucky on the south (Figures 1 and 2). In 1987, 10% of all sites used for these spatial analyses had deposition values exceeding 29 kg/ha for sulfate and 21 kg/ha for nitrate. Both maxima occur in western Pennsylvania and southern Ontario. In 1987, 5% of the eastern United States is estimated to have annual sulfate deposition greater than 30 kg/ha; 25% with annual sulfate deposition greater than 22 kg/ha. For annual nitrate deposition, 5% is greater than 20 kg/ha and 25% is greater than 13 kg/ha in the eastern United States. In the western United States, annual sulfate deposition is estimated to be less than 19 kg/ha and annual nitrate deposition less than 12 kg/ha.

Summertime wet deposition of sulfate is more than double wintertime wet sulfate deposition in most areas of the eastern United States. Summertime deposition of nitrates is also generally higher at most of the eastern United States locations. In the west, seasonal patterns are generally similar, although higher uncertainty exists due to terrain influences on precipitation patterns and the low density of wet deposition sites limit the ability to develop patterns for this type of evaluation. Sulfate concentrations in summer also are generally higher than in winter. The area of summertime maximal sulfate concentration extends west along the southern Great Lakes region as far as northeastern Illinois. Nitrate concentrations for the two seasons are comparable, with the notable exception of the eastern Great Lakes region, where wintertime concentrations can be nearly twice those of summertime.

Similar to earlier years, the area with highest precipitation acidity (lowest pH) in 1987 is centered on western Pennsylvania, eastern Ohio, northern West Virginia, and southwestern New York, where 5% of the sites used in the analysis have average annual pH values less than 4.2 (Figure 3). The area of lowest pH generally coincides with the areas of highest sulfate, nitrate, and hydrogen ion deposition (Figure 4).

Maximal wet deposition of ammonium and calcium occurs in two regions (Figures 5 and 6). One region centers over southern Ontario; the other over Nebraska and Iowa in the Great Plains region.

Trends from 1979-1987

Figure 7 shows that annual sulfate deposition gradually decreased from 1979-1987 for the 39 sites in the analysis. Although not presented, a similar gradual decrease is present for sulfate deposition for the 144 sites during 1982-1987 period. The median sulfate deposition for the 39 sites decreased from approximately 26 kg/ha in 1979 to approximately 21 kg/ha in 1987. All other ion species also decreased from 1979-1987, although hydrogen, nitrate, and ammonium decreases are relatively smaller. Figure 7 shows calcium deposition as an example cation species. Although calcium decreases, the pattern differs from that for sulfate: the sites appear more variable within a year and inter-annual variation appears greater. The median calcium deposition for the 39 sites decreased from approximately 1.6 kg/ha in 1979 to 1.0 kg/ha in 1987.

An overview of the quantitative statistical trend results is in Table 1. The most striking feature of the comparison across ion species is that trend estimates are consistent, except for nitrate and ammonium concentration, with over 50% of the estimates indicating a decreasing trend during the 1979-1987 and the 1982-1987 periods. The percent changes per year for sulfate and calcium concentration are greater over 1979-1987 than over 1982-1987; -2.2% and -6.1% over 1979-1987 for sulfate and calcium, respectively. In contrast, the percent changes per year for deposition are more similar over 1979-1987 and 1982-1987. For both periods, the percent change per year for sulfate and calcium deposition exceeded the percent change in precipitation.

From 1979 to 1987, 36 of 39 wet deposition monitoring sites located mainly in the eastern United States used for trend analysis show an estimated decrease in the concentration of sulfate in precipitation, although most of the decreases are not statistically significant. Nevertheless, the median decrease in sulfate concentration for these 39 stations during this period is approximately 18% (using 1987 as base year). Sulfate deposition shows an estimated decrease for 34 of 39 monitoring sites and a

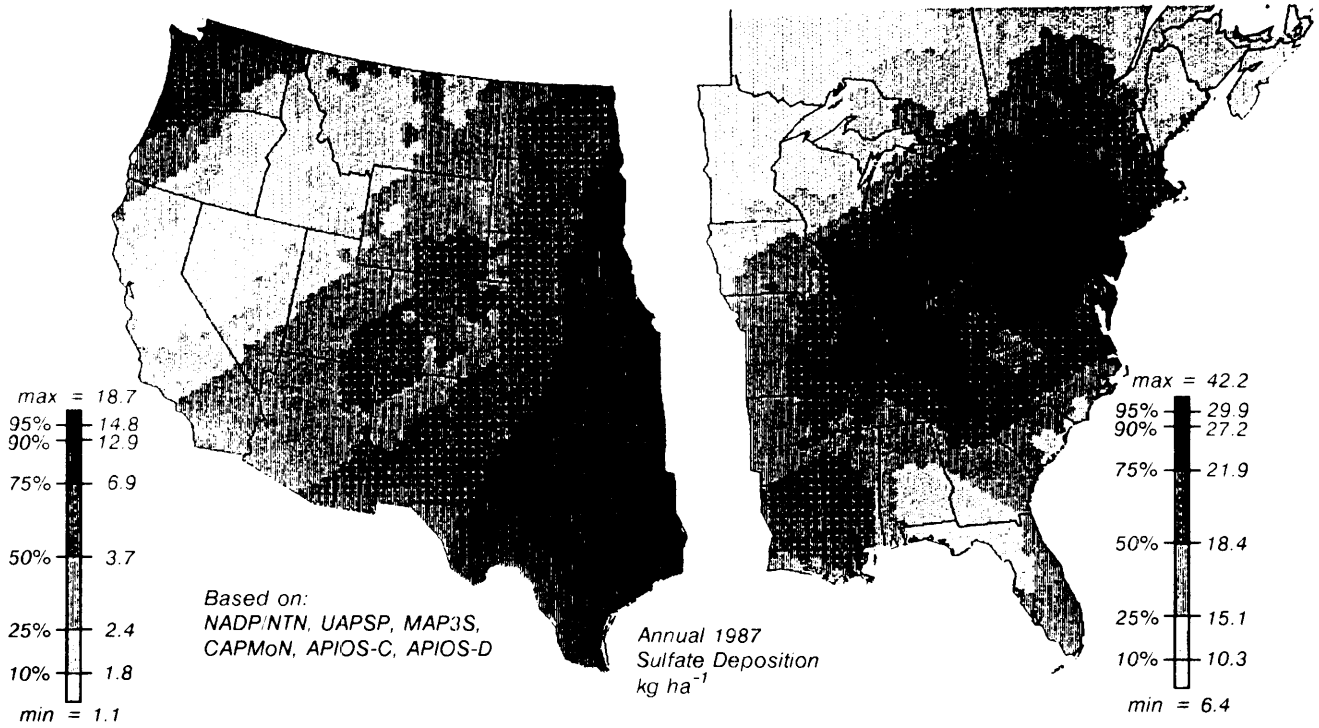

Figure 1. *Annual 1987 spatial distribution of sulfate deposition.*

median decrease for all 39 sites of approximately 27% from 1979 to 1987.

Conclusions

The research project statistical analyses of wet deposition monitoring network data enables several conclusions to be made concerning the 1987 spatial pattern of major wet deposition ion species and the trend observed from 1979-1987.

Maximum deposition of individual wet deposition ion species are located in the northeastern United States and southeastern Canada. These areas have not changed significantly in eastern North America in the past decade. The actual deposition values and areal coverage of those locations have changed from year to year, depending on variations in emissions and meteorological conditions. Spatial patterns of wet deposition are not as well characterized in the western as in the eastern region of North America. This results from the density of the monitoring networks being less in the west than in the east, from the presence of large terrain features in the west, and from large separation of emission sources in the west.

From 1979-1987, more than half of the 39 trend sites have estimated decreasing concentration and deposition trends for all ion species, except ammonium concentration. For sulfate, calcium, chlorine, sodium, potassium, and magnesium, more than 75% of the sites have estimated decreases; and for calcium, sodium, and magnesium over 90% of the sites have estimated decreases. In most cases the estimated decreasing trends are not statistically significant. Nevertheless, the median decrease for these 39 sites in sulfate concentration is approximately 18% and in sulfate deposition is approximately 27%.

From 1982-1987, less than 10% of the 144 trend sites have a statistically significant trend in ion species concentration and deposition. However, a median decrease of 0% to 4% per year in concentration and of 0% to 7% per year in deposition is estimated for the sites. The median decrease for these 144 sites in sulfate concentration is approximately 1% per year and in sulfate deposition 3% per year.

The available monitoring data and statistical analysis procedures limits quantitative generalizations of the estimated magnitudes of decreasing trends in concentration and deposition of ion species. The monitoring sites are not regularly spaced throughout eastern North America and consequently some regions have more representation than others. The statistical analysis procedure addresses trends at individual sites and discussion of trends across all sites does not consider regional trends in a quantitative way.

References

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Simpson, J. C., and A. R. Olsen. 1990. *1987 Wet Deposition Temporal and Spatial Patterns in North America*. EPA/600/4-90/019, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

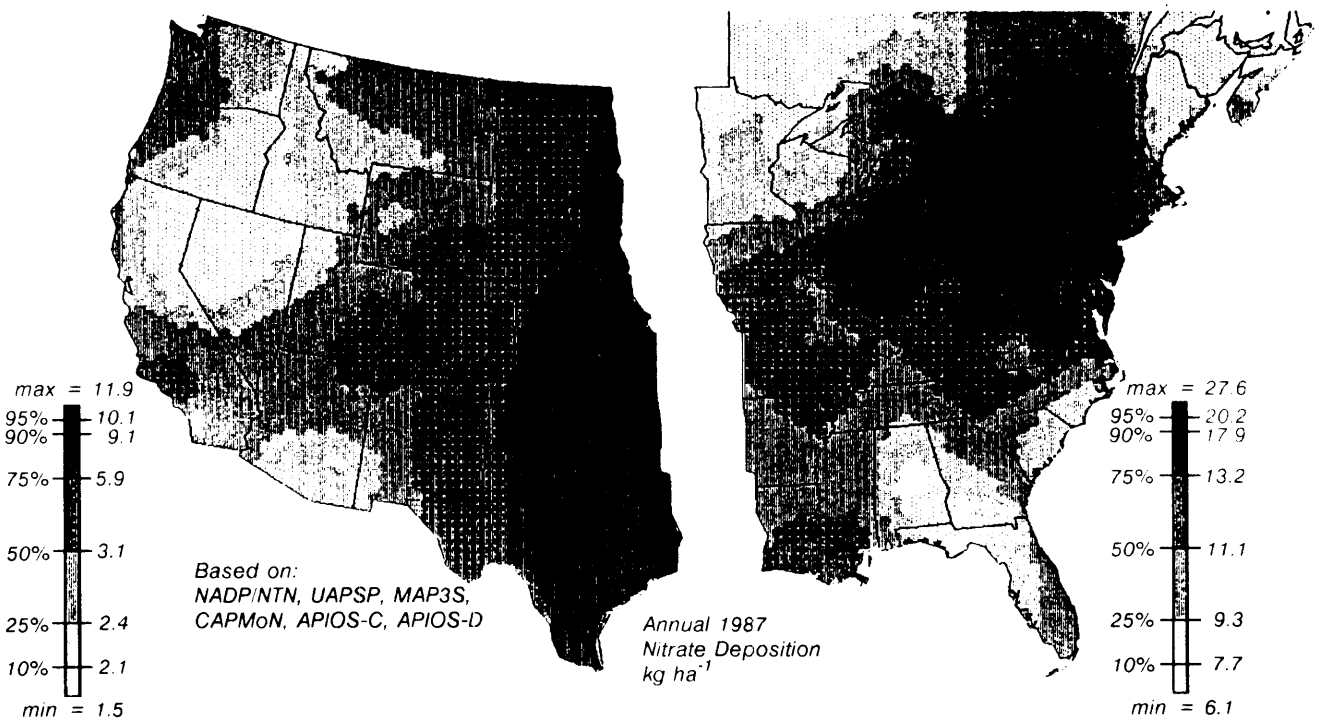

Figure 2. *Annual 1987 spatial distribution of nitrate deposition*

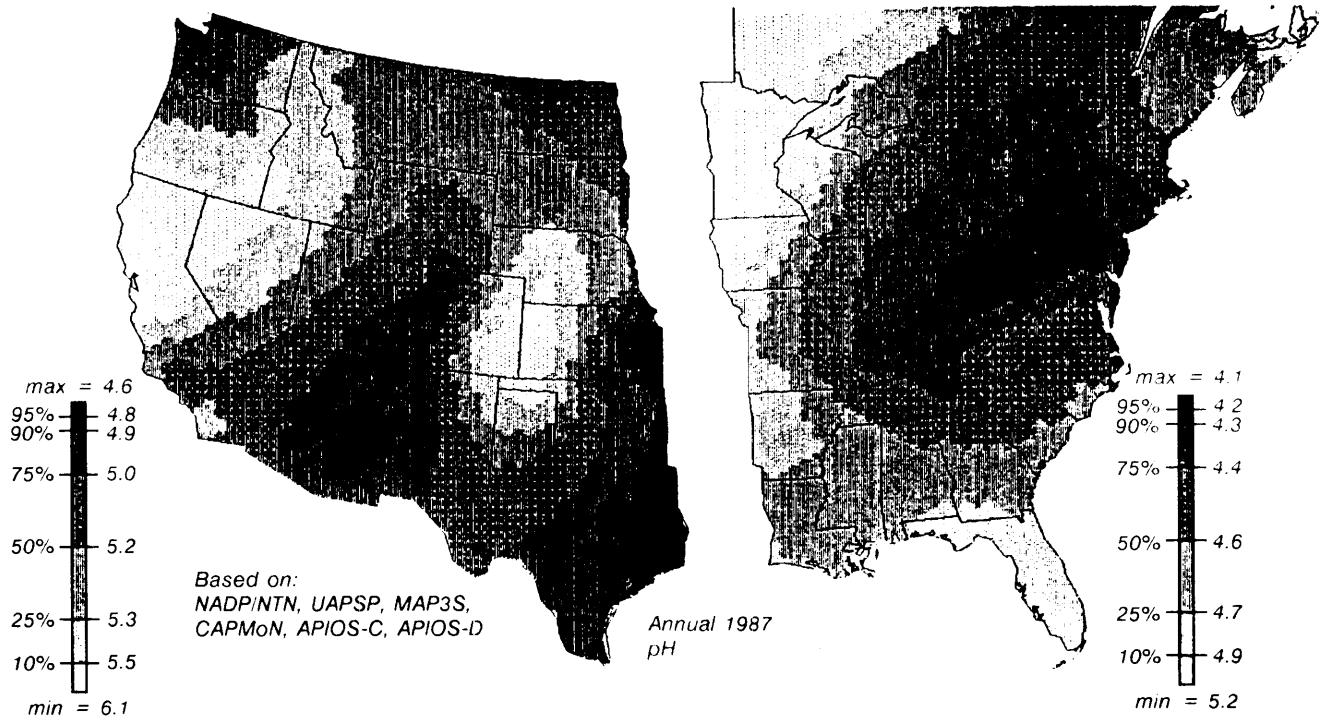

Figure 3. *Annual 1987 spatial distribution of precipitation-weighted pH.*

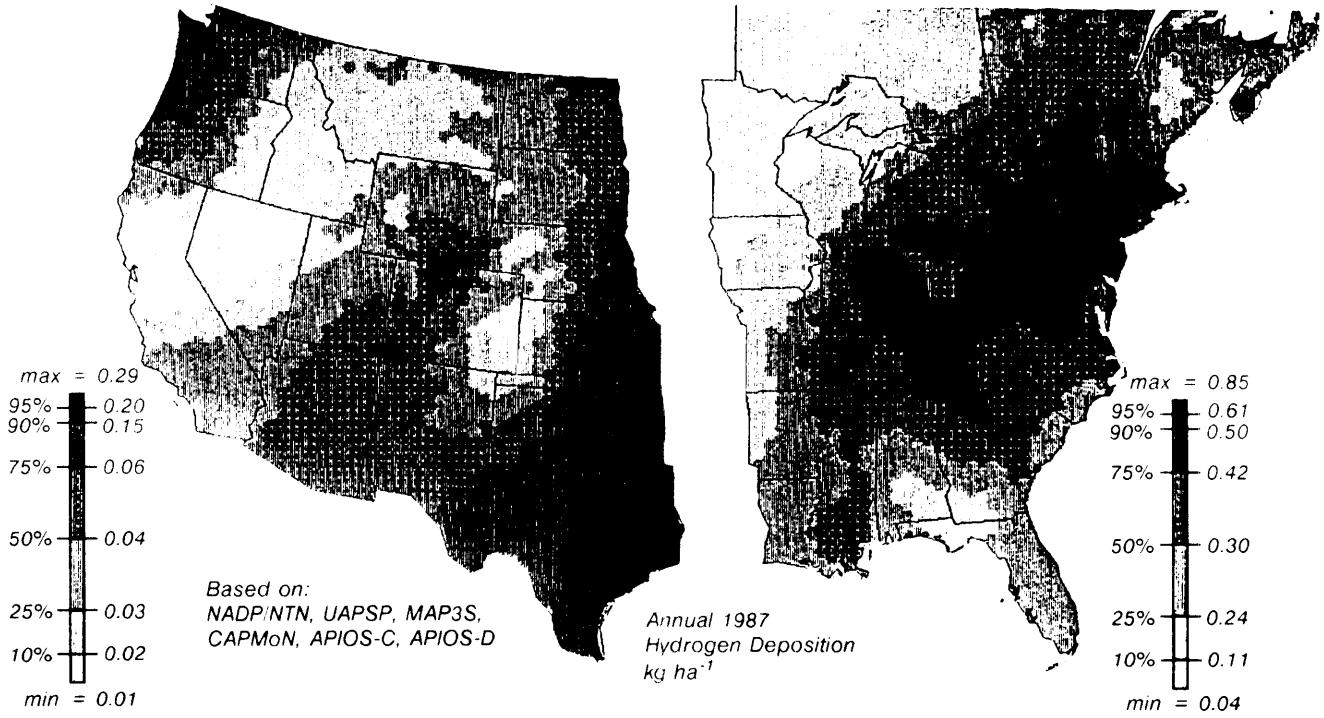

Figure 4. *Annual 1987 spatial distribution of hydrogen ion deposition.*

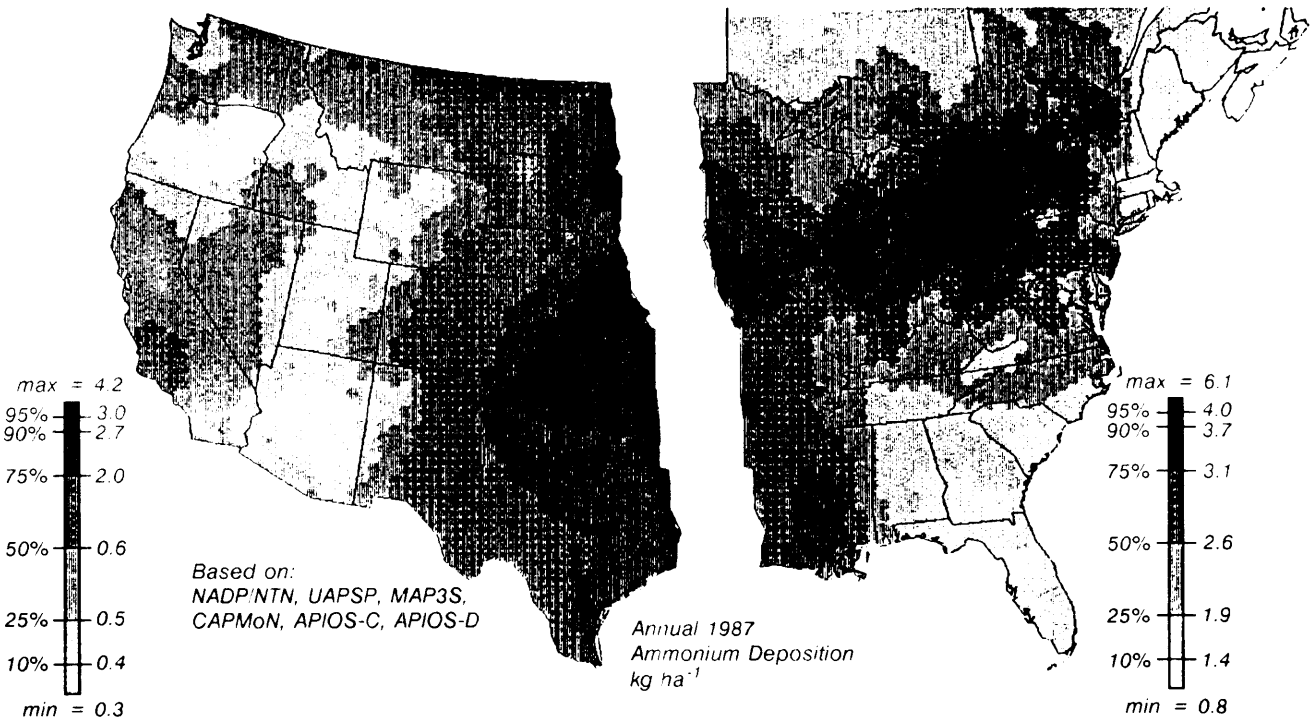

Figure 5. *Annual 1987 spatial distribution of ammonium deposition.*

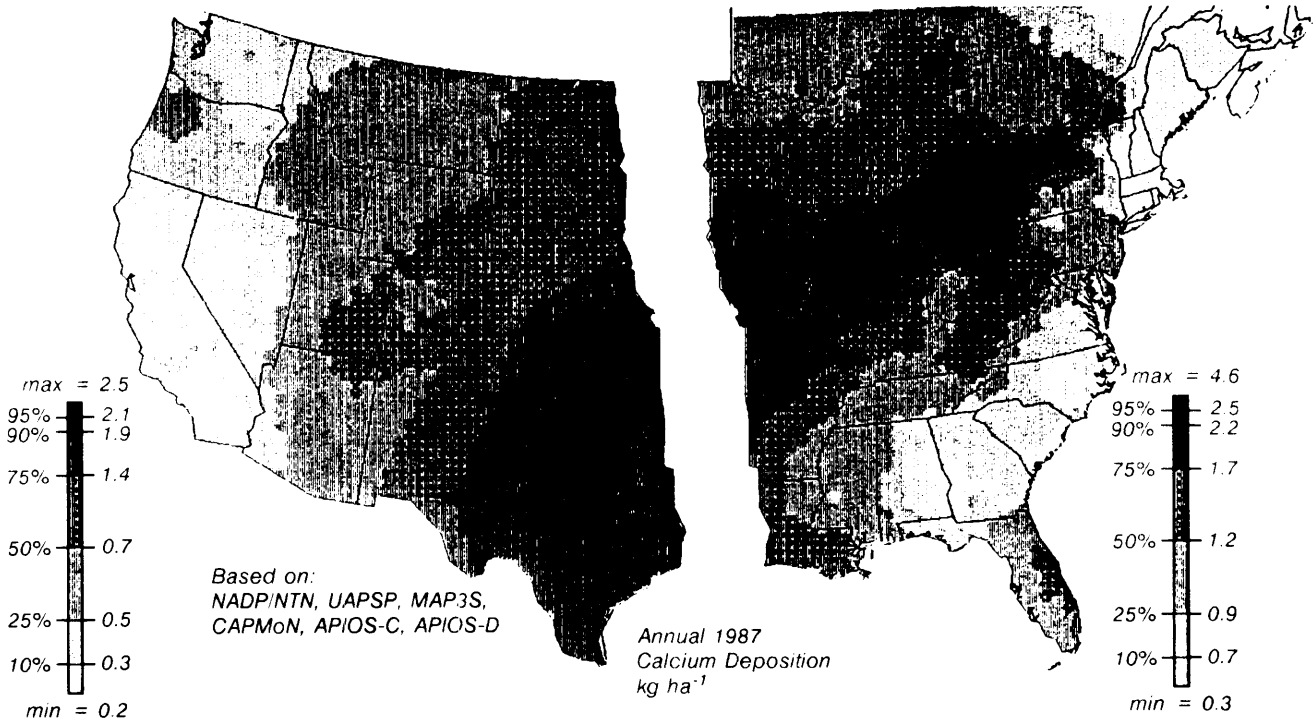

Figure 6. *Annual 1987 spatial distribution of calcium deposition.*

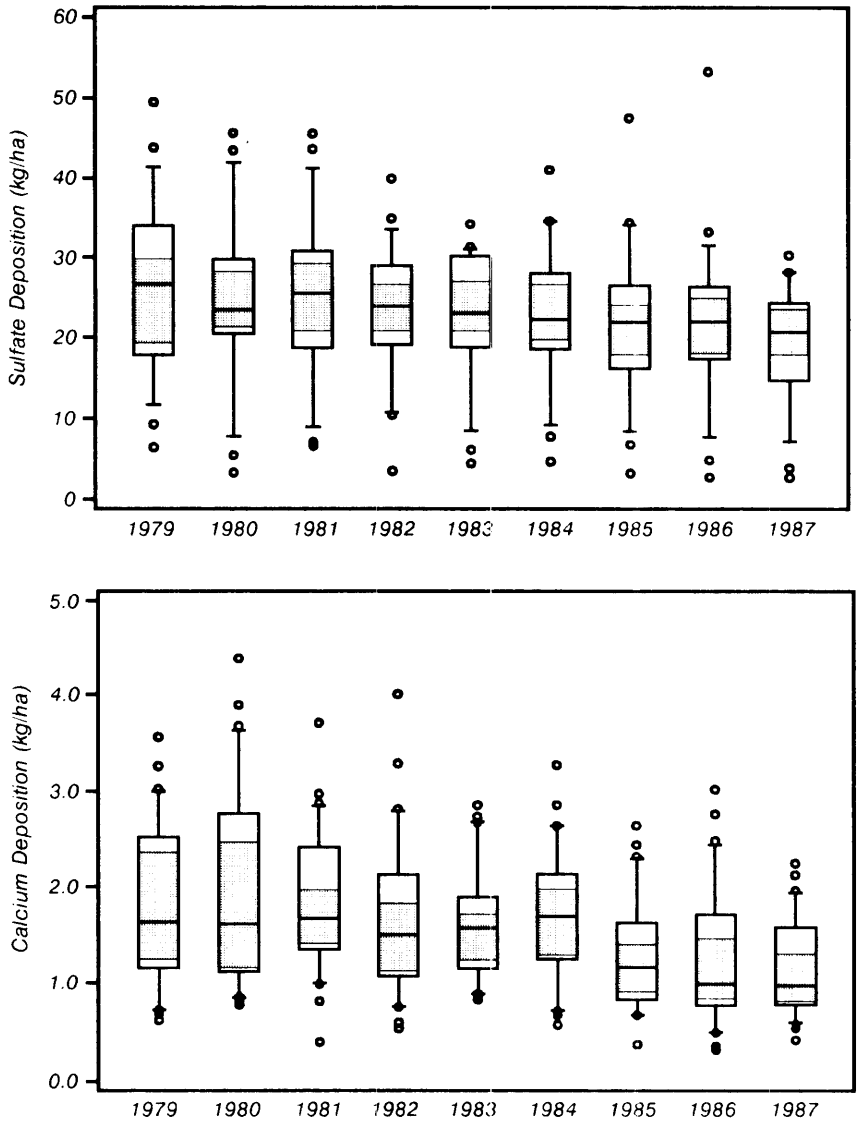

Figure 7. *Temporal pattern of (a) annual sulfate ion wet deposition and (b) annual calcium ion wet deposition. Boxplots are the 10th, 25th, 50th, 75th and 90th percentiles of sites in the 1979-87 trend subset.*

Table 1. *Median and Percent Change of Trend Estimates of Ion Concentration and Deposition for 1979-1987 and 1982-1987 Trend Sites*

	Concentration (μeq/L yr)				Deposition (meq/m²/yr)			
	1979-1987		1982-1987		1979-1987		1982-1987	
Parameter	Est.	%	Est	%	Est.	%	Est.	%
Precipitation	--	--	--	--	-0.04	-0.9	-1.85	-2.4
H^+	-0.05	-0.4	-0.04	-0.2	-0.09	-0.6	-0.50	-2.9
SO_4^{2-}	-0.91	-2.2	-0.28	-1.0	-0.88	-3.0	-1.08	-3.5
NO_3^-	-0.01	-0.1	0.42	1.8	-0.20	-1.2	-0.10	-0.8
NH_4^+	0.12	0.7	0.05	0.3	-0.07	-0.6	-0.25	-2.0
Ca^{2+}	-0.35	-6.1	-0.14	-2.6	-0.29	-5.5	-0.32	-6.3

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The complete report, entitled "1987 Wet Deposition Temporal and Spatial Patterns in North America," (Order No. PB90 251 836/AS; Cost: $31.00, subject to change) will be available only from:
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