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Project Summary

Estimation of Seasonal and Annual Acidic Deposition through Aggregation of Three-Day Episodic Periods

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The Regional Acid Deposition Model (RADM) simulates the complex physical and chemical processes involved in the formation of acidic deposition. However, because of the complexity of RADM it has only been applied to selected episodes of a few days duration. While the detail provided by RADM is highly desirable to understand the interactions between emissions and deposition on a storm-by-storm basis there is also a need for understanding the probable long-term relationship between changing emission patterns and deposition. The cost of simulating and interpreting seasonal or annual deposition patterns using RADM directly would be high.

A method for aggregating episodic deposition estimates has been developed and used to identify meteorological situations which merit simulation by RADM based on their likelihood of producing sulfate ($SO_4^=$) wet deposition at multiple locations across eastern North America, their frequency of occurrence, and their seasonality. The aggregation approach is based on four years (1982-1985) of meteorological and precipitation chemistry data.

The aggregation approach is based on the stratification of three-day periods into categories of similar 850 mb wind flow across eastern North America and subsequent selection of 30 RADM simulation periods from this stratification which represent the range of storm patterns present over eastern North America. The program has also provided the RADM project with scaling factors for use in weighing episodic simulation results to seasonal and annual deposition. The method is shown to improve upon the use of a random selection process in reproducing seasonal and annual wet deposition patterns.

This Project Summary was prepared 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).

Introduction

The development of policies to address problems arising from acid deposition requires a thorough understanding of processes that affect acid deposition. To this end the United States Environmental Protection Agency (EPA) has supported investigations into the physics, chemistry and meteorology of acid deposition. These efforts have culminated in the development of the Regional Acid Deposition Model (RADM), which simulates the processes involved in the emission, transport, transformation and removal of pollutants contributing to acid deposition.

The RADM will be used to assess the impact of different emissions control strategies on the spatial patterns of acid deposition across eastern North America. The RADM is an episodic model, simulating deposition on time scales of about 1 hour to 3 days. Acid deposition policy and assessment issues, however, require deposition pattern estimates on a seasonal and annual

bases. Thus, it is necessary to establish a relationship between individual deposition events and the long-term climatology of acid deposition. The relationship between individual events and climatology is difficult because deposition varies greatly from one event to the next in terms of both the amount of deposition and the relation between deposition and emission sources. Establishment of long-term deposition patterns and source-receptor relationships requires analysis over an extended time period, preferably including several years to account for meteorological variability.

The goal of this study has been to provide methods for representing aggregate long-term patterns of acid deposition from a finite number of samples. These methods involve both the selection of individual deposition events which are representative of recurring climatic patterns and the calculation of climatic averages based on these events. The aggregation methods have been applied to the specific problem of representing the climatology of acid deposition based on in-depth analysis by RADM for a finite sample of events. An array of 30 three-day events has been identified which includes the major climatic patterns that contribute to acid deposition over eastern North America. Assessment of the impact of future changes in precursor emissions will be performed by (1) using RADM to predict impacts for the thirty sample events, and (2) estimating long-term impacts by aggregating from the 30 sample events, based on the techniques described in this report. While designed specifically in support of RADM the methods described here may have broad applicability to other pollutants and to problems that involve the characterization of long-term climatic impacts of human activities.

Procedure

The aggregation technique is based on the hypothesis that there are recurring weather patterns which can be characterized and described in terms of observable meteorological parameters (wind fields, precipitation, etc.). It is further hypothesized that distinct weather patterns will be associated with characteristic patterns of wet deposition, both in terms of spatial extent and deposition amounts. Given those assumptions, long-term wet deposition processes may be analyzed based on a finite number of individual deposition events, each of which is "representative" of a major meteorological category. The goal of the aggregation project has been to identify the degree to which weather patterns may be separated into identifiable categories and to assess how this information would improve our ability to extrapolate case study results to longer-term deposition estimates.

The stratification of events into meteorological categories is used both in the selection of individual events for in-depth analysis with RADM and in the calculation of aggregated estimates for total wet deposition from 30-event samples. Event selection has been designed to include representative episodes from all major meteorological categories and to insure that the selected ensemble includes events with significant wet deposition at sites throughout eastern North America. Estimates for long-term deposition are derived from known deposition rates (either from observations or from RADM analyses) for the 30-event sample. The aggregation concept represents long-term deposition as the sum of deposition from sample events weighted by the frequency of occurrence of each meteorological category from which they were selected. The aggregation technique has subsequently been modified to make use of statistical correlations between wet deposition, category and other meteorological parameters (precipitation, season, etc.) in deriving estimates for long-term deposition.

Testing the aggregation technique poses a special problem because the most important issue, response of the method to changes in precursor emission rates, cannot be tested empirically. A variety of techniques have been used to explore aggregation accuracy. These include the establishment of statistical correlations between observed wet deposition, wind flow pattern and other meteorological variables and application of the aggregation technique to arrays of randomly selected events. Discrepancies between aggregate estimates and observed deposition are compared to the natural uncertainty arising from year-to-year variation in wet deposition. Lastly, an abbreviated model for source-receptor relationships is used to identify similarities and differences between randomly selected 30-day ensembles and long-term averages. These combined tests establish both the level of accuracy and limitations of the aggregation technique.

Identification of representative deposition events and methods of aggregation are based on meteorological and statistical analyses of deposition events that occurred over a 4-year period (1982-1985). Events during this period were divided into categories with similar three-day patterns of 850 mb wind flow across eastern North America. The three-day time period and 850 mb wind fields are broadly representative of the evolution of distinctive storm patterns that are likely to affect atmospheric transport and deposition rates. Events have been selected for analysis by RADM from among the meteorological strata based on their likelihood of producing sulfate ($SO_4^=$) wet deposition at multiple locations across eastern North America, their frequency of occurrence, and their seasonality.

Results and Discussion

The following specific tasks have been completed as part of this project:

1. An extensive data base with daily precipitation and wet deposition of sulfate, nitrate and total H^+ was developed. The data base covered the years 1982-1985 and included 23 sites in the northeastern, southern and midwestern U.S. and southern Canada. Meteorological information used in subsequent analysis was also collected.
2. Techniques of cluster analysis were used to stratify 3-day events over the 4-year period into categories based on the meteorological data described above. Four independent stratification schemes were investigated: stratification by 850 mb wind field, stratification by 850 mb geopotential and mean surface pressure, stratification by 850 mb temperature advection and 500 mb vorticity, and stratification by 500 mb vorticity advection and 850 mb relative humidity. These four stratification schemes were evaluated to find the combination of meteorological parameters which best explained variations in sulfur wet deposition.
3. A set of 19 meteorological categories was compiled based on similarity in wind flow at 850 mb. These 19 categories were each subdivided into "wet" and "dry" cases, making 38 categories. These 38 categories were used as the basis for selection of individual days and derivation of aggregated estimates for annual deposition.
4. Accuracy and validity of the 38-category stratification was evaluated based on the ability to predict annual sulfate deposition at eastern and midwestern sites from a finite sample of 3-day events. We compared estimates for annual deposition derived from a random sample of 3-day events with estimates from a cluster-based sample of events. The standard deviation between estimated and actual deposition was lower by 25% with cluster-based selection.

5. Selection of 30 individual 3-day events for in-depth study with RADM was made. Selection of events was designed to satisfy the following criteria:

   a. representation of the meteorological categories that account for the bulk of dry deposition in the eastern U.S.

   b. Inclusion of days representing a wide variety of circulation patterns, including relatively rare winter circulation patterns.

   c. Inclusion of a number of days with very little wet deposition, to allow for simulation of dry deposition processes.

   d. Selection of individual events within each category by a random process, rather than prescribing specific events.

   e. Accurate representation of total annual deposition at all northeastern and midwestern sites from the ensemble of individual events.

The selected ensemble allows for accurate estimation of summer, winter, and total annual deposition at all sites in the northeast and midwest.

Conclusions

Analysis of observed wet deposition during the 1982-1985 time period shows that deposition rates are statistically correlated with meteorological category with greater than 95% confidence at most sites in eastern North America. The aggregation technique has been used to obtain estimates for annual deposition at 21 sites in eastern North America based solely on observed deposition during the selected 30-day ensemble. The resulting estimates differ from the observed 4-year average wet deposition by amounts comparable to normal year-to-year variations. Aggregated estimates based on meteorological strata are more accurate than estimates from randomly selected events.

The aggregation project has served two purposes:

1. to provide the RADM project with a list of simulation periods which represent the range of storm patterns present over eastern North America. The selection of storm types was based on their likelihood of producing $SO_4^=$ wet deposition at multiple locations across eastern North America, their frequency of occurrence, and their seasonality; and
2. to provide the RADM project with scaling factors for use in weighing episodic simulation results to seasonal and annual deposition.

The aggregation methodology has potential application to other air pollution issues including regional oxidants and regional aerosols. Research is continuing to refine the approach and to quantify its uncertainty and sensitivity, and to apply and test its performance for ambient concentrations as they impact dry deposition and visibility.

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The complete report, entitled "Estimation of Seasonal and Annual Acidic Deposition through Aggregation of Three-Day Episodic Periods," (Order no. PB90-252 628/AS; Cost: $31.00 cost subject to change) will be available only from:
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