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Can Selected RADM Simulations Be Aggregated To Estimate Annual Concentrations Of Fine Particulate Matter?

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ABSTRACT

Ambient air concentrations of fine particulate matter are an issue of increasing concern for the U.S. Environmental Protection Agency. Accordingly, the Clean Air Act and the Amendments of 1990, call for an assessment of past and future regulations to protect both health and visibility. Unfortunately, our most reliable tools for assessing long-term air quality change, Eulerian models, challenge the practical limits of current computer resources and require extensive input data. To reduce the resource requirement, an aggregation method, initially developed for RADM (Regional Acid Deposition Model) acid-deposition applications, is currently being applied to a limited number (thirty) of RADM simulations in order to provide estimates of long-term (annual) ambient air concentrations of fine particulate matter. This paper briefly examines this aggregation technique, its application to fine particulate matter, and the suitability of the original thirty RADM simulations.

INTRODUCTION

Ambient air concentrations of fine particulate matter (diameter ≤ 2.5 μ) are an issue of increasing concern for the U.S. Environmental Protection Agency. Recent epidemiological studies link an increase in mortality and other detrimental health effects, especially to the young, elderly and others with respiratory problems, to fine particulate matter[1]. Fine particulate matter also contributes to the deterioration of visibility, especially in the eastern United States. The Clean Air Act and the Amendments of 1990 call for assessment of past and future regulations to protect both health and visibility. Such an assessment will not only require estimates of changes in air quality attributable to regulatory policy (as opposed to those attributable to changes in meteorology), but estimates of the potential effects to health and visibility as well.

The most reliable tool for estimating air quality change for large regions, both past and future, are regional air quality models such as the Regional Acid Deposition Model (RADM)[2]. This model, and to an even greater degree, future models require massive resources, both human and computer, for each policy and/or meteorological scenario. The benefits analyses proposed for the Clean Air Act Amendments of 1990 require annual timescales. Unfortunately, most Eulerian models, like RADM, challenge the practical limits of current computer resources as well as our ability to collect the pertinent input data on annual scales. As a result, application of such models to determine the long-term relationship between changing emissions patterns and ambient air concentrations is limited.

To circumvent this problem, results from an aggregation method, initially developed for acid-deposition applications[3,4] are currently being applied to a limited number (thirty) of RADM simulations in order to provide estimates of long-term (annual) ambient air concentrations of fine particulate matter. The aggregation method is based on the premise that at any given location,

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ambient air concentrations of fine particulate matter are governed by a finite number of different, though recurring meteorological regimes. If a collection of concentration patterns representative of these different meteorological regimes can be identified, they can be aggregated, using appropriate weights, to produce reasonable estimates of annual averages.

The purpose of this study is to determine whether or not the thirty original RADM simulations selected for aggregation in the acid deposition applications are equally representative for ambient air concentrations of fine particulate matter. Unfortunately, there exists a dearth of fine particulate data, therefore this analysis will employ, as a surrogate, an extinction coefficient (b_{ext}) estimated from midday human observations of visual range at airports[5].

DATA

Meteorological

The cluster analysis, described in the methodology section, utilized eastern North American zonal *u* and meridional *v* 850 mb wind components (ms^{-1}) for 0000 UTC. Winds at 850 mb were selected because of their proximity to the boundary layer, where a majority of pollutant transport occurs. The data, which had a 5° latitude by 5° longitude resolution were extracted from the NMC global analyses for the period 1979-1990. The NMC data were selected in part because they provide information over the Atlantic Ocean with the same resolution as is provided over the continent. To allow compatibility with RADM simulations, which generally have been on the order of three days, the NMC data were rearranged into overlapping three day records (i.e record 1 - days 1, 2, 3; record 2 - days 2, 3, 4, etc.)

Extinction Coefficient

The aggregation results were applied to daily extinction coefficients [b_{ext} (km^{-1})] obtained from Washington University's CAPITA (Center for Air Pollution Impact and Trend Analysis) located in St. Louis, MO. The data were observed at 64 locations (Figure 1) through the eastern two-thirds of the U.S for the period 1979-1990. The light-extinction coefficient is often used to characterize visibility, although, in general, it has limited ability to predict human visibility. The visual range can be estimated from the b_{ext} by using the Koschmieder equation:

$$\text{visual range (km)} = 3.91/b_{ext} \quad (1)$$

with the assumptions that a black target is viewed against the horizon in daylight, and that the atmosphere and the illumination over the sight path are uniform. Only days that were free of precipitation, with relative humidity less than 90% were utilized in this study. The b_{ext} was also corrected for relative humidity.

METHODOLOGY

Clustering

The purpose of objectively defining meteorological categories is to identify recurring atmospheric transport patterns associated with varying concentration patterns of fine particulate matter. Identification of these patterns was necessary to facilitate selection of time periods for simulation by RADM and in the development of the aggregation technique.

Utilizing Ward's method of cluster analysis in an agglomerative, hierarchical mode, each of the 3-day sequences of 850 mb wind flow patterns from 1979 to 1990 were assigned into one of 19 statistically significant meteorological categories[3]. The analysis consisted of 288 data values recorded at 0000 UTC (i.e. 48 grid points x 2 variables (*u* and *v*) x 3 day overlapping records) for each of the 4383 days in the study period. For further information concerning this procedure, consult the original article[3].

Aggregation

The aggregation procedure estimates mean annual extinction coefficients using a set of thirty simulation periods selected from the 19 meteorological categories as described in the original article[4]. The number of simulation periods exceeded the number of meteorological categories because in the original study, the categories were further divided into "wet" and "dry" portions. The resulting 38 categories were reduced to 30 to keep the number of RADM simulations to a manageable number. Calculation of the mean annual extinction coefficients makes use of weighting/scaling factors that are based on the frequency of occurrence and the expected extinction coefficient for each of the categories associated with the events selected for aggregation.

RESULTS

Clustering

Found in Figures 2(a) and 2(b) are two of the 19 meteorological transport patterns associated with Clusters 9 and 12. The length of the vectors is proportional to the wind speed at 850 mb, with the arrows pointing in the direction of the wind flow. Each vector is centered at the location where the wind data were used in the cluster analysis.

Cluster 9, which was the most frequently observed flow pattern, is depicted in Figure 2(a). This 850 mb flow pattern is dominated by a stationary anticyclone situated over the southeastern United States. This pattern occurs when the Bermuda High, normally centered over Bermuda, retrogrades and stalls, resulting in subsidence and a weak anticyclonic circulation over most of the entire domain. Winds tend to be very light over most areas east of the Mississippi River and south of the Great Lakes. Examination of extinction coefficients associated with this cluster (Figure 3(a) indicate large values (generally greater than 0.16 km^{-1}) over much of the eastern U.S. These large coefficients, which again are indicative of low visibilities and thereby hypothesized high fine particulate matter concentrations, are common with such patterns where stagnation, subsidence and little or no precipitation occur[6].

Cluster 12, which occurred less frequently than Cluster 9, is shown in Figure 2(b) and depicts a well-developed low pressure system centered over New England. This 850 mb flow regime results in a strong cyclonic circulation pattern. Transport is strong and from the northwest over most of the domain. Note the vector's lengths as compared to those associated with Cluster 9. This strong northwesterly flow allows migratory anticyclones that originate in relatively "clean" areas of western Canada to traverse the eastern United States in areas north of 35° latitude[7]. As a result, extinction coefficients associated with this cluster (Figure 3(b)) are much smaller, with most of the domain reported mean extinction coefficients less than 0.12 km^{-1}). The main exception is the Gulf Coast area where the flow is not generally influenced by the migratory anticyclone. Here the extinction values reach 0.17 km^{-1}.

The mean cluster extinction coefficients associated with the other 17 clusters, each defining a common flow pattern, lie within the range established by Clusters 9 and 12 (Figure 4). Cluster descriptions can be found in the initial article[3].

Aggregation

Results comparing the observed mean annual extinction coefficients with the aggregated estimates of the mean annual extinction coefficient are very promising as seen in Figure 5 and 6. Aggregated mean annual extinction coefficients at roughly two-thirds of the stations (41 of 64) were within 5% of the actual mean annual values. The correlation between the two data sets was very high, $r^2 = 0.963$. The intercept was nearly zero (-0.005) and the slope nearly one (1.029), indicating little or no systematic bias across the 64 sites. There does, however, appear to be some spatial bias as seen in Figure 6; with a general underestimation found in the northeastern quadrant of the domain, especially in New England, where underpredictions reach 15%. Reasons for this spatial bias are not understood at this time.

CONCLUSIONS

The thirty RADM simulation periods, originally selected for acid-deposition applications, appear to be very representative from an extinction coefficient (inferred fine particulate matter) perspective. Whereas acid-deposition aggregate values were within 20% of the observed values at only 13 of the 20 sites used in the original study, roughly two-thirds (41/64) of the aggregate extinction coefficients were within 5 % of the mean observed coefficients in the current study, and all were within 15%. The correlation between the observed and aggregate coefficients was very high. With the exception of the spatial bias discussed above, little systematic bias was found in the results. It should be noted that some of the increase in the representation of these thirty simulation periods for particulate concentrations (as opposed to acid wet deposition) can be attributed to the removal of uncertainty inherently associated with precipitation. Results of this analysis suggest that the original thirty RADM simulations are indeed sufficient enough to derive annual estimates of fine particulate matter.

DISCLAIMERS

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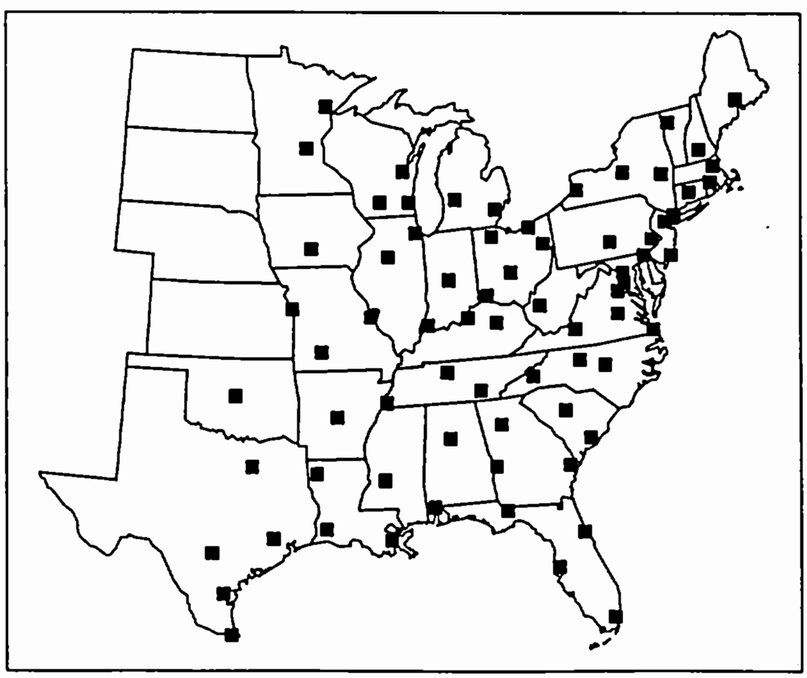

Figure 1. Station location map for b_{ext} coefficient measurements.

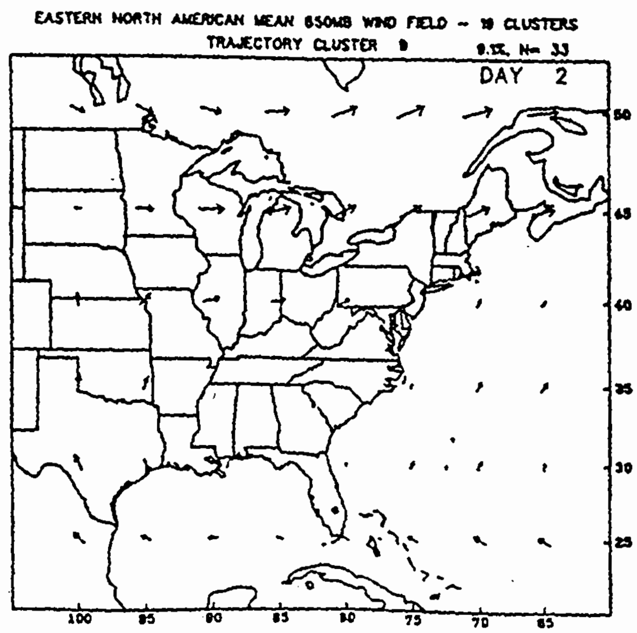

Figure 2(a). Eastern North American 850 mb wind field associated with Cluster 9.

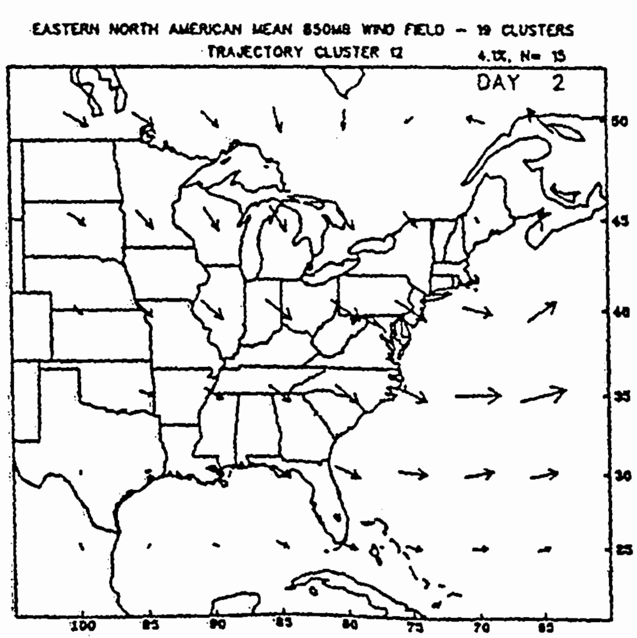

Figure 2(b). Eastern North American 850 mb wind field associated with Cluster 12.

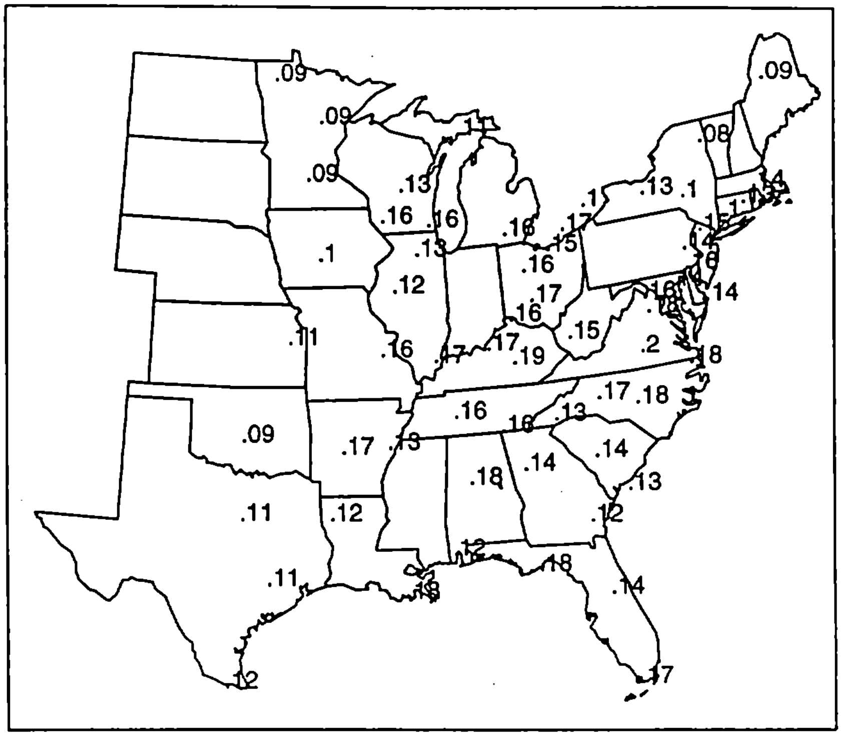

Figure 3(a). Mean b_{ext} (km^{-1}) associated with Cluster 9.

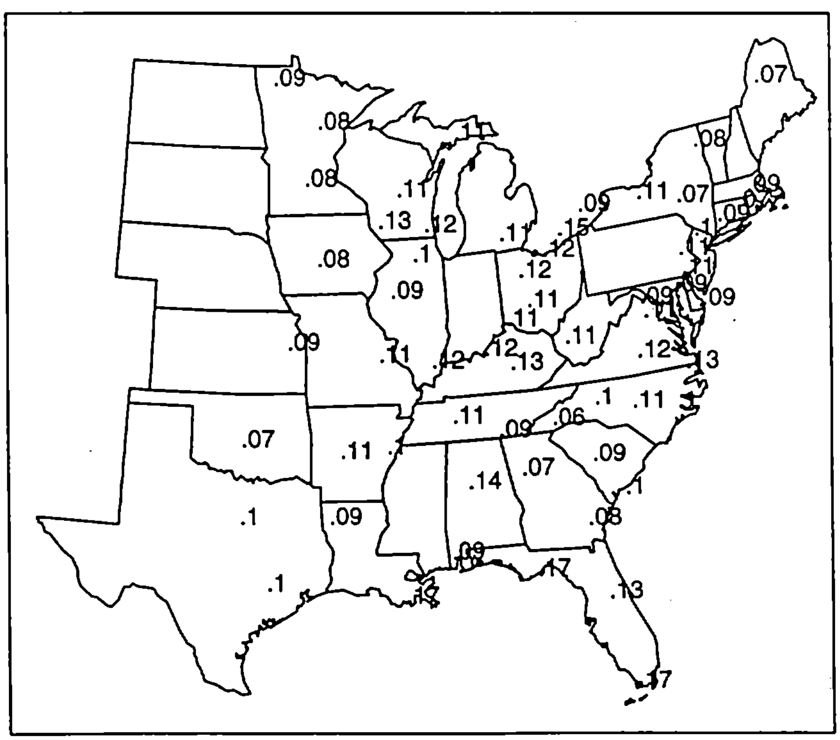

Figure 3(b). Mean b_{ext} (km^{-1}) associated with Cluster 12.

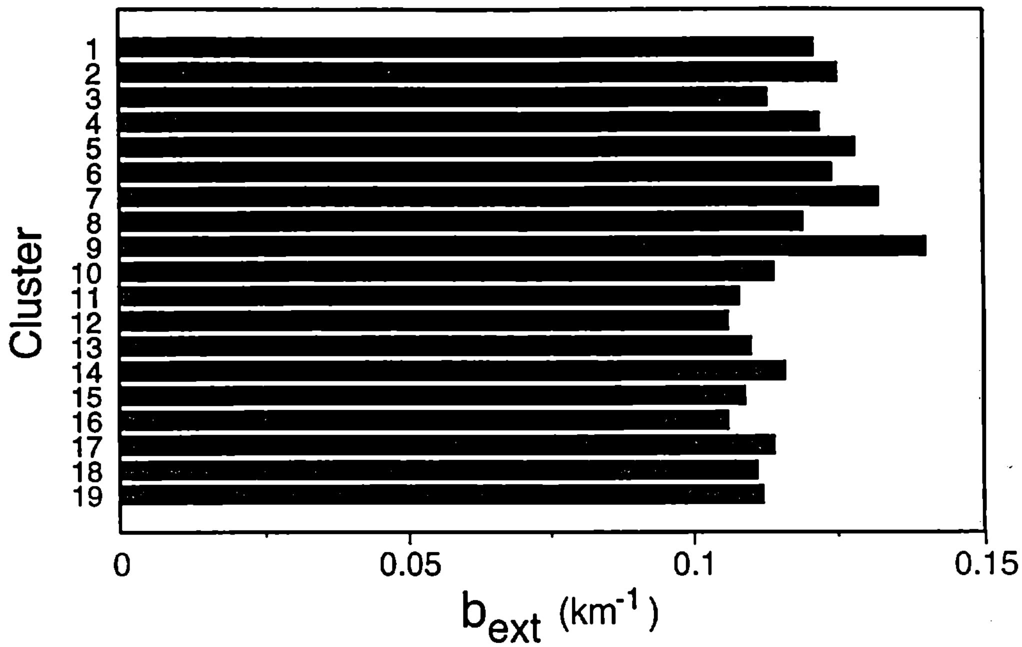

Figure 4. Mean network b_{ext} (km^{-1}) associated with the 19 meteorological clusters.

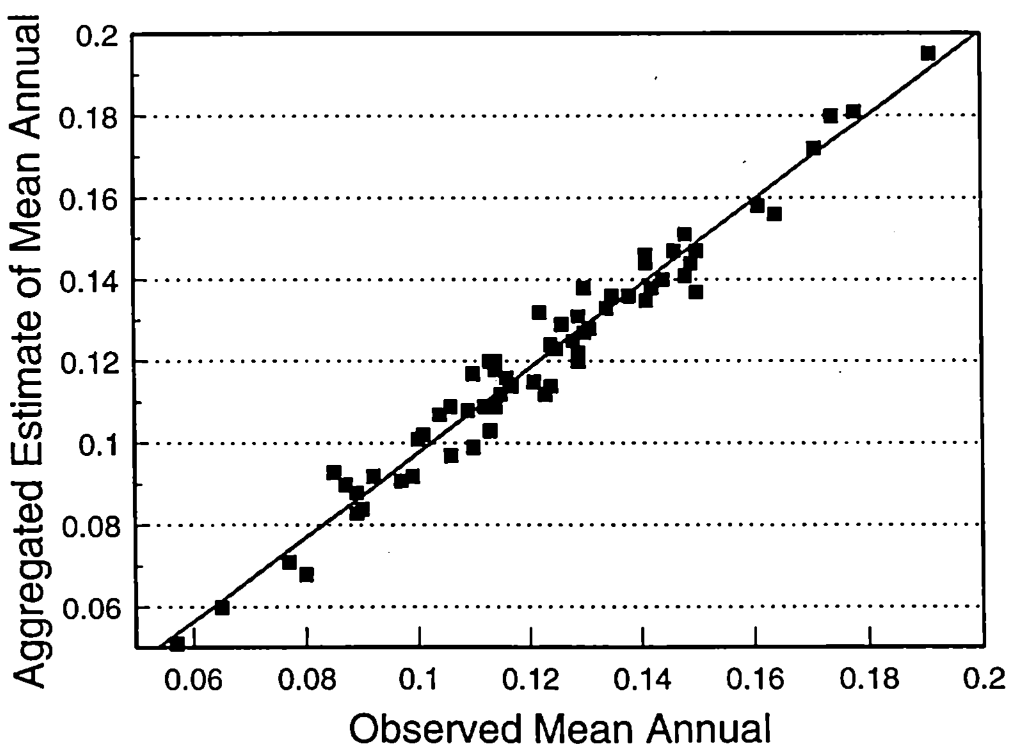

Figure 5. Comparison of the observed and aggregate mean annual b_{ext} (km^{-1}) for the period 1979-1990.

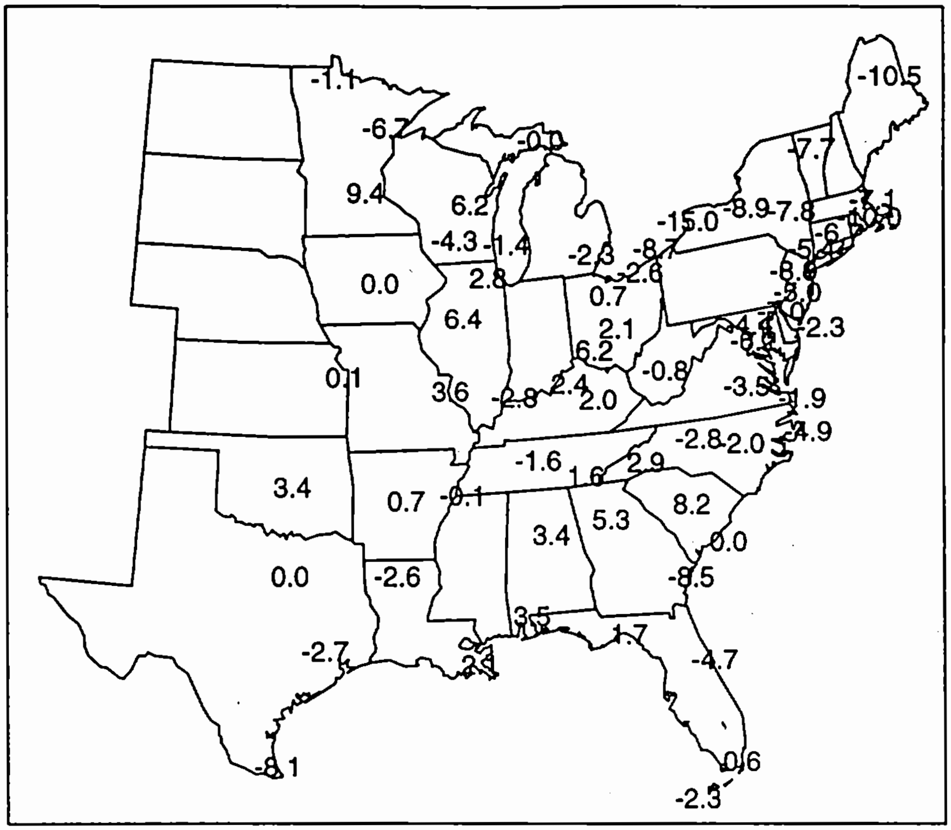

Figure 6. Percent deviation in aggregate estimates of the mean annual b_{ext}. Deviations are relative to the observed annual means (i.e. aggregate-observed/observed).

TECHNICAL REPORT DATA

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16. ABSTRACT

Ambient air concentrations of fine particulate matter are an issue of increasing concern for the U.S. Environmental Protection Agency. Accordingly, the Clean Air Act and the Amendments of 1990, call for an assessment of past and future regulations to protect both health and visibility. Unfortunately, our most reliable tools for assessing long-term air quality change, Eulerian models, challenge the practical limits of current computer resources and require extensive input data. To reduce the resource requirement, an aggregation method, initially developed for RADM (Regional Acid Deposition Model) acid-deposition applications, is currently being applied to a limited number (thirty) of RADM simulations in order to provide estimates of long-term (annual) ambient air concentrations of fine particulate matter. This paper briefly examines this aggregation technique, its application to fine particulate matter, and the suitability of the original thirty RADM simulations.

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