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Project Summary

Atmospheric Turbidity Over the United States from 1967 to 1976

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The purpose of this study was to analyze the observational data from the U.S. Environmental Protection Agency-National Oceanic and Atmospheric Administration turbidity network in the United States for the 1967-1976 decade. The research also compared patterns and trends of background turbidity with a previous report, which covered the six-year period 1961 to 1966.

The results of the turbidity climatological analysis for the 1967 to 1976 time period assessed the geographical, seasonal, and temporal variations in mean background (i.e., nonurban) turbidity. Maximum annual average background turbidity occurs over the Southeast and the Smoky Mountain region and minimum annual average background turbidity occurs over the Rocky Mountains and the interior Southwest. This geographical variation occurred in all four seasons. The annual turbidity cycle was also analyzed; maximum seasonal average turbidity occurred in the summer and minimum seasonal average turbidity occurred in the winter in all regions of the United States. The amplitude of this seasonal change was greatest over the Southeast and smallest over the Rocky Mountain region.

Results of trend analyses indicated increases in turbidity during the 1967 to 1976 decade, especially in the summer season, in the Southeast and the Smoky Mountain region. Increasing urbanization and industrialization in the South are suggested as possible causes for this trend. No increases in background turbidity could be documented in the western states.

To develop a simple, regionally stratified model relating turbidity to urbanization, climatological average turbidity was treated as the sum of two terms, background and excess average turbidity. The relationship between urban population and excess average turbidity was shown to be linear and well correlated ($r = 0.76$). The application of this relationship to predict increases in annual average turbidity based on population growth projections for urban areas was also described.

The technique of separating long-term average values into background and local effects may be useful in predictive investigations of other properties of the atmosphere which are influenced by man's activity.

Regional case studies of turbidity during air pollution episodes produced only marginal results. These poor results are attributed to the fragmented nature of the turbidity record at most stations. Some air mass transport could be hypothesized from the turbidity data as long as visibility records were available for guidance. The results were in contrast to some single station records that have been published showing day-to-day turbidity changes with weather patterns at a given location.

This Project Summary was developed by EPA's Environmental Sciences Research 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

Air pollutants, when dispersed in the atmosphere, can change the optical properties of the atmosphere. These changes may be due to increased absorption and scattering effects resulting from both pollutant gases and particles. Common atmospheric optical properties are the visibility and the turbidity most commonly related to a change in solar intensity and thus to a more or less vertical sight path. By definition, turbidity in the meteorological context is "any condition of the atmosphere which reduces its transparency to radiation, especially to visible radiation." In a quantitative manner, a turbidity coefficient can be calculated from solar intensity measurements.

On hazy days, reductions in total irradiance at the surface can be of considerable magnitude. Some investigators have demonstrated a 20% reduction in total spectral irradiance at the surface (direct + diffuse) on a hazy day as compared to a clear day in Texas. Episodes of high turbidity in the eastern United States have produced conditions in which as much as 85% of the incoming solar radiation appeared as diffuse skylight. In a "clean" atmosphere, approximately 10% to 15% of the incoming radiation appears as skylight.

The data for the present study were obtained from the turbidity observation network set up in the United States in 1960 to 1961 and operated since then as a cooperative U.S. Environmental Protection Agency-National Oceanic and Atmospheric Administration (EPA/NOAA) program. Since 1971, the United States turbidity network has operated as part of a global program guided by the World Meteorological Organization (WMO). The basic instrument used in this turbidity program is the Volz sunphotometer.

The results of the initial six years of operation of the United States network, i.e., 1961 to 1966, were described in an earlier report. The current study continues the analysis of turbidity data and covers the period 1967 to 1976. Since 1966, the size of the network has ranged from 25 to 40 stations. A tabulation of yearly and seasonal average turbidity data for all network stations is given in an appendix to the project report.

Research Techniques and Results

The data for this study was developed from magnetic tape and hard copy versions of the raw data. The nature of the turbidity measurement and the seasonal cycle in turbidity present obstacles to climatological averaging. Since the measurement can be made only when an unobstructed line of sight to the sun (i.e., no clouds blocking the direct beam) exists, the number of observations varies from station-to-station and from season-to-season as well as with prevailing synoptic weather. Data analysis techniques were developed to minimize the potential for bias caused by observing or sampling problems.

Annual Average Background Turbidity

This study of turbidity began with an examination of the average background data from rural and other nonurban stations. Figure 1 shows the annual average background turbidity over the United States for 1967 to 1976. Individual values range from about 0.04 to 0.17. Values for most cities with populations of 100,000 or more are significantly higher than these background levels. The effect of large cities on turbidity was examined with the modeling study.

The annual average turbidity pattern of Figure 1 shows significant differences between eastern and western regions. The highest annual average turbidities occur in the southern Appalachian and Smoky Mountain regions and thus are similar to the results reported for the 1961 to 1966 period. In the West, the minimum average turbidity values occur in the interior basin region generally defined on the east by the crest of the Rockies and on the west by the High Sierra and Cascade ranges.

Background turbidity in summertime, the season with maximum turbidity values, is shown by Figure 2. In the western states and the northern Great Plains, little apparent change occurs from spring to summer. However, in the Southeast, turbidity is approximately two times the spring values, increasing from a spring maximum of 0.16 in the Appalachians to a turbidity coefficient of 0.30 in the summer. More detailed analyses show that this seasonal cycle with a summer maximum is observed generally at all network sites, although the amplitude of the cycle varies from region-to-region. Important factors that can contribute to the summer maximum in turbidity are slower moving stagnant air masses, greater solar radiation leading to increased production of natural and anthropogenic photochemical aerosols, and higher relative humid-

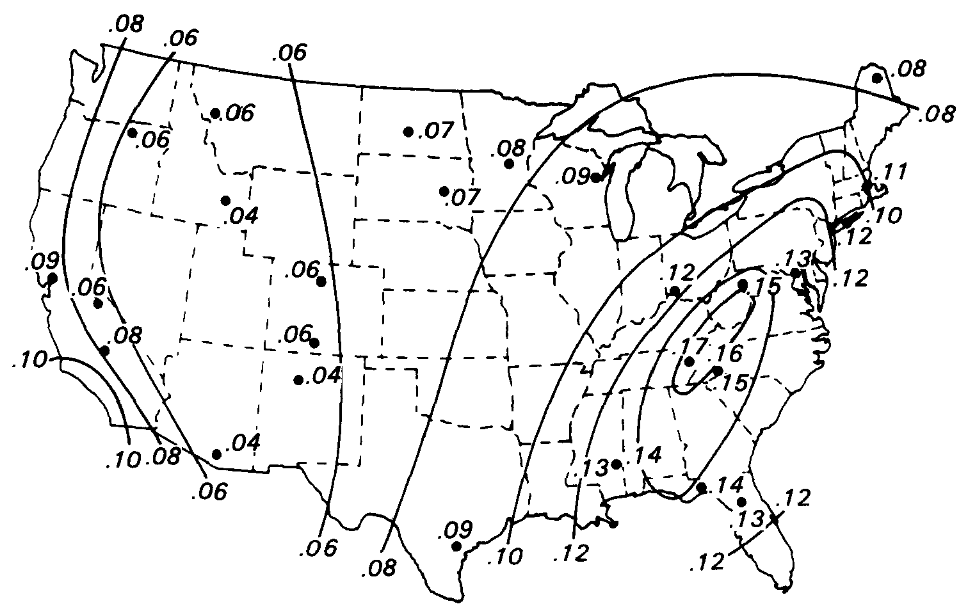

Figure 1. Annual average background turbidity, 1967 to 1976.

ities associated with maritime tropical air masses.

Turbidity Time Trends During the 1967 to 1976 Period

Details of regional differences were determined through an examination of seasonal time trends over the 1967 to 1976 decade at specific sites across the country. The plot for Oak Ridge, Tennessee, (Figure 3), is typical for sites in the Smoky Mountain and southeastern region of the United States. Slight increases in annual average turbidity over the period (shown at the bottom of the figure) are due mainly to strong increases in the summer average values (shown by the seasonal trends in the upper portion). Interestingly, time trends in the winter, spring, and fall average values at Oak Ridge are not pronounced. The strong summer turbidity trend seems to be relatively limited in geographical extent to an area generally east of the Mississippi River.

Background turbidity trends in the upper Midwest are illustrated in Figure 4, which shows the annual and seasonal trends for Green Bay, Wisconsin. Average annual turbidity is about 0.1 compared to about 0.15 at Oak Ridge, and no consistent trend at Green Bay exists over the 10-year period. Green Bay shows, in general, the greatest average turbidity during the summer, but no trend over the 1967 to 1976 decade is discernible in either the summer data or in any of the other seasons. The differences between winter and summer turbidity are also relatively small compared to the stations in the Southeast.

Model Relating Turbidity to Urbanization

Long-term average atmospheric turbidity at an urban location can be considered as the sum of two effects. The first, background turbidity, is influenced by regional differences. The second, the local contribution to turbidity, is influenced by the extent of the urbanization and industrialization of the city where the measurement is made and the influence of any nearby major urban areas. Combining these two factors gives an expression for the long-term average turbidity at a given location and could be applied to predict long-term changes in atmospheric turbidity based on growth projections for urbanized areas. One measure of the relative urbanization of a given city that is frequently projected for a variety of purposes is its population. The source of population data for our study was the United States Census for 1970.

To examine the relationship between population and turbidity, excess turbidity was calculated for the urban network sites by subtracting the background levels (obtained by interpolating on Figure 1) from the observed 1967 to 1976 average turbidity. The results of the turbidity-population correlation are presented in Figure 5. This figure shows the correlation between 1970 population, P, and average 1967 to 1976 turbidity in excess of background levels, $\bar{B}_e$, for 55 available turbidity sites. Linear and polynominal fits were performed; however, three-constant polynominal fits did not give a significantly better correlation than the linear least squares fit. The correlation coefficient is 0.76. The line appears curved in Figure 5 because of the semi-log plot. As might be expected, at populations below 100,000 only a slight excess turbidity occurs above background levels. For cities west of the Mississippi with populations of about 2,000,000, the total urban turbidity is roughly double the background levels. Turbidity doubling occurs with populations of about 5,000,000 for cities east of the Mississippi. This difference results from the geographical differences in background levels.

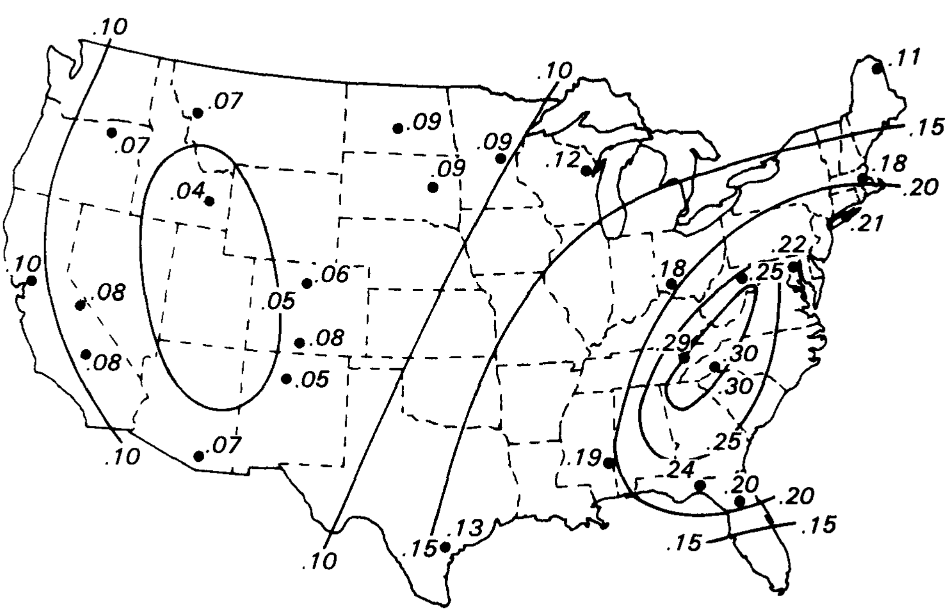

Figure 2. Summer average background turbidity, 1967 to 1976.

Regional Studies

In an attempt to assess regional turbidity during conditions of relatively high air pollution, time periods were sought that had both a high proportion of turbidity network observations for several days at a time and a high air pollution potential weather pattern — namely a slow moving anti-cyclone over the eastern part of the United States. With such data it was hoped that the movement of the pollutant air mass could be tracked across the turbidity station network. No time period was found with an acceptable combination of observational data and synoptic weather. The usual problem was a very sporadic turbidity observational record with large breaks in all the station records. This lack of data continuity could be caused by cloud interference or by the problems of a low priority observation.

As a substitute, an investigation was made of one anticyclonic haze incident that had been studied in some detail by others in the period of June 25 to July 5, 1975 when a large air mass formed and moved slowly across the Ohio Valley, recirculated over the area a second time, then moved across the southeastern states and over the Atlantic Ocean.

During that air mass haze episode, a number of network turbidity stations were within the affected area. The stations were grouped into four general geographic groups — Appalachians, upper Midwest, Ohio Valley, and East Coast — and daily averages for the

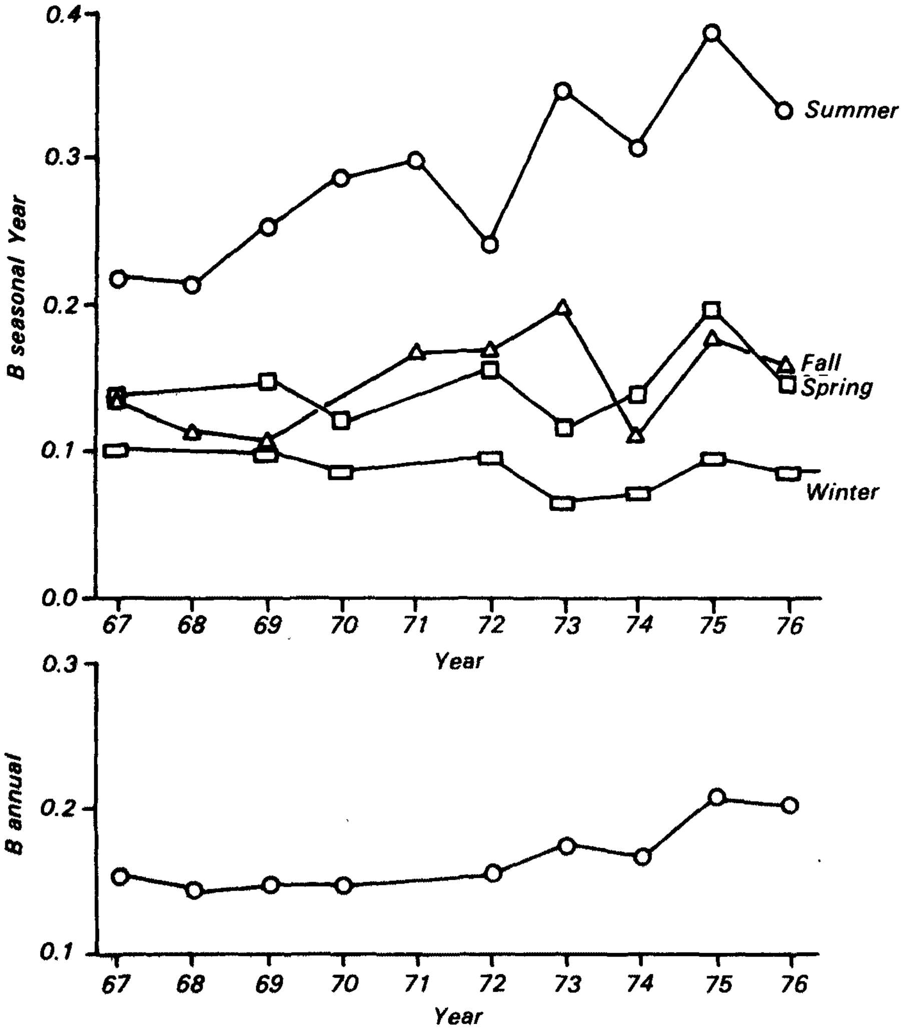

Figure 3. Seasonal and annual trends in mean turbidity at Oak Ridge, Tennessee.

geographic groups were studied. The very sporadic nature of the data set was a major problem; unfortunately this sort of broken data record is very characteristic of the turbidity record.

The upper Midwest, with turbidity measurements at four stations, showed some impact of the air mass haze cloud between June 30 and July 3. During this time period, easterly and southerly flow recirculated the air mass through the upper Midwest.

Because the Ohio Valley turbidity data were not available until June 29, the initial days of the haze episode are not documented. The highest average concentrations for the two Ohio Valley stations occurred on June 29, the day the air mass began its recirculation motion. The East Coast group of stations was, for the most part, on the edge of the haze air mass until the final trajectory southward toward the coast on July 3 and 4.

The Appalachian or southeast section contained a group of seven stations from North Carolina and Tennessee to Tallahassee, Florida. In general, this region had the highest turbidity values during the latter part of the period, between July 3 and 5. These observations are in general agreement with the southward trajectory of the air mass as noted by weather observations of visible haze.

In the analysis of this summer 1975 episode and other episodes, attempts were made to draw meaningful isoline plots of turbidity with little satisfaction because of the scattered nature of the record.

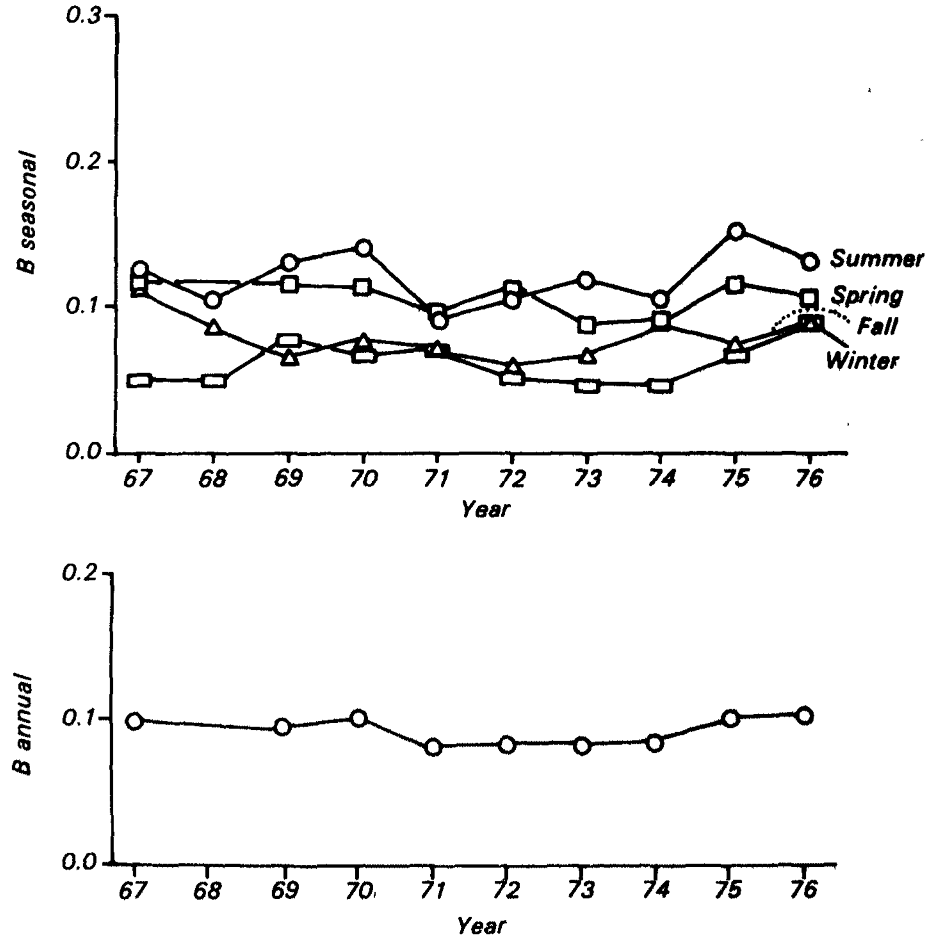

Figure 4. Seasonal and annual trends in mean turbidity at Green Bay, Wisconsin.

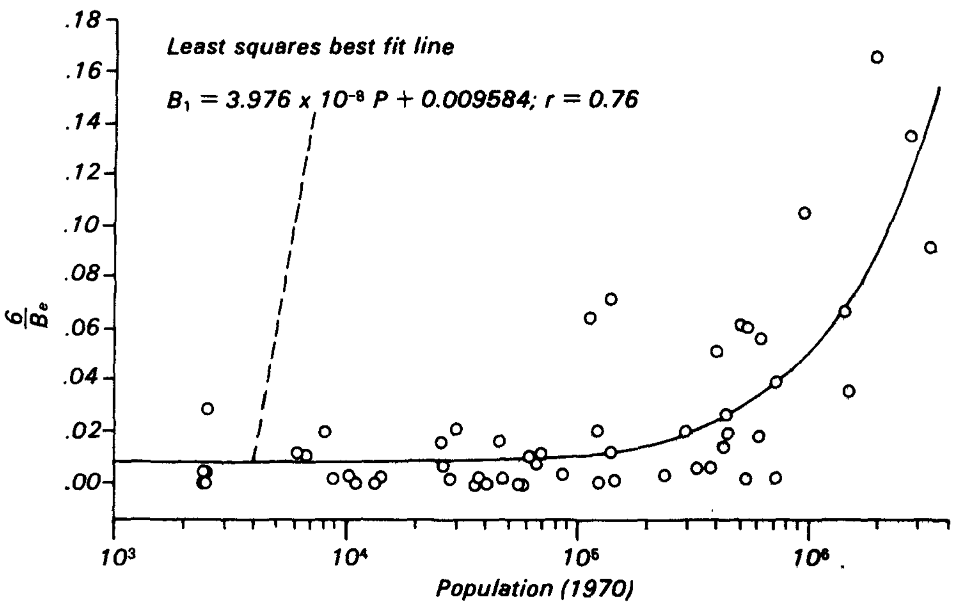

Figure 5. Excess turbidity versus population at network sites.

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***Herbert Viebrock** is the EPA Project Officer (see below).*
The complete report, entitled "Atmospheric Turbidity Over the United States, from 1967 to 1976," (Order No. PB 82-239 369; Cost: $12.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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