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Project Summary

Temporal and Spatial Variability of the Visual Effects of Stack Plumes

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Temporal and spatial variabilities of stack plumes are analyzed by means of field data analysis and computer simulations. In this investigation, photographs from field programs of the study, Visibility Impairment Due to Sulfur Transport and Transformation in the Atmosphere were analyzed via sensitometry, and PLUVUE II model simulations were conducted for a case study. Analysis of the temporal variability of plume visibility led to documentation of the fact that the visual effects of plumes vary with time because of (1) turbulent fluctuations, (2) changes in atmospheric stability, and (3) changes in the observer-plume-sun scattering angle. Likewise, the analysis of the spatial variability of plume visibility led to the fact that the visual effects of plumes vary with downwind distance from the stacks because of (1) turbulent fluctuations, (2) dilution of the plume and/or a change in the observer-plume distance, and (3) changes in the observer-plume-sun scattering angle.

This Project Summary was developed by EPA's Atmospheric 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

The impact of stack plumes on atmospheric visibility has been the subject of extensive experimental and theoretical studies over the past 5 years. Of these studies, the Visibility Impairment Due to Sulfur Transport and Transformation in the Atmosphere (VISTTA) program was comprised of four field programs conducted in 1979 and 1981, as well as an evaluation of the EPA plume visibility models PLUVUE and PLUVUE II.

An important conclusion of these plume-visibility studies is that there is a major discrepancy between the nature of the measurements of plume visibility and computer simulations of plume visibility. Measurements of plume visibility were taken over a given time interval (about 15 to 30 minutes for teleradiometer measurements, and instantaneous measurements for the sensitometry of color slides) and at a given location. Fluctuations of atmospheric turbulence led to plume-visibility effects that varied with time and location. Simulations of plume visibility, on the other hand, were conducted with mathematical models that assumed steady-state conditions, a given atmospheric stability class, and time-averaged dispersion coefficients. The discrepancy between the time- and location-specific nature of experimental measurements and the time-averaged (e.g., dispersion coefficient) and conditions-averaged (e.g., atmospheric stability) nature of model simulations necessarily results in differences between experimental measurements and model simulations.

In this study, we investigated the temporal and spatial variability of plume visibility in a systematic fashion. We analyzed a series of color slides from the 1979 and 1981 VISTTA field programs by means of sensitometry to determine the temporal and spatial variability of plume visual effects. Conclusions can thus be drawn about the uncertainties that will result when using atmospheric data on plume visibility for model evaluation or when using a plume-visibility model in regulatory applications.

Experimental Procedure

The data base utilized in this study consisted of color slides of power plant plumes that were selected from the December 1979 program at the Navajo power plant and from the February 1981 program at the Kincaid power plant. These slides offered the best time series of the visual effects of stack plumes collected during the four VISTTA field programs. A total of 46 slides were chosen for sensitometry (i.e., digitization). These slides were digitized at Perkin-Elmer in Garden Grove, California.

For the temporal variability analysis, each slide was processed at a given location. The section of the photograph to be digitized corresponded to an imaginary vertical line across the plume so that both the background below and above the plume and the plume itself were digitized. The procedure is therefore similar to the vertical scan taken with a teleradiometer. For the spatial variability analysis, 10 vertical scans were performed on the selected slides at equal horizontal intervals that covered the entire slide range. These scans thus corresponded to plume visibility measurements conducted at different downwind distances from the same observation site (i.e., the site where the photograph was taken).

The slide digitization was conducted at three wavelengths by using narrow-band filters with peak transmittance at 450 nm (blue filter), 540 nm (green filter), and above 700 nm (red filter). The sensitometry provided pixel densities for each scan at three wavelengths. The pixel densities obtained from sensitometric curves were then converted to normalized exposures by means of characteristic curves that were constructed from sensitometry of reference slides. The exposure results were then analyzed in a standard fashion to calculate the ratio of plume radiance to sky radiance.

After the digitized data were processed, the digitization scans were reviewed to select the scans that could be analyzed, i.e., those for which a plume was discernible above the noise of the measurements. The list of slides selected for temporal variability analysis was reduced to 32. These 32 slides included sights of the Navajo power plant plume on December 7 and 15, 1979, and of the Kincaid power plant plume on February 20 and 24, 1981.

Temporal Variability of Plume Visibility

The ratios of plume radiance to sky radiance were calculated by the sensitometric technique and plotted for each case study as a function of time. The case studies considered included the Navajo power plant plume observed from two different sites on December 7, 1979, and from one site on December 15, 1979, and the Kincaid power plant plume observed on February 20, 1981, and on February 24, 1981. The later Kincaid power plant plume was dark on the left side and bright on the right side of the slide; the analysis was therefore conducted at two locations on the slide.

The study of the temporal variability of plume visibility has shown that notable variations in the plume visual effects occur as a function of time. These variations, which exceed the uncertainties of the sensitometric measurements, may represent:

1. An evolution of atmospheric stability toward more unstable conditions that lead to a more dispersed and less discernible plume; this effect was observed for the Navajo power plant plume on December 15, 1979, and the Kincaid power plant plume on February 20, 1981.
2. A variation in plume visual effects that results from a change in the scattering angle and the associated varying effects of particulate scattering; this phenomenon was observed in measurements and model simulations of the Kincaid power plant plume on February 24, 1984.
3. Turbulent fluctuations that occur in a random manner and are reflected in nonstationary characteristics of the plume; this phenomenon was observed for the Navajo power plant plume on December 7, 1979.

Spatial Variability of Plume Visibility

The ratios of plume radiance to sky radiance were calculated by the sensitometric technique and plotted for each of the four analyzed case studies as a function of the observed azimuth angle, i.e., as a function of the horizontal distance along the color slide. The four case studies considered were the Navajo power plant plume on December 7 and 15, 1979, and the Kincaid power plant plume on February 20 and 24, 1981.

The study of the spatial variability of plume visibility showed that variations in the plume visual effects occur as the muth of the observer's line of s changes. These variations exceed uncertainties of the sensitometric m urements and may occur in a monot form, representing any of the follov conditions:

1. A decrease in plume visual eff due to dilution of the plume anc an increase in the observer-pl distance; this phenomenon observed for the Navajo power p plume on December 7 and 15, 1
2. A variation in plume visual eff (*e.g., from bright to dark plume*) results from a change in the scat ing angle and the associated v ing effects of particulate scatter this effect was observed and, certain extent, simulated for Kincaid power plant plume on F ruary 24, 1981.
3. Turbulent fluctuations that lea nonhomogeneous characteris of the plume; this phenomenon more evident in observations of Kincaid power plant plume on F ruary 20, 1981.

Conclusions

This investigation demonstrates the visual effects of plumes vary v time because of several factors.

1. Turbulent fluctuations lead to r dom temporal and spatial variati in plume visibility.
2. Evolution of atmospheric stab toward more unstable conditi leads to a temporal variation plume visibility due to a more dil plume.
3. Dilution of the plume and/or crease in the observer-plume tance lead to a spatial variatio plume visibility.
4. A change in the observer-plu sun scattering angle may lea temporal and spatial variation plume visual effects (e.g., fr bright to dark); these temporal spatial variabilities in plume visi ity were documented in our an sis of power plant plumes. Preli nary simulations of the power pl plume visual effects with PLUVUE II model tend to supp our experimental results.

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***William Conner** is the EPA Project Officer (see below).*
The complete report, entitled "Temporal and Spatial Variability of the Visual Effects of Stack Plumes," (Order No. PB 85-200 020/AS; Cost: $8.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
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