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FOREWORD

Toward the end of 1969, several dozen scientists got together in London to spend a day discussing seven papers which had appeared in this journal over the preceeding year.* The symposium topic was Visibility and Air Pollution, and the papers addressed visibility and aerosol concentration, visibility and aerosol composition, the visible length of chimney plumes, and the oxidation of sulfur dioxide in chimney plumes. Eleven years later at the Grand Canyon, the Symposium on Plumes and Visibility brought together some 285 specialists to spend a week discussing the same subjects. It seems appropriate that papers from the Grand Canyon Symposium should also be collected in this journal, which has remain&i the premier forum for research on both pollutant plumes and atmospheric visibility. The similarity in the titles of the two symposia suggests the value of sustained research efforts; the problems of the moment are likely to be the problems of the decade. The differences in substance provide an interesting perspective on the progress that has been made.

The Grand Canyon Symposium took place against a backdrop of recent U.S. legislation aimed at conserving the remarkable clarity of the air in certain national parks and wilderness areas. The visibility research reported here is, consequently, weighted toward highly transparent atmospheres; where papers for the London meeting concerned episodes of 100 pug m- 3 sulfate, relative humidities near saturation, and the disappearance of targets from view, the papers from the Grand Canyon meeting examine episodes of 2 pg m- 3 sulfate, relative humidities far below deliquescence, and the discoloration or obscuration of visible targets. Alumni of the London meeting will find here much that is familiar despite such shifts in scale and focus; optics is arguably the most mature of the atmospheric sciences, and its application to the new terrain has not required the creation of new theory. The Grand Canyon caught one of those exciting moments in scientific history when established principles yield rapid progress in a new class of problems.

The study of pollutant plumes has been revolutionized since the London meeting by the rapid development of airborne sampling and remote sensing techniques, which have brought elevated plumes from large point sources within the reach of investigators. The new capabilities arrived during a period in which, thanks to improved controls and increased stack heights, concern began to shift from the ground-level impact of primary emissions to the long-range effects of their reaction products. One result of this conjunction has been an intense interest in elevated plumes as relatively simple and well defined settings for fundamental studies of dispersion and transformation in the open atmosphere. The Grand Canyon meeting provided the occasion for most of those who have been active in this area to come together and consolidate results and ideas,

The subtitle of the Grand Canyon Symposium-Measurements and Model Components reflects another development of the last decade. Several factors, including the rise of ambient air standards and the redirection of attention to long-range effects of secondary pollutants, have contributed to a proliferation of computer codes designed to simulate the overall behavior of relatively complex atmosphere systems. One of the more ambitious objectives of this Symposium was to stimulate the dissection of these models into components susceptible to direct comparison with experiment. While we were, perhaps inevitably, less successful at this than one

might have wished, there are nevertheless some important examples of such critical evaluation to be found here.

The Symposium on Plumes and Visibility was sponsored by the U.S. Environmental Protection Agency, the Electric Power Research Institute, the U.S. National Park Service, and the Salt River Project, and was conducted under the auspices of the American Meteorological Society and the Optical Society of America. It was conceived by EPA Project Monitor W. E. Wilson, Jr., and brought to life through his unwavering commitment and persuasive advocacy, in collaboration

*Moore D. J. (1969) *Atmospheric Environment* 3,499-500.
tCostle D. M. (1980) J. Air Pollut. *Control Ass. 30,* 632-633.

with Project Monitors G. R. Hilst (EPRI), B. D. Brown (NPS), and P. S. Bhardwaja (SRP). The program was shaped by an active Steering Group consisting of P. S. Bhardwaja, D. L. Blumenthal, B. D. Brown, R. J. Charlson, D. Cronn, K. L. Demerjian, S. L. Eigsti, R. J. Farber, D. Golomb, J. M. Hales, F. F. Hall, G. R. Hilst, P. V. Hobbs, L. E. Niemeyer, R. Snelling, W. H. White, and W. E. Wilson, Jr. The coordinated publication of papers in this early issue is possible only through the contjnuing interest and intense efforts of Editors J. P. Lodge, Jr. and D. J. Moore. Before embarking on this venture, I had not realized how many nice people there are in the world, had not understood how quickly strangers would come to my aid when I needed help. It was through this generous and selfless donation of energy, time, and facilities by countless individuals that the Symposium was the success it was.

Warren H. White
Program Coordinator
Washington University
St. Louis, April 1981

Abstracts of manuscripts in the *Atmospheric Chemistry*, Vol. 15, 1981 issue

Atmospheric and Plume Chemistry

CROSS-SECTIONAL STUDIES OF PLUMES FROM A PARTIALLY SO_2-SCRUBBED POWER PLANT

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Abstract-An instrumented helicopter was used at the Tennessee Valley Authority (TVA) Widows Creek Steam Plant to collect a series of samples at several elevations within the plume at fixed distances downwind. During one segment of this study, much higher oxidation rates were observed in the lower part of the plume than in the upper part. These rates occurred on a day when the plume could be clearly separated into two parts. The upper part could be traced to the 305-m stack, which emits flue gases from combustion of low-sulfur coal. The lower part

could be traced to two remaining sources, one of which is equipped with a wet limestone scrubber for flue gas desulfurization. A detailed analysis of the plume structure ruled out the possibility that the higher oxidation rate was associated with the scrubbed plume. The authors believe that the higher rate was a result of greater dispersion of the lower plume caused by a cross-wind shear and a mechanically induced turbulence resulting from the special topography of the area and by a developing thermal boundary layer. Two edge-of-plume effects-maximum NO, concentration at the border of the plume and a high concentration of condensation nuclei in the vicinity of the plume-are also discussed.

COLORATION OF POWER PLANT PLUMES-NO, OR AEROSOLS?
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Abstract-This article presents an analysis of in situ power plant plume measurements to investigate whether NO, or aerosols dominate as the cause of power plant plume coloration. The analysis uses the ratio of NO, concentration to the aerosol scattering coefficient (b,) to identify which constituent dominates as the cause of coloration (White, 1980). Presentation of plots of this ratio, NO_X, NO_2, **and** b_{sp} as a function of distance from the plant identifies the dominant cause and controlling mechanisms of coloration as a function of distance from the plant. For aerosols with a mass mean diameter greater than 0.5 pm NO, is most frequently the dominant cause of coloration. From plant to plant the frequency that NO, dominates as the cause of coloration is independent of the relative amount of particulate controls used. Instead, the most important variable is the amount of NO_2 at 1 km downwind, presumably reflecting primary NO_X emissions.

THE EFFECTS OF NO,-AEROSOL INTERACTION ON INDICES OF PERCEIVED VISIBILITY IMPAIRMENT
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Abstract-This paper discusses the effects of NO_2 and sulfate aerosols on visibility indices predicted by a plume visibility model. Calculations are performed over a range of ambient conditions and pollutant concentrations consistent with large power plants located in rural western U.S.A. Analysis of model equations and numerical results showed that NO, and sulfate concentrations effect visibility impairment indices in a complex manner. Because the NO_2-sulfate interactions are highly dependent on ambient conditions, designers of screening analysis procedures should consider such effects. The methodology used in this study is applicable to model validation efforts.

ON THE RELATIVE CONTRIBUTIONS OF NO_2 AND PARTICLES TO THE COLOR OF SMOKE PLUMES
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Abstract-This paper studies the relative influences of NO, absorption and particle scattering on plume appearance. Theoretical results are summarized in compact nomograms which permit the

direct comparison of absorption and scattering effects. These show the strong variation of scattering effects with viewing angle and particle size. Available data from several foal and oil-fired power plants in the southwestern U.S. are collated and evaluated in the light of the theory. From the limited data base, it is concluded that particle scattering: (a) controls plume-horizon contrast under most conditions at the older coal-fired plants; (b) is an important near-stack plume colorant at oil-fired plants; (c) may be a significant plume colorant at coal-fired plants equipped with wet scrubbers and (d) does not contribute to brown plume color at coal-fired plants equipped with electrostatic precipitators. Throughout the paper, all results and data are expressed in forms which are invariant under plume dilution, so that fundamental optical relationships are not obscured by the large variations encountered in atmospheric transport and dispersion.

CLOUD CHAMBER STUDIES OF DARK TRANSFORMATIONS OF SULFUR DIOXIDE IN CLOUD DROPLETS

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Abstract-A large (6.6m^3) expansion type cloud chamber, capable of simulating atmospheric clouds for periods up to twenty minutes has been used to investigate the chemical interactions that occur between SO, and cloud droplets under controlled dark conditions.

Specialized apparatus has been developed and tested that will collect the cloud droplets in sufficient quantity for chemical analysis by means of ion chromatography. The cloud droplet collector has been designed specifically to discriminate between cloud droplets and any interstitial aerosols. Other specialized instrumentation includes a CO, laser transmissometer (10.6 pm wavelength) that permits real-time measurement of the liquid water content of the simulated clouds.

The experimental work to date has focused upon the nighttime conversion of SO, to sulfate ions in cloud droplets that form on specific cloud condensation nuclei (CCN). Suitable variation of the size and chemical composition of the CCN is used to control the cloud droplet pH and the concentration of catalysts. Initial SO, concentrations used are approx. 500 ppb.

Results to date indicate that when the CCN are small (~ 0.1 um), the SO, conversion rates are very low and not dependent on CCN composition, including buffers, because of the extreme dilution that occurs during droplet growth. In these cases, the final cloud water pH is generally in the vicinity of 5, apparently due to the self-limiting action of the sulfuric acid production.

On the other hand, when larger, buffered CCN (~0.5 um) are used, SO, conversion rates rise dramatically when the droplet pH is held between 7 and 8, in contrast to those cases where it is held to near 4, as is expected from known reaction kinetics. The addition of catalysts such as manganese also shows markedly higher oxidation rates, especially at low pH values.

SMOG CHAMBER STUDIES OF NO, CHEMISTRY IN POWER PLANT PLUMES

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Abstract-Smog chamber simulations have been conducted in a 17m^3 irradiation chamber with the purpose of identifying the effects of five independent variables on the transformation rates and product distributions of nitrogen and sulfur species in dilute power plant plumes. The study was designed to simulate the conditions in a plume starting at the point where half the NO has been oxidized to NO_2 where the plume will have been extensively diluted with background air

containing hydrocarbons and ozone. The variables studied include: (I) plume hydrocarbon/NO_2 ratio, (2) composition of organics in the diluting air; (3) NO_X/SO_2 ratio; (4) relative humidity; (5) presence of pre-existing acid sulfate aerosol. The starting concentrations and ratios of plume constituents were based on actual plume data.

The results of the study are presented in terms of the impact of the independent variables on the extent of NO_X conversion to products. the rate of NO_X and SO_2 transformation to products, and the relative distribution of gaseous and aerosol nitrate products. Briefly, the NO_X transformation rate is found to be dependent on hydrocarbon composition, hydrocarbon/NO_X ratio, and relative humidity. The rates are essentially independent of SO_2 concentration or the presence of pre-existing H_2SO_4 aerosol surface. The SO_2 transformation rate appears to be independent of all five independent variables. The distribution of the nitrate products, nitric acid, peroxyacetyl nitrate, and particulate nitrate is a function of HC composition, HC/NO_X ratio and irradiation time. The effects of HC composition and HC/NO, ratio decrease at the longer irradiation times characteristic of transport conditions.

GAS-TO-PARTICLE CONVERSION OF SULFUR IN POWER PLANT PLUMES-I. PARAMETRIZATION OF THE CONVERSION RATE FOR DRY, MODERATELY POLLUTED AMBIENT CONDITIONS

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Abstract-Our previous work has shown that, under relatively dry summertime conditions (r.h. < 75 %,), the conversion rate k_1 ($\%h^{-i}$) of SO, to aerosol sulfates in the coal-tired Labadie power plant plume near St. Louis is largely governed by photochemically driven gas-phase reactions involving primary SO_2 and NO_X. and reactive species entrained from the background. Sunlight, plume dilution, and background reactivity are then the principal factors influencing sulfate as well as ozone formation in the plume.

In this paper, the aircraft data of five days of Labadie plume transport (Project MISTT 1976) and five days of transport of TVA's coal-fired Cumberland and 3ohnsonville power plants (Project STATE/Tennessee Plume Study 1978) are analyzed to formulate and test a new parametrization of the conversion rate of sulfur under "dry" summertime conditions (rh. < 75 %). The parametrization, given by $k_2 = (0.03 +/- 0.01)$ *(R* AZ, 0_3), is found to provide a good match to the previously published observed conversion rates on both 9 and 18 July, 1976, for daytime Labadie plume transport up to 200 km *(R* = solar radiation, AZ, = vertical spread of plume, 0_3 = background ozone; hourly-averaged data of St. Louis RAPS). A test of this parameterization against the observed rates in the ten days of MISTT and STATE data of all three plumes yielded very satisfying verification for all data collected under "'dry", cloud-free conditions. Under such conditions, 90% or more of the conversion is believed to occur by the gas-phase mechanism. The parametrization does not apply to liquid phase and heterogeneous conversions in more humid conditions, Also, it does not have the spatial resolution to distinguish between plume core rates and the much enhanced rates in plume edges. Examples of local conversion rates up to 10 % h^{-1} with liquid phase reactions. And 7.5 % h -1 in plume edges are also presented. Otherwise, the conversion rates are generally under 3 % h^{-1}.

The new parametrization is consistent with our present understanding of the pertinent physics and chemistry of gas-phase oxidation of SO_2 under moderately polluted conditions. It is

simple, and requires input data which are relatively routinely monitored. This chemical submodule is suitable for use in long range transport-transformation models. Diurnal and seasonal patterns of the parametrized conversion rate for the St. Louis region are given as examples. Further testing of this parametrization against power plant plume data collected at locations other than in the U.S. Midwest, and during seasons other than summer, is recommended. The validity of the parametrization for oil-fired power plant plumes and for smelter plumes also remains to be tested.

ATMOSPHERIC OXIDATION OF SULFUR DIOXIDE: A REVIEW AS VIEWED FROM POWER PLANT AND SMELTER PLUME STUDIES

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Abstract-An overview is presented of significant historical, recent, and new power plant and smelter plume studies which have been directed at understanding the atmospheric oxidation of sulfur dioxide. It can be concluded that the average rate of oxidation of sulfur dioxide in plumes entering into and mixing with clean air is generally less than 1% hr^{-1} but with polluted urban air the rate can be at least twice as fast. In addition, a diurnal variation in the rate is sometimes observed that is near zero at night and approx. 3 % hr^{-1} during mid-day. Although there is a tendency for some scientific observers to select the homogenous over the heterogenous mechanism as the dominant pathway for the oxidation, the basis for choice is not definitive and most likely both mechanisms are at times operative. Suggestions are advanced for new and important studies that can be performed with technologies just becoming available.

CONVERSION RATES IN POWER PLANT PLUMES BASED ON FILTER PACK DATA: THE OIL-FIRED NORTHPORT PLUME

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Abstract-More than 60 airborne plume studies were conducted at a large oil-fired power station during a 3 ½ year period. These studies were conducted to determine the typical rate of formation of sulfate in the plume and the conditions which most influence these atmospheric processes. The power plant chosen for this program is located in the northeast region of the U.S. and during the course of these studies a typical variety of meteorological conditions were encountered. This is probably the most extensive body of plume data ever gathered from a single power plant. The effect on the oxidation rate was explored for a wide variety of and variation in meteorological conditions.

Plume sulfate rarely accounted for more than 5 % of the total plume sulfur even for plume travel times of up to 4 h. For most experiments more than half of the observed plume sulfate was that emitted from the power plant units. The rate of atmospheric oxidation of sulfur dioxide to sulfate was not readily discernable due to the low rate of conversion and the relatively high amount of the sulfate emitted. The results reported in this paper generally indicate an apparent oxidation rate of less than 1% h^{-1}. A diurnal influence or **effects** due to changes in various meteorological conditions are difficult to discern.

CONVERSION RATES IN POWER PI.ANT PLUMES BASED ON FILTER PACK DATA: THE COAL-FIRED CUMBERLAND PLUME

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Abstract- The TVA Cumberland Steam Plant plume was monitored during the August 1978 Tennessee Plume Study of Project STATE. Samples were obtained by employing a triple screen high-volume assembly which contained (1) a quartz filter for collecting particulate SO_4^{2-}, NO_3^- and NH_4^+, (2) two NaCl impregnated cellulose filters for collecting gaseous nitrate and (3) two K_2CO_3-impregnated cellulose filters for collecting SO_2. Formation rates of sulfate and nitrate in the atmosphere were calculated by using total sulfur as a conservative tracer.

Conversion of SO_2 to SO_4^{2-} varied from ~0.1 0 0.8 % h^{-1} during night and early morning hours; late morning and afternoon rates ranged from ~1-4 % h^{-1}. Plumes were tracked to distances of 200 km and 9 h duration. Rate of formation of NO_3^- from NO was -0.1-3 % h^{-1} and ~3-12 % h^- for similar time periods. Particulate NH_4^+ concentrations generally increased with plume age, but rates of formation varied widely. Mole ratios of NH_4^+/SO_4^{2-} fell within 1-3.

STUDIES OF AEROSOL FORMATION IN POWER PLANTPLUMES-I. GROWTH LAWS FOR SECONDARY AEROSOLS IN POWER PLANT PLUMES: IMPLICATIONS FOR CHEMICAL CONVERSION MECHANISMS*

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Abstract-Numerous field studies have shown that gas-to-particle conversion can be an important source of submicron secondary aerosol in power plant plumes. In this paper, aerosol size distribution data from several field studies have been analyzed to determine particle diameter growth rates by gas-to-particle conversion. The functional dependencies of these growth rates on particle diameter were then compared with theoretical models (i.e. growth laws) to infer possible chemical mechanisms of secondary aerosol formation, Based on this analysis it has been possible to infer the relative contributions of various postulated conversion mechanisms to the aerosol volume formation rate. It has been concluded that the chemical mechanisms of gas-to-particle conversion in power plant plumes depend upon ambient conditions. For the limited set of data analyzed in the paper, aerosol growth resulting from condensation of molecules formed by gas phase reactions was predominant in all cases. For plumes mixing into humid air (> 50% r.h.). however. heterogeneous reactions (e.g. oxidation of dissolved SO_2 in droplets) accounted for up to 20 2, of the aerosol volume formation rate. It is likely that at higher humidities, droplet phase reactions would be still more important.

STUDIES OF AEROSOL FORMATION IN POWER PLANT PLUMES-II. SECONDARY AEROSOL FORMATION IN THE NAVAJO GENERATING STATION PLUME

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Abstract-Aerosol and gas measurements were made with the University of Minnesota Mobile Laboratory (UMML) during the VISITA program (26 June, 1979 to 13 July, 1979) near Page, Arizona. The UMML was stationed on Zilnez Mesa (36.79”N, 110.63”W, elevation 2,200 m) approx. 65 km east of the Navajo coal-fired power plant. Measurements were made both in and out of the power plant plume and were made during the day and night. Measured parameters included aerosol size distributions, Aitken nuclei count, ozone and sulfur dioxide concentrations, the aerosol light scattering coefficient, and meteorological parameters including ultraviolet radiation intensity. Concentrations of NO and NO_X were occasionally measured.

Data show clear evidence of gas-to-particle conversion in the plume with aerosol volume being added in the 0.01 microm t0 0.32 microm dia. range and new particles being formed. The observed excess aerosol volume depends strongly upon the SO_2 concentrations and the time of day with none observed in plume parcels which were not exposed to sunlight. This implies that the excess aerosol in the plume was secondary and was not due to primary particulate emissions from the stack. The fraction of sulfur appearing in the aerosol was inferred from the measurements of SO_2 concentrations and excess aerosol volume concentrations in the plume and was found to correlate with the time integral of the UV flux density received by the plume parcels since pollutant emission. The observed rate of SO_2 conversion was found to be 1.9 +/- 0.8 %, h^{-1} at noon, with a diurnal average of 0.9 +/- 0.4 % h^{-2}.

SULFUR CHEMISTRY IN SMELTER AND POWER PLANT PLUMES IN THE WESTERN U.S.

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Abstract-This paper summarizes the results from studies of SO,(g) to particle conversion in the plume of a copper smelter and two coal fired power plants located in the Great Basin desert region and an oil fired power plant located on the California coast.

Daytime formation of H_2SO_4 from SO_2(g) is dominated by a reaction which is first order in SO_2(g) and is temperature dependent, the rate of reaction increasing with increasing temperature. Neutralization of the H_2SO_4 is limited only by the rate of introduction of basic material from ambient air. NH_3 is not the principal base present except on the California coast. Metal oxides and carbonates (e.g., $CaCO_3$) are the predominant bases present in the inland desert areas.

Two different classes of aerosol S(IV) compounds are formed from the interaction of SO_2(g) with particulate matter, organic S(IV) species which can hydrolyze to give sulfite and inorganic S(IV) complexes. The inorganic species predominate in smelter plumes while formation of both the inorganic and the organic S(IV) compounds occurs in plumes from combustion of fossil fuels. Formation of the inorganic S(IV) complex is equilibrium controlled and is favored by high SO2(g) and soluble aerosol Fe and Cu concentrations and by low aerosol acidity. Formation of the organic S(IV) compound follows first order in SO_2(g) reaction kinetics with the rate being inversely proportional to absolute humidity. The relative amounts of sulfate and the two classes of S(IV) compounds are dependent on the ambient temperature and

humidity. Formation of the organic S(IV) compound predominates under cold dry conditions while formation of sulfate predominates when the air mass is warm and moist.

Particulate Composition

CHARACTERIZATION OF PARTICLES IN THE ARID WEST
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Abstract-This paper describes spatial and temporal variations of airborne particulate matter in the eight western states included in the western fine particle network (WFPN). The samples ware generated by a &site monitoring network of remotely sited dichotomous samplers of the stacked filter and virtual design, with a coarse fraction between 15 um and 2.5 um in dia. and a fine fraction below 2.5, um **dia. The units operate for two 72 h periods each week, delivering samples** analyzed **gravimetrically** for mass end by particle induced X-ray emission (PIXE) for elements sodium and heavier. **Results** are presented for the period October 1979 to May 1980, showing regional patterns of particles especially in the fine modes. **A** sulfur episode which occurred in the southwest is examined via trajectory analysis, while factor analysis is applied to the entire data set to **generate** information on particulate sources.

THE RELATIONSHIP OF FLY ASH LIGHT ADSORPTION TO SMOKE PLUME OPACITY
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Attract- Measuring the fly ash light absorption for coal-fired boilers with the Integrating Plate Method (IPM) is discussed. It is observed that measurement of the optical properties of fly ash may also be useful for comparison with ambient aerosols to identify the relative contribution of primary particulates to downwind visibility. The IPM technique is defined as comparing the light absorption through a clean nuclepore filter to one with a single layer of aerosol by integrating the scattered light so only absorption is measured. Since the light absorption is a strong function of

particle size, careful sizing is required for accurate measurement. Preliminary calibration and fly ash data are reported.

Human Perception of Visibility

DAYTIME VISIBILITY AND NEPHELOMETER MEASUREMENTS RELATED TO ITS DETERMINATION

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Abstract-The ability of a human observer to perform tasks involving visual search and the determination of visual ranges (i.e., visibilities), is a commonly recognized skill that is presently under increasing competition from a variety of sophisticated electro-optical systems. The paper reviews a few of the pertinent psychophysical characteristics related to the human observer's performance, how they are related to some instrumentally measured quantities, and two of the more commonly encountered sources of error in visual determinations of visibility. Comparisons between several observer and instrumental determinations illustrate the link between the two experimental regimes and introduce some appropriate specialized data obtained with an airborne nephelometer. Since the determination of visibility is the simpler special case of determining horizontal path contrast transmittance, several characteristics of the nephelometer data which influence its use in the more general determination of slant path contrast transmittance are illustrated. In this context, the implication of these data in ones ability to accurately model atmospheric influences upon contrast transmittance is introduced. The basic conclusions to be drawn from this paper are twofold. First, that although human visual performance is a complex psychophysical task, there is little doubt that for visibility determinations it can be adequately related to instrumental measurements of atmospheric volume scattering coefficient and second, that a reliable specification of the directional scattering properties of the atmospheric aerosol can be reasonably deduced from this measurement of total volume scattering coefficient alone.

CHARACTERIZATION OF KRAFT PULP MILL PARTICULATE EMISSIONS-A SUMMARY OF EXISTING MEASUREMENTS AND OBSERVATIONS

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Attract-Particulate matter emission sources at a kraft pulp mill include kraft recovery furnaces, lime kilns, smelt dissolving tanks and power boilers. Chemical and physical characteristics of these particulate emissions are reviewed. Measurements of particle size distributions for these sources made with cascade impactors and microscopic counting techniques both before and after particulate control devices such as multiple cyclones, wet scrubbers, and electrostatic precipitators are discussed. In general, particles with equivalent diameters less than 3 microm comprise the bulk of the controlled particulate emissions from all sources. Sodium sulfate is the dominant particulate emission from kraft recovery furnaces, smelt dissolving tanks and lime kilns.

Results from a field investigation of the relationship between human observations of near-stack plume opacity and measured in-stack particulate concentrations and opacities are summarized. Trained certified panels of observers were used in the investigation to estimate plume opacities from two kraft recovery furnaces, a combination wood/coal-fired boiler, and a combination wood/oil-fired boiler at four different pulp mill locations. Plume opacities were varied from near-zero to 45 % by adjustment of the particulate control equipment operation. The effects of different background viewing conditions, observer positions, observer experience levels, and plume characteristics are enumerated. It is concluded that there can be substantial variations between measured in-stack opacities and human perceptions of near-stack plume opacities. The degree of agreement between the human judgements and measured in-stack opacities is significantly affected by the background viewing conditions. It is further shown that even with a panel of six or seven trained observers with similar visual acuity, there can be significant departures of individual opacity readings from the panel mean opacity. Although this investigation deals with questions of human observations of nearstack opacity, it is likely that other studies concerned with human perceptions of visibility impairment at greater downwind distances will have to also address the inherently subjective nature of human visual observations and the effects of background viewing conditions. These factors will make it difficult to correlate human visual observations of plume characteristics to instrumental measures of opacity or opacity-related parameters made at the source,

HUMAN PERCETION OF VIWUAL AIR QUALITY (UNIFORM HAZE)

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Abstract-The National Park Service and the U.S. Environmental Protection Agency are cooperatively conducting ongoing studies of human perception of visual air quality. Major objectives of this program include: (I) determination of the relationship between judgments of visual air quality of actual three dimensional scenes and a surrogate slide representation of that scene, (2) examination of the effect of sun angle and meteorological conditions **on** perceived visual air quality, (3) examination of the effect of demographic background on observer's judgments of visual air quality, (4) establishment of a functional relationship between human perception of visual air quality and various electro-optical parameters for several different scenic vistas and (5) development **of a** model capable of predicting the sensitivity of a park to visual air pollution impact.

Preliminary results of a previous study involving one vista revealed a linear relationship between human perception and apparent vista contrast for constant vista acumination and ground cover. A more general formalism for averaging vista color contrast appeared to account for effects that snow cover and varying illumination have on the sensitivity of perceived visual air

quality to air pollution. These functional relationships are reexamined using a number of southwestern vistas. A first order model capable of predicting perceived visual air quality as a function of change in air pollution is developed. In addition, the relationship between perceived visual air quality of actual three-dimensional scenes and pictoral surrogates is examined.

PERCEPTUAL SIGNIFICANCE OF COLORIMETRIC DATA FOR COLORS OF PLUMES AND HAZE

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Abstraet- Colorimetric reduction of spectroradiometric and spectral absorption and scattering data, by use of C.I.E. (Commission Internationale de l'Eclirage) data is appropriate for assessment of the color appearances of plumes and haze and of vistas seen through haze. Chromatic adaptation needs to be taken into account, however, because a wide variety of chromatjcities (e.g., color temperatures from **4000 K to at least 7000 K) can be** perceived as white under various circumstances. The perceptions of all other colors shift correspondingly. Natural clouds or snow appear white: they have the chromaticity relative to which the perceived hues of all other objects in the same scene (including plumes and haze layers) are perceived. Those hues can be determined by drawing the straight line from that white point through the point representing the plume or haze. The wavelength at which that line intersects the spectrum locus is the dominant wavelength of the plume or haze, or other feature in the vista, for the state of chromatic adaptation of the observer. The dominant wavelength identifies the hue. **The** percentage of the distance from that white point to the spectrum focus is the purity of the plume, haze, or haze-veiled color. The perceived amount of coloration (saturation) can be evaluated as a multiple of the just-noticeable difference from the adaptation white.

THE EFFECTS OF ATMOSPHERIC OPTICAL CONDITIONS ON PERCEIVED SCENIC BEAUTY

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Abstract- This paper describes the results from the first year of a currently on-going study, the objective of which is to investigate the relationships between atmospheric optical conditions and human perceptions of scenic beauty. Color photographs and atmospheric optical measurements, using telephotometers and nephelometers, were taken in the western U.S.A. (Grand Canyon National Park and Mt. Lemmon near Tucson, Arizona) and in the eastern United States (Great Smoky Mountains and Shenandoah national parks). Over 1300 individual observers rated color slides for either visual air quality or scenic beauty **using a** l0-point rating scale. Ratings were transformed to indices using standard psychophysical techniques. Relationships between these perceptual indices and physical parameters characteristic of the given landscape represented in the color slides were investigated using scatter plots, correlation analysis, and multiple linear regression. Physical parameters included visual range, horizon sky chromaticity and luminance, solar zenith and

scattering angles, and cloud conditions.

Results show that observers' ratings of visual air quality and scenic beauty are sensitive to visual range, sky color, and scattering angle. However, in some of the areas investigated, scenic beauty ratings were not affected by changes in visual range. The sensitivity of the scenic beauty of a vista to changes in the extinction coefficient may be useful for establishing visibility goals and priorities.

Optical Properties

ATMOSPHERIC OPTICAL PROPERTIES AND METEOROLOGICAL CONDITIONS

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Abstract-This paper discusses relationships which exist between the optical properties ofzhe atmosphere and meteorological parameters and conditions. Atmospheric visibility is determined by the optical effects of particulate matter (aerosols) in the atmosphere. The dependence of aerosol properties on temperature, humidity, atmospheric vertical structure, and air mass history is demonstrated using several case studies of surface and airborne measurements from different environmental regimes. Some of these relationships have been structured into semiempirical models, examples of which are presented.

OPTICAL PROPERTIES OF PARTICULATE EMISSIONS FROM ON-ROAD VEHICLES

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Abstract-The light absorbing and light scattering properties of on-road vehicle exhaust particulate were determined as a function of traffic composition at the Allegheny Tunnel on the Pennsylvania Turnpike during August-September 1979. This study was one part of a comprehensive experiment aimed at the chemical and physical characterization of vehicle exhaust particulate. Particulate light absorption was determined by the integrating plate method, while light scattering was measured with an integrating nephelometer.

Mass-specific optical coefficients (at 5OO.Onm) have been derived from regressions of the optical and mass emissions data against traffic composition. For diesel vehicles (predominantly heavy-duty, but also including diesel passenger vehicles) the absorption coefficient, b_{abs}, was found to be 5.13 +/- 0.28 $m^2\ g^{-1}$, while the light scattering coefficient, b_{scat}, was 1.99 +/- 0.07 $m^2\ g^{-1}$. Diesel vehicle emissions were responsible for greater than 90 % of the light extinction in the tunnel, although diesels accounted for only 23 % of the vehicle miles travelled. Estimates for b_{abs} and b_{scat} for particulate from gasoline-powered vehicles were 8 +/- 6 m^2g^{-1} and 6 +/- 10 m^2g^{-1}respectively, while the analogous values for ambient particulate were $b_{abs}/M < 8\ m^2g^{-1}$ and $b_{scat}/M = 5.0$ +/- 1.0 m^2g^{-1}.

OPTICAL CHARACTERISTICS OF ATMOSPHERIC AEROSOLS

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Attract- Techniques have been developed to make point measurements of particle size, chemical nature, scattering and absorption extinction coefficients. These measurements have been shown to be sufficient to describe the optical or visual effects of trace materials in urban or rural air. These techniques and methods of analysis are described in this document. Conclusions include: scattering extinction and fine particle mass, absorption extinction and graphitic carbon are highly correlated. SOi- is usually the dominant scattering species and it occurs both in acid and neutral salt (with NH_4^+) forms. The role of organic carbon, especially in rural atmospheres appears small.

Plume Chemistry Modeling

DEVELOPMENT AND APPLICATION OF A REACTIVE PLUME MODEL
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Abstract-A reactive plume model has been developed to simulate pollutant concentration distributions across a plume emanating from a major point source. The model, based on a simple mass balance, is composed of a fixed number of cells that can expand in a prescribed fashion as the plume travels downwind. For an inert pollutant species, there is no net mass flux across the expanding cell boundaries. For reactive or background pollutants, an equivalent diffusion coefficient is used to characterize the across-the-cell mass fluxes. An up-to-date kinetic module., the carbon-bond mechanism, has been incorporated into this model to treat photochemical reactions involving hydrocarbons and oxides of nitrogen. This model has been applied to the Widows Creek Power Plant in Alabama and the Oak Creek Power Plant in Wisconsin. Comparisons between the observed distributions of several key pollutant concentrations and the corresponding model predictions seem to indicate that the model has been able to simulate the pertinent transport, diffusion, and photochemical processes that take place in a reactive plume.

GENERATION OF SECONDARY POLLUTANTS IN A POWERPLANT PLUME: A MODEL STUDY
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Abstract-A plume model is developed where chemistry and meteorology of the boundary layer interact with a power plant plume which is given a spatial resolution in the cross wind direction. Ozone bulges are formed after 2 1/2-3 h or more, with excess ozone 10-20 %, above ambient levels in fair weather during summer for a plume comparable to the St. Louis Labadie power plant plume. The chemical activity peaks first on the plume fringes, later close to the central axis. Hydroxyl exceeds 13 x $l0^6$ molecules cm^{-3} within the plume after a few hours. and the corresponding SO_2 to sulphate conversion rate ranges between 1 and 5 % h^{-1}. Nitric acid formation exceeds sulphuric acid formation during developed stages of the plume. Ambient

emissions of nitrogen oxides and hydrocarbons representative for heavily populated areas tend to reduce the relative size of the ozone bulge compared to cases with lower emissions, and medium size power plants give rise to more excess ozone than larger plants. The ozone bulge disappears when the solar radiation is substantially reduced. The fate of the HSO_2 radicals and its involvement in odd hydrogen regeneration is essential in the understanding of the plume chemistry.

MATHEMATICAL MODEL FOR MULTICOMP0NENT AEROSOL FORMATION AND GROWTH IN PLUMES

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Attract Description of the evolution of the size and chemical composition of aerosols in plumes is fundamental to the ability to predict visibility impairment. Previously it has only been possible to predict changes in aerosol size distributions in plumes. In this work the first model for predicting both size and chemical composition evolution of plume aerosols is presented. Coagulation, homogeneous particle formation, heterogeneous condensation, and particulate phase chemical equilibria and kinetics are explicitly included. **The** model is based on a sectional representation of the size-composition spectrum and computation is easy to implement. This model holds promise to be a standard component of all plume visibility calculations that require plume aerosol size and composition information.

REGIONAL VISIBILITY MODELING FOR THE EASTERN UNITED STATES

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Attract- Visibility modeling over long transport distances is complicated not only by the chemical and removal processes, but also by the multiparty of sources from different areas that contribute to the particle and gaseous concentrations-and visibility impairment-at specific locations. To study interregional pollutant exchanges and their effect on visibility, a regional model has been developed and applied to the eastern United States and the visibility reduction budgeted according to area of origin. The new model, called VISMAP-1, produces short-term (three-hour) and long-term (monthly) sulfate concentrations; visibility calculations are made by applying a mass-to-light-scattering function to the aerosol concentrations. This function is weighted according to relative humidity to account for hygroscopic particle growth. One of the most useful features of this model is its capability to budget fine-particulate and gaseous concentrations in various receptor regions according to the contribution of source regions.

In this analysis for visibility **effects,** three-hour SURE (Sulfate Regional Experiment) sulfate measurements for July 1978 are compared to fine particle calculations to evaluate the model's ability to predict the transport of aerosol sulfur for the shorter averaging period. Visibility is modeled from the sulfate calculations using an empirical mass-to-light-scattering function. This technique is commonly used to determine aerosol light scattering properties at given relative humidities. National Weather Service visual range observations have been compared with the model's visibility calculations; both regional patterns of visibility degradation and the absolute magnitude of the reduction in visual range are evaluated. Preliminary results are encouraging and the VISMAP modeling approach appears to be a useful step toward identifying long-range source/receptor relationships that affect visibility.

Visibility Modeling

COMPARISON OF THE OBSERVED AND PREDICTED VISUAL EFFECTS CAUSED BY POWER PLANT PLUMES

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Abstract-One of the objectives of the June-July and December 1979 E.P.A.-VISTTA field programs was to obtain the data necessary to evaluate the components of the EPA/SAI plume visibility model. The data were obtained through a coordinated set of measurements of specific power plant emissions, meteorological conditions, plume concentrations measured by an aircraft, and through telephotometer measurements of the visual effects of the plume. This paper presents a comparison of measurements obtained between 4 and 32 km downwind from the plant with model predictions. The various components of the plume visibility model were evaluated independently, and it was found that the greatest uncertainties in the model predictions are in the diffusion module, which has the limitations associated with all Gaussian diffusion models. The chemistry module describes plume chemistry well in a clean background atmosphere; however, the rate of NO-to-NO_2 conversion is slightly overpredicted in the model. Predicted secondary aerosol formation is negligible.

The optics module of the visibility model was evaluated by predicting the optical effects of the plume on the basis of the airplane-measured plume concentrations. These calculations were compared with the groundbased telephotometer measurements. The optics module tends to slightly overestimate the plume visual effect; the average absolute relative errors in measurements of the plume/sky intensity ratio are 6.0, 6.4, 3.0 and 4.8 % at 405, 450, 550 and 630 nm, respectively. For contrast values below - 0.06, the contrast predicted by the optics module is within a factor of 2 of the measured values. A major uncertainty in the data is found in the degree of alignment between the airplane and telephotometer measurements.

The overall evaluation of the plume visibility model was carried out with 20 sets of measurements. It was found that the model tends to overestimate the visual effect of the plume. The average absolute relative errors in the plume/sky intensity ratio are 9.7, 10.8, 4.7 and 3.2% at 405, 450, 550 and 630nm, respectively. Sensitivity studies in which NO, and primary particulate emissions were reduced show impairment is mainly a result of plume discoloration caused by ***NO_2*** light absorption.

A DISPERSION-OPTI CS MODEL FOR CALCULATING VISIBILITY IMPAIRMENT AND COMPARISONS OF MODEL ESTIMATES WITH FIELD MEASUREMENTS

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Abstract-This paper describes a computerized dispersion-optics model developed for the U.S. Army which calculates the impairment of visibility caused by the presence of suspended particulates and other obscurants. The dispersion model, which is applicable to point or volume sources is used to calculate plume dispersion and other plume properties including the integrated concentration along any line of sight. The optics model utilizes the output from the dispersion-model calculations and single Mie scattering to calculate light transmittance through the plume, the contrast of objects or the plume against the horizon sky, and the probability that an object is visible. A partial test of the model performance was made by comparing model calculations with measurements taken during 57 smoke trials conducted at the U.S. Army Dugway Proving Ground, Utah. The results of this comparison indicate that the model adequately calculates line-of-sight integrated concentrations measured during these trials, Additional tests of the optics portion of the computer\

ATMOSPHERIC VISIBILITY

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Abstract--The presence of atmospheric particles always causes a reduction of visibility. When looking towards a distant target, the appearance of the target is altered in such a way, that it looks more similar to the horizon. and normally its contrast against the background becomes less with increasing distance. The contrast change can be calculated, if the illumination, the scattering function, the intrinsic brightness of the target and the extinction coefficient of the atmosphere are known. At the distance, where the contrast of the target equals the contrast threshold of the human eye, the target just is visible (i.e.. this distance is the visibility).

The first theoretical considerations of contrast reduction have used a simple homogeneous atmosphere with an absolutely black target seen against the horizon. The result was a formula, giving an inverse relation between the extinction coefficient and the visibility. For more complicated situations extensions of this method can be used. Unfortunately, in most practical applications the necessary parameters of the atmosphere, target, and illumination are only known incompletely, since they may vary as a function of distance from the observer. Therefore, visibilities calculated from the data available at the location of the observer may be different from an observed visibility, as well as visibilities using different targets in different directions.

Observations performed under controlled conditions in the laboratory have shown, that visibilities can be measured with accuracies of a few per cent, and all conclusions which can be drawn from the usual theories have been verified; therefore an estimation of possible errors or deviation from the ideal case (black target, homogeneous illumination and aerosol, contrast threshold of 0.02) can be performed easily.

Most targets are not ideally black. Coniferous forests have luminances relative to the horizon of mostly less than 0.2 and thus the visibility observed maybe up to 4 %, smaller than using an ideal black target. When the targets are in their own shadow, they are dark enough, that a visibility comparable to a black target is observed, brighter targets normally are Iess visible than black targets; the extent of visibility decrease can be calculated if the intrinsic brightness of the target is known, which can be obtained with a high enough accuracy by using nearby model surfaces.

When visibility observations are to be performed in an inhomogeneous atmosphere, under most conditions the average extinction coeficient between target and observer determines the visibility. Therefore the visibility has the advantage of averaging Inhomogeneous illumination can cause the visibility to increase or decrease. Generally, an increase in visibility is attained, when the atmosphere is less illuminated between the target and the observer. Under most unfavourable conditions, such as clouds between the observer and the target and sunshine behind the target, the visibility is 20% larger than with homogeneous illumination. With cloud spacings more likely to exist in the atmosphere, the deviations are in the order of 5 % for some cloud spacings the visibility equals the visibility under homogeneous conditions independently of the position of the clouds.

The contrast threshold of the human can influence the observed visibility, larger contrast thresholds give smaller visibilities. Under normal daylight illumination conditions, the threshold has a constant value, which increases only at illumination levels after sunset or before sunrise. If the targets have a small angular size (less than a few minutes of an arc) the contrast threshold also increases, thus the visibility of this target decreases. Therefore, small targets should not be used at large distances. Mostly the atmospheric aerosol has an extinction coefficient decreasing in magnitude with increasing wavelength. Therefore, targets are better seen inthe red part of the spectrum than in the green or blue part, thus the most important wavelength for vision is at 580-6OO micron.

As laboratory experiments and observations in the atmosphere have **shown, visibilities can be measured** quite accurately. Since variations in visibilities due to changing observation conditions can occur, the determination of a standard visibility is desirable. It can be obtained from the measured visibility, by inclusion of correction factors for the inherent contrast and possible deviations due to inhomogeneous illuminations.

CALCULATION OF MULTIPLY-SCATTERED RADIATION IN CLEAN ATMOSPHERES

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Abstract-Assessment of the effects of air pollution on visibility requires an understanding of atmospheric radiative transfer processes. This paper presents results from both detailed and approximate computations of multiple-scattered solar radiation in the atmosphere. These calculations are intercompared and then compared with telephotometer measurements of the sky intensity obtained during the EPA-sponsored VISTTA (Visibility Impairment by Sulfate Transport and Transformation in the Atmosphere) field programs.

The paper describes compu~tioM1 techniques and the specification of atmospheric radiative properties. Comparisons of predicted and observed intensities are made for various cloudless sky conditions. The conditions range from typical clean tropospheric values to ultraclean conditions that approach a Rayleigh atmosphere. Comparisons made at four wavelengths (405,450, 550 and 630nm) show the influences of observer azimuth and zenith angles and of the solar zenith angle. The results indicate that the horizon intensity values are surprisingly insensitive to aerosol amount for certain azimuth angles. atmosphere. Comparisons made at four wavelengths (405,450, 550 and 630nm) show the influences of observer azimuth and zenith angles and of the solar zenith angle. The results indicate that the horizon intensity values are surprisingly insensitive to aerosol amount for certain azimuth angles.

POTENTIAL FOR QUANTITATIVE ANALYSIS OF UNCONTROLLED ROUTINE PHOTOGRAPHIC SLIDES

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Attract-Historically, some air quality monitoring programs have included color slides taken simply to qualitatively document the visual environment. The possibility of utilizing one such set of slides for quantitative analysis of visibility related indices is examined. This paper focuses on three-color digitization of the photos. An error analysis of contrast measurements from the slides shows them to be comparable to telespectroradiometer readings in overall accuracy, although absolute photometry is not possible. It is proposed that digitized photographs be used to determine spatially averaged visibility indices. Visible texture and fine contrast detail can be quantitatively addressed by Fourier analysis. The occurrence of regional haze can be assessed by the modulation depth of the slide. Modulation depth is the mean square deviation of the light levels divided by the average light level.

REGIONAL ANALYSIS OF FACTORS AFFECTING VISUAL AIR QUALITY

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Abstract-The U.S. Environmental Protection Agency, National Park Service, Visibility Research Center, and University of California at Davis are currently operating a monitoring program in national parks and monuments throughout much of the western United States. Project VIEW, the Visibility Investigative Experiment in the West, includes measurement of visibility parameters

using manual telephotometers, and measurement of particle concentrations averaged over 72 h. Variation of these parameters occurs in both space and time. To better understand these variations, several techniques including principal component analysis and data comparisons among sites are applied to Fall, 1979 data for much of the network. Then the Grand Canyon is chosen for additional analysis. Best and worst case visibility days are determined and compared with particle concentrations. Finally, hypothetical causes for visibility reduction are further verified by computing wind trajectories back in time for these special case days.

Highlights of this preliminary investigatjon include evidence that fine sulfur and fine particles are responsible for visibility variation at the VIEW sites; that fine particle copper may be suitable as a tracer for copper smelter impact and that at the Grand Canyon, the majority of trajectories for days of visibility greater than 310 km come from the north and west, over Utah and Nevada.

REGIONAL AND LOCAL DETERMINATIONS OF PARTICULATE MATTER AND VISIBILITY IN THE SOUTHWESTERN UNITED STATES DURING JUNE AND JULY, 1979

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Abstract-Data on ambient particulate concentrations by size and elemental composition taken in Arizona and Utah are compared to simultaneous telephotometer measurements of standard visual range. Particulate samples were collected during the VISTTA program from 26 June to 11 July 1979, at Zilnez Mesa, Arizona, and compared to similar 24 h measurements made as part of a long-term research program at Zion and Canyonlands National Parks in Utah. Samples were collected with rotating drum Multiday impactors which provide three aerodynamic size ranges; 15pm-3.5pm; 3.5 pm-0.5pm, and less than 0.5pm. Elemental composition of samples was measured using the particle induced X-ray emission (PIXE) system at the Cracker Nuclear Laboratory. Measurements of visibility were made at Canyonlands National Park and Zilnez Mesa using both multiwavelength telephotometers and nephelometers. Results indicate that the particulate matter in each size range behaves to a large degree independently of the other size ranges, but that correlations are often observed between sites. On 29 June, an episode of elevated sulfur concentrations, > 1 microg m^3 of S, was observed at all three sites. Decreased visibilities were recorded for the episode period at both Canyonlands and Ziinez Mesa. Sulfur episodes on 22-24 June and 20-21 July measured at Zion and Canyonlands also correlated well with reduced visibility at Canyonlands. Episodes of reduced visibilities also occurred during periods of stable sulfur v&es. The strongest of these, on 17-18 June, as well as a weaker one, 4-7 June, correlated well with fine soils in the 0.5-3.5 pm size range. The conclusion is that reduced visibility is associated with regional episodes of both increased sulfur and increased fine soils, with best correlations occurring in both cases for sizes somewhat greater than 0.5 microm dia.

THE EFFECTS OF NON-STANDARD CONDITIONS ON VISIBILITY MEASUREMENT

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Abstract-The effects of non-standard visibility observation conditions upon computed visual range(meteorological range) were investigated using data from an eastern U.S. visibility study sponsored by the Electric Power Research Institute. Data collected by multi-wavelen~h telephotometry was specially marked in the field when non-standard conditions were **observed.** The non-standard conditions explored were those which violate the assumptions implicit in routine visual range calculations. These conditions include bright and dark clouds behind the target, bright haze, shadowed targets, and snow-covered targets. The errors caused by non-standard conditions were evaluated by comparing derived visual ranges and observed luminances along affected and non-affected viewing paths. The factors introducing error into visual range calculations during bright haze and bright cloud conditions were found to depend strongly on the relative degrees of light scattering in front of and behind the target. Large errors were noted in visual ranges derived for snow-covered targets if an intrinsic contrast of - 1.0 was assumed; a method for approximating intrinsic skv/target contrast was applied to correct these errors. Recommendations are provided for recognition of non-standard conditions and field flagging of data.

THE ROLE OF RADIATIVE TRANSFER THEORY IN VISIBILITY MODELING: EFFICIENT APPROXIMATE TECHNIQUES

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Abstract-The application of radiative transfer theory to the evaluation of visibility model related skylight radiance distributions is discussed. Considerations of computational efficiency for air quality models operationally applied in the regulatory environment suggest the implementation of analytical approaches when feasible. Both exact and approximate analytical approaches are briefly reviewed. Since available exact treatments are not appropriate for physically realistic cases, approximate treatments are suggested and currently implemented visibility submodels are discussed. Calculations are presented for single scattering, diffuse field, and stream approximation approaches in ultraclean atmospheres. Examination of the accuracies of these alternative analytical approaches indicates that implementation of stream approximations within visibility models may provide a viable option consistent with desired accuracies and appropriate level of effort.

TRANSFER OF VISIBLE RADIATION IN THE ATMOSPHERE

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Abstract-The problem of the transfer of visible radiation in the terrestrial atmosphere is addressed from the visual-air-quality point-of-view. Attention is therefore focused on computations of the luminance, dominant wavelength, and spectral purity of the sky radiation

requiring radiance values for a number of wavelengths in the 0.38-0.78 pm interval of the electromagnetic spectrum. These calorimetric parameters are determined, for five different plane-parallel atmospheric models, from values of the radiances at 23 unequally spaced wavelengths. The diffuse radiation is evaluated after taking into account all orders of scattering, but after neglecting the polarization aspects of the scattered radiation, The atmospheric models studied are for average, cloudfree, mid-latitude summer conditions, and vary from an aerosol-free, absorption-free mode1 at one end to a model with a very large amount of aerosols and absorption by ozone, water vapor and oxygen at the other. These models are assumed to rest on a ground obeying Lambert's law of reflection.

Discussion of results is confined to variations of the aforementioned calorimetric parameters as a function of the zenith angle of observation in a vertical plane passing through the sun and the observer, but for several positions of the sun, and for several atmospheric conditions. For a few selected cases, results obtained after including all orders of scattering are compared with those obtained after consideration of the first scattering of the incoming solar, and outgoing ground-reflected radiation.

The main features of the sunlit sky for various cloud free atmospheric conditions and for various sun's positions are, qualitatively speaking, well-reproduced by the model calculations. Attention is drawn to the need for a detailed comparison of the calorimetric measurements taken simultaneously with the observations of various atmospheric parameters of crucial importance, and computations carried out with the input parameters representative of the experimental conditions; and also to the need for including absorption by other gases and sphericity of the earth-atmosphere system in future modeling studies.

VALIDATION AND SENSITIVITY OF A SIMULATEDPHOTOGRAPH TECHNIQUE FOR VISIBILITY MODELING

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Abstract-The Los Alamos Scientific Laboratory (LASL) visibility model is capable of producing simulated before and after" pictures that illustrate visual effects of smoke plumes. Although the model has been under development for a few years, until recently there had been very little testing of the model against field experience or testing of sensitivity of the model results to numerical approximations used in the model.

Further validation and sensitivity testing of the LASL model began in late 1979. The work focused on three areas: (1) comparison of the LASL model results with plumes encountered in the field, (2) comparison of LASL background-atmosphere model results with measured sky intensities and (3) examination of the variation of model results with changes in the numerical approximations.

The field study took place during August of 1979 in the vicinity of coal-fired power plants in northwestern New Mexico and northern Arizona. Telephotometer, NO_X plume measurements, and aerosol size distribution measurements of aerosols were made in the plumes of three different coal-fired power plants. Photographs were taken of the plumes and simulated photographs were prepared by the model.

Light intensities calculated by the background radiative transfer model were compared to measured light intensities in a very clean atmosphere and in a moderately hazy atmosphere. The measured intensities were derived from photographic densities, or from telephotometer measurements.

In addition to the field measurements, differences resulting from increased numbers of wavelengths in the color representation were examined. We also examined other changes in the numerical approximations. This paper describes the results of these studies.

A PLUME BLIGHT VISIBILITY MODEL FOR REGULATORY USE

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Abstract-The ERT visibility model has been developed over the past two years to estimate, principally for regulatory purposes, plume blight and visibility impairment resulting from point sources. The model combines the concentration fields calculated from single- or multiple-source dispersion models with calculations of the radiative transfer at four wavelengths in the visual range. It accounts for the scattering and/or absorption of the reactive pollutants NO_2, NO_3^- SO_4^{2-}, and carbonaceous and non-carbonaceous TSP. It can consider any geometrically specified line of sight (e.g., to a specific vista from a point in a Class 1 area). The model gives the following information about plume blight visibility degradation: (1) visual range reduction; (2) plume contrast; (3) object contrast degradation; (4) plume discoloration, expressed as a blue/red intensity ratio and (5) object and sky discoloration, expressed as a AE value.

Visibility Monitoring

VISIBILITY IN THE SOUTHWESTERN UNITED STATES FROM SUMMER 1978 TO SPRING 1979

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Abstract-The Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, recognizing the importance of visibility to the experience of a visitor to Class I areas in the United States, entered into an agreement with the National Park Service to initially deploy an

experimental research teleradiometer network at 13 national parks and monuments in the Southwest.

Objectives of the network are to: (1) evaluate the ability of multiwavelength teleradiometers to measure visibility, (2) evaluate the ability of several physical variables to characterize visibility and (3) determine the temporal and spatial dynamics of visibility deterioration on a regional scale.

Visibility is more than the ability to see an object at the distance at which it just disappears. Visibility includes the effects of atmospheric constituents on the ability of an observer to see color, texture, and form of both near and distant vistas. Target apparent contrast and delta contrast are variables that can represent atmospheric visibility, but they are vista specific. Hence, standard visual range, a parameter which tends to normalize differences between targets, remains a useful interpretive parameter for comparing data from different vistas.

Each park vista is also monitored with standardized photography, allowing a pictorial description of visibility. Analysis of data from summer 1978 through spring 1979 shows that winter had the highest standard visual range and spring the lowest. Capitol Reef National Park had the best visibility, while Wupatki National Monument had the worst. Visibility on cloudless days was usually better than on cloudless and cloudy days taken together.

VISIBILITY REDUCTIONS FROM SOIL DUST IN THEWESTERN U.S.

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Abstract-Soil dust can at times contribute significantly to atmospheric turbidity in the western U.S.A. An examination of meteorological surface observations from three sites in the west shows an increase in the number of cases of blowing dust (BD) over the past 30 years, while the mean wind speed associated with BD has decreased in growing, urban areas. Dust is reported more often in developing areas (such as Denver and Tucson) than in less disturbed areas (Winslow, AZ). Dust turbidity models, whose development was stimulated by the 1930s great plains dust bowl catastrophe are applicable to western soils as well and help explain visibility reductions caused by dust. Vehicle generated dust from unpaved roads can limit visibilities to values of one-third or less than the molecular scattering limit. The upper limits to the amounts of dust and visibility reduction to be expected in the west for differing meteorological conditions are calculated. It is estimated that dust devils may occasionally contribute 247 ug m^{3} of dust to the lower atmosphere in the west and a possible correlation between dust devils and human activity is noted.

VISIBILITY TRENDS IN THE VICINITY OF AN ISOLATED POWER PLANT

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Abstract-The Salt River project has been continously monitoring visibility in the vicinity of an isolated coal fired power plant located in Northern Arizona. Daily visibility and regular ambient particulate matter measurements are conducted from a monitoring site situated near to the power plant. Visibility is measured by a photographic photometric technique and a subjective technique

(human observer) and particles are measured with high-volume and size segregated high-volume samplers.

Data obtained from these measurements have been used for determining trends near the monitoring site. It has been found that visibility shows a temporal variation related to meteorological, ambient air quality and visibility reducing pollutants from regional sources. Also, there exists a measurable level of background fine particulate matter which plays a definite role **in** the visibility impairment in the area surrounding the power plant

SPATIAL AND TEMPORAL PATTERN OF EASTERN U.S. HAZINESS: A SUMMARY

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Abstract--One of the key features of the optical environment over the eastern U.S. is the frequent occurrence of regional haziness, particularly during the summer season. Four historical data bases were examined for estimation of the regional trend in haziness over the past 80 years: the surface visibility observations currently operated by the National Weather Service; historical visibility at Blue Hill MA, the NOAA-WMO turbidity network measuring the extinction of solar radiation with a sun photometer since the 1960's; and a set of direct solar radiation monitoring stations operated since 1910.

In the 1970's the lowest visibility occurred in the region of the Ohio River. The strongest increase of haziness was noted in the states adjacent to the Smoky Mountains: the average visibility there has decreased from 24 to 10km since **1948. That** region also exhibits the highest turbidity (vertical optical depth of the aerosol). The spatial trends of coal consumption indicate a consistency with the spatial trends in haziness.

EFFECTS OF A COAL-FIRED POWER PLANT AND OTHER SOURCES ON SOUTHWESTERN VISIBILITY (INTERIM SUMMARY OF EPA'S PROJECT VISTTA)

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Abstract-VISTTA (Visibility impairment due to Sulfur Transport and Transformation in the Atmosphere) is a cooperative program involving numerous government agencies, private companies, and universities. This paper summarizes the measurements and the results to date of

the summer and winter, 1979, VISTTA plume measurement programs conducted near the Navajo Generating Station (NGS), Page, Arizona.

During the program, ground and airborne measurements of aerosol size distribution, chemistry and optical properties, as well as gaseous reactant concentrations were made in the plume and in background air. Extensive regional and plume telephotometer measurements, airborne measurements along telephotometersite paths, background meteorological measurements, and source aerosol and chemistry measurements were also made. Various types of visibility measurements were compared with one another and with calculations of light extinction made using aerosol and NO, data. The measured plume optical effects were compared to those predicted using the EPA-SAI plume visibility model (PLUVUE).

The results of the study to date indicate that:

For the NGS plume, under most lighting and viewing conditions, NO_2, dominates the blue light extinction and brown coloration due to the plume.

For distances up to 100km or more for power plants like NGS, secondary aerosol formation can be ignored in visibility models under the dry conditions studied.

Widespread areas of elevated aerosol concentrations were documented in the southwest due to long range transport from the southern California area, and to wild fires. Other causes of regional haze are known to exist but were not documented in this study.

Evaluation of the chemistry, aerosol growth, and optics components of the PLUVUE plume visibility model showed predictions to be in reasonable agreement with the measurements. More uncertainty was encountered with the diffusion component. A set of nine reactions among NO_X NO_2, 0_3, 0_3, SO_2, OH, H_2O, and $O(^1D)$ was found to adequately simulate the plume chemistry for the clean dry background conditions at NGS.

CHARACTERIZATION OF THE REGIONAL HAZE IN THE SOUTHWESTERN UNITED STATES

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Abstract-As part of project VISTTA, aircraft sampling flights over non-urban portions of Arizona and Utah were conducted on 6 days in June and July 1979. The spatial distribution of "regional haze" is mapped in terms of the particle light scattering coefficient. Fine particle elemental composition was obtained from impactor and filter samples integrated over each flight path. One sampling day, 6/29/79, is characterized by reduced visibility throughout the sampling region. Possible sources are discussed.

THE CHEMISTRY, AEROSOL PHYSICS, AND OPTICAL PROPERTIES OF A WESTERN COAL-FIRED POWER PLANT PLUME

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Ahatract-Data obtained from the airborne measurements in the plume of the Navajo Generating Station (NGS) in June-Jufy and December 1979 as part of the EPA project VISTTA are reported. Source test and airborne data for the ratios SO_2/NO_X, particulates/SO_2, and the size distribution of the primary particles **agreed to within the variability of the emissions. NO, concentrations in the plume were in agreement with the photostationary steady state relations; there was no evidence for additional oxidant formation at distances up to 115** km. The formation of sulfate and nitric acid was strongly suppressed in the concentrated plume, where ozone is depleted. Sulfate conversions of less than 0.1% were typically observed for plume ages of 2 to 3 h in the **morning sunlight. The highest SO_2 oxidation rates observed** in the dilute plume were 0.8%/h in the summer between 59 and 89 km in the late morning and 0.2 %/h in the winter between 93 and 108 km in the afternoon. Nitric acid was always observed in the plume, and the rate of conversion of NO_X to nitric acid was 3 to 10 times the rate of conversion of SO_2 to sulfate. Ammonia concentrations were adequate to neutralize the secondary sulfate, but not to saturate the plume with ammonium nitrate. Particulate nitrates were not observed. New aerosol was reliably detected only in the 0.01 to 0.1 pm size range, which is ineffective at scattering light. Growth of particles larger than 0.1 pm was hard to detect in the presence of the variations in the background aerosol concentration. The emissions which affect the plume visibility are NO_X and fly ash, which was predominantly in the 2-7um size range. Secondary aerosol formation in the NGS plume can be neglected in visibility models for distances up to 100 km, but significant amounts of NO_X were removed by oxidation. On the average, extinction due to fly ash and NO_2 were equal for blue tight for 7% conversion of NO_X to NO_2, and for green light at 26% conversion. Fly ash always dominated extinction in the red. Telephotometer sight path flight data were obtained for plume visibility model validation.

Visibility and Regional Transport

A CASE STUDY OF VISIBILITY AS RELATED TO REGIONAL TRANSPORT
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Abstract-The study of the potential effect of long-range transport from the Los Angeles Basin to the Mohave Desert-Grand Canyon area on visual range is one of the principal goals of the visibility program in the Mohave network. One episode was investigated during an intensive study period in July-August, 1980. Conclusive evidence of transport episodes was obtained by

measurements of anthropogenic chIorfluoromethanes in the impacted areas, but the quantitative significance in terms of visibility could not assessed for two reasons. First, the maximum plume impact occurred at night and, second, the changes in visibility as observed by three different methods were not large enough to state that a change that could be associated with a change in the synoptic flow patterns.

REGIONAL HAZE CASE STUDIES IN THE SOUTHWESTERN U.S.--II. SOURCE CONTRIBUTIONS

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Abstract-The contributions of major source types to air quality and visibility in the desert southwestern U. S. near Page, AZ are determined for five distinctly different periods in June, July and December, 1979. The analysis is based on temporal and spatial patterns of parameters observed during 4 weeks of sampling carried out as part of Project VISTTA (1979) and other studies. These patterns are related to known source characteristics and computed air trajectories. An episode of low visibility accompanied by very high concentrations of carbon and potassium is traced to smoke from unusually large wildfires in southern Arizona. The unambiguous chemical and physical signal observed during this period serves to calibrate the emission transport simulation and back trajectory calculations. Three incursions of southern California pollutants throughout the southwest are identified--one in each of the months in which sampling was conducted. A low visibility summer incursion, during which sulfate concentrations increased by about 2 microg m^3, followed several days of stagnation in southern California with high sulfate and **ozone** conditions. A high visibility summer incursion, during which ozone concentrations increased but sulfate concentrations did not, followed an episode of high ozone and low sulfate concentrations in southern California. Both incursions were accompanied by a pronounced shift toward larger sulfate particle sizes. The bulk of the secondary pollutants observed during both incursions may have been formed in the strongly oxidizing southern California atmosphere.

SOME OBSERVATIONS OF POLLUTANT TRANSPORT ASSOCIATED WITH ELEVATED PLUMES

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Abstract--The chemistry of long-range pollutant transport is strongly influenced by atmospheric dispersion characteristics. Recent aircraft plume sampling has suggested that the dispersion growth of elevated plumes may be significantly slower than would be predicted from the well-known behavior of ground-based plumes. The slower growth of the elevated plumes would lead not only to significant plume impact at farther downwind distances but would increase the importance of chemical reactions in the plume and the downwind impact on visibility.

Plume dispersion data at large downwind distances are quite limited. Standard diffusion graphs have been extrapolated to 100 km from the wealth of data available at smaller downwind distances.

A large number of aircraft flights have been made by Meteorology Research Inc. (MRI) in the last four years under the sponsorship of EPA and others. A number of these flights have

sampled individual plumes to distances up to 100 km under a variety of environmental conditions. The data tend to show that elevated plumes (above the surface mixing layer) may grow at a much slower rate than those existing within the boundary layer. Differences in growth rate may be associated with differences in turbulent characteristics or with differences in wind direction (shear) within the two layers.

The aircraft data provide an opportunity to extend the dispersion information available at downwind distances that are of importance in intermediate scale pollutant transport. The paper deals with an analysis of these data, an examination of the environmental characteristics associated with the sampling flights and a comparison of the results with the limited supply of observational data already available.

THE LONG-RANGE DISPERSION OF A PLUME FROM AN **ISOLATED POINT SOURCE**

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Abstract-The dispersion of the plume from a sulphide smelter at Mount Isa, Austral& has berm determined at **distances of** up **to 1000 km from** the source. **Simultaneous measurements** by an airborne correlation spectrometcr, flame **photometer and** aitken counter have allowed accurate determinations of plume width at them large distances.

Radiosonde and pilot-balloon data from four positions spanning the region have bean used **to calculate** the trajectories **of each of the plumes measured iu the study. In each 4~ge the measured plume position was in good agreement with the position predicted on the basis of the wind data.**

A simple model based on the diurnal variation of the structure of the atmosphere, as well as the turning of the wind with height, is shown to account adequately for the measurements of plume width during well mixed atmospheric conditions et distances of between 25 and l000 km from the source.

THE OXIDATION AND LONG-RANGE TRANSPORT OF SULPHUR DIOXIDE IN A REMOTE REGION

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Abstract-The flux of sulphurdioxide has been measured in the plume of a remotely situated smelter (Mount Isa, Australia) at distances of up to 1000 km from the source. These measurements were made with an airborne correlation spectrometer in plumes ranging in age from 1.0 to 42.5 h, the latter corresponding to a photolytic age of almost two periods of daylight. Ground-based experiments were also performed to determine the rate of dry deposition of suiphur dioxide in the area situated about 500 km from the source.

The implications of an error in the deposition velocities, reported by Mime J. W., Roberts D. B. and Williams D. J. (Atmos. Envir. 13, 373-380, 1979.), are considered. The average velocity for the Mount Isa region is higher than that previously employed by Roberts D. B and Williams D. J. (Atmos. Envir. 13, 1485-1489,1979). Along with a reassessment of the diurnal model and the average mixing height encountered by Roberts and Williams, this necessitates a

reduction in the estimate of the photochemical oxidation rate of sulphur dioxide from 0.25 to 0.15 % h^{-1}, when averaged over 24 h.

It is shown in this study that the rate of loss of sulphur dioxide from the plume out to the furthest distances measured can be accounted for by the combined processes of atmospheric oxidation and dry deposition, as determined by Roberts and Williams for much shorter distances (< 26Okm). The lifetime of suphur dioxide in the region under study is shown to be fourteen days, with about half of the loss being due to atmospheric oxidation

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VERIFICATION OF A THREE-DIMENSIONAL TRANSPORT MODEL USING TETROON DATA FROM PROJECT STATE

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Abstract- During August 1978, The Environmental Protection Agency (EPA) conducted a major field study at the Cumberland Steam Plant of the **Tennessee** Valley Authority. This study, known as the Tennessee Plume Study, was conducted as part of the EPA Sulfur Transport and Transformation in the Environment (STATE) Project. The field experiments included the release and tracking of tetroons from Cumberland during numerous intervals within the period of the study. On 15 August, 10 tetroons were released, traveling distances ranging from less than 25 km to in excess of 200 km. The tetroon position data were compared with three-dimensional (3-D) kinematic trajectory predictions from a 3-D regional-scale dynamic model. The average directional error was 7” where the maximum error was 14” and an error of less than 2” prevailed for 2 trajectories. The average displacement error was 9 % of the observed path of the tetroon, with the maximum being 30 % and an error of 3 % or less prevailing for 4 trajectories.

AIRBORNE DOWN LOOKING LIDAR MEASUREMENTS DURING STATE 78

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Abstract- EPA’s airborne downlooking dye lidar was operated during the STATE field program in western Kentucky/Tennessee in the summer of 1978. In this paper, lidar estimates of height of the atmospheric mixing layer are shown and compared with in ***situ*** measurements. Lidar estimates of crosswind and vertical dimensions of TVA power plant plumes are compared with appropriate literature values and with in ***situ*** estimates from data compiled by other STATE investigators; wherever necessary, data are adjusted to ensure compatibility with respect to sampling time. In addition, lidar measurements of plume rise are compared with model calculations.

The lidar estimates of mixing layer height were usually slightly higher than ***in situ*** counterparts, presumably because aerosols may rise and become trapped above the base of the elevated stable layer. Values of plume rise computed using the Briggs models were generally similar to those indicated from lidar measurements although considerable scattering of data existed; supplementary data indicated that the scatter could be reduced with the inclusion of the vertical shear of the horizontal wind in the models. When adjustment with respect to sampling

time was accomplished, the lidar values of plume dimensions compared reasonably well with values obtained using data collected by ***in situ*** measurement platforms. The situations sampled by the lidar were almost exclusively at night or in the daytime when the plume was above the top of the mixing layer. For such situations, effects of initial mixing due to buoyancy and diffusion are apparent in the vertical plume spread. Effects of initial mixing due to buoyancy, turning of the horizontal wind with height, and diffusion are apparent in the downwind plume spread; this was surmised through comparison of the lidar plume dimensions with the Pasquill-Gifford dispersion curves. The data, thus, provide additional evidence that information on the plume buoyancy, turning of the wind with height, and the height of the plume in relation to that of the mixing layer must be included in any new scheme or any adaptation of an existing scheme for the estimation of the spread for large, elevated buoyant plumes.

WILDFIRES

LARGE FIRE WINDS, GASES AND SMOKE*
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Abstract-ExperimentAI, free-burning wood fires larger than 5 ha were similar in convection column volume after the initial buoyant, ring-vortex rose from the ground. The fire generated strong vorticity patterns which propagated upward into the convection column. The rotation suppressed lateral entrainment and mixing after the buoyant vortex ring had passed. The mixing height of the convection column was determined by vertical wind shear. Maximum smoke, complex hydrocarbon concentrations, combustion gas concentrations, oxygen depletion and visibility reduction and radiation extinction occurred during the first 210s of the fires.