Assessing the Potential Visibility Benefits of Clean Air Act Title IV Emission Reductions

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ABSTRACT

Assessments are made of the benefits of the 1990 Clean Air Act Title IV(CAAAIV), Phase 2, SO2 and NOX reduction provisions, to the visibility in typical eastern and western Class 1 areas. Probable bands of visibility impairment distribution curves are developed for Shenandoah National Park, Smoky Mountain National Park and the Grand Canyon National Park, based on the existing emissions, "Base Case", and for the CAAAIV emission reductions, "CAAA Case". The distribution curves display the hours per year or season, falling into bands of visibility impairment. The "deciview", (dv), is used as the visibility impairment metric.

Emission projections for 2010 are developed with improved versions of the National Acid Precipitation Assessment Program emission projection models. The updated models incorporate the U.S. Environmental Protection Agency unit-level SO2 allowances and generalized NOX reductions. Source-receptor transfer matrices created with the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model are used with existing emission inventories and with the emission projections to calculate atmospheric concentrations of sulfate and nitrate at the receptors of interest for existing and projected emission scenarios. The Visibility Assessment Scoping Model (VASM) is then used to develop distributions of visibility impairment. VASM combines statistics of observed concentrations of particulate species and relative humidity with ASTRAP calculations of the relative changes in atmospheric sulfate and nitrate particulate concentrations in a Monte Carlo approach to produce expected distributions of hourly particulate concentrations and RH. Light extinction relationships developed in theoretical and field studies are then used to calculate the resulting distribution of visibility impairment. Successive Monte Carlo studies are carried out to develop sets of visibility impairment distributions with and without the CAAAIV emission reductions to gain insight into the detectability of expected visibility improvements.

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INTRODUCTION

Successful accomplishment of the mission of the U.S. Department of Energy(DOE), to ensure a secure and economic supply of energy to meet domestic needs while simultaneously enhancing the environment, requires an understanding of the existing environmental situation as well as an understanding of the relationships between various energy supply options and their environmental and economic consequences. The existing situation reflects not only what we see today but the expectations of existing legislation, such as the 1990 Clean Air Act Amendments, the benefits of which have not yet been fully realized. While CAAAIV mandated large national reductions in emissions of SO2 and lesser reductions in emissions of NOX, for the primary purpose of reducing acid rain, these reductions were also expected to reduce atmospheric haze. The results reported in this paper are aimed at determining the atmospheric haze reduction benefits of the 1990 Clean Air Act Amendments, particularly the Title IV provisions(CAAAIV), so that these expectations can then serve as the baseline for evaluating the benefits of potential additional enhancement measures.

An estimate of the typical visibility improvements for eastern Class 1 areas from SOX emission reduction, similar to the CAAAIV reductions, was included in the National Acid Precipitation Assessment Program (NAPAP) 1990 Integrated Assessment Report[1]. Subsequent to that study, a DOE visibility assessment process was established; the process has been regularly upgraded to reflect growing data bases and improved scientific understanding of visual impairment[2,3,4,5]. Estimates of visibility improvement have also been made by the U.S. Environmental Protection Agency (EPA)[6].

APPROACH

The DOE assessment approach is summarized as follows:

- For sensitive receptor areas of interest, 1985 -1992 observations of atmospheric particulate species [SO4-, NO3-, dust, elemental C (EC), and organic C(OC)] are processed statistically to determine current mean concentrations and distributions.
- Similar statistics are gathered for relative humidity (RH) from suitable nearby meteorological stations.
- The Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model[7] is exercised to develop source-receptor matrices for SOX emissions and SO4- concentrations, and NOX emissions and NO3-/HNO3 concentrations.
- Emission projections for year 2010 are developed with improved versions of the NAPAP emission projection models. The updated models incorporate EPA unit-level SO2 allowances and generalized NOX reductions.
- The Visibility Assessment Scoping Model (VASM), uses the above statistical concentration data in Monte Carlo routines to assign sets of hourly particulate concentration for potential future periods for existing(Base Case) emissions. Future CAAAIV hourly concentrations of SO4- and NO3- are assigned by applying the seasonal or annual CAAAIV to current SO4 and NO3 aerosol change ratios, developed by inputting CAAAIV to current emissions patterns into ASTRAP, to each hourly concentration value. Future concentrations of dust, EC, and OC are assumed to be unaffected by CAAAIV and remain at their above Monte Carlo values.
- Hourly concentrations and statistical RH values are processed in VASM, using appropriate extinction algorithms, to compute hourly visibility impairment in deciviews(dv), the unit used by the National Park Service to report visual impairment[8].
- Multiple estimates of seasonal or annual distributions are produced by exercising additional Monte Carlo simulation sets in VASM.

Recently the authors presented the results of a study that utilized upgraded versions of ASTRAP and VASM in evaluating the impact of climatological variability on visibility impairment[9]. Climatological, in this case, is the year-to-year changes in the daily frequencies and characteristics of the fields of key meteorological variables such as wind, precipitation, and relative humidity. Modeling results indicated that distributions of visibility impairment could vary considerably from year to year even with emissions held constant, due to this climatological variability.

Observed distributions of summer visibility impairment in the Grand Canyon for 1988 through 1992 (Fig. 1), a period during which aggregated SO2 emissions were relatively unchanged, also vary markedly, presumably from climatological variability as well as from unreported emission changes from natural and anthropogenic sources. Because this "background" visibility variability appears large in magnitude, compared to the changes expected from significant emission reductions, the detectability of an improvement in visibility is an assessment issue requiring particular treatment.

Improved treatment of climatological variability has been incorporated into VASM to provide decision makers with tools to address both the magnitude and the detectability of emission scenario benefits. This study provides estimates of the benefits of the CAAAIV emission reductions for (1) CAAA Case vs. Base Case for the same Monte Carlo sequences of variable values and (2) CAAA Case for a "typical" simulation vs. a set of Base Case simulations for three locations of interest:

- Shenandoah National Park,
- Smoky Mountain National Park, and
- Grand Canyon National Park.

Existing and projected visibility is characterized with distributions of the number of daylight hours during which various levels of perceived visibility impairment, or haze, would be experienced during a season or year.

In order to improve the clarity of the results for decision makers, the assessment results are reported for hours of impairment falling into 5 dv bands, thus providing smoother curves for easier interpretation. The observed distributions of haze in the Grand Canyon, resolved in Fig. 1 to 1 dv, are shown in Fig. 2 smoothed to 5 dv resolution, together with a previous typical VASM result for contemporary emissions and 1980-1990 climatology. Although the VASM result in Fig. 2 is only one realization of the summer dv distributions that VASM could generate, it nevertheless appears to be a reasonable average of the set of analyses of summer observations.

In the results to follow, the VASM extinction algorithms for the eastern sites (Shenandoah and Smoky Mountain National Parks) have been updated to incorporate new extinction efficiency results from work by Middleton[10] and NAPAP estimates of background (non-anthropogenic) SO4- and NO3- concentrations[11]. Particulate observations from which distributions are developed were made in the late 1980s and early 1990s, while RH statistics are from 30-year averages. Unless otherwise described, ASTRAP results are for the climatology of 1980-1990 and the intrastate spatial distributions of emissions as reflected in the 1985 NAPAP inventory.

RESULTS

Shenandoah National Park: The magnitude of haze reduction resulting from the CAAAIV is approximated in Figure 3, which compares the annual haze distribution for a typical Monte Carlo simulation with Base Case emissions, with the distribution generated with this simulation for emissions after CAAAIV implementation. While the shift for this typical simulation is not dramatic, about 1.5 dv, the increased frequency of good visibility (low dv) and

reduced frequency of bad visibility (high dv) after CAAAIV implementation is clearly seen. This particular Base Case realization, Scenario 2 out of a set of 10, was selected as the basis for magnitude evaluation as the most representative of the 10 Base Case distributions generated with different Monte Carlo sequences. Figure 4 shows all 10 Base Case simulations along with the Scenario 2 CAAAIV reduction simulation. The Scenario 2 CAAAIV reduction simulation is shown to fall generally within the normal noise band of Base Case simulations, suggesting that it will be difficult for the casual observer to detect that an improvement has been made.

Base Case vs. CAAAIV Case comparisons have been made for each of the above simulations and the results show significantly different haze reduction magnitudes for each different simulation. Simulations which contain meteorology with a high propensity for sulfate formation, show higher benefit for SO2 reductions; while simulations with low propensity for sulfate formation show little benefit for SO2 reductions.

Smoky Mountain National Park: The CAAAIV scenario exhibits about the same improvement over the Base Case (Fig. 5) as that for Shenandoah, but the annual distributions reflect somewhat more visual impairment than do the corresponding distributions for Shenandoah. The distributional differences in separate Monte Carlo sequences (Fig. 6) are about as large as was the case for Shenandoah, and as is the case at Shenandoah, it will be difficult for the casual observer to detect that an improvement has been made.

Grand Canyon National Park: The CAAAIV scenario here also reflects emission reductions expected from installation of scrubbers on the Navajo Generating Station (NGS) and significant reductions from the smelter industry. The overall expected change in the annual dv distribution (Fig. 7) is about the same as that for the eastern sites (1-2 dv); however, the improvement appears more noticeable because the dv distribution and noise are lower overall than at the eastern sites. The CAAAIV dv distribution is clearly lower than any of 10 Monte Carlo simulations of existing conditions (Fig. 8); this was not true for the 10 simulation runs for the eastern sites. Similar comparisons for the summer dv distributions in the Grand Canyon (Figs. 9 and 10) show improvement that is less obvious than is the case for the annual analyses. This is likely because the NGS source, for which emissions will be greatly reduced, is NE of the Canyon and NE flow is much less common in summer than in winter.

When combined with our earlier analysis of climatological variability in visibility assessment[9], our results indicate that improved visibility will result from implementation of CAAAIV, but that improvement will be relatively modest, and difficult to quantify with confidence from air quality measurements without a significant period of monitoring observations, perhaps 5-10 years.

Because ASTRAP simulations of the changes in SO4- and NO3- concentrations play a key role in the exercise of VASM, it is informative to compare ASTRAP simulations with observations. A meteorological data set (wind and precipitation fields, updated several times daily) for 1980-1990 has been processed for ASTRAP for the entire 11-year period (used in the results above) and for each individual year. Source-receptor matrices produced for each summer of meteorology and the intrastate emission distribution of summer 1985 are combined with statewide emission totals for each summer of 1980-1990[12] to produce the modeled Shenandoah SO4- trend in Fig. 11; the corresponding trend of the mean of June-August observations is also shown.

The magnitudes are quite comparable except for 1986 and 1987, for which modeled results are about 50% higher than observations. Without discounting the limitations in a highly parameterized, assessment-oriented model such as ASTRAP, there are two other potential factors that affect this particular comparison. First, the model is predicting the mean concentration for a complete 3-mo period, while observations are 24-hr mean concentrations measured twice a week when data recovery is complete, which is not always the case. Second,

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use of the source-receptor transfer matrix in trend calculations implies an assumption that all emission sources within a source region (state) vary uniformly from one year to the next. If the emission variations of important individual sources varied in a different manner than their corresponding statewide totals, that would not be reflected in the modeled trend.

Caveats about the VASM/ASTRAP approach: Of necessity the assessment process uses simplified forms of more robust scientific models and there are considerable uncertainties in some of the data bases and assumed relationships in the assessment process. Among the simplifications and limitations are the following:

- We assume that aerosol extinctions are independent and independently variant with RH, subsequent VASM models will incorporate a dependency adjustment.
- Aerosol extinction is assumed based on external mixing, however their algorithms assume other mixing and growth forms; improvements are planned.
- VASM aerosol variance simulation routines are based on limited data bases. VASM is known to somewhat underestimate the magnitude of observed visibility variances.
- ASTRAP meteorological inputs do not resolve mesoscale circulations, known to be particularly important around the Grand Canyon.
- Our knowledge of the absorption characteristics of elemental and organic carbon compounds is relatively recent and subject to change.
- Emission, transformation, removal and transport of OC, EC, and dust need to be modeled in ASTRAP or other regional model. Policy analysis will require differentiation between anthropogenic and natural contributions.
- Because of resolution limitations and model simplifications, ASTRAP underestimates natural variability.

Subsequent versions of VASM and ASTRAP will be incorporating improvements in these areas and their impact on assessment results can then be determined. Given this understanding of the status of assessment science development, the following general conclusions are offered.

CONCLUSIONS

General regional haze will decrease in future years in both the east and the west as a result of CAAAIV and other provisions of the 1990 Clean Air Act Amendments. The improvements are likely to be relatively modest, averaging about 1-2 dv, and both temporally extensive monitoring and detailed modeling analysis will be necessary to quantify the improvement resulting from implementation of the legislation. It may be even more difficult to demonstrate to the general public the effectiveness of the legislation, because of the infrequency of individual visits to the scenic remote areas and the large natural variation in haze.

The fact that SO4- and NO3- aerosols make up only a relatively small portion of the annual visibility extinction budget (Fig. 12) helps to explain why the visibility benefits of CAAAIV are not dramatic. Further improvements in visibility are dependent on our ability to reduce concentrations of OC, EC, and dust, significant portions of which are presumably due to natural and generally uncontrollable sources.

ACKNOWLEDGMENTS

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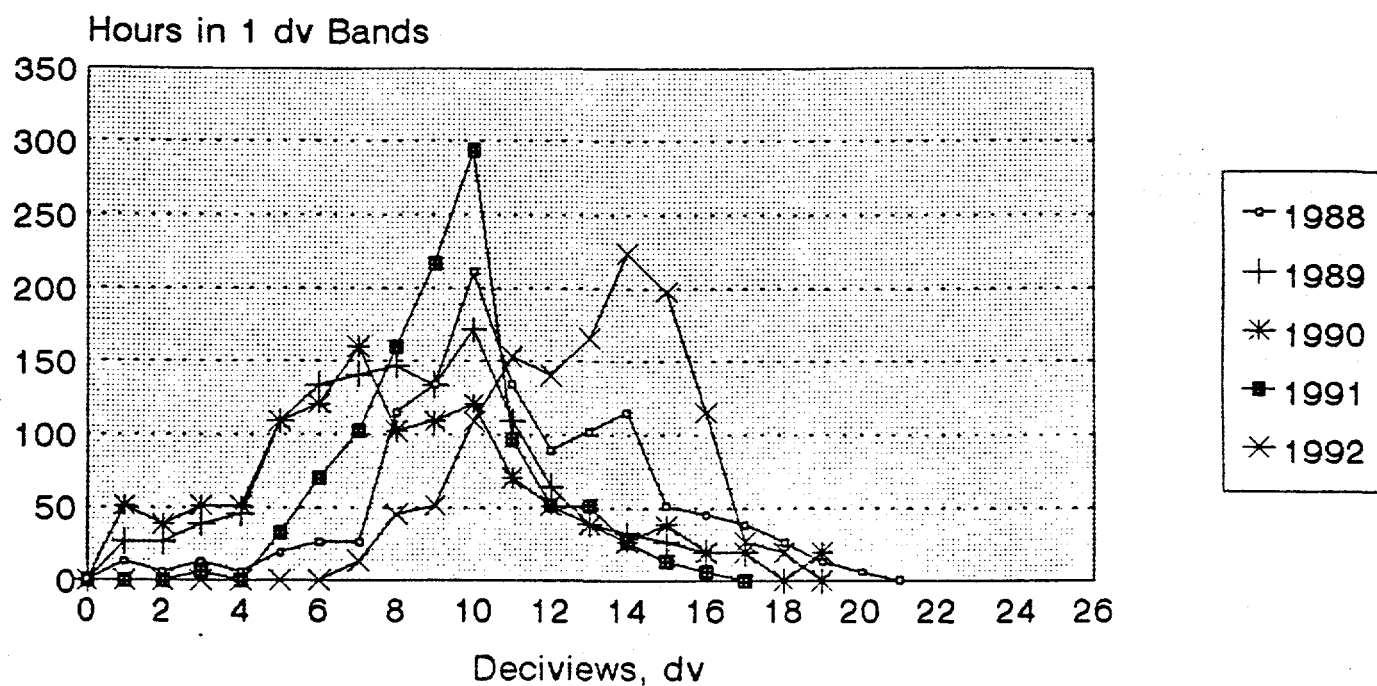
Hours in 1 dv Bands

Figure 1. Frequency Distribution of Haze, Deciviews, Grand Canyon south rim, Summers of 1988-92, 1 dv resolution.
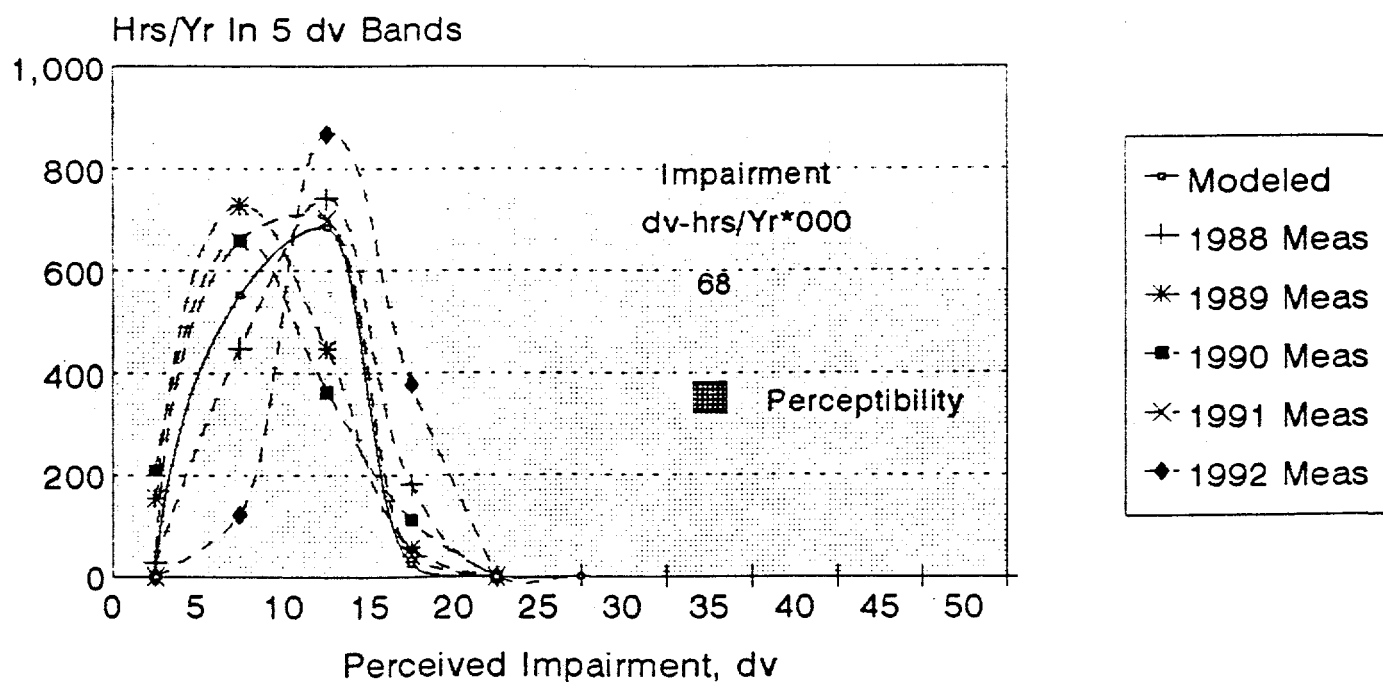
Hrs/Yr In 5 dv Bands

Figure 2. Frequency Distribution of Haze, Deciviews, Grand Canyon south rim, Summers of 1988-92, 5 dv resolution; including VASM model comparison.
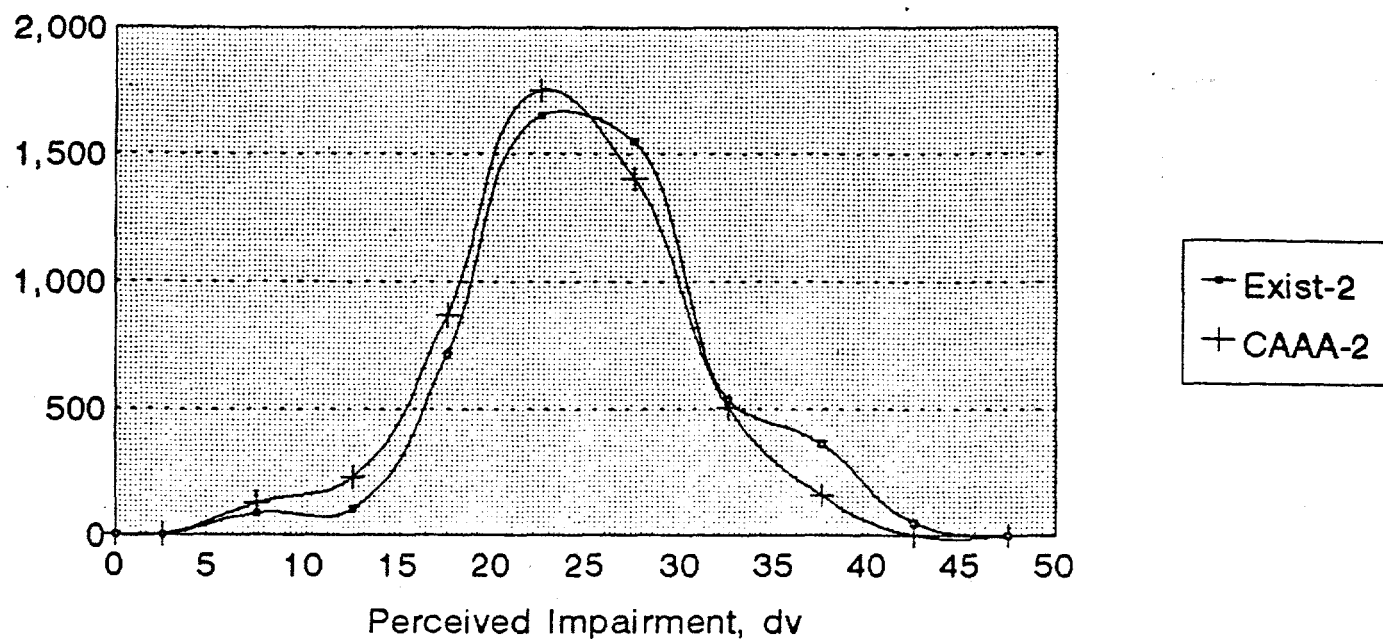
Figure 3. Annual haze distribution curves, typical meteorology simulation, Existing versus CAAAIV, Shenandoah National Park, 5 dv resolution.
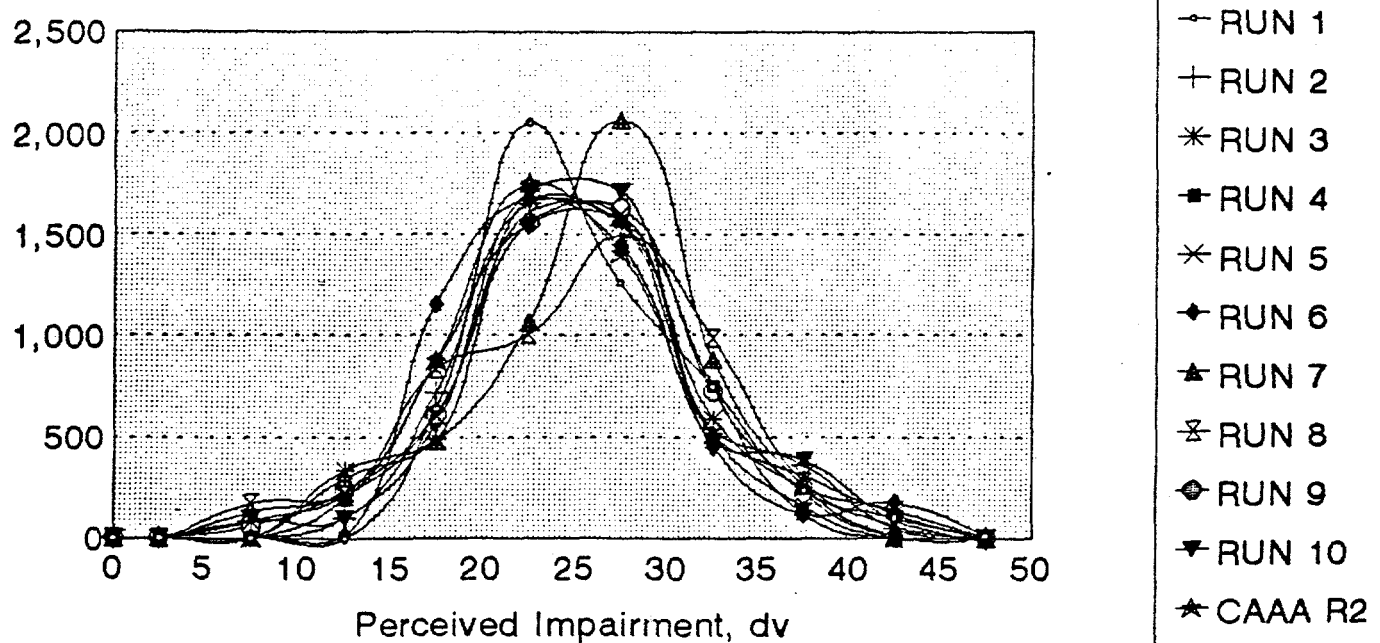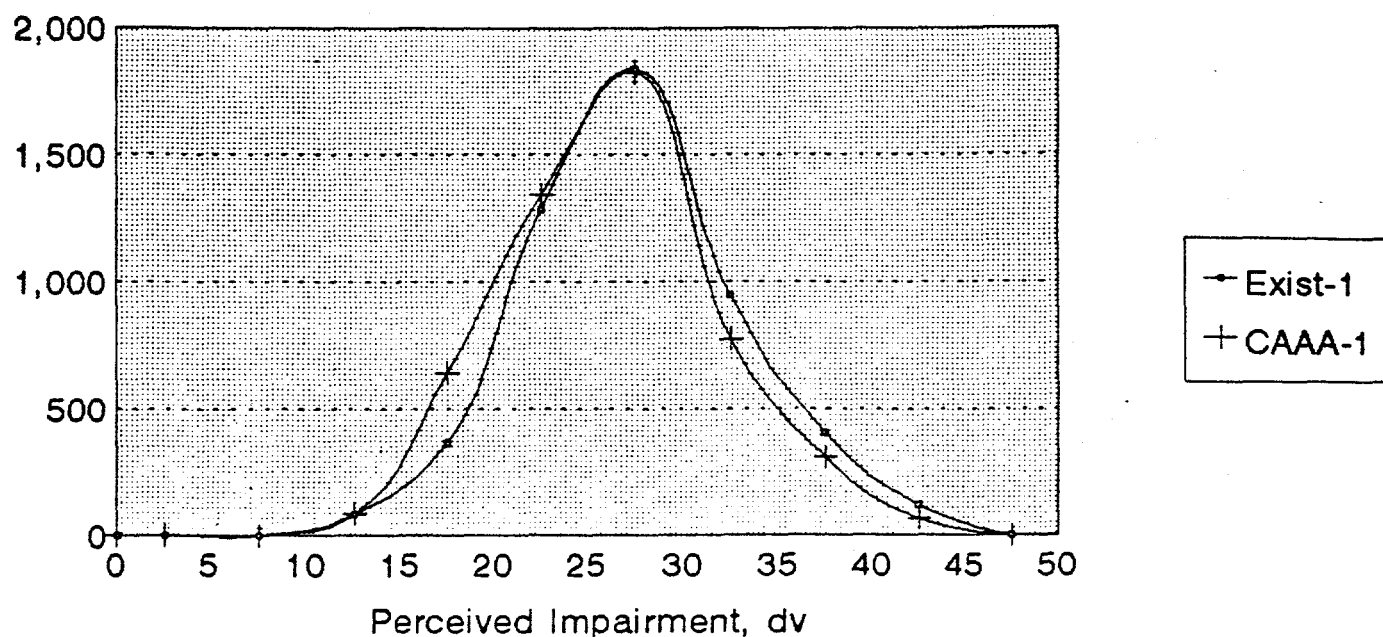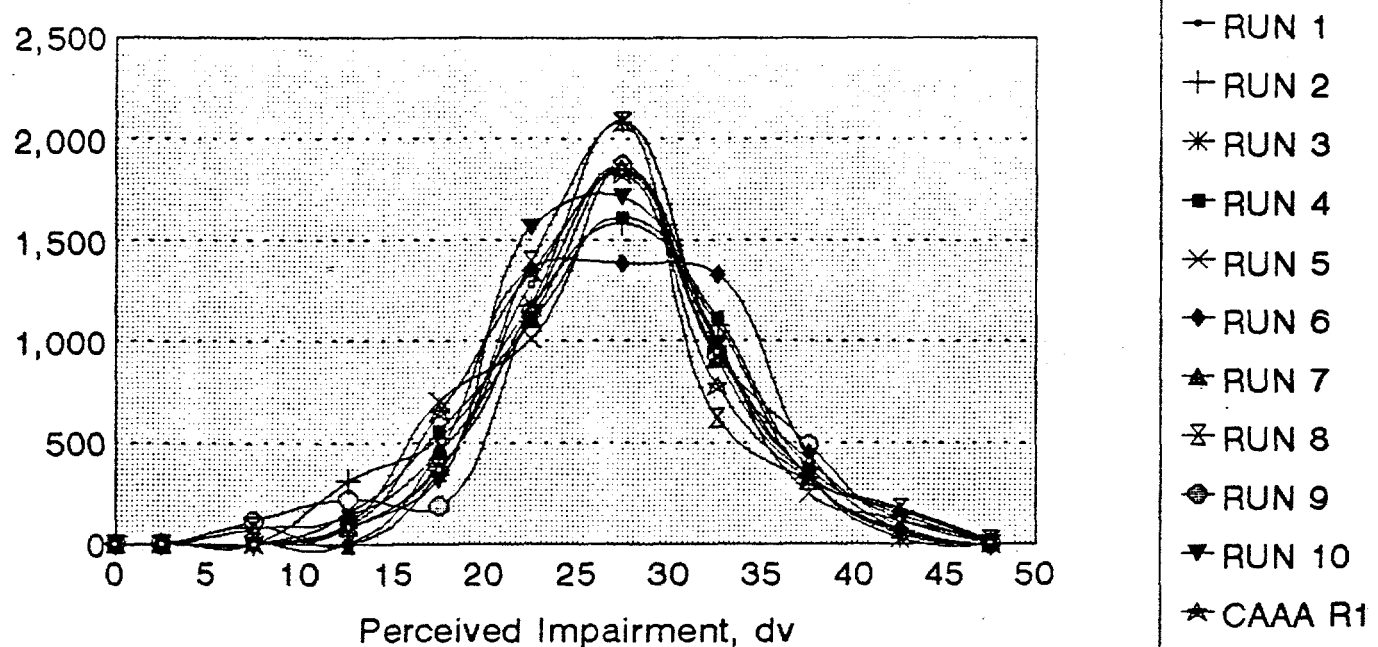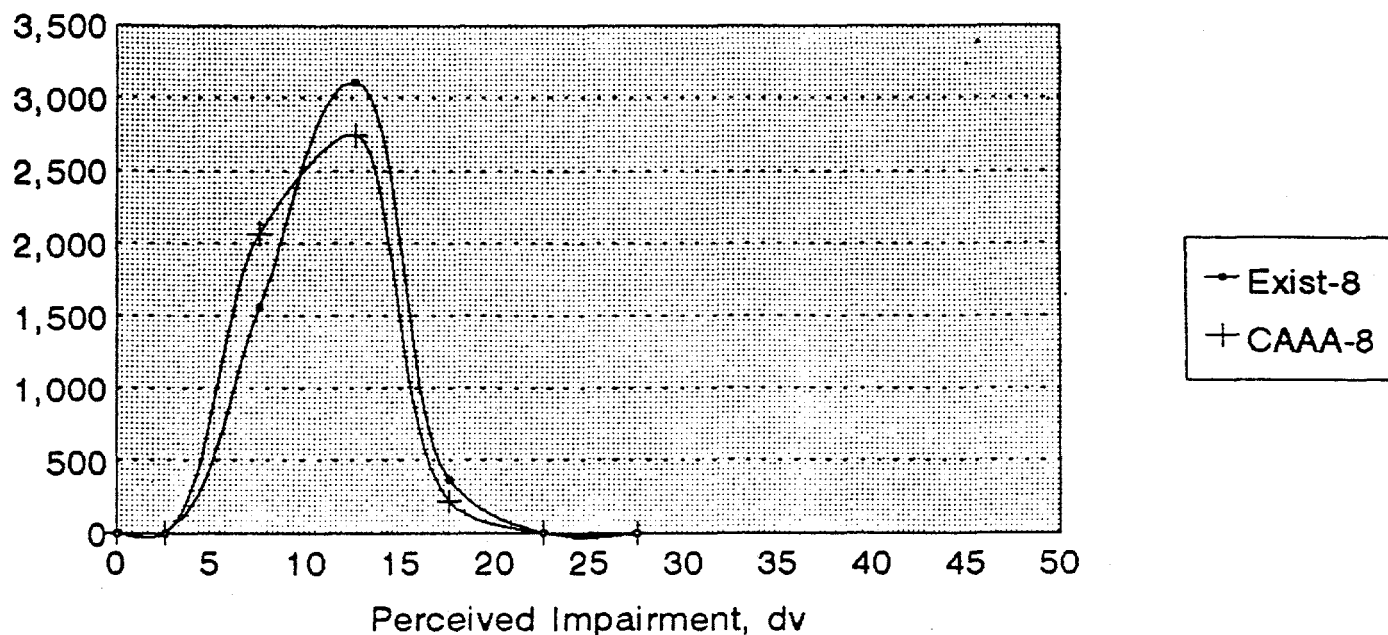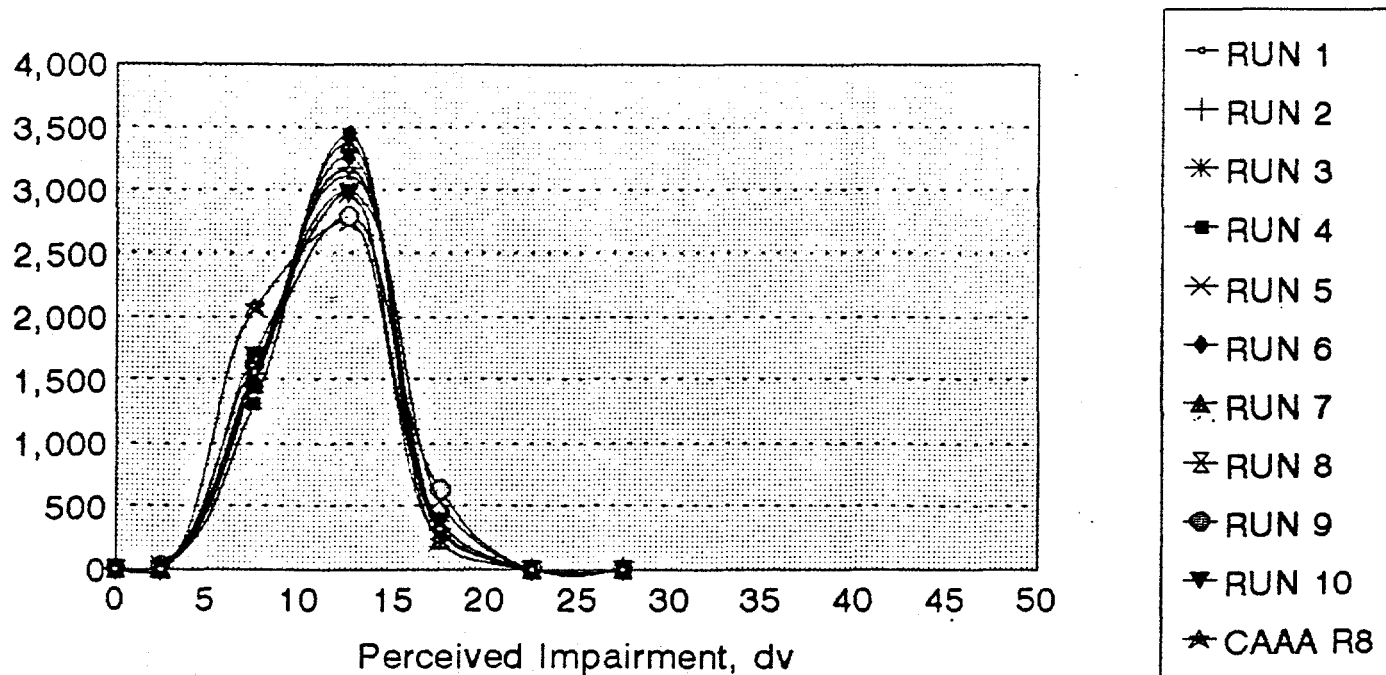

Figure 4. Annual haze distribution, 10 consecutive simulations, with Existing versus CAAAIV for typical simulation, Shenandoah National Park, 5 dv resolution.

Figure 5. Annual haze distribution curves, typical meteorology simulation, Existing versus CAAAIV, Smoky Mountain National Park, 5 dv resolution.

Figure 6. Annual haze distribution, 10 consecutive simulations, with Existing versus CAAAIV for typical simulation, Smoky Mountain National Park, 5 dv resolution.

Figure 7. Annual haze distribution curves, typical meteorology simulation, Existing versus CAAAIV, Grand Canyon National Park, 5 dv resolution.

Figure 8. Annual haze distribution, 10 consecutive simulations, with Existing versus CAAAIV for typical simulation, Grand Canyon National Park, 5 dv resolution.
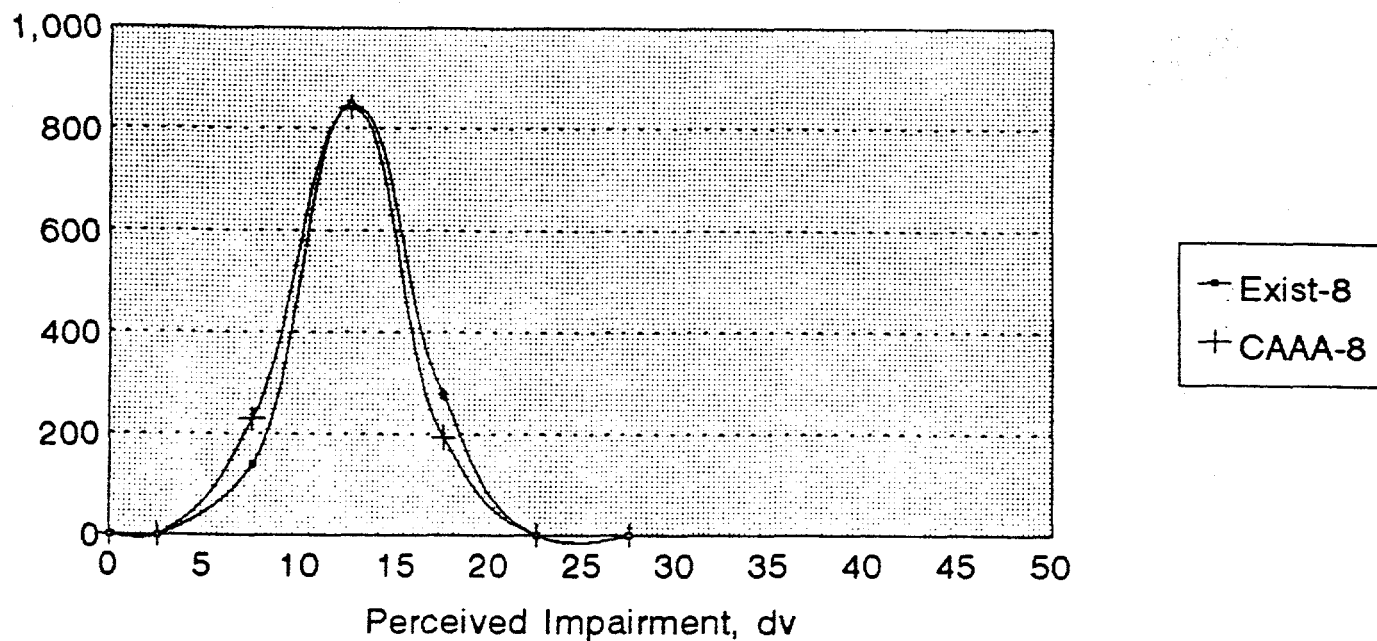
Figure 9. Summer haze distribution curves, typical meteorology simulation, Existing versus CAAAIV, Grand Canyon National Park, 5 dv resolution.
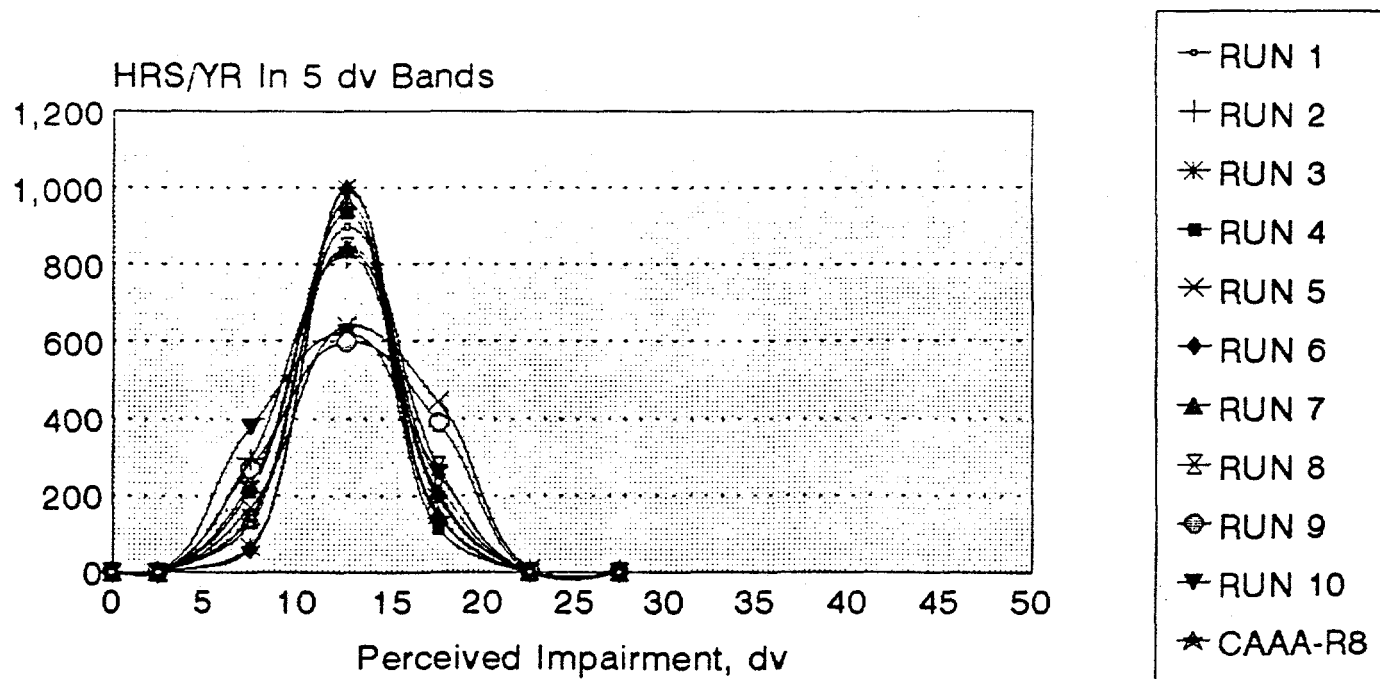

Figure 10. Summer haze distribution, 10 consecutive simulations, with Existing versus CAAAIV for typical simulation, Grand Canyon National Park, 5 dv resolution.
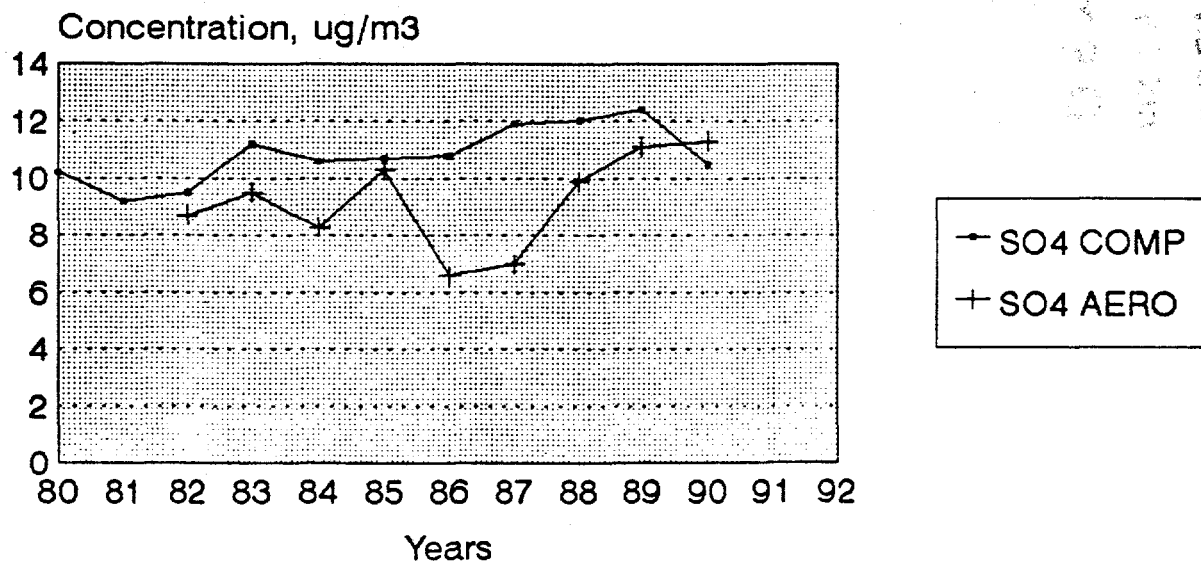
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Concentration, ug/m3

Figure 11. ASTRAP modeled sulfate concentrations using individual year meteorology and emissions compared with NPS measurements, 1980-90.
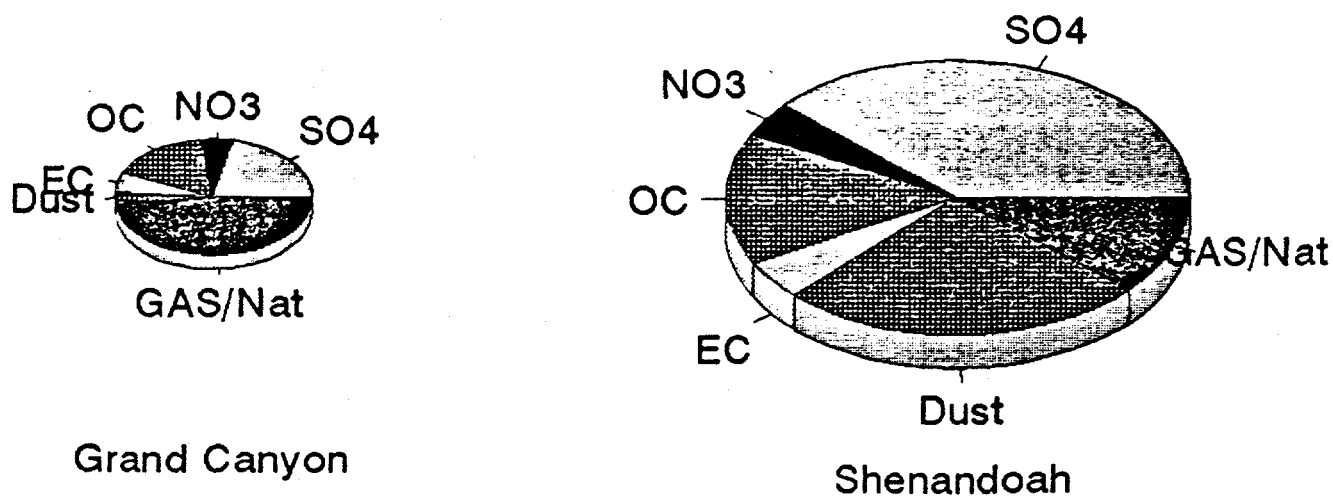

Grand Canyon

Shenandoah

Figure 12. Visibility Extinction Budgets, East and West.