CLIMATOLOGICAL VARIABILITY IN REGIONAL AIR POLLUTION

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DISCLAIMER

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ABSTRACT: Effects of climatological and meteorological variability on means and distributions of air pollution parameters, particularly those related to regional visibility, are illustrated. Over periods of up to a decade climatological variability may mask or overstate improvements resulting from emission controls. The importance of including climatological uncertainties in assessing potential policies, particularly when based partly on calculated source-receptor relationships, is highlighted.

Although some air pollution modeling studies examine events that have already occurred (*e.g.*, the Chernobyl plume) with relevant meteorological conditions largely known, most pollution modeling studies address expected or potential scenarios for the future. Future meteorological conditions, the major pollutant forcing function other than emissions, are inherently uncertain although much relevant information is contained in past observational data. For convenience in our discussions of regional pollutant variability unrelated to emission changes, we define meteorological variability as short-term (within-season) pollutant variability and climatological variability as year-to-year changes in seasonal averages and accumulations of pollutant variables. In observations and in some of our simulations the effects are confounded because for seasons of two different years both the mean and the within-season character of a pollutant variable may change. Note that climatological and meteorological variability do not refer here to the variability of climate or meteorology but rather to their induced effects on pollutant behavior.

Expressed in relative terms, climatological variability usually increases as the spatial and temporal scales over which the pollutant parameters are averaged decrease. Seasonal variability from one year to the next tends to be greater than annual variability (Shannon *et al.*, 1985). Similarly, the climatological variability at a single location tends to be greater than the variability averaged over a region. Climatological variability can enhance or mask the effects of emission trends. For evaluation of past data there is frequently less interest in examining climatological variability for its own sake than in being able to quantify and remove climatological variability before performing trend analysis. Such quantification of climatological variability requires the aid of a model or models, ranging from relatively simple conceptual models (*e.g.*, assuming that wet deposition of pollutants varies with aggregated precipitation) to regional models that examine different aspects of variability. One might quantify climatological variability by multiple exercise of a model with the climatology from a series of individual years while holding emissions temporally constant. Results can then be used to adjust an observed trend. After removing temperature-related effects on ozone concentrations, Rao *et al.* (1995) concluded that ozone concentrations have decreased in recent years in the northeastern United States. Shannon (1992) isolated the 1979-1988 trends in regional wet deposition of sulfate associated with SO_2 emission trends, and deduced that emission reductions were dominant during the first four years and that climatological variability controlled regional variability thereafter.

Climatological variability should be considered in evaluating the probable effectiveness of potential future emission control policies. The primary reason is to create a realistic distribution of possible pollutant outcomes rather than a single deterministic estimate without associated uncertainty. In addition, quantification of climatological variability is desirable so that the likelihood of detecting the pollutant trend associated with the control action, perhaps as a function of the number of years of monitoring, can be assessed. Trexler and Shannon (1995) examined the expected improvement in visibility from SO_2 emission reductions mandated by recent legislation. We use source-receptor relationships from the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model (Shannon, 1985), together with emissions vectors aggregated at the state level, observed means and variations on various temporal scales of relative humidity (RH) and concentrations of particulate species, and light attentuation equations for those species as functions of RH and concentration, in the Visibility Assessment Scoping Model

(VASM) (Trexler and Laulainen, 1992). To generate realistic short-term distributions of visual impairment, VASM varies RH and particulate concentrations of sulfate, nitrate, elemental carbon, organic carbon, fine-particle dust, and coarse-particle dust through Monte Carlo techniques by assuming lognormal distributions for the particulate species and a diurnal curve superimposed on a normal distribution for RH.

A recent series of applications of VASM/ASTRAP has examined potential future distributions of visual impairment in scenic parks in the United States. Although the research is still in progress, some preliminary results can be shown here. In Figure 1, distributions of summer visibility impairment in deciviews (dv), an increasingly accepted visibility metric that is analogous to the logarithmic decibel scale for sound, are estimated for Shenandoah National Park in the eastern United States for conditions before and after the approximately 50% reduction in SO_2 emissions currently underway. The distributions, which are quite smooth because each curve represents the average of 9,000 (90 days * 100 years) simulations of 15 daylight hours per day, reflect a mean overall improvement of about 3 dv. Although this improvement may seem small, the typical observer can detect a difference of between 1 and 2 dv in a scenic view. In addition, limits exist as to how much improvement can be obtained solely by SO_2 controls because sulfate causes only about one-half of visibility impairment in the nonurban East and about one-fifth in the nonurban West, with the remainder due to other particulate species, NO_2 gas, and natural Raleigh scattering (Trijonis *et al.*, 1990).

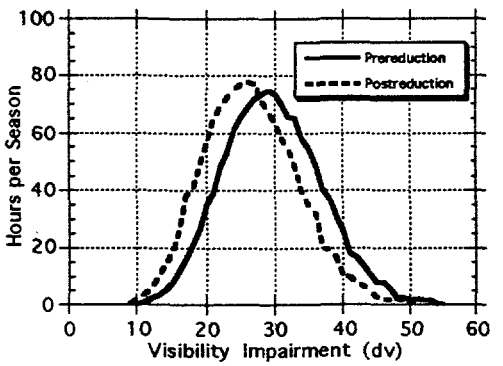

Figure 1: Mean expected summer distributions of visual impairment at Shenandoah National Park before and after the emission reductions mandated by the 1990 Clean Air Act Amendments, as calculated with VASM.

VASM results indicate a typical mean shift of 2-3 dv between sunrise (maximum RH) and midafternoon (minimum RH) due to the RH difference. Light attentuation by hygroscopic particles such as sulfate increases exponentially for RH values above 70%; visibility thus tends to be worst at sunrise. Sometimes researchers have a greater interest in the change in the frequency of relatively dirty or relatively clean days; by selecting a critical deciview value, one can easily estimate such changes from the expected distributions. Our calculations indicate that the occurrences at Shenandoah of visual impairment above 40 dv can be expected to be reduced over 50% after the emission reductions are completed.

A particular season will typically exhibit a much more irregular distribution of visual impairment, because only about 20 to 40 changes of air mass will occur during the season. A set of VASM simulations of visual impairment for a single summer are shown in Figure 2 for mean prereduction and postreduction sulfate concentrations; also shown are two cases representing mean sulfate conditions 14% higher and 18% lower than the expected postreduction mean. This corresponds to the range of ASTRAP results calculated with each of 11 summers of meteorological data.

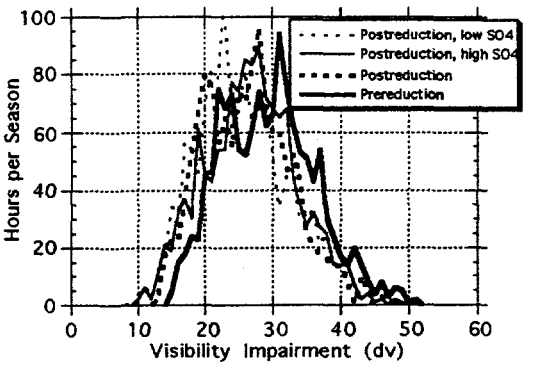

Figure 2: Single-year simulations from VASM of summer distributions of visual impairment at Shenandoah before and after emission reductions, plus postreduction cases of higher and lower mean concentrations of sulfate from ASTRAP estimates of climatological variability. Within-season meteorological variability differs for each case.

A range of about ±15% in the post-reduction seasonal average of sulfate results in relatively modest changes in the distribution of visual impairment (roughly ±1 dv). This is not unexpected because (1) the deciview parameter is logarithmic and (2) we have not

yet included climatological variability of the other particulate species. For clarity in assessment and policy analysis, expected mean distributions as in Figure 1 are the most useful modeling output. Changes expected after a sufficiently long period of averaging can be clearly depicted. Observations of visual impairment for a single season, on the other hand, can be expected to exhibit the irregularities illustrated in Figure 2 (Trexler and Shannon, 1995). Both presentations are useful in demonstrating expected outcomes and potential variations about those outcomes.

An evaluation of visibility should examine variations in both mean conditions and distributions about those mean conditions. In evaluation of acidic deposition, for which the most important ecological effects are largely controlled by long-term loading, long-term variability is more emphasized than short-term variability (Streets *et al.*, 1985). Climatological variability can be the major factor controlling year-to-year variability of pollutant parameters, particularly when emission changes are relatively small. In some cases, an apparent trend over a period of 5 to 10 years can simply be the result of the particular sequence of climatological conditions. This point is illustrated in Figure 3, in which ASTRAP simulations for average summer atmospheric concentrations of sulfate at Shenandoah National Park indicate a significant upward trend from 1982 through 1990, even though the model simulations hold emissions temporally constant at 1985 levels. The slope of the modeled trend is similar to that of the observations, in large part because aggregated emissions of SO_2 changed little during the period. Little direct correlation is seen between modeled and observed concentrations because of the sharply lower observed concentrations in 1986 and 1987. In addition to the usual suspects (model inadequacies), the discrepancies may be due to substate emission changes that are not reflected in aggregated totals or to calculations of observed seasonal means from limited sampling (two days per week at best).

ASTRAP calculations indicate that Ohio and Pennsylvania SO_2 sources contribute the greatest shares (aggregated by state) of the summer sulfate concentrations at Shenandoah. Their source-receptor contributions, normalized by emission rate, can change significantly from year to year (Figure 4). A targeted emission control strategy based upon the 1983 source-receptor relationships might be very different than a strategy based upon 1982 calculations. Such variations indicate that emission control policies should reflect the best estimate of source-receptor relationships averaged over multiple years, rather than for any single, perhaps atypical year.

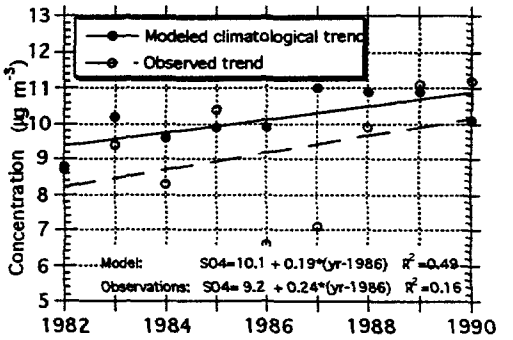

Figure 3: Comparison of the observed trend in average summer atmospheric concentration of sulfate at Shenandoah with a modeled trend from ASTRAP simulations in which climatology varies but emissions are held constant. Equations describing the linear trends are shown.

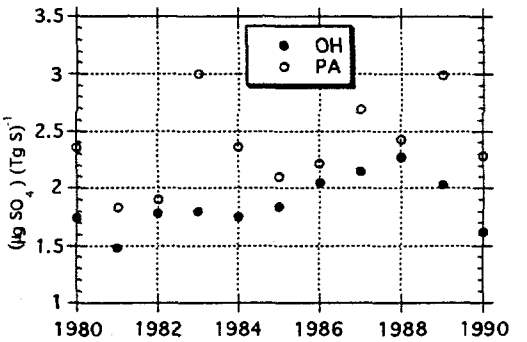

Figure 4: ASTRAP estimates of the normalized contribution of aggregated SO_2 sources of Ohio and Pennsylvania to average summer sulfate concentrations at Shenandoah.

Models invariably simplify nature. Although other meteorological parameters such as mixed-layer depth, temperature, or incident radiation may influence pollutant variability, often by affecting chemical transformation rates, here we examine only climatological variability related to patterns of a single-layer transport wind (resolved over grids of either 150- to 175-km or 300- to 350-km spacing and updated four times daily) and total precipitation (resolved over a grid of 100- to 115-km spacing and updated 2 to 4 times daily). The mean diurnal and seasonal effects of other variables, such as RH and temperature, are parameterized without year-to-year variability

in our approach. Because we cannot address all relevant meteorological variables in our study, we likely underestimate overall climatological variability.

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