EXPANDING THE HORIZONS OF THE VISIBILITY ASSESSMENT SCOPING MODEL (VASM)

Jack D. Shannon
Environmental Research Division
Argonne National Laboratory
Argonne, IL 60439

4A.3 EXPANDING THE HORIZONS OF THE VISIBILITY ASSESSMENT SCOPING MODEL (VASM)

Jack D. Shannon
Argonne National Laboratory
Argonne, IL 60439

INTRODUCTION

The Visibility Assessment Scoping Model (VASM) has successfully simulated seasonal distributions of hourly visual impairment, or haziness, that compare favorably with observations for both relatively polluted eastern sites and relatively pristine western sites in the United States (Shannon *et al.*, 1997). The VASM approach combines regional modeling of seasonal mean concentrations of key anthropogenic particle species with Monte Carlo statistical techniques using past monitoring data and relative humidity (RH) climatology. The Monte Carlo method requires as input the seasonal geometric mean and standard deviation of daily concentrations of six particle species: sulfate, nitrate, organic carbon, elemental carbon, and dust in the fine particle mode (aerodynamic diameter less than 2.5 μm), and dust in the coarse particle mode (diameter between 2.5 and 10 μm). (NOTE: the coarse-particle mode is treated as dust regardless of actual speciation.) In addition, the Monte Carlo method uses inter-species seasonal correlations of daily concentrations, RH climatology (seasonal means, standard deviations of daily averages, and typical diurnal patterns), and predicted future mean seasonal concentrations for one or more particle species. The VASM technique thus far has been applied in integrated assessment only where fine-particle monitoring and speciation measurements have taken place for a time sufficient for reliable statistical input into the Monte Carlo process (Henrion *et al.*, 1997; Shannon, 1998). Thus, haziness changes resulting from emission changes have been quantitatively evaluated only at those monitoring locations. For use in comprehensive cost-benefit analyses consistent with estimation of the total costs of emissions controls, it is desirable to extend the estimation of changes in haziness to the entire region of interest.

2. APPROACH

The simplest approach to extending the results of VASM analyses to benefits analysis for large regions (the eastern United States, for example) would be to assume that the mean or median decrease in haziness at the selected sites examined can be applied to the entire region. Such an estimate might actually be quite representative if certain conditions hold:

- VASM calculations are made for a set of monitoring sites (typically in the Interagency Monitoring of Protected Visual Environments [IMPROVE] network [Malm *et al.*, 1994]), that include both relatively polluted locales such as Shenandoah and Great Smoky National Parks in the southern Appalachians, and relatively clean locales such as Acadia in coastal Maine and Isle Royale in Lake Superior (to avoid the equivalent of a sampling bias).
- The focus is on a single emission species (SO_2).
- The emissions policies examined are quite broad in their effects on emission patterns (and thus on the regional sulfate pattern).

The simple averaging approach becomes more problematic when multiple pollutant species are being more tightly controlled or when the emissions changes are more focused spatially. In any case, to demonstrate that such a simplified approach is adequate, one would need to compare it with a more spatially complete assessment of improvements in visibility.

Although the monitoring of haziness and fine-particle concentrations is likely to increase because of new and proposed regulations about $PM_{2.5}$ concentrations and regional haze, considerable time must pass before suitable quality controlled data become available for use in assessment. Thus, some form of interpolation or extrapolation of the data from monitoring sites is likely to remain necessary for extension of VASM across a large region, whether the eastern United States or the entire country.

In this initial approach to extending VASM spatially, we seek to estimate distributions of haziness through two alternate interpolation methods: (1) we interpolate the statistics of haziness distributions produced by VASM for monitoring sites; (2) we interpolate the observed particle concentration statistics, obtain relative humidity climatology for the additional locations, and then exercise VASM with those input values. (For these evaluations we examine only current conditions and thus need not exercise an air quality model to predict future concentrations of sulfate or other particle species.)

Before illustrating the interpolation approaches, several caveats about the interpolation methods should be emphasized. These methods may work well for variables whose regional patterns have relatively smooth gradients, but would be expected to miss intervening "hot spots," or subregional areas with significantly greater particle concentrations or greater haziness over a season because of local particle emissions or near-source particle formation. Subregional areas of much improved visibility might well exist for short periods because of the cleansing effects of precipitation; however, they would not be common over a season. Large urban areas in particular may have more impairment of visibility than the surrounding region. Another potential problem in the extrapolation of statistics may result from site elevation differences;

Corresponding author address: Jack D. Shannon, Environmental Research Division, Building 203, Argonne National Laboratory, Argonne, IL 60439

mountainous sites may be above the regional mixed layer part of the time, particularly during the cooler portion of the year, and thus may experience typically lower particle concentrations and better visibility than sites at lower elevations. To some extent, elevation differences may be confounded with urban-rural differences, because urban areas tend to be at lower elevations, while much of the IMPROVE monitoring occurs at elevated sites in the mountains. As will be seen, our interpolation example is affected by both urban-rural differences and elevation differences.

VASM results are usually presented as seasonal distributions of daily visual range (km) or haziness (deciviews). Such presentations are also suitable for demonstrating the results of interpolation to a single location, as will be the case in the example to follow. If results were presented for a grid of interpolated points across the region, however, a single parameter such as the median visual range or haziness value would be more suitable for two-dimensional contouring.

A significant advantage of the VASM approach has been its ease of use and speed on a desktop computing platform, but combining that ease of use with a spatially broader application is not a simple matter. In an integrated assessment, the Tracking and Analysis Framework (Henrion *et al.*, 1997),VASM simulations of the seasonal distributions of daily noontime haziness for all four seasons and two emission scenarios, at 5-y intervals from 1980 to 2030 and at seven locations, required about three minutes on a Power Mac 6100/60. Because all calculations are saved during an application of a model in the Analytica^{TM} language (in which this version of VASM is written), the effect of a modeling change, such as a different optical extinction formula for sulfate, can be calculated quickly, because only the internal variables affected by that change are recalculated. Such temporal efficiencies come at a cost in required computer memory, however, so the number of receptor haziness distributions that can be examined in a single model run is limited. While ultimately a cost-benefit analysis might require use of only a single parameter of the haziness distribution, such as the mean or median value, determination of a parameter of the distribution currently requires VASM calculation of the entire distribution.

Inspection of a plot of the eastern IMPROVE monitoring sites reveals that the Washington, DC, site is convenient for testing the interpolation methods, because there are surrounding stations at Shenandoah National Park, VA; Dolly Sods in the Monongahela National Forest, WV; and Brigantine National Wildlife Reserve, NJ. Several factors confound the interpolation, however. Both Shenandoah and Dolly Sods are rural sites at elevations above 1 km, while the DC urban site is near sea level. The Brigantine site, also rural, is near the Atlantic Ocean and thus would experience greater concentrations of sea salt particles than the other sites.

For an initial evaluation of the urban perturbation in particle concentrations, we compare the concentration averages at the three surrounding sites with concentration averages for Washington, as shown in Table 1. The urban-rural differences in concentrations of elemental carbon and nitrate fine particles are most pronounced and consistent through the year, with the urban concentration averages 2.5 to 3.0 times higher for nitrate and 3.5 to 4.0 times higher for elemental carbon. The ratios for organic carbon fine particles show a strong seasonal trend ranging from 2.8 in winter to 1.4 in summer, perhaps due to the larger role of natural emissions in the warm season. Except for winter, the urban-rural differences for sulfate, fine dust, and coarse dust may well lie within the uncertainty (unquantified, but presumably large) of this analysis approach. The implication of the results in Table 1 is that if urban concentrations are interpolated from measurements at the predominantly rural IMPROVE monitoring sites for subsequent VASM simulations, urban concentrations are likely to be significantly underestimated unless the urban-rural difference is parameterized.

Table 1: Comparison of seasonal average particle concentrations prior to 1994 at an urban site (Washington, DC) with the average of rural sites at Shenandoah National Park, VA; Dolly Sods, WV; and Brigantine, NJ ($\mu g\ m^{-3}$).

season	locale	sulfate	nitrate	organic C	elemental C	fine dust	coarse dust
	urban	5.92	3.40	3.32	1.85	2.51	19.84
winter	rural	3.93	1.19	1.19	0.50	0.92	3.84
	ratio	**1.5**	**2.9**	**2.8**	**3.7**	**2.7**	**5.2**
	urban	7.38	2.52	2.66	1.50	2.83	8.63
spring	rural	5.98	0.90	1.48	0.39	1.85	5.82
	ratio	**1.2**	**2.8**	**1.8**	**3.8**	**1.5**	**1.4**
	urban	10.46	1.36	3.04	1.82	4.52	8.74
summer	rural	11.35	0.48	2.23	0.43	5.25	6.92
	ratio	**0.9**	**2.8**	**1.4**	**4.2**	**0.9**	**1.3**
	urban	6.95	2.07	3.12	1.9	2.42	7.30
autumn	rural	5.83	0.79	1.82	0.5	1.83	5.14
	ratio	**1.2**	**2.6**	**1.7**	**3.8**	**1.3**	**1.4**

3. RESULTS

Lognormal means and standard deviations of concentration, together with the average between-species correlation matrix (all averaged for the three rural sites) are combined with RH climatology specific to Washington in VASM simulations in one approach to VASM interpolation. An alternate interpolation averages the haziness distributions simulated by VASM for each of the rural sites. (NOTE: the approaches weight each rural site equally; a more rigorous approach could take into account the relative separation from Washington of each receptor, thereby giving Shenandoah greater weight.) Finally, simulations are made with particle concentration statistics and RH climatology for Washington, to evaluate the importance of the urban-rural and terrain differences on analysis. The seasonal distributions of haziness produced by the alternate methods are compared in Figure 1a-d.

For the more pristine end of the haziness distributions, results for the two interpolation methods are almost identical. For winter and spring, the distributions remain very similar through the 90th percentile, but in autumn (and to a lesser extent in summer), interpolation of particle statistics produces greater haziness at the upper ends of the distributions. The reasons for this are not yet clear. The VASM simulations using only DC data indicate a generally greater level of haziness, particularly in winter (about 5 deciviews), considerably more than the change expected by 2010 (seasonal median improvements of 1.3 to 2.2 deciviews) from the implementation of the utility SO_2 reductions mandated by the Acid Rain Provisions of the 1990 Clean Air Act Amendments (Shannon *et al.*, 1996, 1997). This result emphasizes the need either to obtain urban particle measurements for use in VASM and other visibility assessment models or to develop parameterizations of the urban perturbations on the regional particle concentration fields, perhaps as a function of population. In summer and autumn, when the urban perturbations in particle concentrations appear to be at a relative minimum because visual impairment is dominated by regional-scale sulfate, the interpolated particle concentrations produce VASM simulations that are slightly hazier at the 90th percentile than the simulations using only DC data.

To evaluate the two interpolation approaches more thoroughly in future work, we will compare their performance in evaluating the changes associated with two different emission scenarios; an assessment of visibility benefits using VASM results focused on the improvement in visual range resulting from emission reductions rather than the absolute level of visual range (Burtraw *et al.*, 1997). To improve the VASM approach for application in comprehensive integrated assessments, we want to parameterize local perturbations related to elevation, as well as perturbations resulting from urban emissions. The planned parameterization development will be greatly benefited by the availability of the growing databases from IMPROVE and other networks, but special care will be required because the emission fields have been changing significantly in the mid-90s.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy, Office of Energy Research and Office of Fossil Energy, under contract W-31-109-Eng-38. Mention of commercial products does not constitute endorsement.

REFERENCES

Burtraw, D., A. Krupnick, E. Mansur, D. Austin, and D. Farrell, 1997: *The Costs and Benefits of Reducing Acid Rain.* Discussion Paper 97-31-REV, Resources for the Future, Washington, DC.

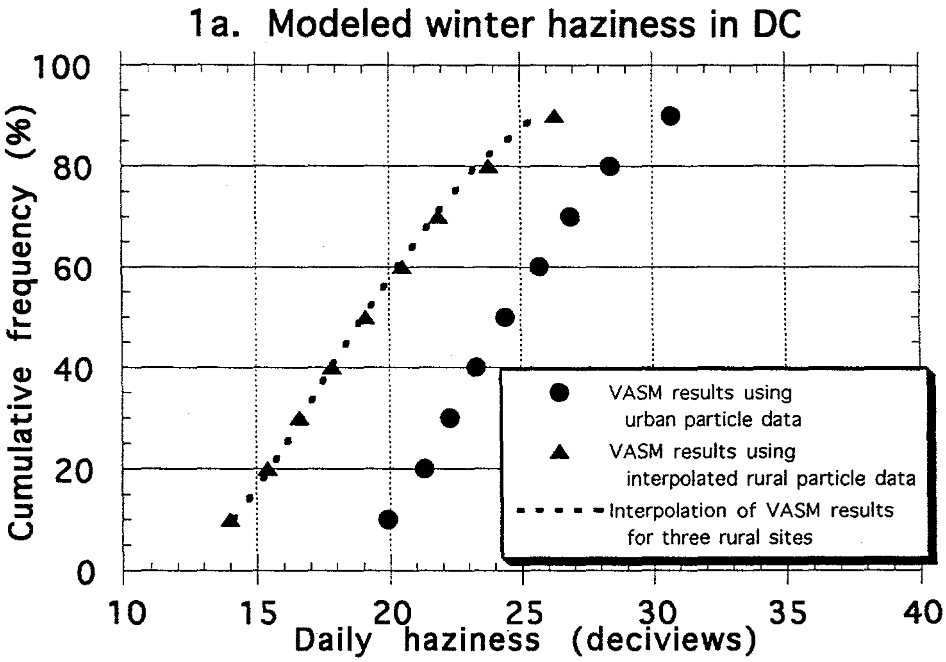
Henrion, M., R. Sonnenblick, and C. Bloyd, 1997: Innovations in integrated assessment: the Tracking and Analysis Framework (TAF). In *Proc., Acid Rain and Electric Utilities II Conf.*, 21-22 January, 1997, Scottsdale, AZ, Air & Waste Management Association, Pittsburgh, 978-992.

Malm, W. C., J. Sisler, D. Huffman, R. A. Eldred, and T. A. Cahill, 1994: Spatial and seasonal trends in particle concentration and optical extinction in the United States. *J. Geophy. Res.* **99(D1),** 1347-1370.

Shannon, J. D., 1998: Modeling air pollution in the Tracking and Analysis Framework (TAF). (These Proceedings.)

Shannon, J. D., J. Camp, and E. C. Trexler, Jr., 1996: Effects of the 1990 Clean Air Act Amendments on distributions of visual impairment. *Proc., 9th Joint Conf. on Applications of Air Pollution Meteorology with A&WMA*, American Meteorological Society, Boston, 570-574.

Shannon, J. D., E. C. Trexler, Jr., and R. Sonnenblick, 1997: Modeling visibility for assessment. *Atmos. Environ.* **31**, 3719-3727.



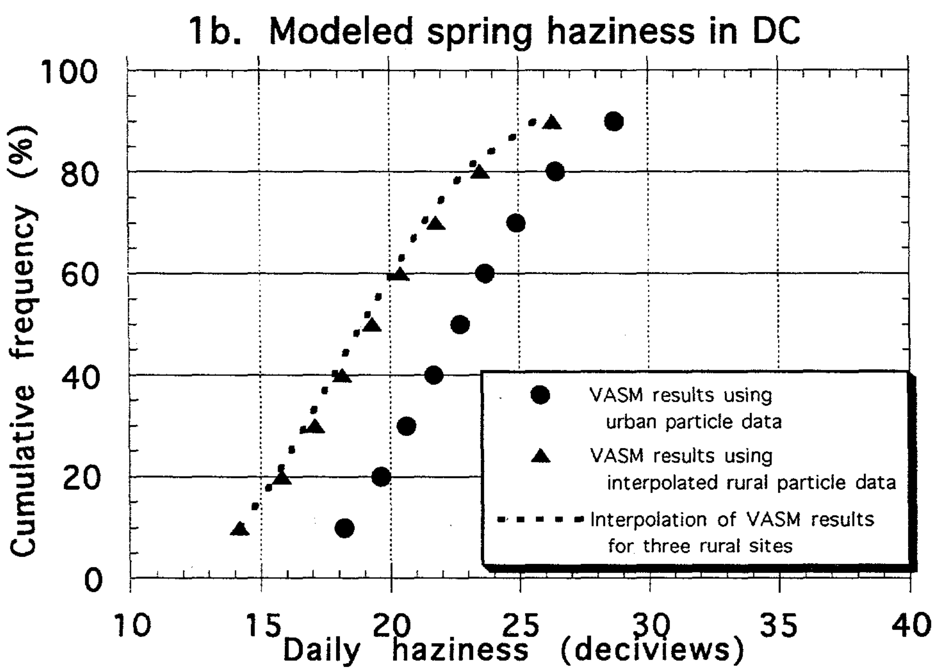
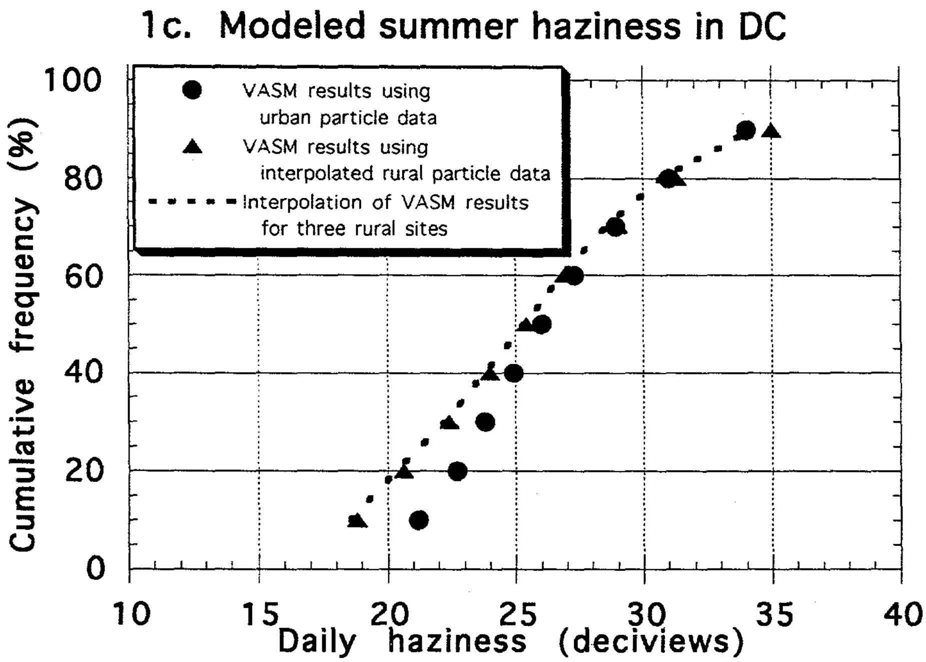


Figure1a-b: Alternate modeled winter and spring distributions of daily haziness in Washington DC: DC particle concentration data and relative humidity used in VASM, interpolated particle concentrations (from Shenandoah, Dolly Sods, and Brigantine) and DC relative humidity used in VASM, and interpolated haziness distributions from VASM simulations for the three surrounding sites.



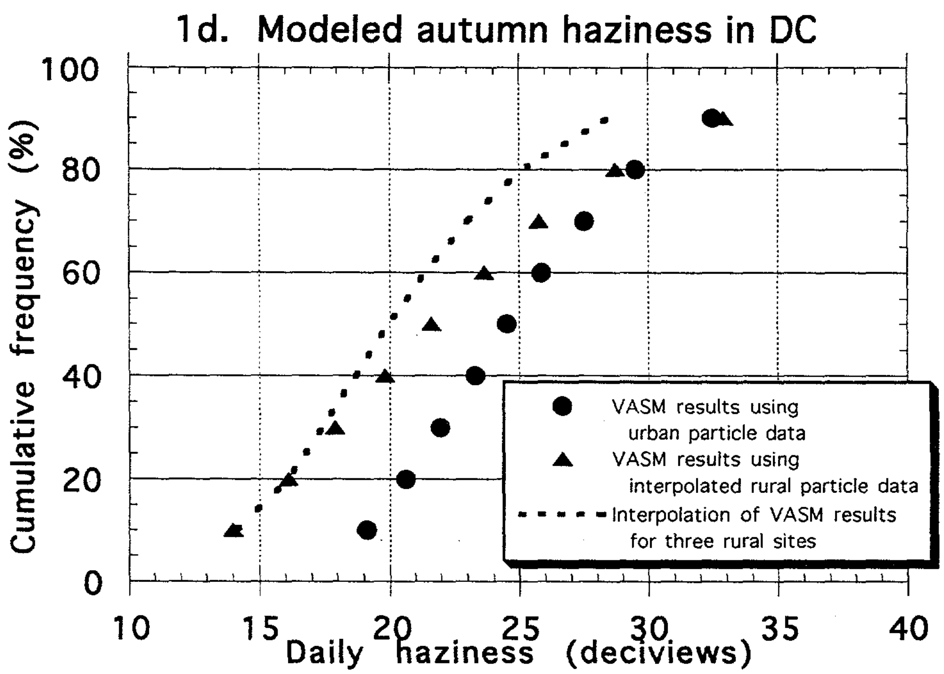


Figure1c-d: Alternate modeled summer and autumn distributions of daily haziness in Washington DC: DC particle concentration data and relative humidity used in VASM, interpolated particle concentrations (from Shenandoah, Dolly Sods, and Brigantine) and DC relative humidity used in VASM, and interpolated haziness distributions from VASM simulations for the three surrounding sites.