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SEMI-EMPIRICAL ANALYSIS OF THE POTENTIAL VISIBILITY IMPROVEMENTS FROM SO_2 EMISSION CONTROLS IN THE EASTERN UNITED STATES

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when these data are missing, estimates of the ranges of reasonable values for paramemeteorological classification. The method allows the computation of the visibility improvement in each region for each meteorological regime using an intuitive "fractional" approach that can be described by the following steps (see Zannetti et al.,[6] for a complete description of this methodology):

1. Atmospheric light extinction is due to the concentration of fine particles and other components. SO_2 emission controls will affect only part of the fraction of light extinction that is due to fine particles.

2. The fine particle aerosol is composed of sulfate-containing particles and of particles containing other species (but no sulfates). SO_2 emission controls will affect only the fraction of fine particles that contains sulfates.

3. Fine sulfur-containing particles are a fraction of the total concentration of sulfur in the atmosphere in both gaseous and particulate form. They are mostly produced by SO_2-to-SO_4^{2-} chemical transformations that appear to be nonlinear. Therefore, although SO_2 emission controls will proportionately decrease the total ambient sulfur, the fine sulfates may decrease to a lesser extent because of the nonlinear chemistry.

4. Total ambient sulfur in one geographical area is due to both local emissions and transported sulfur from other regions. SO_2 emission controls will affect only the fraction of sulfur that is of local origin or that is transported from the regions affected by the control scenario.

We have applied this methodology as an illustrative example to the eastern United States. The main results of our analysis are estimates of the visibility improvements expected from a 12-million-ton-per-year (12 MTPY) SO_2 emission reduction scenario (a reduction in emissions of about 55 percent) in the 31 eastern states. Our estimates of visibility improvements show (see Section 3) that a reduction of this size would generate improvements of visual range that, as regional annual averages over eight regions throughout the eastern United States, vary from 8 percent (6;11) to 11 percent (8;15), where the two numbers between parentheses indicate "lower" and "upper" estimates, respectively. The "medium" values of these estimates are the central estimates of our analysis, while we view the "lower" and "upper" values as the medium values plus/minus one standard deviation. Thus, we estimate that there is a 68 percent probability that the true annual average improvements will be between the lower and upper values. These numbers indicate that the relative visibility improvements are much smaller than the relative SO_2 emission reduction, with an "efficiency" (i.e., percent visual range improvement divided by percent emission reduction) that varies from 0.15 (0.11; 0.20) to 0.21 (0.15; 0.28). The reasoning used to arrive at these efficiencies will be fully explained in the following sections.

In the rest of this paper, Section 2 presents the mathematical description of our semi-empirical method, while Section 3 shows the application of the method to the eastern United States. Conclusions and recommendations are presented in Section 4.

THE SEMI-EMPIRICAL METHOD

This section describes our intuitive "fractional" approach in a quantitative, analytical form. (A more complete analytical discussion can be found in Zannetti et al.[6]) Let us assume that our impact area is divided into suitable regions, whose meteorology can be classified into meteorological regimes. Then, we can define as $(\Delta LE)_{jk}/(LE)_{jk}$ the fractional improvement (a negative number) in light extinction in a region j during a day characterized by the k-th meteorological regime, where the light extinction LE (in units of $10^{-4}m^{-1}$) is related to the visual range VR (in meters) by

$$LE = 10^4 \cdot (3.0/VR) \tag{1}$$

which assumes a constant threshold of 5%.

Then the following identity can be written, where all the increments of Δ are negative,

$$\frac{(\Delta LE)_{jk}}{(LE)_{jk}} = \overset{\text{I}}{(\Delta E/E)} \; \overset{\text{II}}{\frac{\Delta E_j/E_j}{\Delta E/E}} \; \overset{\text{III}}{\frac{(\Delta S)_{jk}/(S)_{jk}}{\Delta E_j/E_j}} \; \overset{\text{IV}}{\frac{(\Delta SO_4)_{jk}/(SO_4)_{jk}}{(\Delta S)_{jk}/(S)_{jk}}} \; \overset{\text{V}}{\frac{(\Delta F^{(w)})_{jk}/(F^{(w)})_{jk}}{(\Delta SO_4)_{jk}/(SO_4)_{jk}}} \; \overset{\text{VI}}{\frac{(\Delta LE)_{jk}/(LE)_{jk}}{(\Delta F^{(w)})_{jk}/(F^{(w)})_{jk}}} \tag{2}$$

The meaning of the six terms (I through VI) in this identity is discussed below.

Term I represents the average fractional SO_2 emission reduction throughout all the regions j. $(\Delta LE)_{jk}/(LE)_{jk}$, divided by Term I, gives the efficiency of SO_2 emissions control on light extinction; this efficiency can be applied to any control scenario.

Term II is the ratio between the local fractional SO_2 control in region j and the average for all the regions j. It reflects the fact that the degree of control could differ from one region to the next.

Term III is the ratio between the fractional improvement of total sulfur concentration, in a region j during the meteorological regime k, and the local fractional SO_2 control. This term, after some analytical manipulation is equal to

$$f^L_{jk} + f^D_{jk}\,\frac{\Delta E_{j'(jk)}/E_{j'(jk)}}{\Delta E_j/E_j} \tag{3}$$

and can be interpreted as the sum of the "local" efficiency f^L_{jk} plus the "distant" efficiency f^D_{jk} adjusted by the ratio between upwind (i.e., in region j') and local (i.e., in region j) fractional SO_2 controls. These efficiencies are simply

$$f^L_{jk} = (S)^L_{jk}/(S)_{jk} \tag{4}$$

$$f^D_{jk} = (S)^D_{jk}/(S)_{jk} = 1 - f^L_{jk} \tag{5}$$

where $(S)^L_{jk}$ and $(S)^D_{jk}$ are the local and distant contribution to $(S)_{jk}$, respectively.

We indicate the product of Terms II and III by a_{jk}, which is the "transport" efficiency of SO_2 emissions controls on total sulfur concentrations and includes all transport and deposition phenomena. Therefore,

$$\frac{(\Delta S)_{jk}}{(S)_{jk}} = a_{jk}\,\frac{\Delta E}{E} \tag{6}$$

The term a_{jk} is less than unity for regions j in which local and upwind fractional SO_2 emission controls are smaller than the average $\Delta E/E$. Vice versa, larger-than-average controls may generate values of a_{jk} greater than one.

Term IV is the ratio between the fractional improvement of the concentration of sulfate particles (including associated cations) and the fractional improvement of the concentration of the total sulfur. This term, when less than unity, allows the inclusion of the nonlinearity of the SO_2-to-SO_4^{2-} reaction. This needs to be included since recent studies (e.g., by Seigneur et al.[7]) have shown that a given fractional decrease in ambient sulfur will generate a smaller fractional decrease of sulfate. We indicate this term as β_{jk}. Therefore,

$$\frac{(\Delta SO_4)_{jk}}{(SO_4)_{jk}} = \beta_{jk}\,\frac{(\Delta S)_{jk}}{(S)_{jk}} \tag{7}$$

Term V is the ratio between the fractional improvement of the concentration of fine particles (including water) and the fractional improvement of the concentration of the sulfate particles (including associated cations but not including water). This term, which we indicate below by $\gamma_{jk}^{(w)}$, is equal to $(SO_4^{(w)})_{jk}/(F^{(w)})_{jk}$, the sulfate fraction of fine particles at ambient relative humidity. Therefore,

$$\frac{(\Delta F^{(w)})_{jk}}{(F^{(w)})_{jk}} = \gamma_{jk}^{(w)}\,\frac{(\Delta SO_4)_{jk}}{(SO_4)_{jk}} \tag{8}$$

where, after some analytical manipulation,

$$\gamma_{jk}^{(w)} = \frac{\gamma_{jk}}{\gamma_{jk} + (1-\gamma_{jk})\left[h_{ns}\left(\frac{1-(RH)_{jk}}{1-RH_o}\right)^{\beta_s-\beta_{ns}} + (1-h_{ns})\left(\frac{1-(RH)_{jk}}{1-RH_o}\right)^{\beta_s}\right]} \tag{9}$$

Here $\gamma_{jk} = (SO_4)_{jk}/(F)_{jk}$ is the sulfate fraction of fine particles as measured at the relative humidity RH_o (i.e., where most of the water is removed from the ambient sampling filters), h_{ns} is the fraction of the nonsulfate fine particles that are hygroscopic, and $(RH)_{jk}$ is the average ambient relative humidity. The exponents β_s, and β_{ns} are used[8,9,10] to estimate the actual sulfate and hygroscopic nonsulfate fine particle mass concentrations $SO_4^{(w)}$ and $NS^{(w)}$ (which include the mass of water associated with these materials), respectively, from the measurements SO_4 and NS made at relative humidity RH_o, as,

$$SO_4^{(w)} = \left(\frac{1 - RH_o}{1 - RH}\right)^{\beta_s} SO_4 \tag{10}$$

$$NS^{(w)} = \left(\frac{1 - RH_o}{1 - RH}\right)^{\beta_{ns}} NS \tag{11}$$

Term VI indicates the fraction of light extinction that is attributable to fine particles at ambient conditions, including water. We indicate this term by $\delta_{jk}^{(w)}$. Therefore,

$$\frac{(\Delta LE)_{jk}}{(LE)_{jk}} = \delta_{jk}^{(w)} \frac{(\Delta F^{(w)})_{jk}}{(F^{(w)})_{jk}} \tag{12}$$

By substituting Equations (6), (7), (8) and (12) into Equation (2), we obtain

$$\frac{(\Delta LE)_{jk}}{(LE)_{jk}} = \alpha_{jk}\,\beta_{jk}\,\gamma_{jk}^{(w)}\,\delta_{jk}^{(w)} \frac{\Delta E}{E} = \theta_{jk}^{(w)} \frac{\Delta E}{E} \tag{13}$$

where

$$\theta_{jk}^{(w)} = \alpha_{jk}\,\beta_{jk}\,\gamma_{jk}^{(w)}\,\delta_{jk}^{(w)} \tag{14}$$

The value $\theta_{jk}^{(w)}$ can be seen as the efficiency of the total SO_2 emissions control on light extinction, i.e., the percent light extinction improvement divided by the total percent emission reduction, for each region j and meteorological regime k.

The calculation of the light extinction fractional improvement $(\Delta LE)_{jk}/(LE)_{jk}$ by Equation (13) allows the calculation of the visual range fractional improvement $(\Delta VR)_{jk}/(VR)_{jk}$, which, from Equation (1), is

$$\frac{(\Delta VR)_{jk}}{(VR)_{jk}} = -\frac{1}{1 + \dfrac{(LE)_{jk}}{(\Delta LE)_{jk}}} \tag{15}$$

Consequently, in each region j, the annual average fractional improvement in visual range is

$$\left[\overline{\frac{(\Delta VR)}{(VR)}}\right]_j = \sum_{k=1}^{k_{max}} p_{jk} \frac{(\Delta VR)_{jk}}{(VR)_{jk}} \tag{16}$$

where p_{jk} is the relative frequency of occurrence of the meteorological regime k in the region j.

AN APPLICATION OF THE METHOD TO THE EASTERN UNITED STATES

To illustrate how our semi-empirical approach can be used, this section presents an example of its application to the eastern United States. (A more complete description of this application, using an earlier form of the method, can be found in Zannetti et al.[6]). In this application we chose the three-year period 1979-1981 since it was characterized by non unusual meteorological conditions and relatively steady SO_2 emissions.

Geography

In order to apply this method, the eastern United States was divided into four impact areas:

1.	Northeast (NE):	Maine, Vermont, New Hampshire, Massachusetts, Connecticut, New York, Pennsylvania, Rhode Island
2.	North Central (NC):	Illinois, Indiana, Ohio, Kentucky, West Virginia
3.	Central Coast (CC):	New Jersey, Delaware, Maryland, Virginia, North Carolina, South Carolina (with the addition of the District of Columbia)
4.	South Central (SC):	Tennessee, Mississippi, Alabama, Georgia

These four areas were further subdivided into urban and rural sections, resulting in eight regions ($j = 1, 2, \ldots, 8$). Naturally, the urban/rural differentiation does not affect α and β, since these parameters are based on the average regional meteorology, but it does affect $\gamma^{(w)}$ since the sulfate fraction of the fine particles is generally larger in rural areas[11,12,13], and $\delta^{(w)}$ since the fraction of light extinction due to fine particles is generally lower in urban areas, where urban activities generate a relatively higher concentration of coarse particles.

Meteorology

We analyzed the daily weather maps for each day during the three-year period 1979-1981 and classified the air mass for each region and each day, according to the meteorological classification scheme described below. All days with midday relative humidity $\geq$85 percent were placed in one class ($k = 8$) that reflected times in which meteorology was likely to play a major role in visibility impairment through precipitation or fog. For RH < 85 percent, air mass transport classes ($k = 1, 2, \ldots, 7$) were defined[14] as

- k = 1: cPk, continental polar colder
- k = 2: cPw, continental polar warmed
- k = 3: mT, maritime tropical
- k = 4: Tr, transitional
- k = 5: cT, continental tropical
- k = 6: cP2, standardized continental high pressure zone
- k = 7: mP, maritime polar

The Calculation of Regional Averages

The visibility and aerosol data that we collected represent point estimates at specific locations. To use these data in our methodology, we calculated regional averages of visual range and aerosol concentrations. This was accomplished by selecting, in each of the eight regions, three airport locations (for visual range and relative humidity observations) and several aerosol monitoring locations. Regional averages were then computed by averaging the available data during each day in each region. Days with large variation among the selected stations (i.e., measurements whose range of variation was larger than their average) were eliminated, in order to filter out those few cases with large, unrepresentative spatial variations.

The Estimates of a_{jk} and Their Uncertainty

As discussed in Section 2, a_{jk} is the product of Terms II and III in Equation (2). Term II, the area-specific fractional emission reduction, was evaluated using emissions given in Table 2-5(e) of the SAI report,[4] which provides a 13.1 MTPY SO_2 control covering the eastern and midcontinent states. We adjusted these numbers proportionally downward to reflect a 12 MTPY SO_2 control.

Term III in Equation (2) is the sum of the local efficiency plus the adjusted distant efficiency, as given by Equation (3). We evaluated this term by assuming $f^L_{jk} = f^D_{jk} = 0.5$, i.e., that total sulfur concentrations are due 50 percent to local SO_2 sources (i.e., in the same region j) and 50 percent to distant upwind sources. This assumption is not unreasonable, based on previous studies (see for example the Congressional Report[15]), but it is a major simplification of the complex phenomena related to transport, diffusion and deposition of atmospheric sulfur.

In order to calculate $\Delta E_{j'}/E_{j'}$, we identified the upwind region (or regions)j'(jk) for each region j and meteorological regime k. For upwind regions j' outside the emission control area (i.e., outside the regions j = 1, 2, . . ., 8), we assumed a fixed value $\Delta E_{j'}/E_{j'} = -0.05$ for air masses coming from Canada and the Atlantic Ocean, to represent the effect of decreased background concentrations as a consequence of the emission reduction, and $\Delta E_{j'}/E_{j'} = -0.27$ for air masses coming from midcontinent states, which are affected by the emission reduction scenario, but have not been explicitly included in the regional classification (j = 1, 2, . . ., 8). The former value (−0.05) is our upper bound estimate of recirculation effects, while the latter value (−0.27) was taken from the SAI report.[4]

Based on all the above assumptions, we obtained an evaluation of a_{jk}, which is presented in Table I. We believe that the uncertainty in this evaluation is high, due to uncertainty in the emission data and, especially, the air mass trajectories. Therefore, our estimate of the standard deviation of the error in estimating a_{jk} is one fifth of the interval between the maximum (1.11) and the minimum (0.41) a_{jk} values in Table I.

The Estimates of β_{jk} and Their Uncertainty

As discussed in Section 2, β_{jk} is Term IV in Equation (2) and represents the nonlinearity of the SO_2-to-SO_4^{2-} reaction as described in Equation (7).

We applied the results by Seigneur et al.[5] to estimate β_{jk} based on estimates of the cloudiness of each air mass k in region j. Relatively cloud-free skies were associated with $\beta_{jk} = 1$ ("linear" chemistry), medium cloudiness with $\beta_{jk} = 0.85$, and extensive cloudiness with $\beta_{jk} = 0.70$. (Intermediate values were assigned to the Tr and cT air mass classes.) The estimated values of β_{jk} are presented in Table II.

This evaluation is based on subjective interpretations of a theoretical modeling analysis and, consequently, our evaluation of the standard deviation of the error in estimating β_{jk} is, again, one fifth of the interval between maximum (1.0) and the minimum (0.7) values in Table II.

The Estimates of $\gamma_{jk}^{(w)}$ and Their Uncertainty

As discussed in Section 2, γ_{jk} is Term V in Equation (2), i.e., the sulfate fraction (including the cation) of fine particles (including water), as described by Equation (8). This means that measured anion SO_4^{2-} concentrations need to be multiplied by a factor λ, i.e.,

$$SO_4 = \lambda SO_4^{2-} \tag{17}$$

in order to give the total sulfate mass concentration. In this study, we chose λ = 1.25, which represents a mixture of primarily NH_4HSO_4 and some $(NH_4)_2SO_4$.

We computed $\gamma_{jk}^{(w)}$ using Equation (9), under the assumptions h_{ns} = 0.5, β_s = 1, β_{ns} = 1, and RH_o = 0.4. Using the data from the EPA Inhalable Particulate Monitoring Network, the γ_{jk} values were extracted from the few days in our data base with fine sulfate measurements, which provided the γ/λ values presented in Table III. Table IV shows the final values of $\gamma_{jk}^{(w)}$ produced by the above calculation.

The above data, computed from a limited data base, seem to be about 10 percent lower than the literature data, which were collected mostly during episodic conditions. This fact, among other considerations, allows us to conclude that, using the data in Table IV for $\gamma_{jk}^{(w)}$, a skewed distribution can be assumed for the error, such that

$$\sigma_{\gamma_{jk}}^{-} = 0.1\ \gamma_{jk}^{(w)} \tag{18}$$

and

$$\sigma_{\gamma_{jk}}^{+} = 0.2\ \gamma_{jk}^{(w)} \tag{19}$$

The Estimates of δ_{jk} and Their Uncertainty

The coefficients $\delta_{jk}^{(w)}$, which represent the fraction of light extinction due to fine particles (including water), were computed using the regression coefficients of the linear regression between the values $(LE)_{jk}^{(d)}$ and $(F)_{jk}^{(d)}/(1-(RH)_{jk}^{(d)})$. The superscript d (d = 1, 2, . . ., N_{jk}) indicates a day in which the air mass transport class k occurs in region j. The computed $\delta_{jk}^{(w)}$ values are presented in Table V. Because of the lack of a solid data base for the estimate of $\delta_{jk}^{(w)}$ and the somewhat unclear results that were obtained from our regression analysis, we estimated the standard deviation of the error in $\delta_{jk}^{(w)}$ to be quite high, at about 0.1.

Results

From the above estimates of α, β, $\gamma^{(w)}$, and $\delta^{(w)}$, we calculated, using Equation (14), the "efficiencies" $\theta_{jk}^{(w)}$ and, using the above error analysis, their standard errors $\sigma_{\theta_{jk}}^{-}$ and $\sigma_{\theta_{jk}}^{+}$, below and above the average, respectively. These standard errors allow the calculation of the lower bound θ_{jk}^{-} and upper bound θ_{jk}^{+}. These "medium," "low," and "high" estimates of $\theta_{jk}^{(w)}$, that are presented in Table VI, allow the calculation of the corresponding "medium," "low," and "high" visual range improvements, using Equations (13) and (16).

The estimated average regional improvements of visual range, as described by Equation (16), are presented in Table VII. (Improvements were multiplied by 100 in order to show percentage values.) Finally, Table VIII shows the corresponding "efficiency" of the SO_2 emission reduction with respect to visual range improvement, i.e., the percent improvements in Table VII divided by the average percent emission reduction (55 percent). These efficiencies, whose medium values vary from 0.15 to 0.21, can be used to calculate the visibility improvements of SO_2 control scenarios different from the one (12 MTPY, 55 percent) used in this study.

CONCLUSIONS AND RECOMMENDATIONS

Our semi-empirical approach provides a straightforward methodology for the assessment of the visibility improvements from SO_2 emission controls. Its application to the eastern United States shows that while short-term "episodic" efficiencies may sometimes be high, the regional annual efficiency of SO_2 controls on visibility impairment seems to be much less than 1.

Based on the investigations that we performed during this project and the results presented in the previous sections, we are able to formulate a series of research recommendations that aim at a better understanding of the effects of alternative pollution control scenarios on visibility in the eastern United States. Our specific recommendations are the following:

1. Use of other regional models for comparison and investigation, especially for a "modeling" evaluation of a_{jk}.
2. Research (field, laboratory, and theoretical) on the nonlinearity of the SO_2-to-SO_4^{2-} transformation (i.e., evaluation of β_{jk}).
3. Field experiments to provide more reliable data bases for assessing the actual role of sulfates and other pollutants on visibility impairment in the eastern United States, as a function of the different meteorological regimes (i.e., evaluation of $\gamma_{jk}^{(w)}$ and $\delta_{jk}^{(w)}$).
4. Use of a panel of scientists for expert judgment evaluation of the parameters α, β, $\gamma^{(w)}$, and $\delta^{(w)}$ used in our methodology, especially in the absence of complete data.

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ADDITIONAL NOTE

One of the reviewers of this paper suggested alternative values for the parameters α, γ and δ. Although there was no time to fully evaluate the reviewer's comments and rerun the simulations under different assumptions, we emphasize that our illustrative calculations are based on one perception of available data. As the discussion shows, in many cases we had to make assumptions based on inferences from limited information; and there is room for differences of opinion concerning these inferences. In our analysis, we have tried to reflect the full range of possible annual average values for the parameters, and feel that all reasonably possible values will lie within the ranges we have presented. Nevertheless, to fully exploit the potential of this method, we encourage alternative evaluations of the parameters using models, data analysis, laboratory experiments and expert judgement evaluation by a panel of scientists.

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Table I. Evaluation of α_{jk}.

j	Region	k = 1 cPk	k = 2 cPw	k = 3 mT	k = 4 Tr	k = 5 cT	k = 6 cP2	k = 7 mP
1 and 2	NE	0.69	0.83	0.97	0.72	1.04	0.83	0.50
3 and 4	NC	0.78	0.77	0.95	0.84	0.84	1.11	1.04
5 and 6	CC	0.91	0.91	0.41	0.89	0.89	0.76	0.41
7 and 8	SC	0.84	0.86	0.52	0.89	0.72	0.95	0.84

Table II. Evaluation of β_{jk}.

	k = 1 cPk	k = 2 cPw	k = 3 mT	k = 4 Tr	k = 5 cT	k = 6 cP2	k = 7 mP
Any Region j	0.85	0.85	0.70	0.75	0.80	1.00	0.70

Table III. Values of γ/λ extracted from available data

j	Region	Maritime	Continental
1	NE Urban	0.33	0.28
2	NE Rural	0.37	0.30
3	NC Urban	0.34	0.27
4	NC Rural	0.35	0.27
5	CC Urban	0.31	0.34
6	CC Rural	0.35	0.35
7	SC Urban	0.28	0.29
8	SC Rural	0.35	0.30

Table IV. Evaluation of $\gamma_{jk}^{(w)}$

j	Region	k = 1 cPk	k = 2 cPw	k = 3 mT	k = 4 Tr	k = 5 cT	k = 6 cP2	k = 7 mP
1	NE urban	0.35	0.37	0.43	0.42	0.36	0.38	0.44
2	NE rural	0.38	0.38	0.49	0.43	0.41	0.38	0.50
3	NC urban	0.37	0.36	0.44	0.40	0.37	0.34	0.49
4	NC rural	0.37	0.36	0.46	0.42	0.37	0.34	0.51
5	CC urban	0.42	0.42	0.43	0.45	0.43	0.42	0.42
6	CC rural	0.44	0.45	0.46	0.49	0.47	0.44	0.49
7	SC urban	0.37	0.37	0.37	0.38	0.39	0.37	0.36
8	SC rural	0.37	0.39	0.46	0.42	0.39	0.37	0.45

Table V. Evaluation of $\delta_{jk}^{(w)}$.

j	Region	k = 1 cPk	k = 2 cPw	k = 3 mT	k = 4 Tr	k = 5 cT	k = 6 cP2	k = 7 mP
1	NE urban	0.60	0.62	0.75	0.61	0.60	0.75	0.75
2	NE rural	0.70	0.70	0.75	0.70	0.70	0.75	0.75
3	NC urban	0.73	0.65	0.85	0.62	0.73	0.60	0.92
4	NC rural	0.73	0.70	0.85	0.70	0.73	0.70	0.92
5	CC urban	0.60	0.60	0.67	0.61	0.60	0.60	0.60
6	CC rural	0.70	0.84	0.89	0.70	0.70	0.70	0.70
7	SC urban	0.67	0.61	0.85	0.90	0.60	0.60	0.92
8	SC rural	0.70	0.94	0.85	0.90	0.70	0.70	0.92

Table VI. Evaluation of $\theta_{jk}^{(w)}$.

j	Region	k = 1 cPk	k = 2 cPw	k = 3 mT	k = 4 Tr	k = 5 cT	k = 6 cP2	k = 7 mP
Medium								
1	NE urban	0.12	0.16	0.22	0.14	0.18	0.24	0.11
2	NE rural	0.16	0.19	0.25	0.16	0.24	0.24	0.13
3	NC urban	0.18	0.15	0.25	0.16	0.18	0.23	0.33
4	NC rural	0.18	0.16	0.26	0.18	0.18	0.27	0.34
5	CC urban	0.19	0.19	0.08	0.19	0.18	0.19	0.07
6	CC rural	0.24	0.29	0.12	0.23	0.23	0.24	0.10
7	SC urban	0.18	0.17	0.12	0.23	0.14	0.21	0.19
8	SC rural	0.19	0.27	0.14	0.25	0.16	0.25	0.24
Low (-1σ)								
1	NE urban	0.09	0.13	0.18	0.11	0.15	0.18	0.08
2	NE rural	0.12	0.15	0.21	0.12	0.20	0.19	0.09
3	NC urban	0.14	0.12	0.20	0.13	0.14	0.19	0.26
4	NC rural	0.14	0.13	0.21	0.15	0.14	0.22	0.27
5	CC urban	0.16	0.16	0.05	0.15	0.15	0.15	0.05
6	CC rural	0.19	0.23	0.07	0.18	0.19	0.18	0.06
7	SC urban	0.14	0.13	0.08	0.18	0.11	0.17	0.15
8	SC rural	0.15	0.21	0.10	0.20	0.12	0.20	0.19
High ($+1\sigma$)								
1	NE urban	0.17	0.21	0.29	0.19	0.23	0.30	0.16
2	NE rural	0.21	0.25	0.32	0.21	0.31	0.31	0.18
3	NC urban	0.23	0.20	0.32	0.21	0.23	0.29	0.41
4	NC rural	0.23	0.21	0.33	0.24	0.23	0.34	0.43
5	CC urban	0.26	0.26	0.12	0.24	0.24	0.25	0.10
6	CC rural	0.31	0.37	0.17	0.30	0.30	0.31	0.14
7	SC urban	0.23	0.22	0.16	0.29	0.18	0.28	0.25
8	SC rural	0.24	0.34	0.19	0.32	0.21	0.32	0.31

Table VII. Average regional improvements (in percent) in visual range.

j	Region	medium	$\left[\frac{(\Delta VR)}{(VR)}\right]_j \times 100$ low (-1σ)	high ($+1\sigma$)
1	NE urban	8	6	11
2	NE rural	10	8	14
3	NC urban	10	8	14
4	NC rural	11	9	15
5	CC urban	8	6	11
6	CC rural	11	8	15
7	SC urban	9	7	12
8	SC rural	11	8	15

Table VIII. Efficiency of the SO_2 emission reduction on visual range improvement.

j	Region	medium	low (-1σ)	high ($+1\sigma$)
1	NE urban	0.15	0.12	0.21
2	NE rural	0.18	0.14	0.25
3	NC urban	0.19	0.14	0.26
4	NC rural	0.20	0.16	0.27
5	CC urban	0.15	0.11	0.20
6	CC rural	0.20	0.14	0.27
7	SC urban	0.16	0.12	0.22
8	SC rural	0.21	0.15	0.28