CHAPTER 5

SPATIAL DISTRIBUTIONS OF RECONSTRUCTED LIGHT EXTINCTION AND LIGHT EXTINCTION BUDGETS

In the previous chapter, a model for reconstructing light extinction was presented. In this chapter, this model is used to derive the reconstructed light extinction coefficient for the 43 sites examined here. In addition, the relative contribution of various aerosol components to total light extinction are combined into a light extinction budget.

5.1 Reconstructing Light Extinction from Aerosol Measurements

To review the discussion presented in Chapter 4, the light extinction coefficient is the sum of several components:

$$b_{ext} = b_{scat} + b_{abs} = b_{Ray} + b_{sp} + b_{ag} + b_{ap} \qquad (5.1)$$

where b_{ext} = light extinction coefficient,
b_{scat} = light scattering coefficient,
b_{abs} = light absorption coefficient,
b_{Ray} = Rayleigh light scattering coefficient,
b_{sp} = light scattering coefficient due to particles,
b_{ag} = light absorption coefficient due to gases, and
b_{ap} = light absorption coefficient due to particles.

The Rayleigh scattering coefficient (b_{Ray}) is the light scattered by molecules of gas in the natural atmosphere (i.e., oxygen and nitrogen, primarily). The Rayleigh scattering coefficient will vary with atmospheric pressure. For this report, we assume the Rayleigh scattering coefficient is 10 Mm^{-1} (inverse megameters) at all sites.

In most instances, b_{sp} and b_{ap} are primarily responsible for visibility reduction. The light absorption coefficient due to gases (b_{ag}) is dominated in the atmosphere by the effect of nitrogen dioxide (NO_2) gas. For this report, we assume this component is negligible, however, this assumption may not be correct at locations close to significant NO_x emission sources (e.g., urban areas or power plants).

The approach used here to estimate scattering assumes externally mixed aerosols. The light scattering coefficient can then be calculated (or reconstructed) from aerosol concentrations by taking Equation (5.1) and describing the light scattering contributed by aerosol component (*i*) as the product of the aerosol component's concentration (C_i) and its light scattering efficiency (b_i). Thus, the total light scattering coefficient is simply the sum of the light extinctions of each aerosol component:

$$b_{ext} = b_{Ray} + \sum \beta_i C_i \qquad (5.2)$$

Equation (5.2) can be cast into the following form for the aerosol components measured as part of the IMPROVE program:

$$\begin{aligned} b_{ext} &= b_{Ray} + \beta_{sulfate}[SULFATE] + \beta_{NITRATE}[NITRATE] + \beta_{OC}[OCM] \\ &+ \beta_{SOIL}[SOIL] + \beta_{CM}[CM] + b_{abs} \end{aligned} \qquad (5.3)$$

where b_{ext} is the total light extinction coefficient (in Mm^{-1}), b_{Ray} is the Rayleigh scattering coefficient (10 Mm^{-1}), the â's are the light extinction coefficients for each component (in m^2/g), and the parameters in brackets ([ ]) are the concentrations of the aerosol components (in ìg/m^3). To complete the equation for estimating extinction the channel A determination of absorption, b_{abs}, is used.

The values of light scattering efficiency (in m^2/g) used in this report are as follows:

Sulfates and Nitrates	3 $f_T(RH)$
Organic Carbon	4
Fine Soil	1
Coarse Particles	0.6

In this report, we assume that coarse particles and fine soil particles are from a single natural source, wind-blown dust. Thus, the scattering calculated for these two components is combined into a single category and is reported as coarse scattering.

The function $f_T(RH)$ is a correction factor to account for the liquid water that may be part of the hygroscopic aerosol components. These functions are dependent on the relative humidity (RH) at the given site. In this report, light extinction, due to a soluble species at site *s*, is derived using hourly RH values less than or equal to 98% and the equation is

$$b_{ext,s} = \beta F_{T,s} \bar{c} \qquad (5.4)$$

where

$$F_{T,s} = \overline{f_T\left(RH_s\right)} \qquad (5.5)$$

Using Equation (5.3), extinction budgets for a time interval may be calculated by replacing $f_T(RH_s)$ with $F_{T,s}$ and by using the average concentration of each species over the same time interval as the mass concentration.

Using the data for the collocated sites, a polynomial curve was fitted to the annual and seasonal data as defined by

$$F = b_0 + b_2\left(100/\left(100-\overline{RH}\right)\right)^2 + b_3\left(100/\left(100-\overline{RH}\right)\right)^3 + b_4\left(100/\left(100-\overline{RH}\right)\right)^4 \qquad (5.6)$$

Table 5.1 shows the results of the regressions for Tang's weighted correction factors. For those sites without collocated optical and RH data the annual and seasonal factors can be calculated. In this fashion, all 43 sites are treated the same enabling the same spatial coverage used for aerosol mass concentrations.

Table 5.1 Parameters of the best-fit quadratic equation relating the relative humidity light extinction correction factors (F_T) to average site relative humidity ($F = b_o + b_2(1/(1-rh))^2 + b_3(1/(1-rh))^3 + b_4(1/(1-rh))^4$).

Season	Intercept	T2	T3	T4	r^2
Spring	0.76	0.31	-0.004	-0.004	0.95
Summer	0.51	0.47	-0.081	0.004	0.95
Autumn	-0.03	0.83	-0.196	0.014	0.93
Winter	1.19	0.29	-0.033	0.001	0.87
ANNUAL	0.52	0.53	-0.095	0.006	0.94

5.2 Reconstructed Light Extinction and Light Extinction Budgets

Spatial patterns in the reconstructed light extinction are similar to those observed for aerosols since reconstructed light extinction is calculated from aerosol concentrations. However, since light scattering efficiencies of sulfates and nitrates are larger than other fine aerosols because of associated water, and since light-absorbing carbon has a relatively high extinction efficiency, the extinction budgets are somewhat different from fine aerosol budgets.

Figure 5.1 shows isopleths of the total reconstructed light extinction coefficient (including Rayleigh) for the entire three-year period, March 1992 through February 1995. The highest light extinction (>100 Mm^{-1}) occurs in the eastern United States; the highest extinction for a rural site occurs at Sipsey Wilderness Area in northern Alabama at 157 Mm^{-1} followed by Mammoth Cave National Park at 148 Mm^{-1} then Dolly Sods Wilderness Area at 145 Mm^{-1}. The highest extinction of 183 Mm^{-1} is reported at Washington D.C., an urban site. The lowest extinction (<30 Mm^{-1}) generally occurs in the intermountain west in the Great Basin and Colorado Plateau regions. The lowest extinction for the lower 48 states is at Bridger Wilderness Area at 26 Mm^{-1}. The lowest extinction for the entire United States is at Denali National Park in Alaska with an annual extinction of 23 Mm^{-1}. Jarbidge Wilderness Area and Great Basin National Park have an annual extinction of 28 Mm^{-1} and 27 Mm^{-1}, respectively.

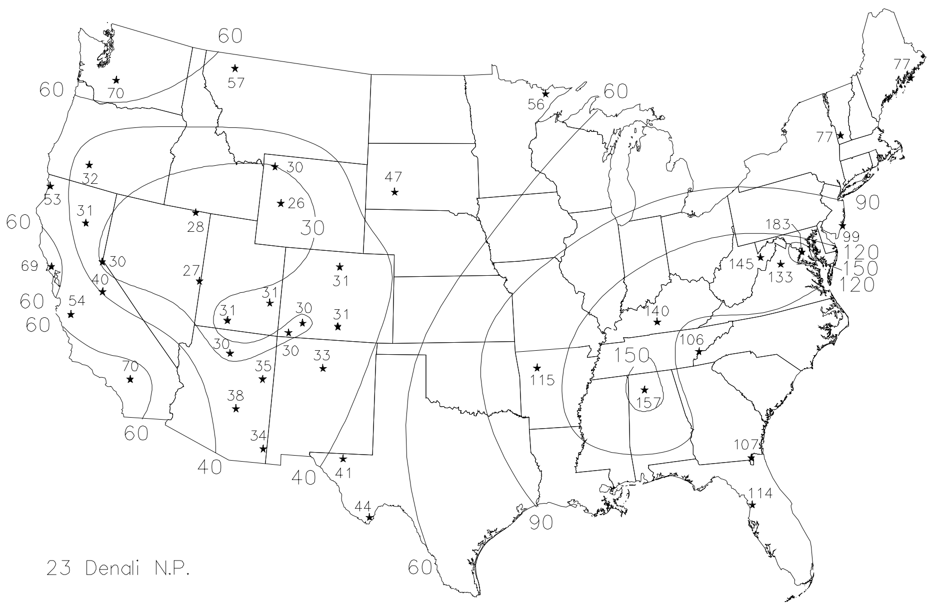

Figure 5.1 Three-year averages of total reconstructed light extinction coefficient (Mm^{-1}) for each of the reported sites in the IMPROVE network in the United States.

5.2.1 Characteristics of the Regions

Tables 5.2, 5.3, and 5.4 summarize the seasonal and annual averages of the reconstructed light extinction coefficients for each of the 21 regions in the United States, averaged over three years of the IMPROVE monitoring program, March 1992 through February 1995.

Table 5.2 shows the breakdown of extinction among fine and coarse particle scattering and light absorption. In addition, this table shows the percentage of total light extinction (including Rayleigh) that is caused by aerosol light extinction (both scattering and absorption). Also, the average relative humidity for each region is reported. Table 5.3 shows the aerosol light extinction as well as the contributions of sulfate, nitrate, organic carbon, light absorption, and coarse particles (including fine soil). Table 5.4 shows the aerosol light extinction budgets: the fractions (percent) of total aerosol (non-Rayleigh) light extinction contributed by sulfate, nitrate, organic carbon, light absorption, and coarse particles (including fine soil).

The characteristics of each region, in alphabetic order, are briefly discussed.

<u>Alaska.</u> The Alaska region consists only of the measurements at Denali National Park. The three-year annual average extinction is 23.2 Mm^{-1}, of which aerosol extinction constituted 57%. The seasonal variation is small and varies from a low of 20.9 Mm^{-1} in the autumn to a high of 26 Mm^{-1} in the summer. However, the extinction attributable to nitrate and organics show significant seasonal variation. Nitrate extinction ranges from a low of 0.4 Mm^{-1} in the summer to a high of 0.8 Mm^{-1} in the winter. Organics extinction, on the other hand, is highest in the summer at 6.4 Mm^{-1} and lowest in the winter at 2.8 Mm^{-1}. Sulfate is the largest contributor to aerosol extinction at an annual average of 37% and ranges from a seasonal high in the winter of 42.8% to a summer low of 24%. The next largest contributor is organics at a seasonal average of 29% ranges from a summer high of 40.1% to a winter low of 23%. The remaining contributors on an annual basis in order of importance are absorption at 17.8%, soil and coarse particles at 12%, and nitrate at 4.3%.

<u>Appalachian Mountains.</u> This region consists of three sites, Dolly Sods Wilderness Area in the Monongahela National Forest, Shenandoah National Park, and Great Smoky Mountains National Park. With an annual extinction of 128 Mm^{-1} this region is typical of many eastern rural venues. The seasonal variation of extinction is about a factor of 2, ranging from 88 Mm^{-1} in the winter to 181 Mm^{-1} during summer. The seasonal variation is almost entirely due to sulfate extinction, which varies by a factor of 3 from 44 Mm^{-1} in the winter to 129 Mm^{-1} in the summer. Similarly, extinction due to organics, which averages 11.7 Mm^{-1} annually, varies from a winter low of 9.2 Mm^{-1} to 14.7 Mm^{-1} during the summer. Nitrates show a significant variation that is opposed to the variation displayed by sulfates and organics. Nitrate extinction is lowest in the summer at 3.8 Mm^{-1} and in the winter it is 12.1 Mm^{-1}. The seasonal variation of sulfates, organics, and nitrates are driven by seasonal changes in meteorology and photochemistry. For sulfates and organics this leads to higher concentrations during the summer. This coupled with the fact that RH is highest in the summer leads to high extinction efficiencies for sulfate aerosols. Nitrates, on the other hand, are quite volatile. The lower temperatures during the winter lead to higher concentrations of nitrates. Sulfate extinction comprises the largest fraction of aerosol extinction accounting for 68% annually and varies from a high during the summer of 75.7% down to 56.2% in the winter. The next highest contributor on an annual basis is absorption (12.4%), followed by organics (9.9%), nitrates (6.4%), and soil and coarse particles (3.1%).

<u>Boundary Waters.</u> This region, in northern Minnesota, is represented by the Boundary Waters Canoe Area in the Superior National Forest. Annual average extinction here is about 56 Mm^{-1} of which 82% is due to the ambient aerosol. The seasonal variation is slight, and ranges from a high in the winter of 61.3 Mm^{-1} to as low as 52.7 Mm^{-1} in the spring. Sulfate contributes the most to extinction at 50.9% annually and ranges between 44.1% for the winter and up to 54.8% in the spring. Annually, the next largest contributor is organics (16.4%) followed by nitrate (14.5%), absorption (13.4%), and soil and coarse particles (4.8%).

Table 5.2 Seasonal and annual averages of reconstructed total light extinction coefficient (Mm^{-1}) for the 21 regions in the IMPROVE network. Also shown are the light scattering coefficients resulting from fine and coarse aerosols, light absorptions for carbonaceous aerosol, percentage of total extinction resulting from aerosols, and the average region relative humidity.

Season	Total Extinction	Fine Scattering	Coarse Scattering	Absorption	Percent Aerosol	Relative Humidity
Alaska						
Spring	23.4	8.9	2.0	2.5	57	56
Summer	26.0	10.6	1.9	3.5	62	64
Autumn	20.9	7.9	1.3	1.7	52	72
Winter	21.2	8.3	1.1	1.7	53	68
ANNUAL	23.2	9.3	1.6	2.4	57	65
Appalachian						
Spring	107.8	79.2	3.8	14.8	91	67
Summer	180.7	147.6	4.9	18.1	94	76
Autumn	124.9	97.6	2.9	14.5	92	74
Winter	88.3	65.4	2.2	10.8	89	74
ANNUAL	128.0	100.0	3.4	14.6	92	73
Boundary Waters						
Spring	52.7	33.6	2.5	6.7	81	62
Summer	54.0	34.9	2.5	6.6	81	76
Autumn	53.3	35.7	2.0	5.5	81	79
Winter	61.3	43.7	1.8	5.9	84	77
ANNUAL	56.0	37.6	2.2	6.2	82	74
Cascade Mountains						
Spring	70.4	48.1	2.8	9.6	86	82
Summer	87.4	65.0	2.5	10.0	89	83
Autumn	69.6	47.0	2.5	10.1	86	86
Winter	45.3	27.1	1.6	6.5	78	91
ANNUAL	70.5	49.1	2.3	9.0	86	86
Central Rocky Mountains						
Spring	33.9	15.8	3.9	4.3	71	65
Summer	34.0	13.7	4.3	6.1	71	49
Autumn	29.5	12.3	2.9	4.4	66	55
Winter	22.9	8.6	1.9	2.4	56	58
ANNUAL	29.8	12.2	3.2	4.3	66	57

Table 5.2 Continued

Season	Total Extinction	Fine Scattering	Coarse Scattering	Absorption	Percent Aerosol	Relative Humidity
Colorado Plateau						
Spring	30.9	12.7	3.4	4.8	68	48
Summer	33.6	13.8	3.9	5.9	70	44
Autumn	31.6	13.5	2.8	5.3	68	48
Winter	29.3	13.5	2.0	3.8	66	61
ANNUAL	31.4	13.4	3.0	4.9	68	50
Florida						
Spring	115.3	85.5	4.7	15.2	91	70
Summer	112.1	78.8	9.1	14.1	91	75
Autumn	104.5	77.5	4.2	12.7	90	77
Winter	102.0	72.0	4.0	16.0	90	75
ANNUAL	110.6	80.5	5.5	14.6	91	74
Great Basin						
Spring	28.3	9.8	4.2	4.2	65	50
Summer	32.1	10.9	5.6	5.5	69	34
Autumn	27.9	10.3	3.4	4.2	64	49
Winter	23.7	9.3	1.8	2.7	58	64
ANNUAL	27.9	10.1	3.7	4.1	64	49
Lake Tahoe						
Spring	45.1	17.2	5.2	12.8	78	53
Summer	42.6	15.9	4.1	12.6	77	42
Autumn	52.6	21.1	3.8	17.7	81	48
Winter	62.0	25.2	6.1	20.7	84	57
ANNUAL	50.3	19.7	4.7	15.8	80	50
Mid Atlantic						
Spring	92.5	61.6	6.5	14.3	89	72
Summer	128.2	93.0	7.7	17.6	92	76
Autumn	88.5	55.8	5.6	17.1	89	68
Winter	90.2	57.0	4.6	18.6	89	66
ANNUAL	98.8	66.0	5.9	16.9	90	71
Mid South						
Spring	123.8	92.2	3.7	17.9	92	68
Summer	163.9	128.1	7.5	18.2	94	78
Autumn	126.5	97.1	3.8	15.7	92	74
Winter	127.0	98.0	3.0	16.0	92	77
ANNUAL	137.0	105.6	4.5	17.0	93	74

Table 5.2 Continued

Season	Total Extinction	Fine Scattering	Coarse Scattering	Absorption	Percent Aerosol	Relative Humidity
Northeast						
Spring	61.7	41.3	2.9	7.4	84	69
Summer	102.7	80.0	3.0	9.7	90	79
Autumn	79.7	58.9	2.6	8.2	87	79
Winter	65.8	45.0	2.6	8.2	85	74
ANNUAL	77.3	56.1	2.7	8.4	87	75
Northern Great Plains						
Spring	49.9	29.3	4.1	6.6	80	64
Summer	44.2	24.0	3.8	6.3	77	63
Autumn	41.5	21.8	3.9	5.8	76	62
Winter	52.1	34.5	2.1	5.5	81	72
ANNUAL	46.6	27.1	3.5	6.1	79	65
Northern Rocky Mountains						
Spring	48.2	26.4	3.6	8.2	79	77
Summer	49.0	25.1	5.7	8.2	80	71
Autumn	67.6	39.7	4.9	13.1	85	80
Winter	67.0	46.1	1.9	8.9	85	86
ANNUAL	57.2	33.6	4.0	9.6	83	79
Pacific Coast						
Spring	55.4	33.6	5.9	5.8	82	73
Summer	55.5	34.5	5.6	5.4	82	72
Autumn	62.8	39.3	5.3	8.2	84	71
Winter	56.5	36.4	3.7	6.5	82	75
ANNUAL	58.4	36.8	5.2	6.4	83	73
Sierra-Humboldt						
Spring	32.9	15.3	2.9	4.6	70	67
Summer	37.6	18.1	3.0	6.4	73	71
Autumn	31.0	13.5	2.3	5.2	68	55
Winter	24.2	9.6	1.2	3.5	59	66
ANNUAL	31.6	14.2	2.4	5.0	68	65
Sierra Nevada						
Spring	44.8	23.8	3.9	7.0	78	63
Summer	48.9	23.9	4.4	10.6	80	44
Autumn	39.7	18.6	3.6	7.4	75	45
Winter	23.7	9.6	2.1	2.1	58	56
ANNUAL	40.0	19.8	3.5	6.7	75	52

Table 5.2 Continued

Season	Total Extinction	Fine Scattering	Coarse Scattering	Absorption	Percent Aerosol	Relative Humidity
Sonoran Desert						
Spring	35.9	14.0	5.0	6.9	72	37
Summer	39.8	17.6	4.9	7.2	75	43
Autumn	35.5	15.7	3.4	6.4	72	45
Winter	32.5	14.9	2.7	4.9	69	56
ANNUAL	36.2	15.8	4.0	6.4	72	45
Southern California						
Spring	102.3	73.6	6.2	12.5	90	55
Summer	80.3	47.9	7.4	15.0	88	45
Autumn	54.6	27.5	8.2	8.9	82	41
Winter	35.6	19.8	1.9	3.9	72	51
ANNUAL	69.7	43.8	5.8	10.2	86	48
Washington D.C.						
Spring	155.1	102.8	5.5	36.8	94	62
Summer	216.6	160.7	5.4	40.4	95	68
Autumn	188.8	131.6	5.3	41.8	95	68
Winter	161.1	101.9	5.5	43.7	94	62
ANNUAL	182.5	126.5	5.4	40.6	95	65
West Texas						
Spring	41.0	18.1	5.6	7.3	76	41
Summer	51.2	26.3	6.7	8.2	80	54
Autumn	39.7	19.2	4.8	5.7	75	53
Winter	37.1	18.3	3.7	5.1	73	53
ANNUAL	42.3	20.5	5.2	6.6	76	50

Table 5.3 Seasonal and annual averages of reconstructed aerosol light extinction coefficient (Mm^{-1}) for the 21 regions in the IMPROVE network. Also shown are the light extinction coefficients (Mm^{-1}) resulting from sulfate, nitrate, organic carbon, light absorption, and coarse particles/fine soil.

Season	Aerosol Extinction	Sulfate	Nitrate	Organics	Absorption	Soil and Coarse
Alaska						
Spring	13.4	5.3	0.5	3.1	2.5	2.0
Summer	16.0	3.8	0.4	6.4	3.5	1.9
Autumn	10.9	4.5	0.5	2.9	1.7	1.3
Winter	11.2	4.8	0.8	2.8	1.7	1.1
ANNUAL	13.2	4.9	0.6	3.8	2.4	1.6
Appalachian						
Spring	97.8	60.6	7.9	10.7	14.8	3.8
Summer	170.7	129.1	3.8	14.7	18.1	4.9
Autumn	114.9	78.5	6.9	12.1	14.5	2.9
Winter	78.3	44.0	12.1	9.2	10.8	2.2
ANNUAL	118.0	80.7	7.6	11.7	14.6	3.4
Boundary Waters						
Spring	42.7	23.4	4.1	6.1	6.7	2.5
Summer	44.0	22.5	1.4	11.1	6.6	2.5
Autumn	43.3	22.7	6.4	6.7	5.5	2.0
Winter	51.3	22.6	15.1	5.9	5.9	1.8
ANNUAL	46.0	23.4	6.7	7.5	6.2	2.2
Cascade Mountains						
Spring	60.4	30.3	5.9	11.9	9.6	2.8
Summer	77.4	46.7	6.8	11.5	10.0	2.5
Autumn	59.6	29.9	4.5	12.6	10.1	2.5
Winter	35.3	14.4	3.6	9.2	6.5	1.6
ANNUAL	60.5	32.4	5.4	11.3	9.0	2.3
Central Rocky Mountains						
Spring	23.9	9.1	2.2	4.4	4.3	3.9
Summer	24.0	5.4	0.9	7.4	6.1	4.3
Autumn	19.5	5.6	1.1	5.6	4.4	2.9
Winter	12.9	3.6	1.0	4.0	2.4	1.9
ANNUAL	19.8	5.6	1.2	5.4	4.3	3.2

Table 5.3 Continued

Season	Aerosol Extinction	Sulfate	Nitrate	Organics	Absorption	Soil and Coarse
Colorado Plateau						
Spring	20.9	6.5	1.4	4.7	4.8	3.4
Summer	23.6	6.9	1.0	5.9	5.9	3.9
Autumn	21.6	6.6	1.0	5.9	5.3	2.8
Winter	19.3	7.1	2.0	4.4	3.8	2.0
ANNUAL	21.4	6.9	1.3	5.2	4.9	3.0
Florida						
Spring	105.3	65.5	6.7	13.3	15.2	4.7
Summer	102.1	61.2	5.8	11.8	14.1	9.1
Autumn	94.5	60.1	5.8	11.6	12.7	4.2
Winter	92.0	50.3	8.3	13.4	16.0	4.0
ANNUAL	100.6	61.1	6.8	12.5	14.6	5.5
Great Basin						
Spring	18.3	4.0	1.0	4.8	4.2	4.2
Summer	22.1	3.4	0.6	7.0	5.5	5.6
Autumn	17.9	3.7	0.7	5.9	4.2	3.4
Winter	13.7	3.5	1.4	4.4	2.7	1.8
ANNUAL	17.9	3.7	0.9	5.5	4.1	3.7
Lake Tahoe						
Spring	35.1	4.5	2.1	10.5	12.8	5.2
Summer	32.6	4.3	1.2	10.4	12.6	4.1
Autumn	42.6	3.7	1.9	15.5	17.7	3.8
Winter	52.0	2.3	2.9	20.0	20.7	6.1
ANNUAL	40.3	3.9	2.0	13.9	15.8	4.7
Mid Atlantic						
Spring	82.5	42.9	9.2	9.5	14.3	6.5
Summer	118.2	72.5	6.5	13.9	17.6	7.7
Autumn	78.5	36.2	7.3	12.3	17.1	5.6
Winter	80.2	29.4	14.4	13.2	18.6	4.6
ANNUAL	88.8	44.1	9.7	12.2	16.9	5.9
Mid South						
Spring	113.8	66.7	12.6	13.0	17.9	3.7
Summer	153.9	107.1	5.6	15.5	18.2	7.5
Autumn	116.5	74.2	8.5	14.4	15.7	3.8
Winter	117.0	60.8	24.7	12.5	16.0	3.0

ANNUAL	127.0	78.8	12.9	13.8	17.0	4.5

Table 5.3 Continued

Season	Aerosol Extinction	Sulfate	Nitrate	Organics	Absorption	Soil and Coarse
Northeast						
Spring	51.7	30.4	4.4	6.5	7.4	2.9
Summer	92.7	65.6	4.1	10.3	9.7	3.0
Autumn	69.7	45.2	6.5	7.1	8.2	2.6
Winter	55.8	29.5	8.1	7.5	8.2	2.6
ANNUAL	67.3	42.4	5.8	7.9	8.4	2.7
Northern Great Plains						
Spring	39.9	18.2	5.7	5.4	6.6	4.1
Summer	34.2	14.5	1.3	8.2	6.3	3.8
Autumn	31.5	11.1	4.0	6.7	5.8	3.9
Winter	42.1	17.5	11.8	5.2	5.5	2.1
ANNUAL	36.6	15.3	5.4	6.4	6.1	3.5
Northern Rocky Mountains						
Spring	38.2	13.3	2.8	10.3	8.2	3.6
Summer	39.0	11.4	1.5	12.2	8.2	5.7
Autumn	57.6	16.0	4.9	18.8	13.1	4.9
Winter	57.0	21.9	12.7	11.5	8.9	1.9
ANNUAL	47.2	15.5	4.8	13.2	9.6	4.0
Pacific Coast						
Spring	45.4	18.6	8.9	6.1	5.8	5.9
Summer	45.5	21.8	7.0	5.7	5.4	5.6
Autumn	52.8	19.0	10.3	10.0	8.2	5.3
Winter	46.5	10.4	18.4	7.6	6.5	3.7
ANNUAL	48.4	18.1	11.4	7.3	6.4	5.2
Sierra-Humboldt						
Spring	22.9	7.1	2.7	5.5	4.6	2.9
Summer	27.6	8.0	1.7	8.4	6.4	3.0
Autumn	21.0	4.7	1.6	7.1	5.2	2.3
Winter	14.2	3.6	1.8	4.1	3.5	1.2
ANNUAL	21.6	5.9	1.9	6.4	5.0	2.4
Sierra Nevada						
Spring	34.8	10.7	5.6	7.6	7.0	3.9
Summer	38.9	7.1	2.1	14.7	10.6	4.4
Autumn	29.7	5.9	2.8	10.0	7.4	3.6

Winter	13.7	3.3	2.0	4.3	2.1	2.1
ANNUAL	30.0	7.5	3.2	9.0	6.7	3.5

Table 5.3 Continued

Season	Aerosol Extinction	Sulfate	Nitrate	Organics	Absorption	Soil and Coarse
Sonoran Desert						
Spring	25.9	6.5	1.4	6.0	6.9	5.0
Summer	29.8	9.7	1.1	6.8	7.2	4.9
Autumn	25.5	8.0	0.9	6.8	6.4	3.4
Winter	22.5	7.8	1.8	5.4	4.9	2.7
ANNUAL	26.2	8.3	1.3	6.2	6.4	4.0
Southern California						
Spring	92.3	13.7	47.2	12.6	12.5	6.2
Summer	70.3	11.5	20.3	16.1	15.0	7.4
Autumn	44.6	6.4	12.5	8.6	8.9	8.2
Winter	25.6	4.6	10.8	4.5	3.9	1.9
ANNUAL	59.7	9.8	23.5	10.5	10.2	5.8
Washington D.C.						
Spring	145.1	64.8	21.0	17.0	36.8	5.5
Summer	206.6	128.4	11.9	20.4	40.4	5.4
Autumn	178.8	84.7	25.3	21.6	41.8	5.3
Winter	151.1	46.8	31.5	23.6	43.7	5.5
ANNUAL	172.5	83.0	22.9	20.6	40.6	5.4
West Texas						
Spring	31.0	10.3	1.1	6.6	7.3	5.6
Summer	41.2	17.2	1.9	7.2	8.2	6.7
Autumn	29.7	12.2	1.2	5.8	5.7	4.8
Winter	27.1	11.1	2.0	5.2	5.1	3.7
ANNUAL	32.3	12.8	1.5	6.2	6.6	5.2

Table 5.4 Seasonal and annual averages of percentage contributions to the reconstructed aerosol light extinction coefficient (light extinction budget) for the 21 regions in the IMPROVE network for sulfate, nitrate, organic carbon, absorption, and coarse particle/fine soil.

Season	Sulfate	Nitrate	Organics	Absorption	Soil and Coarse
Alaska					
Spring	39.5	3.8	23.2	18.9	14.7
Summer	24.0	2.2	40.1	21.6	12.1
Autumn	41.3	4.8	26.6	15.5	11.8
Winter	42.8	7.0	24.8	15.4	9.9
ANNUAL	37.0	4.3	29.0	17.8	12.0
Appalachian					
Spring	62.0	8.1	10.9	15.2	3.9
Summer	75.7	2.2	8.6	10.6	2.9
Autumn	68.3	6.0	10.5	12.6	2.5
Winter	56.2	15.5	11.8	13.8	2.8
ANNUAL	68.4	6.4	9.9	12.4	2.9
Boundary Waters					
Spring	54.8	9.6	14.2	15.6	5.7
Summer	51.1	3.1	25.2	14.9	5.7
Autumn	52.5	14.7	15.4	12.8	4.7
Winter	44.1	29.4	11.6	11.4	3.5
ANNUAL	50.9	14.5	16.4	13.4	4.8
Cascade Mountains					
Spring	50.2	9.7	19.6	15.8	4.6
Summer	60.3	8.8	14.8	12.9	3.2
Autumn	50.1	7.6	21.2	16.9	4.2
Winter	40.7	10.1	26.1	18.5	4.5
ANNUAL	53.5	9.0	18.7	14.9	3.9
Central Rocky Mountains					
Spring	38.1	9.2	18.6	17.9	16.3
Summer	22.3	3.9	30.7	25.2	17.8
Autumn	28.7	5.7	28.6	22.4	14.7
Winter	28.2	8.0	30.8	18.5	14.5
ANNUAL	28.6	6.3	27.1	21.7	16.4

Table 5.4 Continued

Season	Sulfate	Nitrate	Organics	Absorption	Soil and Coarse
Colorado Plateau					
Spring	31.2	6.8	22.4	23.1	16.4
Summer	29.3	4.1	24.9	25.1	16.5
Autumn	30.3	4.8	27.2	24.5	13.2
Winter	37.0	10.1	22.8	19.7	10.3
ANNUAL	32.3	6.1	24.3	23.1	14.2
Florida					
Spring	62.2	6.3	12.6	14.4	4.4
Summer	60.0	5.7	11.6	13.9	8.9
Autumn	63.6	6.1	12.3	13.5	4.5
Winter	54.6	9.0	14.5	17.4	4.4
ANNUAL	60.8	6.8	12.5	14.5	5.5
Great Basin					
Spring	21.9	5.5	26.3	23.2	23.0
Summer	15.2	2.8	31.5	25.1	25.4
Autumn	20.5	3.9	33.1	23.4	19.1
Winter	25.6	9.9	32.1	19.6	12.7
ANNUAL	20.7	4.9	30.7	23.0	20.8
Lake Tahoe					
Spring	12.9	6.0	30.0	36.4	14.7
Summer	13.1	3.7	32.0	38.6	12.5
Autumn	8.6	4.4	36.5	41.6	8.8
Winter	4.5	5.6	38.4	39.9	11.7
ANNUAL	9.7	4.9	34.5	39.2	11.8
Mid Atlantic					
Spring	52.1	11.1	11.6	17.4	7.9
Summer	61.4	5.5	11.8	14.8	6.5
Autumn	46.2	9.3	15.6	21.8	7.1
Winter	36.7	17.9	16.5	23.2	5.8
ANNUAL	49.7	10.9	13.8	19.0	6.7
Mid South					
Spring	58.6	11.0	11.4	15.7	3.3
Summer	69.6	3.6	10.0	11.8	4.9
Autumn	63.6	7.3	12.3	13.5	3.2

ANNUAL	62.0	10.2	10.9	13.4	3.5

Table 5.4 Continued

Season	Sulfate	Nitrate	Organics	Absorption	Soil/Coarse
Northeast					
Spring	58.9	8.5	12.6	14.3	5.7
Summer	70.7	4.4	11.1	10.5	3.3
Autumn	64.9	9.4	10.2	11.8	3.7
Winter	52.8	14.5	13.4	14.7	4.6
ANNUAL	63.1	8.7	11.7	12.5	4.1
Northern Great Plains					
Spring	45.6	14.3	13.5	16.5	10.2
Summer	42.5	3.9	23.9	18.5	11.2
Autumn	35.4	12.6	21.2	18.6	12.3
Winter	41.6	28.0	12.3	13.0	5.1
ANNUAL	41.7	14.9	17.4	16.6	9.5
Northern Rocky Mountains					
Spring	34.8	7.3	27.0	21.4	9.4
Summer	29.3	3.9	31.2	21.0	14.6
Autumn	27.7	8.5	32.6	22.7	8.4
Winter	38.4	22.3	20.2	15.7	3.4
ANNUAL	32.9	10.3	28.0	20.3	8.6
Pacific Coast					
Spring	41.0	19.7	13.4	12.9	13.1
Summer	47.9	15.4	12.5	11.8	12.3
Autumn	36.0	19.5	19.0	15.5	10.0
Winter	22.4	39.4	16.3	13.9	8.0
ANNUAL	37.3	23.6	15.1	13.3	10.7
Sierra-Humboldt					
Spring	31.2	11.7	24.1	20.3	12.8
Summer	29.1	6.2	30.5	23.4	10.9
Autumn	22.6	7.8	33.8	25.0	10.7
Winter	25.5	12.7	28.9	24.4	8.4
ANNUAL	27.3	9.0	29.4	23.2	11.1
Sierra Nevada					
Spring	30.7	16.0	21.7	20.2	11.3
Summer	18.2	5.4	37.9	27.3	11.3
Autumn	19.7	9.3	33.8	25.1	12.1

Winter	24.1	14.2	31.2	15.1	15.4
ANNUAL	25.0	10.8	30.1	22.4	11.7

Table 5.4 Continued

Season	Sulfate	Nitrate	Organics	Absorption	Soil and Coarse
Sonoran Desert					
Spring	25.2	5.5	23.2	26.7	19.4
Summer	32.7	3.6	22.8	24.3	16.6
Autumn	31.3	3.6	26.5	25.2	13.4
Winter	34.8	7.8	23.8	21.7	11.9
ANNUAL	31.5	5.0	23.8	24.3	15.4
Southern California					
Spring	14.9	51.2	13.7	13.5	6.8
Summer	16.3	28.9	22.9	21.3	10.6
Autumn	14.4	27.9	19.3	20.0	18.4
Winter	17.8	42.1	17.4	15.3	7.4
ANNUAL	16.4	39.3	17.6	17.1	9.7
Washington D.C.					
Spring	44.7	14.5	11.7	25.4	3.8
Summer	62.2	5.8	9.9	19.6	2.6
Autumn	47.4	14.2	12.1	23.4	3.0
Winter	31.0	20.8	15.7	28.9	3.6
ANNUAL	48.1	13.3	11.9	23.6	3.1
West Texas					
Spring	33.3	3.6	21.5	23.5	18.2
Summer	41.7	4.7	17.4	19.9	16.3
Autumn	41.3	4.0	19.4	19.1	16.2
Winter	41.0	7.3	19.2	18.9	13.6
ANNUAL	39.6	4.7	19.2	20.3	16.2

Cascade Mountains. This region is represented by two sites, Mount Rainier National Park southeast of Seattle, and Columbia River Gorge on the Hood River National Forest. The site at Columbia River Gorge has operated for one year out of the last six and only Mount Rainier is reported here. The average annual extinction for this region is 70.5 Mm^{-1}, of which 86% is due to aerosols. The seasonality is significant and ranges from a high in the summer of 87.4 Mm^{-1} then drops to a low in the spring of 45.3 Mm^{-1}. The seasonality is driven primarily by sulfate. Sulfate extinction ranges from a summer high of 46.7 Mm^{-1} then drops to 14.4 Mm^{-1} in the summer. Organics show very little variance between seasons and has an annual average value of 11.3 Mm^{-1}. The largest contributor to aerosol extinction is sulfate (53.5%), followed by organics (18.7%), and absorption (14.9%). Nitrates account for 9% of aerosol extinction and coarse extinction accounts for 3.9%.

Central Rocky Mountains. The measurements in this region are made at five locations in the mountainous Class I areas of Colorado and Wyoming, including the Bridger and Weminuche Wilderness Areas, Rocky Mountain and Yellowstone National Parks, and Great Sand Dunes National Monument. All five sites have been operated for six years and show an annual average total extinction for the three-year period of 29.8 Mm^{-1}, of which 66% is due to aerosol extinction. The seasonal variation is significant and has a maximum in the summer of 34 Mm^{-1} and decreases to 22.9 Mm^{-1} during the winter. The seasonal variance is driven primarily by organic extinction and absorption. Organic extinction peaks at 7.4 Mm^{-1} in the summer and drops in the winter to 4 Mm^{-1}, absorption ranges for 6.1 Mm^{-1} in the summer and drops to 2.4 Mm^{-1} in the winter. Sulfates (28.6%) contribute the most to extinction annually followed by organics (27.1%), absorption (21.7%), coarse mass (16.4%), and nitrate is the smallest contributor (6.4%). During the summer sulfate is the third largest contributor at 22.8% with organics contributing the most at 30.7% followed by absorption at 25.2%.

Coastal Mountains. This region includes three Class I areas along and near the coast of northern California: Pinnacles National Monument, Point Reyes National Seashore, and Redwoods National Park. The average annual extinction during the three-year period for this area is 58.4 Mm^{-1} with 83% due to aerosol extinction. The annual variance is very slight and only ranges between 55.4 Mm^{-1} during the spring and 62.8 Mm^{-1} in the autumn. However, extinction due to sulfate and nitrate show large seasonal variances that are opposed to each other. Sulfate extinction obtains its maximum in the summer at 21.8 Mm^{-1} when nitrate extinction is at its minimum of 7 Mm^{-1}. When nitrate extinction obtains its maximum of 18.4 Mm^{-1} during the winter sulfate extinction is at its minimum of 10.4 Mm^{-1}. Organic extinction and absorption obtain their maxima in the autumn of 10 Mm^{-1} and 8.2 Mm^{-1}, respectively. On an annual basis, the largest contributor to aerosol extinction is sulfate (37.3%), followed by nitrate (23.6%), organics (15.1%), absorption (13.3%), and coarse particles (10.7%). The contribution from sulfate shows considerable variation ranging from a high in the summer of 47.9% to 22.4% in the winter when its contribution is eclipsed by nitrate, which contributes 39.4%.

Colorado Plateau. This region in the Four Corners' states of the Southwest is the most intensively monitored in the IMPROVE network. There are six sites, most of them within the so-called Golden Circle of national parks: Bandelier, Bryce Canyon, Canyonlands, Grand Canyon, Mesa Verde, and Petrified Forest National Parks. The three-year annual average for total extinction is relatively low at 31.4 Mm^{-1}, 68% of which is aerosol extinction. There is a very slight variance between seasons of total extinction ranging from 29.3 Mm^{-1} in the winter to as high as 33.6 Mm^{-1} during the winter. The peaking of extinction in the winter is unlike most other regions. Here sulfate extinction obtains its maximum of 7.1 Mm^{-1} and is lowest in the spring at 6.5 Mm^{-1}, and is at its next lowest in the autumn at 6.6 Mm^{-1}. However, the seasonality of nitrate extinction is typically high during the winter at 2.0 Mm^{-1} and lowest during the summer at 1.0 Mm^{-1}. The largest contribution to annual aerosol extinction is sulfate (32.3%) followed by organics (24.3%), absorption (23.1%), coarse particles (14.2%), and nitrate (6.1%). However, during the summer, extinction contributions from sulfate (29.3%), organics (24.9%), and absorption (25.1%) are about on par with each other.

Florida. This region now consists of two sites, Chassahowitzka National Wildlife Refuge north of Tampa and Okefenokee National Wildlife Refuge on the Georgia-Florida border. Previously, this site was represented by Everglades National Park, which has been downgraded to a channel A only monitoring site. The annual total extinction for this region is 111 Mm^{-1}, 91% is due to aerosol extinction. Very little seasonal variance exists here, with spring having the most extinction of 115 Mm^{-1} and winter the least at 102 Mm^{-1}. The largest contributor to aerosol extinction is from sulfates (60.8%) followed by absorption (14.5%), organics (12.5%), nitrate (6.8%), and coarse particles (5.5%).

Great Basin. The Great Basin of Nevada is represented by two sites. The site at Jarbidge Wilderness Area in northeastern Nevada was implemented in March of 1988, and the other site at Great Basin National Park began operating in May of 1992. The annual average extinction during the three-year period for this region is quite low at 27.9 Mm^{-1}, with 64% from aerosol extinction, the only region with less extinction is Alaska. A slight seasonal variation exists between 32.1 Mm^{-1} during the summer and 23.7 Mm^{-1} during the winter. On an annual basis the largest contributor to extinction is organics (30.7%) followed by absorption (23%), soil and coarse particles (20.8%), and sulfate (20.7%). This region is unique in that sulfate is the fourth largest contributor to extinction. This holds for two out of the four seasons (spring and summer). During the other seasons, sulfate extinction is larger than extinction from soil and coarse making sulfate the third largest contributor.

Lake Tahoe. Two sites represent the Lake Tahoe region: one is located in Bliss State Park, the other is close to the south end of the lake. The average extinction for this area is 50.3 Mm^{-1} with a modest seasonality with winter being the maximum season at 62 Mm^{-1}, and summer being the clearest at 42.6 Mm^{-1}. The seasonality is driven by organics and absorption, whose winter values of 20.6 Mm^{-1} and 20.7 Mm^{-1}, respectively, are about twice their summer levels. The dominant contributors to aerosol extinction are absorption (39.2%) and organics (34.5%), followed by soil and coarse particles (11.8%), sulfate (9.7%), and nitrate (4.9%).

Mid Atlantic. This region, represented by the Edmond B. Forsythe Wildlife Refuge, just west of Atlantic City, New Jersey, has an average annual reconstructed extinction of 98.8 Mm^{-1}. There is a significant seasonality, with extinction moving from a high during the summer of 128 Mm^{-1}, to 88.5 Mm^{-1} in the autumn. Sulfates move between 72.5 Mm^{-1} in the summer and decreases to 29.4 Mm^{-1} during winter and are responsible for the seasonality. Nitrate has an average winter value of 14.4 Mm^{-1}, about twice of all other seasons. Sulfates contribute about half (47.5%) of the aerosol extinction, followed by absorption (19.0%), organics (13.8%), nitrate (10.9%), and soil and coarse particles the least (6.7%).

Mid South. Three sites represent this region: Sipsey Wilderness Area in northern Mississippi, Upper Buffalo Wilderness Area in northern Arkansas, and Mammoth Cave National Park in Kentucky. This region has the highest levels of reconstructed extinction for a rural area. The only exception is Washington, D.C., which is an urban area. The average annual reconstructed extinction is 137 Mm^{-1} with a significant seasonal variation of 164 Mm^{-1} between the summer high and the spring low of 124 Mm^{-1}. Sulfate dominates the aerosol extinction and is responsible for much of the seasonality observed. Sulfate extinction is highest in the summer at 107 Mm^{-1} and lowest in the spring at 60.8 Mm^{-1}. Organics, and elemental carbon all have seasonal trends that peak in the summer but are lowest in the winter for organics and autumn for absorption. On an annual average, sulfate contributes 62% of the aerosol extinction peaking in the summer (69.6%) and is least in the winter (52%). The next largest contributor annually is absorption (13.4%) followed by organics (10.9%), and nitrate (10.2%).

Northeast. The northeastern United States is represented by measurements at two sites: Acadia National Park on the coast of Maine, which began operating in March of 1988; and, Lye Brook Wilderness Area in Vermont, which began operations in September of 1991. The average annual extinction during the three-year period for the Northeast is 77.3 Mm^{-1} of which aerosol extinction accounts for 87%. There is a significant seasonal variation of 61.7 Mm^{-1} with the spring being the least and the highest occurs during the summer at 102.7 Mm^{-1}. Sulfates and organics are responsible for most of the seasonal variation with sulfates varying from 29.5 Mm^{-1} to 65.6 Mm^{-1} between winter and summer, and similarly organics vary between 6.5 Mm^{-1} in the spring to 10 Mm^{-1} in the summer. Nitrate extinction obtains its maximum during the winter at 8.1 Mm^{-1} and its minimum at 4.1 Mm^{-1} during the summer. The largest contributor to extinction is from sulfates at 63.1% annually. The next highest contributor is absorption (12.5%), followed by organics (11.7%), nitrate (8.7%), and soil and coarse particles (4.1%).

Northern Great Plains. Only one set of aerosol measurements was made in this region, at Badlands National Monument in South Dakota, where reconstructed light extinction averaged 46.6 Mm^{-1}. Unlike most other regions extinction was highest in spring and lowest in autumn. This seasonality is driven primarily by sulfate and nitrate extinction. Sulfate extinction obtains a maximum of 18.2 Mm^{-1} in the spring and has its seasonal minimum of 11.1 Mm^{-1} in the autumn. Nitrate extinction in the spring, at 5.7 Mm^{-1}, is more than four times its summer extinction of 1.3 Mm^{-1}. The maximum nitrate extinction of 11.8 Mm^{-1} occurs in the winter. The main contributor to annual extinction is sulfate, which accounts for 41.7% of the extinction. The next highest contributor is absorption at 16.6% followed by organics at 17.4%, nitrate (14.9%), and coarse mass (9.5%).

Northern Rocky Mountains. This region is represented by one site at Glacier National Park close to the Canada border. Here, the reconstructed light extinction coefficient is 57.2 Mm^{-1} for an annual average of 83% due to aerosols. There is a modest seasonality ranging between 67.6 Mm^{-1} in the autumn down to 48.2 Mm^{-1} during the spring. The seasonality is driven by sulfate and nitrate extinction. Sulfate and nitrate extinctions peak during the winter at 22.9 Mm^{-1} and 12.7 Mm^{-1}, respectively. The largest contributor to aerosol extinction is sulfate (32.9%) followed by organics (28%), and absorption (20.3%).

Sierra-Humboldt. The region further north in the Sierra Nevada and Humboldt Mountain Ranges was measured at Crater Lake National Park in Oregon and Lassen Volcanoes National Park in northern California. For this region, total reconstructed light extinction averaged 31.6 Mm^{-1} with maximum extinction in summer (37.6 Mm^{-1}) and minimum extinction in winter (23.2 Mm^{-1}). The seasonality is primarily variations from sulfate and organic extinctions and absorption. Organic carbon, sulfate, and elemental carbon contribute almost equally to annual extinction at 29.4%, 27.3%, and 23.2%, respectively.

Sierra Nevada. The aerosol in the Sierra Nevada region is monitored at two sites: Yosemite National Park has been monitored since March 1988, monitoring at Sequoia-Kings Canyon began in March of 1992. The average reconstructed light extinction is 40 Mm^{-1} with a strong seasonal component that has a winter minimum of 23.7 Mm^{-1} and a summer maximum of 48.9 Mm^{-1}. The seasonality is driven primarily by organics and absorption with both species peaking during the summer at 14.7 Mm^{-1} and 10.3 Mm^{-1}, then dropping to 4.3 Mm^{-1} and 2.1 Mm^{-1} their minimum during the winter. Sulfate, to a lesser extent, is responsible for the seasonality, while its maximum occurs in the spring at 10 Mm^{-1}. Its summer extinction drops off to 7.1 Mm^{-1} and obtains its seasonal low in the winter of 3.3 Mm^{-1}.

Sonoran Desert. This region in southeastern Arizona was measured at two sites: Chiracahua and Tonto National Monuments. The three-year average reconstructed extinction is 36.2 Mm^{-1} and varies from a summer high of 39.8 Mm^{-1} to a winter low of 32.5 Mm^{-1}. The seasonality is due to changes in extinction from sulfate, organics, and absorption. Sulfate and absorption obtain their seasonal maxima of 9.7 Mm^{-1} and 7.2 Mm^{-1} during the summer. The largest contributor to extinction is sulfate (31.5%) followed by absorption (24.3%), and organics (23.8%).

Southern California. Measurements in this region were made in San Gorgonio National Monument, east of the Los Angeles metropolitan area. Total reconstructed light extinction averaged over the three-year period was 69.7 Mm^{-1} and varied from a seasonal high of 102 Mm^{-1} in the spring to as little as 35.6 Mm^{-1} in the winter. The seasonality is driven primarily by nitrates and to a lesser extent sulfate, organics, and absorption, all of which obtain their maximum in the spring and their minimum in the winter. This region is unique in that nitrates are by far the largest contributor to annual extinction (39.3%) followed by absorption (17.1%), and organics (17.6%), sulfate (16.4%), and soil and coarse particles (9.7%).

Washington D.C. The highest light extinction coefficient, reconstructed from aerosol concentration, was found in Washington. It averaged 182 Mm^{-1} over the three-year period. Extinction was highest in the summer (216 Mm^{-1}) and lowest in the spring (155 Mm^{-1}). Most of the seasonality is due to sulfate. In the summer, sulfate extinction averaged 128 Mm^{-1}, much higher than other seasons. Except for nitrate, the other species were fairly constant between seasons. Sulfate is the dominate contributor to light extinction, contributing nearly half (48.1%), followed by absorption (23.6%), nitrate (13.3%), organics (11.5%), and soil and coarse particles (3.1%).

West Texas. Total light extinction reconstructed from the aerosol measurements at Big Bend and Guadalupe Mountains National Parks averaged 42.3% over the three-year period. A modest seasonality is evident with the highest extinction in the summer (51.2 Mm^{-1}) and the least during the winter (37.1 Mm^{-1}). The seasonality is primarily due to sulfate, which is the largest contributor to aerosol extinction (39.6%) followed distantly by absorption (20.3%), organics (19.2%), soil and coarse particles (16.2%), and nitrate (4.7%).

5.2.2 Spatial Trends in Reconstructed Light Extinction in the United States

Figure 5.2 shows the sulfate light extinction coefficient averaged over the three-year period of IMPROVE (March 1992 - February 1995). Note that the highest sulfate extinction occurs in the eastern United States, and the lowest sulfate extinction occurs in Oregon, Nevada, Idaho, and Wyoming. The major gradient in sulfate light extinction is from the eastern United States to the nonurban West. However, there is also a gradient from the San Francisco Bay Area and from the Pacific Northwest to the nonurban west. Sulfate extinction is more than half of the total aerosol light extinction in the eastern and north central United States. In the Appalachians, Middle Atlantic states, and the Northeast, sulfate contributes about two thirds of aerosol light extinction. In the worst season for sulfate (summer), sulfate's share is even higher, reaching three quarters in the eastern United States.

Figure 5.3 shows the nitrate light extinction. There is a gradient from east to west, with relatively high nitrate contributions in the Washington D.C. area. However, the strongest gradient is from the urban areas of California, especially the Los Angeles metropolitan area, to the California desert. Nitrate contributions to aerosol light extinction are generally less than 10%, except in California, where nitrate can contribute as much as 40% and the upper midwest where nitrate extinction contributes in excess of 15%.

Figure 5.4 shows isopleths of the light extinction due to organics throughout the United States, averaged over the three-year period. Note that extinction caused by organic carbon is largest in the eastern United States and in the Pacific Northwest, and lowest in the Golden Circle of parks in southern Utah and northern Arizona. The fraction of aerosol light extinction contributed by organic carbon ranges from a high of more than 30% in the Great Basin Region to less than 20% in the urban areas of California and in much of the eastern United States. The reason that organic carbon is a smaller share of aerosol extinction in the East is the much larger contribution of sulfate extinction there.

Figure 5.5 shows isopleths of the extinction caused by absorption. Absorption is highest in the Pacific Northwest and in the eastern United States and lowest in the nonurban west. However, the greatest contribution by absorption is in the nonurban west, Great Basin region, and the Sonoran Desert, with more than 20% of extinction from absorption being routine. Except for the coastal regions of northern California, Oregon, and Washington, most of the western United States has a contribution from absorption in excess of 18%.

Figure 5.6 shows isopleths of light extinction due to coarse material throughout the United States, averaged over the three-year period. Extinction caused by coarse material is highest in the

Coastal Mountains, West Texas, Mid South, Florida, Appalachian, and Mid Atlantic regions. The least contribution occurs in the Northeast, Colorado Plateau, and portions of the Central Rockies. The fraction of aerosol extinction contributed by coarse material shows an east-west dichotomy with the eastern United States having the lowest percentages with the Mid South and Appalachian regions at about 3%. In the West, there is a large region that encompasses the Central Rockies, Sonoran Desert, West Texas, and the Great Basin that routinely exceeds 15%.

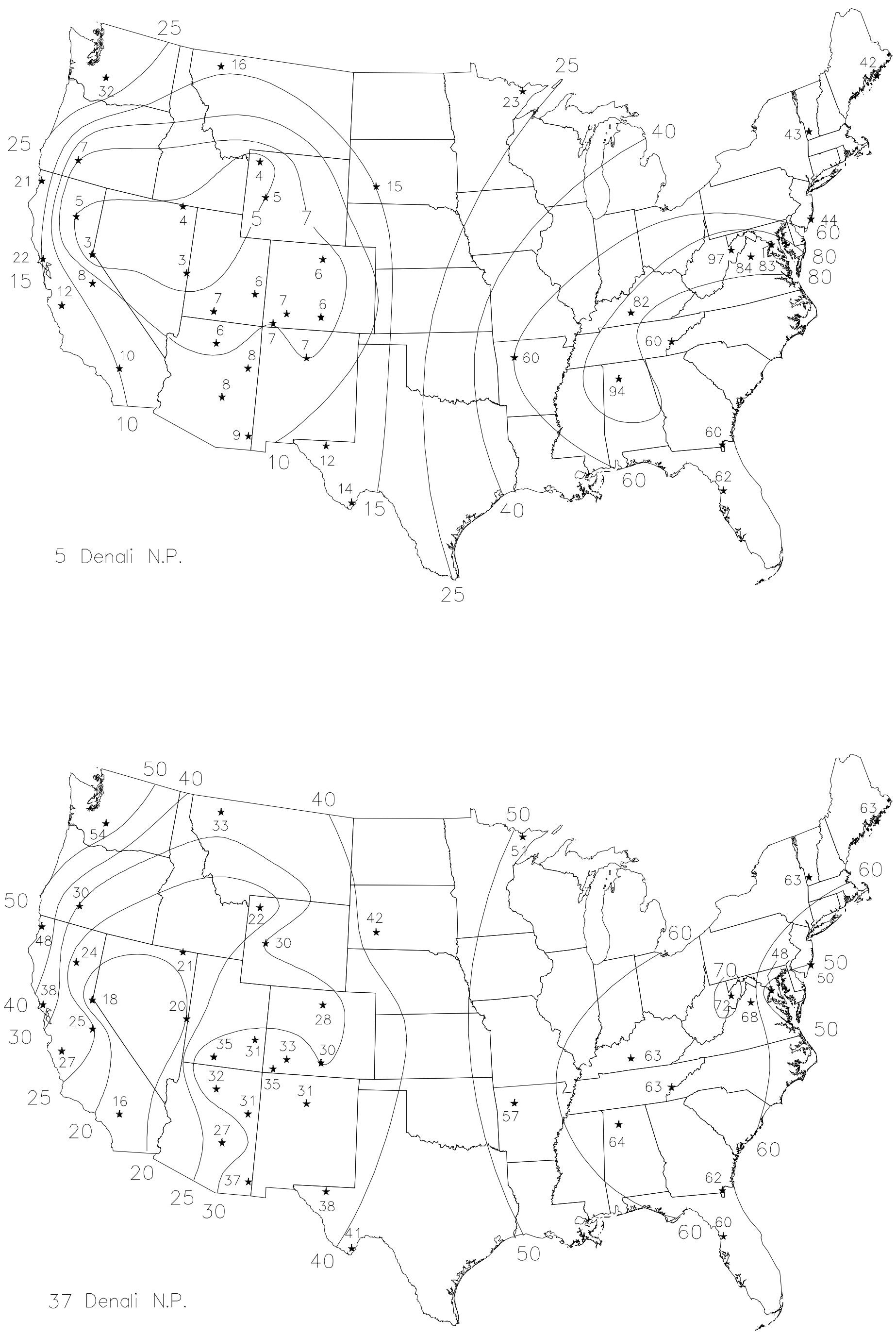

Figure 5.2 Three-year averages of reconstructed sulfate light extinction coefficient in Mm^{-1} (top) and sulfate fraction in percent of aerosol light extinction (bottom), for each of the sites in the IMPROVE network reported for the United States.

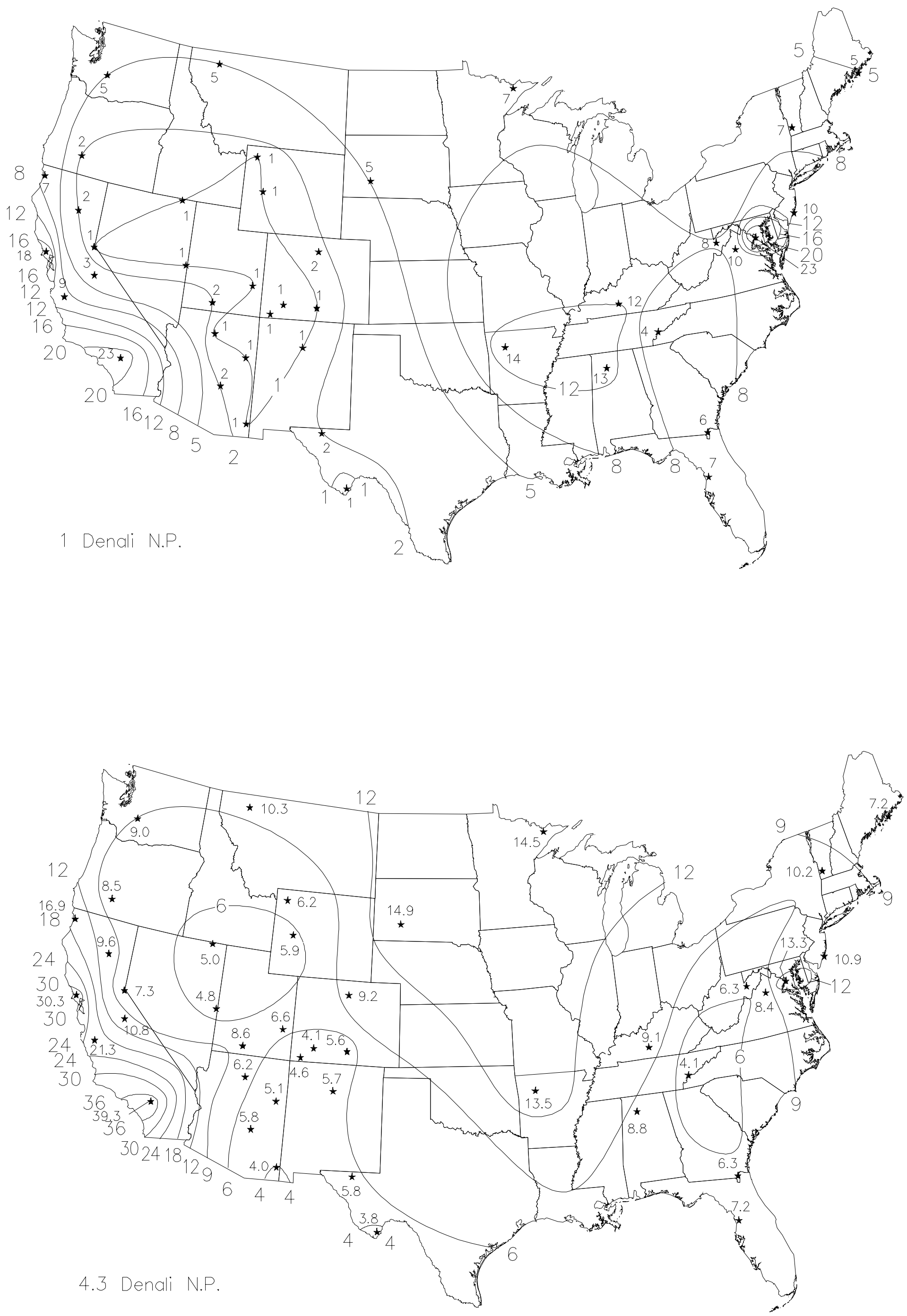

Figure 5.3 Three-year averages of reconstructed nitrate light extinction coefficient in Mm^{-1} (top) and nitrate fraction in percent of aerosol light extinction (bottom), for each of the sites in the IMPROVE network reported for the United States.

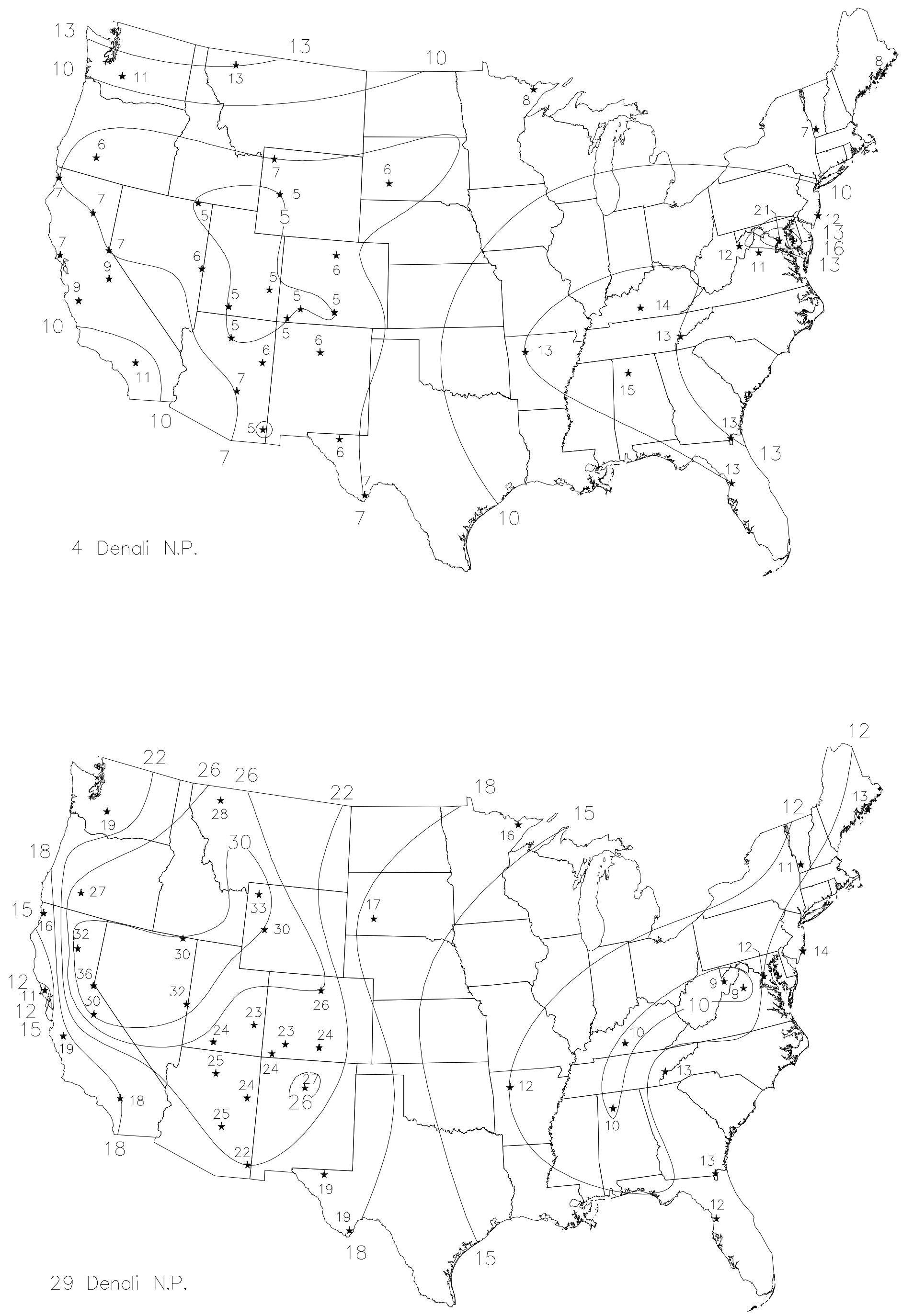

Figure 5.4 Three-year averages of reconstructed organic carbon light extinction coefficient in Mm^{-1} (top) and organic carbon fraction in percent of aerosol light extinction (bottom), for each of the sites in the IMPROVE network reported for the United States.

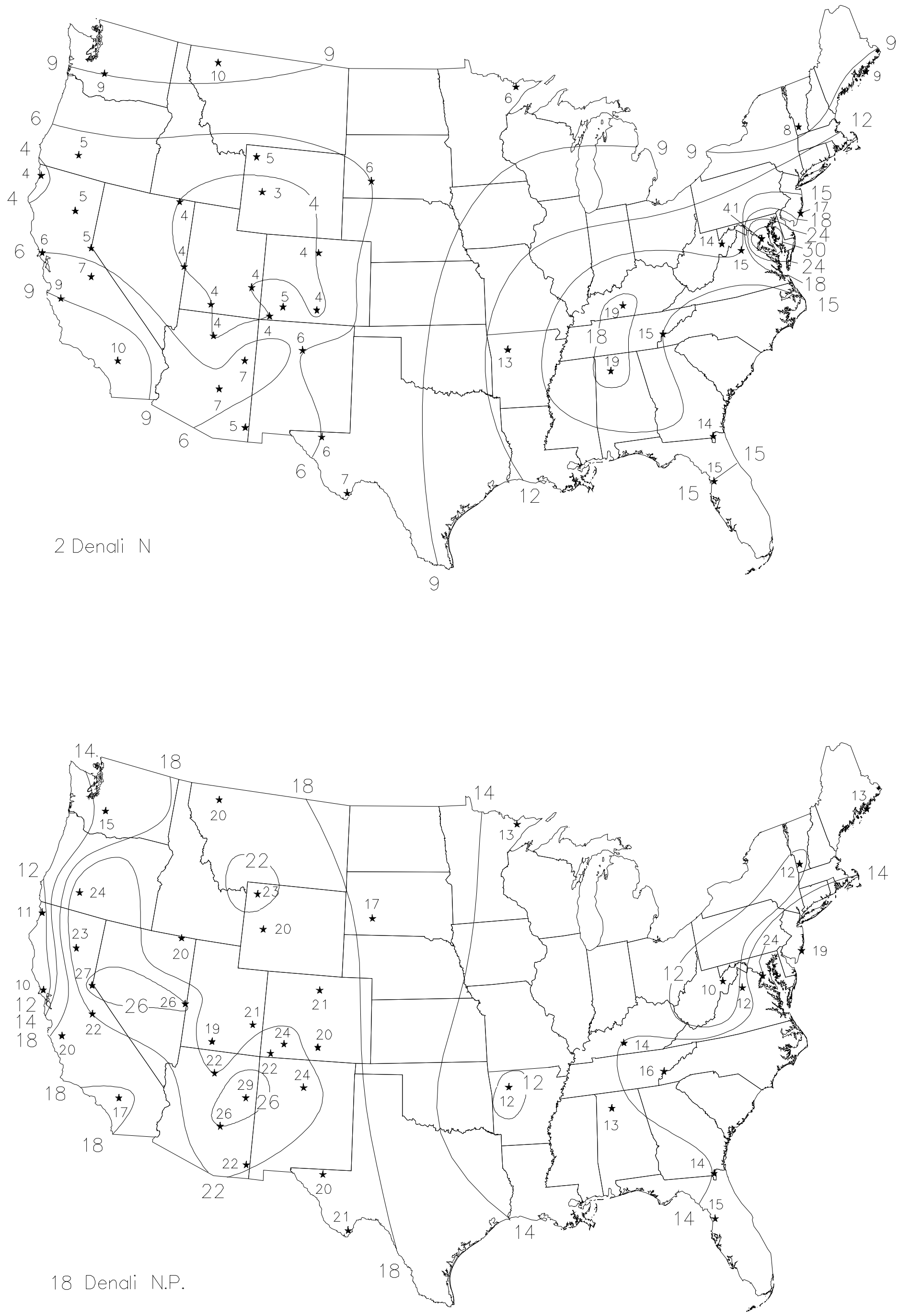

Figure 5.5 Three-year averages of reconstructed absorption coefficient in Mm^{-1} (top) and absorption fraction in percent of aerosol light extinction (bottom), for each of the sites in the IMPROVE network reported for the United States.

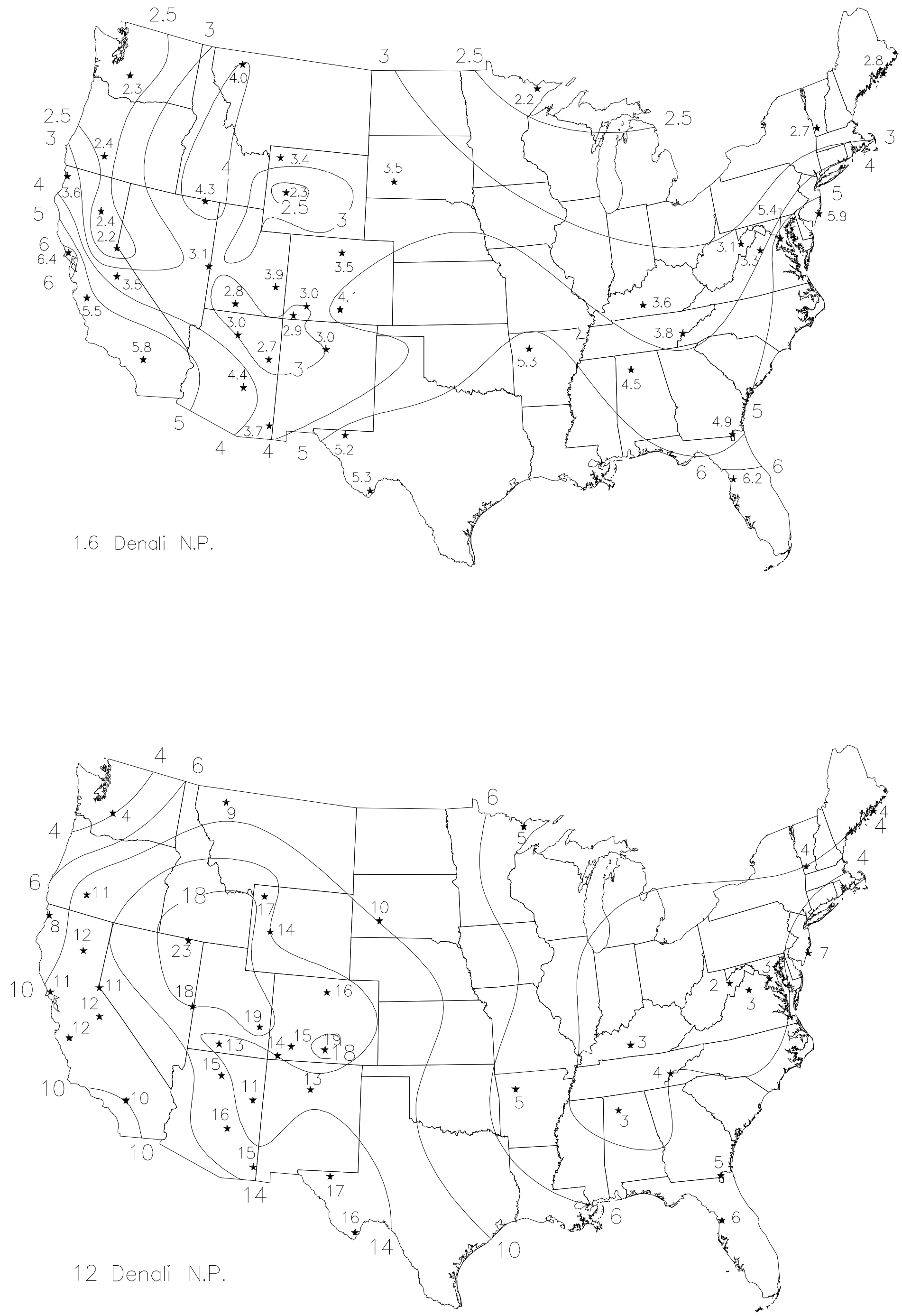

Figure 5.6 Three-year averages of reconstructed light extinction due to coarse material in Mm^{-1} (top) and percent of aerosol extinction (bottom), for each of the sites in the IMPROVE network reported for the United States.

5.2.3 Spatial Trends in Visibility in the United States

To show the effect on visibility of aerosol extinction the deciview (*dv*) scale is applied to the total (Rayleigh included) aerosol extinction (see Chapter 1). By utilizing the *dv* scale the effect of aerosol extinction on the human visual system is portrayed as a linear scale of visibility degradation. Pristine or Rayleigh conditions have a *dv* of zero. A one or two *dv* change is usually associated with the minimal or just noticeable change (JNC) in visibility perceived by the average individual.

Figure 5.7 shows isopleths of deciviews averaged over the three-year period. There is a broad region that includes the Great Basin, most of the Colorado Plateau and portions of the Central Rockies that has visibility impairment of less than 10 *dv* or better visibility. Moving in any direction from this region generally results in a gradient of increasing *dv*. West of the Sierra Range and including southern California have *dv* values in excess of 15. To the north a maximal value of 20 *dv* occurs at Mount Rainier. The northwest United States and all of the eastern half of the United States have in excess of 15 *dv* of impaired visibility and the region east of the Mississippi, and south of the Great Lakes have impairment in excess of 24 *dv* with the Appalachian region exceeding 26 *dv*. The highest annual *dv* is reported at Washington D.C. with an impairment of 29 *dv* followed by Sipsey at 28 *dv*.

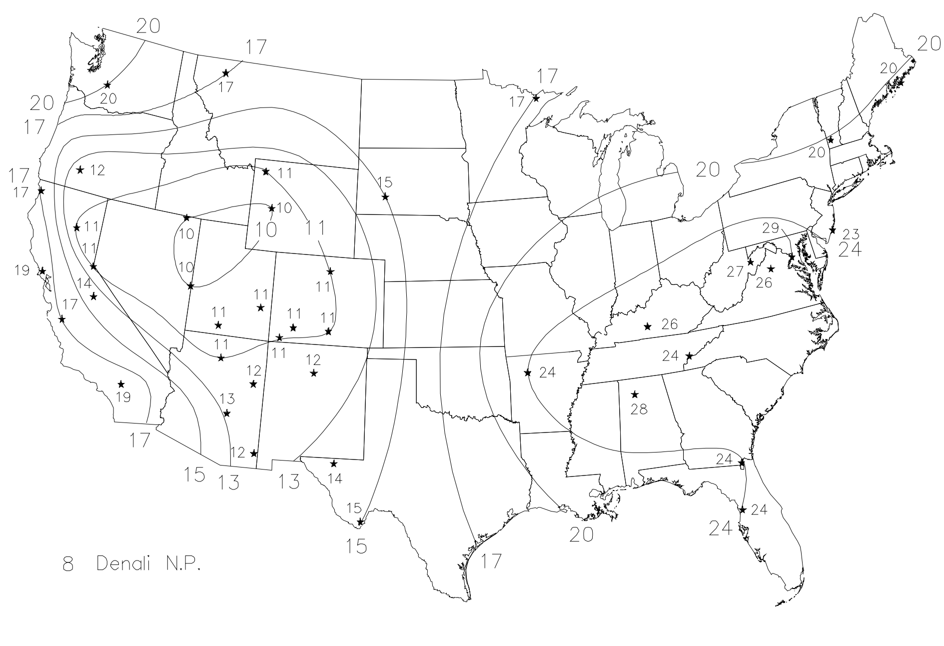

Figure 5.7 Average visibility impairment in deciviews calculated from total (Rayleigh included) reconstructed light extinction for the three-year period, March 1992 through February 1995, of IMPROVE.

Isopleths of *dv* for the winter, spring, summer, and autumn are shown in Figure 5.8 through Figure 5.11, respectively. The general spatial trend noted above for the annual average generally holds true for each season's average *dv* trend. Specifically, the least impairment or lowest *dv*'s generally occur in all or part of the Great Basin, Colorado Plateau, and Central Rockies with gradients of increasing *dv* in any direction. One interesting exception to this occurs in the winter (Figure 5.8), which shows an "island" of impaired visibility in the middle of the Colorado Plateau region at Canyonlands with a *dv* of 12. It is also of interest to note that the eastern United States is almost uniformly above 20 *dv* of impairment for all four seasons.

The best visibility in the West occurs during the winter (Figure 5.8) with a minimum *dv* of 7 being reported at Bridger Wilderness followed by 8 *dv* at Jarbidge. The region of 10 or less *dv*'s encompasses a broad expanse that covers the Sierra-Humboldt, Sierra Nevada, Great Basin, Central Rockies, and the northwestern half of the Colorado Plateau. In the eastern half of the United States the season of best visibility is split between winter and spring. In the Northeast and Florida, the winter is best for visibility, while the Appalachian and Mid-West are variable between sites. However, all sites east of the Mississippi and south of the Great Lakes site have impairment in excess of 20 *dv*'s for both the spring and winter.

Summertime visibilities (Figure 5.10), except for the Coastal Range, are generally the worst. Only small portions of the Great Basin, Central Rockies, and Colorado Plateau regions have impaired visibilities slightly below 12 *dv*. In the East, including the Ozark Plateau, there is a broad region east of the Mississippi with more than 26 *dv* of impairment in visibility. Moreover, Washington, Shenandoah, and Sipsey exceed 30 *dv*'s in impairment.

Visibility impairment in the spring (Figure 5.9) and autumn (Figure 5.11) are quite comparable. The exceptions to this are in the East where extinction is higher in the autumn, while in the intermountain west, autumn is generally less impaired, particularly in the Central Rockies and the Sierra-Humboldt regions. Southern California has better visibility in the autumn.

5.3 Summary

The following are the major patterns in light extinction reconstructed from aerosol measurements and relative humidity during the three-year period of IMPROVE (March 1992-February 1995):

1. Spatial Patterns. Following the patterns observed in fine aerosol concentrations, reconstructed light extinction is highest in the eastern United States and in urban California and lowest in the nonurban west.

2. Major Contributors to Light Extinction. Fine aerosols are the most effective in scattered light and are the major contributors to light extinction. In most cases, the sulfate component of fine aerosol is the largest single contributor to light extinction. This is because sulfate, being hygroscopic, generally has a higher light extinction efficiency than other species due to associated liquid water. This is especially true in the eastern United States, where relative humidity is high. In the Appalachian Mountains (Shenandoah and Great Smoky Mountains),

sulfate accounts for 2/3 of the total aerosol light extinction throughout the year, and 3/4 of the total in summer. Sulfate is the largest single contributor to light extinction in 14 of the 21 regions, and is comparable with organics as the most significant contributor in three additional regions (Northern Rockies, Central Rockies, and Sierra-Humboldt). Organic carbon is the largest single contributor to light extinction in three of the 21 regions (Great Basin, Sierra Nevada, and Lake Tahoe) and is a major contributor in the two previously mentioned regions. Smaller contributions come from wind-blown dust (coarse particles and fine soil) and nitrate. Nitrate is the single largest contributor to light extinction only in southern California.

3. Smaller Contributors. After sulfate and organic carbon, nitrate, and wind-blown dust (coarse particles and fine soil) generally contribute equal amounts. Light-absorbing carbon is generally the smallest contributor.

4. Seasonality. Generally, reconstructed light extinction is highest in summer and lowest in winter; however, there are many exceptions to this general rule. Higher extinction occurs in summer generally because of relatively elevated sulfate and carbonaceous aerosol concentrations.

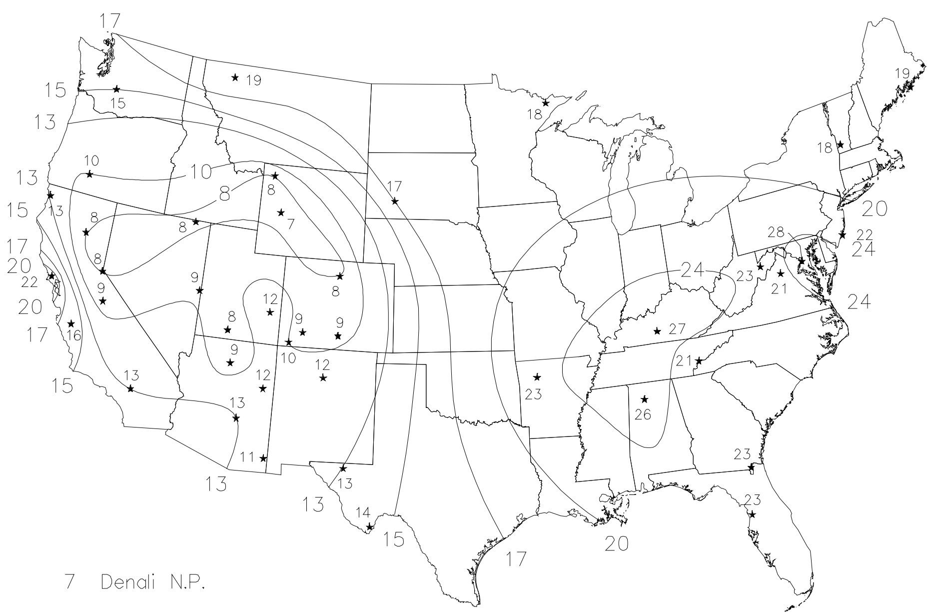

Figure 5.8 Average winter visibility impairment in deciviews calculated from total (Rayleigh included) reconstructed light extinction for the three-year period, March 1992 through February 1995, of IMPROVE.

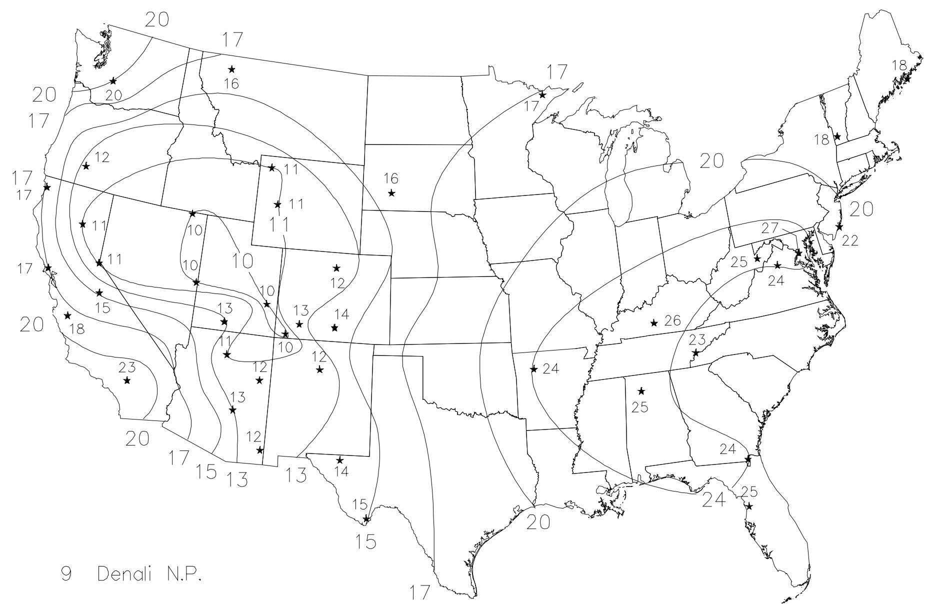

Figure 5.9 Average spring visibility impairment in deciviews calculated from total (Rayleigh included) reconstructed light extinction for the three-year period, March 1992 through February 1995, of IMPROVE.

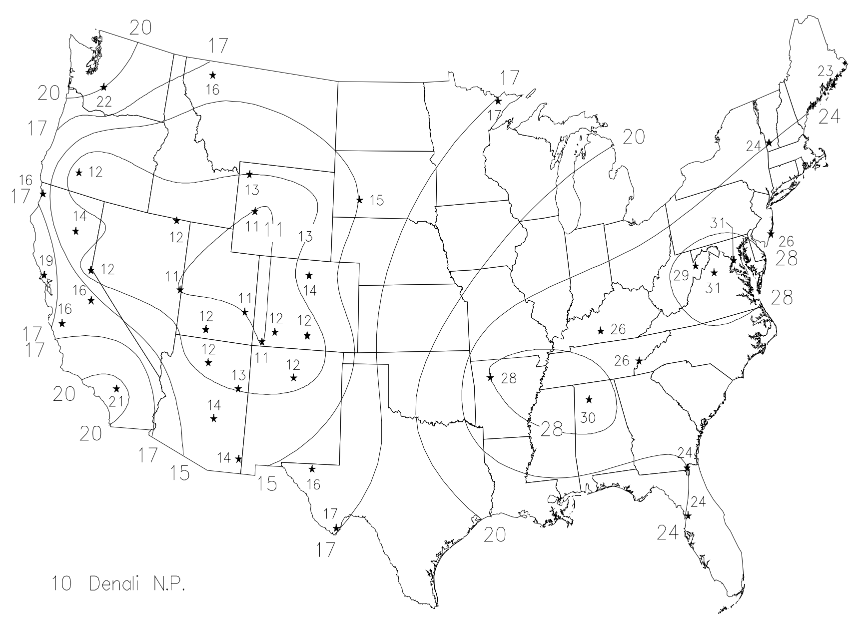

Figure 5.10 Average summer visibility impairment in deciviews calculated from total (Rayleigh included) reconstructed light extinction for the three-year period, March 1992 through February 1995, of IMPROVE.

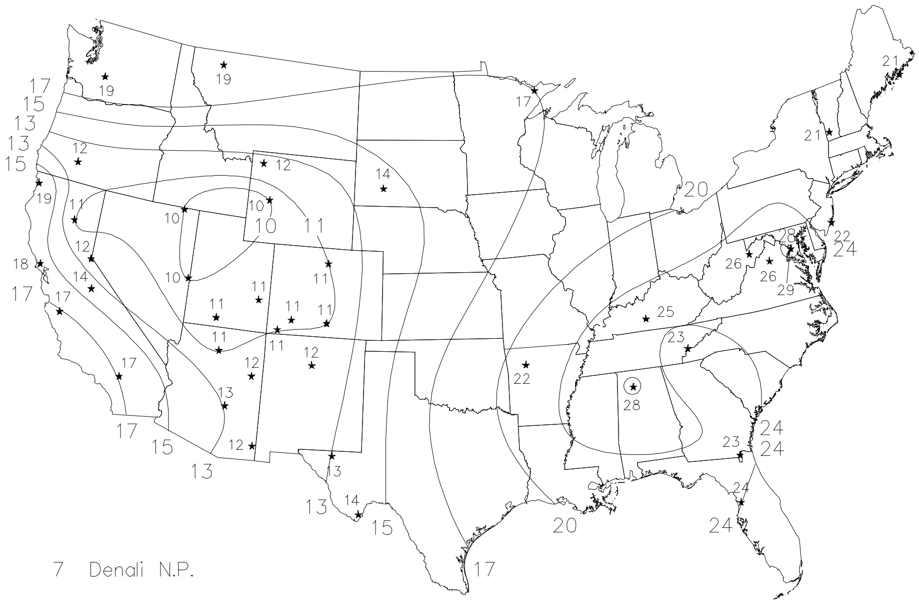

Figure 5.11 Average autumn visibility impairment in deciviews calculated from total (Rayleigh included) reconstructed light extinction for the three-year period, March 1992 through February 1995, of IMPROVE.