

CHAPTER 5: See the Graphic Viewer for the latest trends

TRENDS ANALYSIS

Only recently has the IMPROVE aerosol network, initiated in March 1988, matured to a point where long-term trends of average ambient aerosol concentrations and reconstructed extinction can be assessed. There is now sufficient data to also examine trends in the aerosol concentrations and extinction for the clear and hazy days.

Characterization of trends, however, with only 11 years of data, can be a highly subjective exercise such that slopes and their significance can vary depending on the technique employed. Using ordinary least squares (OLS) regression approach is questionable with such small data sets as the results can be highly influenced by outliers plus standard deviations and standard errors can be large. In another approach, developed by Theil [1950], outlier data points do not significantly influence the results. Slopes of trend lines are calculated for each site by first finding the slope between all possible pairs of data points, then sorting the results from smallest or most negative to the largest and finally, the median value in the case of an odd number of pairs is selected as the estimated slope, or in the case of even number of pairs the average of the two slopes that straddle the median is used as the estimate. The significance of the Theil slope is found by assuming that the “true” slope is zero, then calculating the probability that the estimated slope occurred by chance. This technique has also been adopted by the Environmental Protection Agency (EPA) for estimating trends in air quality data.

In this report, we examine trends of the distribution of $PM_{2.5}$ mass concentrations, reconstructed extinction and deciview, and their associated constituents at the IMPROVE sites with eleven years of data.

The trends are examined by sorting each year's data into three groups based on the cumulative frequency of occurrence of $PM_{2.5}$: lowest fine mass days, 0–20%; median fine mass days, 40–60%; and highest fine mass days, 80–100%. Each group is then labeled by its mid point (e.g., 10th, 50th, 90th percentiles). After sorting each group's average concentrations of $PM_{2.5}$ and selecting the associated principal aerosol species, scattering and/or absorption of each species, reconstructed light extinction, and deciview are calculated.

In addition to statistical concerns, there is always the underlying year-to-year variability due to meteorology. While the importance of meteorologically induced trends cannot be ignored, when trying to deduce the effect of emission changes, the role of meteorology is beyond the scope of this discussion.

The Theil slope estimates for a five-year rolling average of fine mass and deciview for the 90, 50, and 10 percentile groups are presented in Table 5.1. Each slope is paired with the probability for rejection. Plots of the data that went into the regressions can be found in Appendix B.

Table 5.1 *The Theil slope estimates for a five-year rolling average of fine mass and deciview for the 90, 50, and 10 percentile groups. Each slope is paired with the probability for rejection.*

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
ACADIA NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-67.05	0.015	-133.08	0.000	-187.13	0.001
Sulfate	-39.21	0.005	-81.73	0.001	-95.43	0.191
Nitrate	-6.84	0.000	-10.01	0.015	-30.21	0.001
Organic	-11.12	0.119	-13.00	0.119	-69.13	0.015
Light-Absorbing Carbon	-11.20	0.000	-25.08	0.000	-35.58	0.000
Fine Soil	2.72	0.068	0.06	0.500	-1.32	0.500
Coarse Mass	-72.01	0.191	153.37	0.068	261.62	0.015
Particle extinction (1/Mm/yr)						
Total	-0.67	0.005	-1.21	0.000	-1.34	0.001
Sulfate	-0.41	0.005	-0.85	0.001	-1.00	0.191
Nitrate	-0.07	0.000	-0.10	0.015	-0.32	0.001
Organic	-0.04	0.119	-0.05	0.119	-0.28	0.015
Absorption	-0.11	0.000	-0.25	0.000	-0.36	0.000
Soil	0.00	0.068	0.00	0.500	0.00	0.500
Coarse	-0.04	0.191	0.09	0.068	0.16	0.015
Deciview (dv/yr)	-0.22	0.005	-0.23	0.000	-0.12	0.005
BADLANDS NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-46.29	0.001	-103.81	0.005	39.25	0.119
Sulfate	-7.60	0.281	-0.36	0.500	-8.24	0.386
Nitrate	2.93	0.191	-27.60	0.015	148.86	0.005
Organic	-18.98	0.001	-23.26	0.068	9.29	0.191
Light-Absorbing Carbon	0.17	0.500	-1.22	0.191	-5.79	0.191
Fine Soil	-20.13	0.005	-38.28	0.001	-97.54	0.001
Coarse Mass	11.61	0.500	-35.88	0.281	-280.13	0.001
Particle extinction (1/Mm/yr)						
Total	-0.12	0.035	-0.40	0.005	0.75	0.035
Sulfate	-0.06	0.281	0.00	0.500	-0.06	0.386
Nitrate	0.02	0.191	-0.21	0.015	1.13	0.005
Organic	-0.08	0.001	-0.09	0.068	0.04	0.191
Absorption	0.00	0.500	-0.01	0.191	-0.06	0.191
Soil	-0.02	0.005	-0.04	0.001	-0.10	0.001
Coarse	0.01	0.500	-0.02	0.281	-0.17	0.001
Deciview (dv/yr)	-0.05	0.068	-0.12	0.005	0.10	0.015

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
BANDELIER NATIONAL MONUMENT						
Particle mass (ng/m³/yr)						
Fine Mass	-64.47	0.005	-72.32	0.000	70.28	0.035
Sulfate	-35.89	0.005	-5.60	0.281	26.47	0.015
Nitrate	-1.35	0.119	-5.59	0.015	1.50	0.386
Organic	-23.71	0.015	-55.13	0.005	-14.73	0.068
Light-Absorbing Carbon	5.54	0.000	-4.27	0.015	-5.28	0.015
Fine Soil	-13.31	0.035	-10.30	0.191	41.48	0.005
Coarse Mass	-261.48	0.015	-310.53	0.119	139.00	0.035
Particle extinction (1/Mm/yr)						
Total	-0.35	0.005	-0.46	0.001	0.19	0.035
Sulfate	-0.20	0.005	-0.03	0.281	0.15	0.015
Nitrate	-0.01	0.119	-0.03	0.015	0.01	0.386
Organic	-0.10	0.015	-0.22	0.005	-0.06	0.068
Absorption	0.06	0.000	-0.04	0.015	-0.05	0.015
Soil	-0.01	0.035	-0.01	0.191	0.04	0.005
Coarse	-0.16	0.015	-0.19	0.119	0.08	0.035
Deciview (dv/yr)	-0.17	0.015	-0.18	0.001	0.07	0.068
BIG BEND NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	26.97	0.191	51.01	0.035	285.08	0.001
Sulfate	-0.34	0.500	37.85	0.001	109.93	0.005
Nitrate	-0.67	0.386	3.01	0.119	11.02	0.068
Organic	7.87	0.191	-16.11	0.005	21.63	0.119
Light-Absorbing Carbon	-0.67	0.500	-0.45	0.500	1.27	0.500
Fine Soil	21.49	0.035	27.77	0.035	116.61	0.005
Coarse Mass	-41.71	0.119	116.98	0.068	568.37	0.005
Particle extinction (1/Mm/yr)						
Total	0.00	0.500	0.20	0.005	1.29	0.005
Sulfate	0.00	0.500	0.19	0.001	0.55	0.005
Nitrate	0.00	0.386	0.02	0.119	0.06	0.068
Organic	0.03	0.191	-0.06	0.005	0.09	0.119
Absorption	-0.01	0.500	0.00	0.500	0.01	0.500
Soil	0.02	0.035	0.03	0.035	0.12	0.005
Coarse	-0.03	0.119	0.07	0.068	0.34	0.005
Deciview (dv/yr)	0.00	0.500	0.07	0.005	0.23	0.005
BRYCE CANYON NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-23.83	0.005	-8.96	0.035	85.89	0.015
Sulfate	-15.18	0.005	-21.00	0.015	7.17	0.281
Nitrate	3.21	0.005	1.59	0.068	-9.23	0.068
Organic	-10.38	0.035	4.35	0.386	80.55	0.015
Light-Absorbing Carbon	3.79	0.005	3.50	0.068	12.24	0.015
Fine Soil	-7.93	0.035	2.26	0.191	-1.47	0.500
Coarse Mass	-124.55	0.035	-137.06	0.035	-203.40	0.001
Particle extinction (1/Mm/yr)						
Total	-0.18	0.035	-0.17	0.005	0.39	0.068
Sulfate	-0.11	0.005	-0.15	0.015	0.05	0.281
Nitrate	0.02	0.005	0.01	0.068	-0.07	0.068
Organic	-0.04	0.035	0.02	0.386	0.32	0.015
Absorption	0.04	0.005	0.04	0.068	0.12	0.015

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
Soil	-0.01	0.035	0.00	0.191	0.00	0.500
Coarse	-0.08	0.035	-0.08	0.035	-0.12	0.001
Deciview (dv/yr)	-0.10	0.035	-0.08	0.015	0.10	0.035
BRIDGER WILDERNESS AREA						
Particle mass (ng/m³/yr)						
Fine Mass	0.11	0.500	-34.08	0.035	-18.54	0.500
Sulfate	-9.31	0.068	-5.79	0.068	-20.63	0.015
Nitrate	0.11	0.500	-0.98	0.386	-0.14	0.500
Organic	4.12	0.119	-28.14	0.035	48.89	0.068
Light-Absorbing Carbon	3.36	0.001	4.66	0.015	9.22	0.068
Fine Soil	-2.65	0.015	-10.34	0.068	-43.10	0.015
Coarse Mass	-85.61	0.068	-69.01	0.035	-280.96	0.015
Particle extinction (1/Mm/yr)						
Total	-0.08	0.191	-0.14	0.035	-0.13	0.191
Sulfate	-0.06	0.068	-0.04	0.068	-0.13	0.015
Nitrate	0.00	0.500	-0.01	0.386	0.00	0.500
Organic	0.02	0.119	-0.11	0.035	0.20	0.068
Absorption	0.03	0.001	0.05	0.015	0.09	0.068
Soil	0.00	0.015	-0.01	0.068	-0.04	0.015
Coarse	-0.05	0.068	-0.04	0.035	-0.17	0.015
Deciview (dv/yr)	-0.05	0.191	-0.07	0.068	-0.03	0.386
CANYONLANDS NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-64.44	0.005	-83.14	0.005	-99.11	0.001
Sulfate	-43.08	0.005	-37.82	0.005	-27.35	0.001
Nitrate	-5.33	0.068	-4.75	0.119	-28.09	0.015
Organic	-10.52	0.015	-27.43	0.005	-16.74	0.281
Light-Absorbing Carbon	4.66	0.001	0.39	0.281	3.58	0.119
Fine Soil	-15.45	0.005	-15.83	0.000	-20.39	0.119
Coarse Mass	4.68	0.386	-73.71	0.386	-152.11	0.068
Particle extinction (1/Mm/yr)						
Total	-0.26	0.035	-0.34	0.015	-0.49	0.015
Sulfate	-0.22	0.005	-0.19	0.005	-0.14	0.001
Nitrate	-0.03	0.068	-0.02	0.119	-0.14	0.015
Organic	-0.04	0.015	-0.11	0.005	-0.07	0.281
Absorption	0.05	0.001	0.00	0.281	0.04	0.119
Soil	-0.02	0.005	-0.02	0.000	-0.02	0.119
Coarse	0.00	0.386	-0.04	0.386	-0.09	0.068
Deciview (dv/yr)	-0.13	0.035	-0.13	0.015	-0.14	0.015
CHIRICAHUA NATIONAL MONUMENT						
Particle mass (ng/m³/yr)						
Fine Mass	30.24	0.068	25.91	0.119	96.33	0.005
Sulfate	-1.49	0.386	30.67	0.005	66.31	0.015
Nitrate	4.48	0.015	3.91	0.000	9.47	0.068
Organic	13.92	0.015	-23.18	0.035	-6.36	0.500
Light-Absorbing Carbon	4.16	0.001	-1.12	0.119	-2.61	0.281
Fine Soil	8.09	0.068	9.51	0.119	32.57	0.001
Coarse Mass	156.51	0.005	-22.06	0.119	-96.24	0.191
Particle extinction (1/Mm/yr)						
Total	0.23	0.000	0.08	0.119	0.27	0.015
Sulfate	-0.01	0.386	0.16	0.005	0.35	0.015

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
Nitrate	0.02	0.015	0.02	0.000	0.05	0.068
Organic	0.06	0.015	-0.09	0.035	-0.03	0.500
Absorption	0.04	0.001	-0.01	0.119	-0.03	0.281
Soil	0.01	0.068	0.01	0.119	0.03	0.001
Coarse	0.09	0.005	-0.01	0.119	-0.06	0.191
Deciview (dv/yr)	0.10	0.001	0.03	0.119	0.07	0.035
CRATER LAKE NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-48.14	0.001	-48.84	0.035	112.28	0.015
Sulfate	-9.07	0.005	-9.38	0.119	-9.80	0.191
Nitrate	-0.72	0.281	-2.88	0.119	4.34	0.386
Organic	-27.45	0.001	-38.29	0.015	69.10	0.015
Light-Absorbing Carbon	-0.73	0.500	4.26	0.191	9.92	0.119
Fine Soil	-8.49	0.000	-7.92	0.015	30.49	0.005
Coarse Mass	-97.56	0.035	-98.77	0.015	-264.69	0.035
Particle extinction (1/Mm/yr)						
Total	-0.27	0.001	-0.24	0.068	0.20	0.191
Sulfate	-0.07	0.005	-0.07	0.119	-0.08	0.191
Nitrate	-0.01	0.281	-0.02	0.119	0.03	0.386
Organic	-0.11	0.001	-0.15	0.015	0.28	0.015
Absorption	-0.01	0.500	0.04	0.191	0.10	0.119
Soil	-0.01	0.000	-0.01	0.015	0.03	0.005
Coarse	-0.06	0.035	-0.06	0.015	-0.16	0.035
Deciview (dv/yr)	-0.18	0.005	-0.10	0.119	0.05	0.119
DENALI NATIONAL PARK AND PRESERVE						
Particle mass (ng/m³/yr)						
Fine Mass	-18.55	0.015	-19.61	0.119	-48.62	0.191
Sulfate	-6.29	0.035	-19.14	0.068	-14.08	0.035
Nitrate	-0.11	0.500	-0.06	0.281	-1.89	0.119
Organic	-14.96	0.068	-3.98	0.281	1.29	0.500
Light-Absorbing Carbon	1.73	0.015	5.78	0.001	1.27	0.500
Fine Soil	-1.48	0.119	-11.07	0.015	-40.68	0.005
Coarse Mass	-108.05	0.191	-95.48	0.386	-290.46	0.015
Particle extinction (1/Mm/yr)						
Total	-0.12	0.191	-0.13	0.068	-0.34	0.119
Sulfate	-0.05	0.035	-0.16	0.068	-0.12	0.035
Nitrate	0.00	0.500	0.00	0.281	-0.02	0.119
Organic	-0.06	0.068	-0.02	0.281	0.01	0.500
Absorption	0.02	0.015	0.06	0.001	0.01	0.500
Soil	0.00	0.119	-0.01	0.015	-0.04	0.005
Coarse	-0.07	0.191	-0.06	0.386	-0.17	0.015
Deciview (dv/yr)	-0.08	0.191	-0.08	0.119	-0.10	0.191
GLACIER NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-73.28	0.005	-135.39	0.001	-134.39	0.035
Sulfate	-27.31	0.005	4.06	0.281	-36.23	0.005
Nitrate	-3.91	0.015	-3.01	0.015	-23.47	0.119
Organic	-23.93	0.035	-89.58	0.000	-50.96	0.281
Light-Absorbing Carbon	4.92	0.015	-2.24	0.281	-26.02	0.001
Fine Soil	-11.74	0.005	-28.37	0.000	-30.93	0.281
Coarse Mass	-222.54	0.015	-346.44	0.015	-190.79	0.281

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
Particle extinction (1/Mm/yr)						
Total	-0.72	0.005	-0.70	0.005	-1.30	0.015
Sulfate	-0.33	0.005	0.05	0.281	-0.43	0.005
Nitrate	-0.05	0.015	-0.04	0.015	-0.28	0.119
Organic	-0.10	0.035	-0.36	0.000	-0.20	0.281
Absorption	0.05	0.015	-0.02	0.281	-0.26	0.001
Soil	-0.01	0.005	-0.03	0.000	-0.03	0.281
Coarse	-0.13	0.015	-0.21	0.015	-0.11	0.281
Deciview (dv/yr)	-0.28	0.005	-0.17	0.015	-0.20	0.015
GREAT SAND DUNES NATIONAL MONUMENT						
Particle mass (ng/m³/yr)						
Fine Mass	-71.62	0.005	-84.16	0.005	-24.14	0.386
Sulfate	-15.95	0.015	0.80	0.386	18.05	0.015
Nitrate	-9.46	0.005	-3.13	0.191	0.72	0.500
Organic	-42.01	0.005	-42.24	0.001	10.48	0.386
Light-Absorbing Carbon	-0.55	0.119	-1.08	0.035	7.75	0.015
Fine Soil	-4.32	0.281	-37.62	0.015	-35.85	0.119
Coarse Mass	-294.48	0.001	-514.94	0.001	278.93	0.191
Particle extinction (1/Mm/yr)						
Total	-0.53	0.001	-0.56	0.001	0.30	0.035
Sulfate	-0.11	0.015	0.01	0.386	0.12	0.015
Nitrate	-0.06	0.005	-0.02	0.191	0.01	0.500
Organic	-0.17	0.005	-0.17	0.001	0.04	0.386
Absorption	-0.01	0.119	-0.01	0.035	0.08	0.015
Soil	0.00	0.281	-0.04	0.015	-0.04	0.119
Coarse	-0.18	0.001	-0.31	0.001	0.17	0.191
Deciview (dv/yr)	-0.30	0.001	-0.20	0.001	0.10	0.068
GREAT SMOKY MOUNTAINS NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	0.60	0.500	-140.01	0.005	200.81	0.015
Sulfate	9.88	0.191	-98.08	0.035	259.17	0.005
Nitrate	-11.90	0.015	-34.91	0.001	-30.52	0.005
Organic	-15.89	0.386	-25.53	0.119	3.01	0.386
Light-Absorbing Carbon	2.63	0.386	-10.92	0.191	-15.09	0.068
Fine Soil	5.82	0.191	-5.39	0.191	27.64	0.281
Coarse Mass	4.13	0.500	44.85	0.281	-143.56	0.191
Particle extinction (1/Mm/yr)						
Total	0.02	0.500	-1.27	0.005	2.23	0.035
Sulfate	0.10	0.191	-0.96	0.035	2.53	0.005
Nitrate	-0.12	0.015	-0.34	0.001	-0.30	0.005
Organic	-0.07	0.386	-0.10	0.119	0.01	0.386
Absorption	0.03	0.386	-0.11	0.191	-0.15	0.068
Soil	0.01	0.191	-0.01	0.191	0.03	0.281
Coarse	0.00	0.500	0.03	0.281	-0.09	0.191
Deciview (dv/yr)	0.00	0.500	-0.15	0.005	0.10	0.068
GUADALUPE MOUNTAINS NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-2.60	0.386	35.69	0.119	281.09	0.015
Sulfate	10.65	0.281	51.06	0.005	1.82	0.386
Nitrate	1.90	0.191	1.31	0.068	8.11	0.068
Organic	-15.98	0.000	-18.30	0.001	-25.90	0.068

Table 5.1 Continued.

Variable	Trend	Significance	Trend	Significance	Trend	Significance
	Coeff. Group 10	Group 10	Coeff. Group 50	Group 50	Coeff. Group 90	Group 90
Light-Absorbing Carbon	2.07	0.005	0.82	0.005	-7.36	0.015
Fine Soil	3.86	0.191	-4.24	0.500	276.83	0.000
Coarse	-42.21	0.068	-45.08	0.191	98.27	0.191
Particle extinction (1/Mm/yr)						
Total	-0.02	0.500	0.23	0.191	0.31	0.281
Sulfate	0.06	0.281	0.28	0.005	0.01	0.386
Nitrate	0.010	0.191	0.01	0.068	0.05	0.068
Organic	-0.06	0.000	-0.07	0.001	-0.10	0.068
Absorption	0.02	0.005	0.01	0.005	-0.07	0.015
Soil	0.00	0.191	0.00	0.500	0.28	0.000
Coarse	-0.03	0.068	-0.03	0.191	0.06	0.191
Deciview (dv/yr)	0.00	0.500	0.07	0.191	0.05	0.281
JARBIDGE WILDERNESS AREA						
Particle mass (ng/m³/yr)						
Fine Mass	26.72	0.035	-12.37	0.386	173.22	0.035
Sulfate	-3.20	0.281	-11.13	0.015	-16.10	0.005
Nitrate	4.60	0.068	1.94	0.068	9.62	0.191
Organic	18.53	0.015	2.42	0.386	127.31	0.015
Light-Absorbing Carbon	3.41	0.001	4.83	0.005	16.93	0.005
Fine Soil	4.84	0.119	-7.64	0.500	25.08	0.191
Coarse Mass	-69.90	0.068	-50.04	0.068	142.48	0.068
Particle extinction (1/Mm/yr)						
Total	0.05	0.281	-0.02	0.386	0.81	0.035
Sulfate	-0.02	0.281	-0.06	0.015	-0.09	0.005
Nitrate	0.03	0.068	0.01	0.068	0.06	0.191
Organic	0.07	0.015	0.01	0.386	0.51	0.015
Absorption	0.03	0.001	0.05	0.005	0.17	0.005
Soil	0.01	0.119	-0.01	0.500	0.03	0.191
Coarse	-0.04	0.068	-0.03	0.068	0.09	0.068
Deciview (dv/yr)	0.03	0.281	0.00	0.500	0.23	0.035
LASSEN VOLCANIC NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-20.83	0.035	-10.56	0.386	138.58	0.015
Sulfate	-4.73	0.281	18.54	0.001	26.57	0.015
Nitrate	4.91	0.015	10.32	0.035	10.21	0.035
Organic	-19.72	0.035	-49.78	0.015	42.83	0.015
Light-Absorbing Carbon	0.78	0.119	-4.44	0.015	1.32	0.500
Fine Soil	-1.82	0.035	7.02	0.191	50.85	0.001
Coarse Mass	-239.74	0.001	-372.94	0.005	-616.48	0.000
Particle extinction (1/Mm/yr)						
Total	-0.22	0.001	-0.21	0.035	0.20	0.191
Sulfate	-0.04	0.281	0.14	0.001	0.20	0.015
Nitrate	0.04	0.015	0.08	0.035	0.08	0.035
Organic	-0.08	0.035	-0.20	0.015	0.17	0.015
Absorption	0.01	0.119	-0.04	0.015	0.01	0.500
Soil	0.00	0.035	0.01	0.191	0.05	0.001
Coarse	-0.14	0.001	-0.22	0.005	-0.37	0.000
Deciview (dv/yr)	-0.15	0.015	-0.10	0.035	0.05	0.281
MESA VERDE NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	11.24	0.281	58.92	0.035	147.62	0.005

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
Sulfate	-17.53	0.015	25.44	0.005	10.46	0.191
Nitrate	2.51	0.119	-1.64	0.119	13.39	0.001
Organic	10.21	0.068	-0.64	0.500	6.63	0.119
Light-Absorbing Carbon	11.02	0.000	6.57	0.015	5.81	0.119
Fine Soil	3.74	0.068	23.19	0.035	123.21	0.001
Coarse Mass	-262.62	0.001	-106.10	0.191	-29.78	0.386
Particle extinction (1/Mm/yr)						
Total	-0.13	0.119	0.17	0.005	0.30	0.035
Sulfate	-0.10	0.015	0.14	0.005	0.06	0.191
Nitrate	0.01	0.119	-0.01	0.119	0.07	0.001
Organic	0.04	0.068	0.00	0.500	0.03	0.119
Absorption	0.11	0.000	0.07	0.015	0.06	0.119
Soil	0.00	0.068	0.02	0.035	0.12	0.001
Coarse	-0.16	0.001	-0.06	0.191	-0.02	0.386
Deciview (dv/yr)	-0.08	0.119	0.05	0.005	0.10	0.015
MOUNT RAINIER NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-47.90	0.015	-139.61	0.005	-405.17	0.001
Sulfate	-24.41	0.001	-10.19	0.281	-120.82	0.035
Nitrate	-3.45	0.015	3.40	0.119	-25.01	0.005
Organic	-15.75	0.068	-100.30	0.001	-216.11	0.000
Light-Absorbing Carbon	-5.70	0.005	-23.66	0.000	-52.09	0.001
Fine Soil	-0.93	0.119	-8.92	0.005	5.57	0.119
Coarse Mass	-116.98	0.119	-66.25	0.119	-258.13	0.035
Particle extinction (1/Mm/yr)						
Total	-0.74	0.005	-0.81	0.068	-4.33	0.005
Sulfate	-0.47	0.001	-0.20	0.281	-2.32	0.035
Nitrate	-0.07	0.015	0.07	0.119	-0.48	0.005
Organic	-0.06	0.068	-0.40	0.001	-0.86	0.000
Absorption	-0.06	0.005	-0.24	0.000	-0.52	0.001
Soil	0.00	0.119	-0.01	0.005	0.01	0.119
Coarse	-0.07	0.119	-0.04	0.119	-0.16	0.035
Deciview (dv/yr)	-0.32	0.015	-0.15	0.119	-0.42	0.005
PETRIFIED FOREST NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-92.75	0.001	-93.89	0.005	-15.91	0.386
Sulfate	-35.45	0.005	-23.79	0.015	5.79	0.500
Nitrate	-0.67	0.386	-2.92	0.119	-1.54	0.191
Organic	-27.74	0.015	-29.74	0.015	-29.29	0.015
Light-Absorbing Carbon	-9.67	0.001	-25.03	0.000	-21.21	0.000
Fine Soil	-21.01	0.001	-6.21	0.386	19.27	0.281
Coarse Mass	-82.76	0.068	-216.12	0.015	-214.62	0.068
Particle extinction (1/Mm/yr)						
Total	-0.50	0.005	-0.67	0.005	-0.50	0.035
Sulfate	-0.19	0.005	-0.13	0.015	0.03	0.500
Nitrate	0.00	0.386	-0.02	0.119	-0.01	0.191
Organic	-0.11	0.015	-0.12	0.015	-0.12	0.015
Absorption	-0.10	0.001	-0.25	0.000	-0.21	0.000
Soil	-0.02	0.001	-0.01	0.386	0.02	0.281
Coarse	-0.05	0.068	-0.13	0.015	-0.13	0.068
Deciview (dv/yr)	-0.20	0.005	-0.25	0.005	-0.13	0.035

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
<i>PINNACLES NATIONAL MONUMENT</i>						
Particle mass (ng/m³/yr)						
Fine Mass	-85.05	0.015	-201.24	0.000	-378.19	0.000
Sulfate	-29.08	0.001	-49.38	0.001	-42.68	0.005
Nitrate	-38.92	0.000	-70.04	0.000	-215.57	0.000
Organic	-3.40	0.191	-78.71	0.000	-89.93	0.001
Light-Absorbing Carbon	-1.19	0.191	-13.60	0.005	-27.65	0.000
Fine Soil	-7.48	0.005	-3.46	0.386	11.77	0.035
Coarse Mass	-268.10	0.015	-409.69	0.000	-234.49	0.068
Particle extinction (1/Mm/yr)						
Total	-0.77	0.001	-1.61	0.000	-2.76	0.000
Sulfate	-0.22	0.001	-0.36	0.001	-0.32	0.005
Nitrate	-0.29	0.000	-0.52	0.000	-1.59	0.000
Organic	-0.01	0.191	-0.32	0.000	-0.36	0.001
Absorption	-0.01	0.191	-0.14	0.005	-0.28	0.000
Soil	-0.01	0.005	0.00	0.386	0.01	0.035
Coarse	-0.16	0.015	-0.25	0.000	-0.14	0.068
Deciview (dv/yr)	-0.30	0.001	-0.37	0.001	-0.42	0.000
<i>POINT REYES NATIONAL SEASHORE</i>						
Particle mass (ng/m³/yr)						
Fine Mass	19.33	0.035	-117.00	0.035	-500.74	0.001
Sulfate	-0.08	0.500	-21.15	0.015	23.93	0.035
Nitrate	2.05	0.386	-24.50	0.068	-302.31	0.005
Organics	20.47	0.015	-83.76	0.035	-246.62	0.001
Light-Absorbing Carbon	1.94	0.035	-11.87	0.005	-52.65	0.001
Fine Soil	1.22	0.035	7.49	0.005	2.67	0.191
Coarse Mass	-798.63	0.000	-542.54	0.005	-653.07	0.005
Particle extinction (1/Mm/yr)						
Total	-0.38	0.035	-1.21	0.015	-5.09	0.005
Sulfate	0.00	0.500	-0.27	0.015	0.31	0.035
Nitrate	0.03	0.386	-0.32	0.068	-3.89	0.005
Organic	0.08	0.015	-0.34	0.035	-0.99	0.001
Absorption	0.02	0.035	-0.12	0.005	-0.53	0.001
Soil	0.00	0.035	0.01	0.005	0.00	0.191
Coarse	-0.48	0.000	-0.33	0.005	-0.39	0.005
Deciview (dv/yr)	-0.12	0.119	-0.25	0.015	-0.50	0.005
<i>REDWOOD NATIONAL PARK</i>						
Particle mass (ng/m³/yr)						
Fine Mass	-40.78	0.001	-118.24	0.000	-233.53	0.000
Sulfate	-9.21	0.001	-10.25	0.015	-39.34	0.001
Nitrate	-4.20	0.001	-10.73	0.000	-20.40	0.015
Organic	-24.51	0.001	-94.26	0.000	-155.02	0.000
Light-Absorbing Carbon	-0.13	0.500	-12.32	0.000	-23.85	0.000
Fine Soil	2.66	0.015	3.67	0.068	0.50	0.500
Coarse Mass	-154.94	0.005	-11.14	0.500	-161.85	0.000
Particle extinction (1/Mm/yr)						
Total	-0.57	0.001	-1.02	0.000	-2.51	0.000
Sulfate	-0.24	0.001	-0.26	0.015	-1.01	0.001
Nitrate	-0.11	0.001	-0.28	0.000	-0.53	0.015
Organic	-0.10	0.001	-0.38	0.000	-0.62	0.000
Absorption	0.00	0.500	-0.12	0.000	-0.24	0.000

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
Soil	0.00	0.015	0.00	0.068	0.00	0.500
Coarse	-0.09	0.005	-0.01	0.500	-0.10	0.000
Deciview (dv/yr)	-0.23	0.005	-0.20	0.001	-0.27	0.000
ROCKY MOUNTAIN NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-26.83	0.005	-66.59	0.001	20.03	0.191
Sulfate	-17.20	0.001	-22.72	0.015	-19.29	0.015
Nitrate	-8.38	0.005	-9.31	0.119	-12.18	0.281
Organic	-7.51	0.119	-43.85	0.015	10.08	0.386
Light-Absorbing Carbon	6.90	0.001	3.50	0.015	4.72	0.119
Fine Soil	-4.44	0.386	-1.49	0.386	38.86	0.068
Coarse Mass	94.15	0.281	-70.26	0.281	-76.56	0.119
Particle extinction (1/Mm/yr)						
Total	-0.05	0.119	-0.38	0.005	-0.08	0.068
Sulfate	-0.10	0.001	-0.13	0.015	-0.11	0.015
Nitrate	-0.05	0.005	-0.05	0.119	-0.07	0.281
Organic	-0.03	0.119	-0.18	0.015	0.04	0.386
Absorption	0.07	0.001	0.04	0.015	0.05	0.119
Soil	0.00	0.386	0.00	0.386	0.04	0.068
Coarse	0.06	0.281	-0.04	0.281	-0.05	0.119
Deciview (dv/yr)	-0.04	0.191	-0.15	0.015	0.00	0.191
SAN GORGONIO WILDERNESS AREA						
Particle mass (ng/m³/yr)						
Fine Mass	36.67	0.281	-227.48	0.005	-852.61	0.000
Sulfate	3.39	0.191	4.91	0.500	-78.48	0.000
Nitrate	9.95	0.191	-90.74	0.005	-516.36	0.005
Organic	19.58	0.035	-55.48	0.035	-142.23	0.001
Light-Absorbing Carbon	-1.82	0.119	-11.65	0.015	-35.87	0.015
Fine Soil	12.85	0.119	-75.56	0.015	-60.51	0.001
Coarse Mass	-107.78	0.191	-687.65	0.015	-1113.99	0.000
Particle extinction (1/Mm/yr)						
Total	0.15	0.281	-1.46	0.015	-5.56	0.000
Sulfate	0.02	0.191	0.03	0.500	-0.52	0.000
Nitrate	0.07	0.191	-0.60	0.005	-3.42	0.005
Organic	0.08	0.035	-0.22	0.035	-0.57	0.001
Absorption	-0.02	0.119	-0.12	0.015	-0.36	0.015
Soil	0.01	0.119	-0.08	0.015	-0.06	0.001
Coarse	-0.07	0.191	-0.41	0.015	-0.67	0.000
Deciview (dv/yr)	0.03	0.386	-0.25	0.015	-0.50	0.001
SHENANDOAH NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-27.71	0.119	-268.58	0.001	-78.23	0.281
Sulfate	3.23	0.386	-155.40	0.005	-19.64	0.500
Nitrate	-10.16	0.386	-10.63	0.281	-6.08	0.191
Organic	-17.10	0.000	-76.79	0.005	26.94	0.500
Light-Absorbing Carbon	3.13	0.119	-20.23	0.005	-6.50	0.386
Fine Soil	-0.13	0.500	-1.35	0.191	-13.33	0.191
Coarse Mass	-51.55	0.281	-213.69	0.035	-353.70	0.000
Particle extinction (1/Mm/yr)						
Total	-0.03	0.386	-2.53	0.005	-0.41	0.191
Sulfate	0.04	0.386	-1.76	0.005	-0.22	0.500

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
Nitrate	-0.12	0.386	-0.12	0.281	-0.07	0.191
Organic	-0.07	0.000	-0.31	0.005	0.11	0.500
Absorption	0.03	0.119	-0.20	0.005	-0.07	0.386
Soil	0.00	0.500	0.00	0.191	-0.01	0.191
Coarse	-0.03	0.281	-0.13	0.035	-0.21	0.000
Deciview (dv/yr)	0.00	0.281	-0.27	0.005	0.00	0.281
TONTO NATIONAL MONUMENT						
Particle mass (ng/m³/yr)						
Fine Mass	-38.91	0.005	-41.63	0.015	-33.63	0.191
Sulfate	-36.22	0.001	-3.52	0.386	-19.57	0.119
Nitrate	5.74	0.191	3.07	0.191	-3.23	0.386
Organic	-15.13	0.005	-24.68	0.001	-21.05	0.281
Light-Absorbing Carbon	4.79	0.000	1.20	0.191	-8.39	0.068
Fine Soil	8.09	0.068	-17.50	0.191	16.72	0.068
Coarse Mass	-103.68	0.035	-268.76	0.005	106.70	0.191
Particle extinction (1/Mm/yr)						
Total	-0.25	0.001	-0.29	0.015	-0.21	0.191
Sulfate	-0.15	0.001	-0.02	0.386	-0.08	0.119
Nitrate	0.02	0.191	0.01	0.191	-0.01	0.386
Organic	-0.06	0.005	-0.10	0.001	-0.08	0.281
Absorption	0.05	0.000	0.01	0.191	-0.08	0.068
Soil	0.01	0.068	-0.02	0.191	0.02	0.068
Coarse	-0.06	0.035	-0.16	0.005	0.06	0.191
Deciview (dv/yr)	-0.10	0.005	-0.10	0.035	-0.05	0.281
WEMINUCHE WILDERNESS AREA						
Particle mass (ng/m³/yr)						
Fine Mass	4.37	0.386	-30.09	0.005	-49.95	0.035
Sulfate	1.39	0.386	-22.69	0.015	8.64	0.191
Nitrate	1.61	0.005	0.95	0.068	7.36	0.005
Organic	-2.80	0.191	-19.95	0.015	-40.24	0.119
Light-Absorbing Carbon	1.90	0.191	-1.22	0.015	-3.66	0.119
Fine Soil	-1.00	0.500	3.43	0.119	-11.57	0.281
Coarse Mass	-132.37	0.068	-104.45	0.068	-234.32	0.015
Particle extinction (1/Mm/yr)						
Total	-0.06	0.386	-0.25	0.035	-0.29	0.119
Sulfate	0.01	0.386	-0.16	0.015	0.06	0.191
Nitrate	0.01	0.005	0.01	0.068	0.05	0.005
Organic	-0.01	0.191	-0.08	0.015	-0.16	0.119
Absorption	0.02	0.191	-0.01	0.015	-0.04	0.119
Soil	0.00	0.500	0.00	0.119	-0.01	0.281
Coarse	-0.08	0.068	-0.06	0.068	-0.14	0.015
Deciview (dv/yr)	-0.02	0.500	-0.10	0.015	-0.10	0.068
YELLOWSTONE NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-108.85	0.000	-97.55	0.005	2.64	0.386
Sulfate	-20.43	0.000	-11.13	0.005	-0.49	0.500
Nitrate	-9.18	0.001	-11.87	0.015	0.69	0.386
Organic	-60.94	0.000	-15.82	0.015	108.14	0.035
Light-Absorbing Carbon	-4.89	0.001	-4.89	0.005	-3.44	0.191
Fine Soil	-11.17	0.005	-49.24	0.001	-63.64	0.068
Coarse Mass	-249.71	0.000	-150.36	0.000	-999.63	0.000

Table 5.1 Continued.

Variable	Trend Coeff. Group 10	Significance Group 10	Trend Coeff. Group 50	Significance Group 50	Trend Coeff. Group 90	Significance Group 90
Particle extinction (1/Mm/yr)						
Total	-0.65	0.000	-0.39	0.005	-0.28	0.035
Sulfate	-0.13	0.000	-0.07	0.005	0.00	0.500
Nitrate	-0.06	0.001	-0.08	0.015	0.00	0.386
Organic	-0.24	0.000	-0.06	0.015	0.43	0.035
Absorption	-0.05	0.001	-0.05	0.005	-0.03	0.191
Soil	-0.01	0.005	-0.05	0.001	-0.06	0.068
Coarse	-0.15	0.000	-0.09	0.000	-0.60	0.000
Deciview (dv/yr)	-0.36	0.000	-0.15	0.015	-0.05	0.068
YOSEMITE NATIONAL PARK						
Particle mass (ng/m³/yr)						
Fine Mass	-20.60	0.068	-24.45	0.068	270.37	0.035
Sulfate	-17.27	0.005	-15.74	0.191	-40.35	0.015
Nitrate	-5.40	0.015	-34.46	0.005	-39.00	0.005
Organic	4.86	0.386	18.59	0.005	302.48	0.035
Light-Absorbing Carbon	-1.48	0.068	-2.98	0.035	12.81	0.281
Fine Soil	-3.45	0.119	9.42	0.119	29.84	0.015
Coarse Mass	60.40	0.281	-239.78	0.015	-239.92	0.005
Particle extinction (1/Mm/yr)						
Total	-0.13	0.068	-0.34	0.035	0.72	0.068
Sulfate	-0.12	0.005	-0.10	0.191	-0.27	0.015
Nitrate	-0.04	0.015	-0.23	0.005	-0.26	0.005
Organic	0.02	0.386	0.07	0.005	1.21	0.035
Absorption	-0.02	0.068	-0.03	0.035	0.13	0.281
Soil	0.00	0.119	0.01	0.119	0.03	0.015
Coarse	0.04	0.281	-0.14	0.015	-0.14	0.005
Deciview (dv/yr)	-0.05	0.035	-0.12	0.015	0.13	0.119

5.1 SELECTED EXAMPLES OF TRENDS IN FINE MASS (PM_{2.5}) AND DECIVIEW

As an example, Figure 5.1 shows plots of the 10, 50, and 90 percentile groups at Pinnacles National Monument for both PM_{2.5} and deciview. The sample year (SYEAR) on the horizontal axis begins in March of each year. The horizontal axis for the five-year rolling average indicates the center year of the five-year period (CYEAR) on the x-axis. Pinnacles has significant negative slopes for all subgroups for both deciview and PM_{2.5}. For instance, both the trends for group 90 in PM_{2.5} and deciview (dv) are decreasing at a statistically significant rate of 378.2 ng/m³ and 0.42 dv/yr. Figure 5.2 shows the same plots for Badlands National Park, a site with a significant group 90 positive slope for visibility impairment of 0.10 dv/yr but a decreasing trend in the group 50 and group 10 percentile. Plots for Big Bend National Park (Figure 5.3) demonstrates statistically significant positive trends in deciview for group 90 and group 50, while group 10 trends are insignificant.

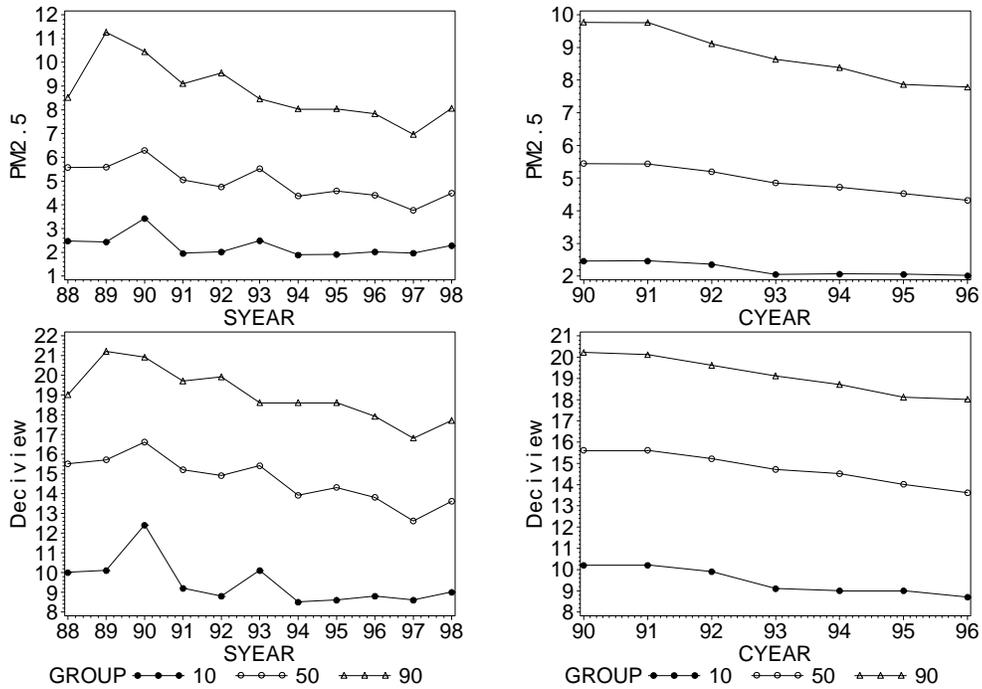


Figure 5.1 Trends in annual and five-year rolling averages for $PM_{2.5}$ and deciview for Pinnacles National Monument.

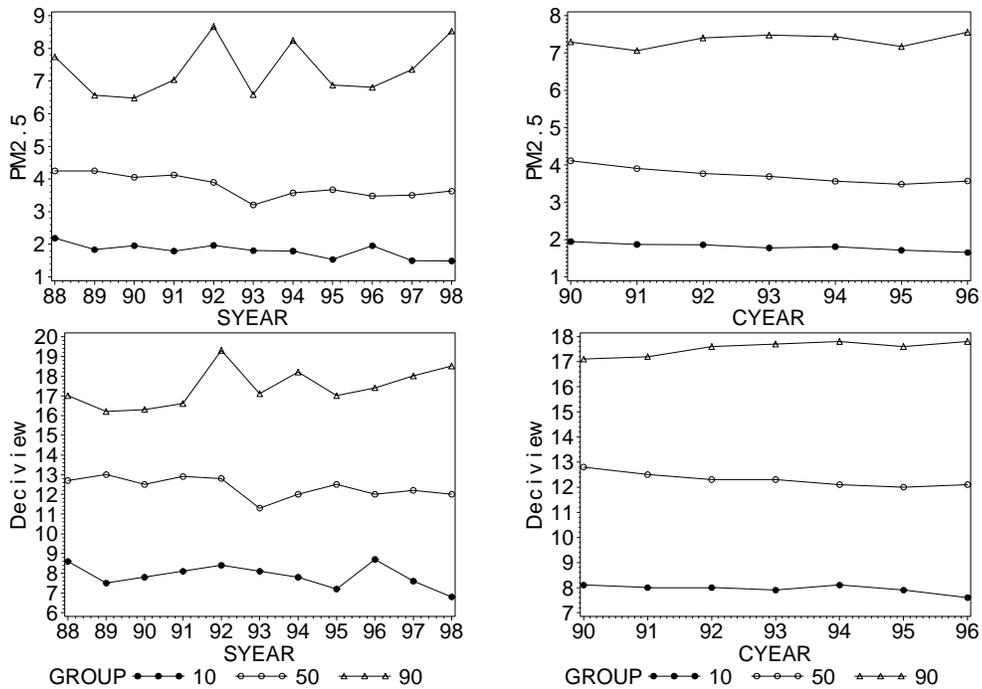


Figure 5.2 Trends in annual and five-year rolling averages for $PM_{2.5}$ and deciview for Badlands National Park.

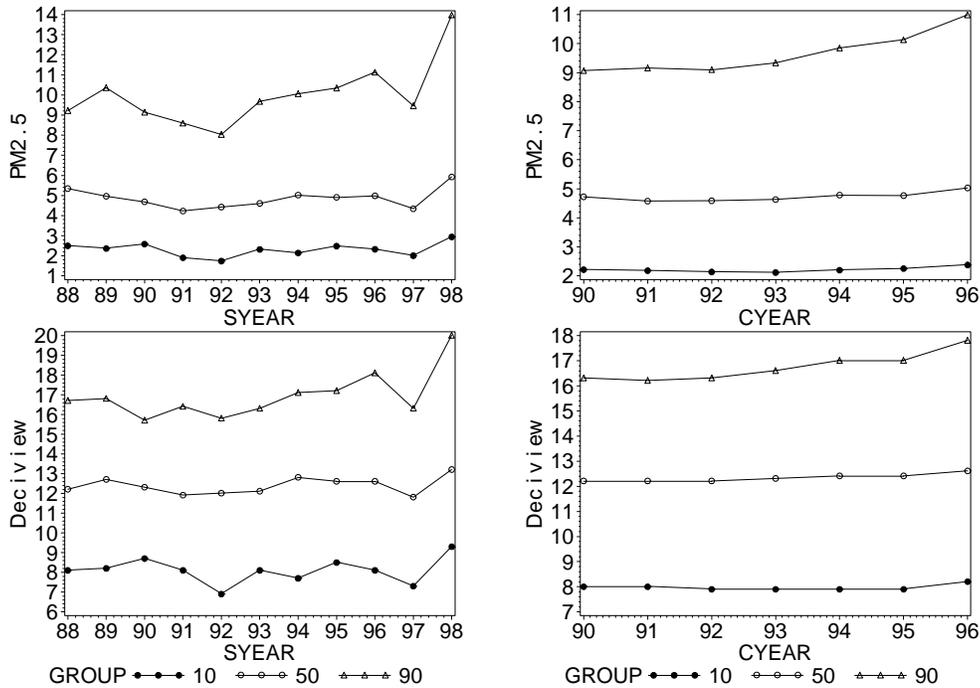


Figure 5.3 Trends in annual and five-year rolling averages for PM_{2.5} and deciview for Big Bend National Park.

5.2 TRENDS IN PM_{2.5} AND DECIVIEW ACROSS THE UNITED STATES

A map summarizing results of the trend analysis for the five-year rolling average deciviews and aerosol extinction are shown in Figures 5.4 and 5.5, respectively, for group 90. Similar presentations are made for sulfate, nitrate, organics, fine soil, and coarse mass in Figures 5.6, 5.7, 5.8, 5.9, and 5.10. (Additional maps of trends, using annual average data, in scattering and/or extinction for each species are presented in Appendix C.) The icons mark the site locations, a solid dot indicates an insignificant slope, the empty arrow indicates a positive or negative slope significant in the range of $0.05 < p \leq 0.1$ level of probability, and the solid arrow indicates a positive or negative slope that is significant at better than the 0.05 ($p \leq 0.05$) level. A decreasing trend in deciview or extinction indicates improving visibility, while an increasing trend indicates worsening visibility.

Referring to Figure 5.4, group 90, the haziest days, has nine sites with positive and significant slopes indicating the visibility is getting worse on the haziest days, eleven sites where visibility is improving at a statistically significant rate, and nine sites where visibility remains the same. A summary of these sites follows:

Northern Great Plains: Badlands National Park, representing the Northern Great Plains region, has a statistically significant slope of 0.10 dv/yr. The trend toward increased haziness is driven by an increase in nitrate primarily in 1992 and forward as shown in Figure 5.11. (Temporal plots of group 90, 50 and 10 annual average species extinctions for all monitoring sites are presented in Appendix D.)

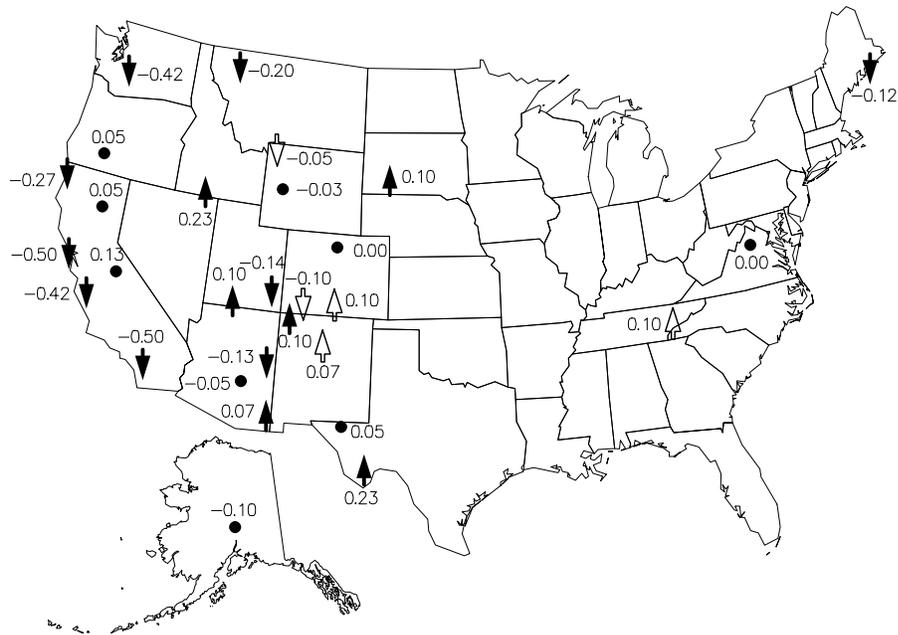


Figure 5.4 Map summarizing the trends in deciview (dv/yr) for group 90 (top 20% of fine mass) days. The icons mark the site locations, a solid dot indicates an insignificant slope, the empty arrow indicates a positive or negative slope that is significant in the range of $0.05 < p \leq 0.1$ level of probability, and the solid arrow indicates a positive or negative slope that is significant at better than 0.05 ($p \leq 0.05$) level of probability.

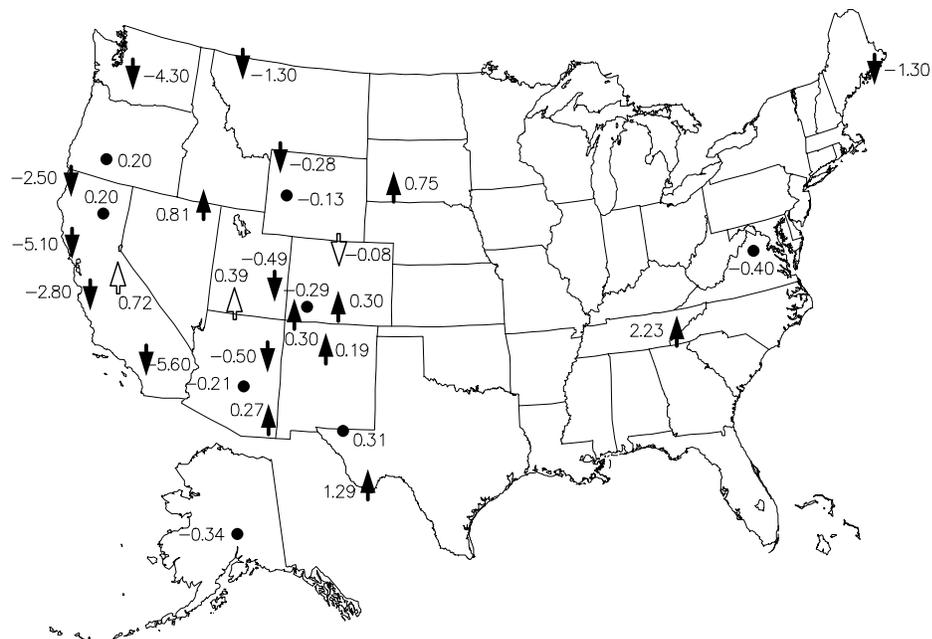


Figure 5.5 Map summarizing the trends in aerosol extinction (1/Mm/yr) for group 90 (top 20% of fine mass) days. The icons mark the site locations, a solid dot indicates an insignificant slope, the empty arrow indicates a positive or negative slope that is significant in the range of $0.05 < p \leq 0.1$ level of probability, and the solid arrow indicates a positive or negative slope that is significant at better than 0.05 ($p \leq 0.05$) level of probability.

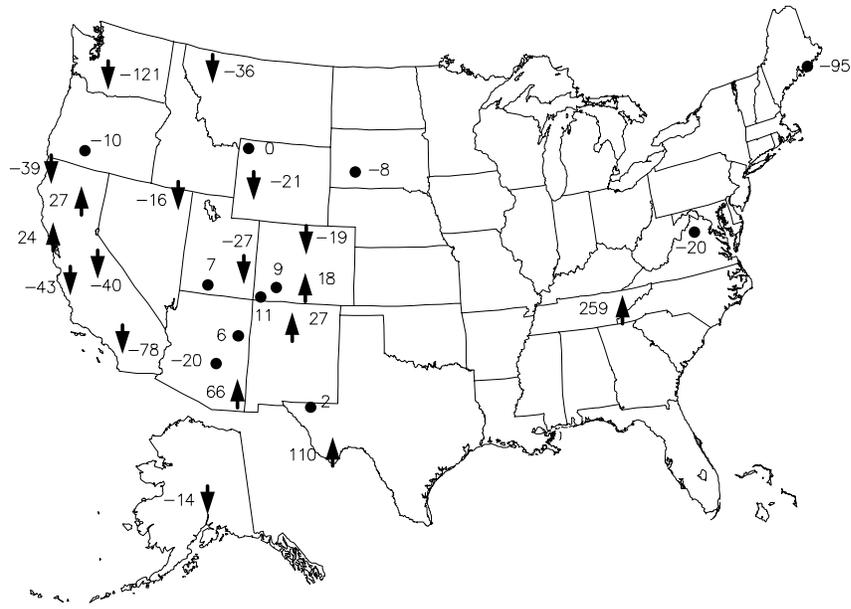


Figure 5.6 Map summarizing the trends in sulfate mass concentration ($\text{ng}/\text{m}^3/\text{yr}$) for group 90 (top 20% of fine mass) days. The icons mark the site locations, a solid dot indicates an insignificant slope and the solid arrow indicates a positive or negative slope that is significant at better than 0.05 ($p \leq 0.05$) level of probability.

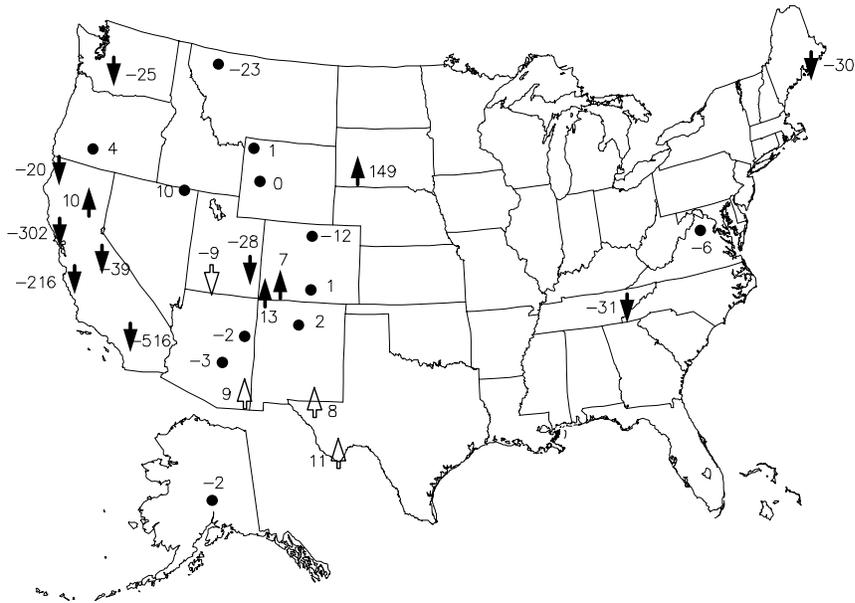


Figure 5.7 Map summarizing the trends in nitrate mass concentration ($\text{ng}/\text{m}^3/\text{yr}$) for group 90 (top 20% of fine mass) days. The icons mark the site locations, a solid dot indicates an insignificant slope, the empty arrow indicates a positive or negative slope that is significant in the range of $0.05 < p \leq 0.1$ level of probability, and the solid arrow indicates a positive or negative slope that is significant at better than 0.05 ($p \leq 0.05$) level of probability.

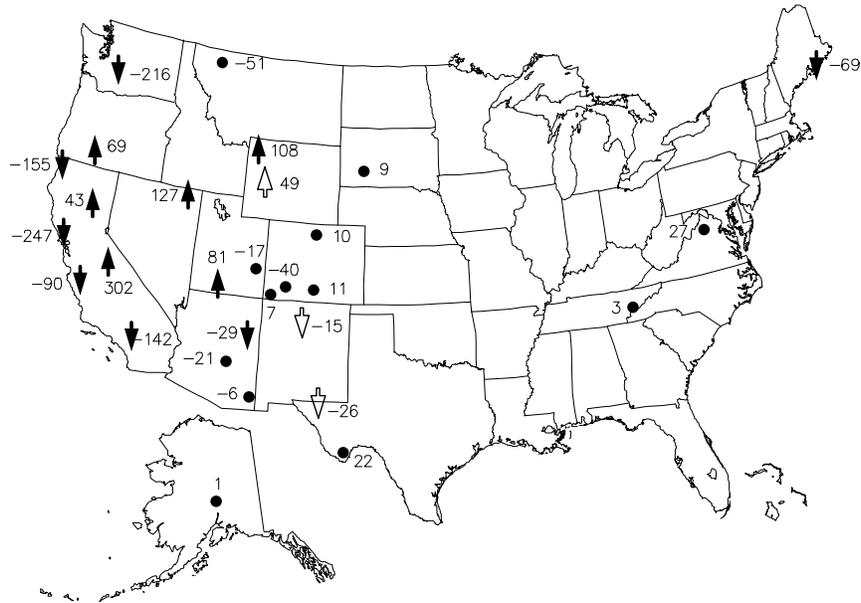


Figure 5.8 Map summarizing the trends in organic mass concentration ($\text{ng}/\text{m}^3/\text{yr}$) for group 90 (top 20% of fine mass) days. The icons mark the site locations, a solid dot indicates an insignificant slope, the empty arrow indicates a positive or negative slope that is significant in the range of $0.05 < p \leq 0.1$ level of probability, and the solid arrow indicates a positive or negative slope that is significant at better than 0.05 ($p \leq 0.05$) level of probability.

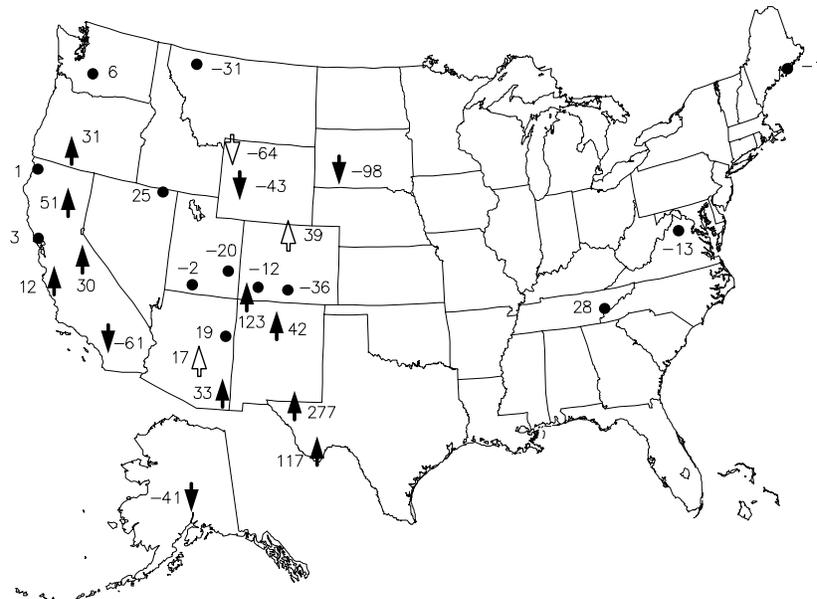


Figure 5.9 Map summarizing the trends in fine soil mass concentration ($\text{ng}/\text{m}^3/\text{yr}$) for group 90 (top 20% of fine mass) days. The icons mark the site locations, a solid dot indicates an insignificant slope, the empty arrow indicates a positive or negative slope that is significant in the range of $0.05 < p \leq 0.1$ level of probability, and the solid arrow indicates a positive or negative slope that is significant at better than 0.05 ($p \leq 0.05$) level of probability.

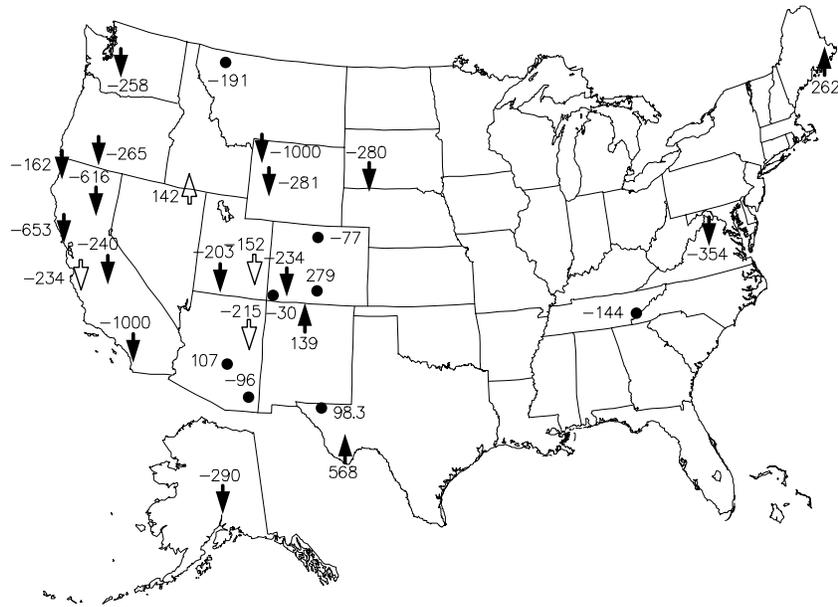


Figure 5.10 Map summarizing the trends in coarse mass concentration ($\text{ng}/\text{m}^3/\text{yr}$) for group 90 (top 20% of fine mass) days. The icons mark the site locations, a solid dot indicates an insignificant slope, the empty arrow indicates a positive or negative slope that is significant in the range of $0.05 < p \leq 0.1$ level of probability, and the solid arrow indicates a positive or negative slope that is significant at better than 0.05 ($p \leq 0.05$) level of probability.

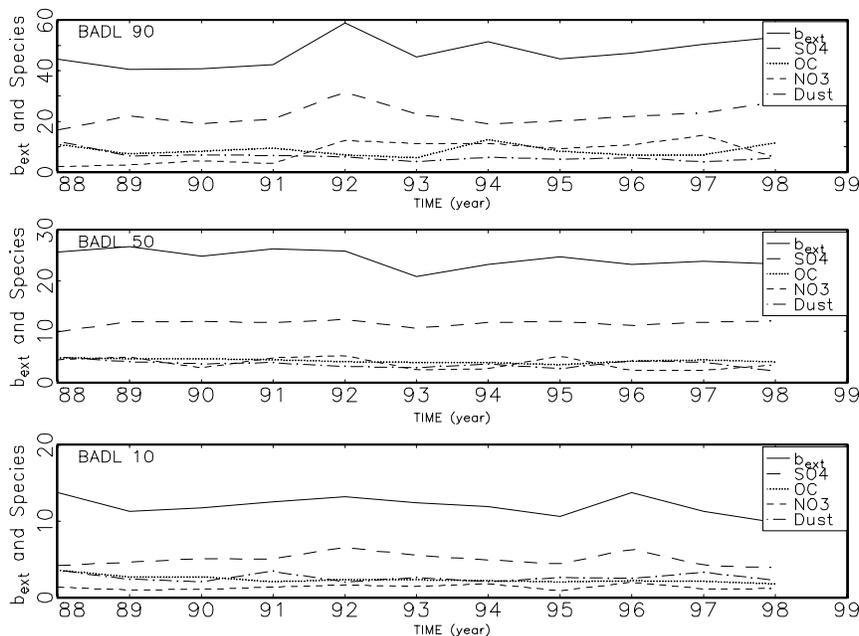


Figure 5.11 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Badlands National Park. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in $1/\text{Mm}$ and time is in years.

Great Basin: Jarbidge Wilderness Area in the Great Basin region has a significant slope of 0.23 dv/yr. The increasing haziness at Jarbidge is primarily driven by an increasing organic mass concentration as shown in Figures 5.8 and 5.12. These same figures show that sulfates are actually decreasing only to be offset by the organic mass fraction.

Central Rocky Mountains: Great Sand Dunes National Monument is the only monitoring site in the Central Rocky Mountain region to show a significant trend toward increasing haziness. Sulfates were shown to be increasing at a statistically significantly rate, while the slope of coarse mass was positive but not statistically significant (see Figures 5.6 and 5.10). These two species combine to form a significant trend in visibility that is driven primarily by one year (1994) when coarse mass was approximately twice that of other years (see Figure 5.13). Without the 1994 year visibility would be judged to not have changed at Great Sand Dunes. At Yellowstone National Park and Weminuche Wilderness Area, visibility is improving, while at Rocky Mountain National Park and Bridger Wilderness Area no change was recorded. Even though overall visibility is improving at Yellowstone, organics show a statistically significant increase in organics due primarily to two “fire” years in 1994 and 1996 (see Figure 5.14). The 1994 and 1996 fire years also show up as an increase in the organic mass concentration trends in the Sierra Nevada, Sierra-Humboldt, Great Basin, and parts of the Colorado Plateau and Central Rocky Mountain regions (see Figure 5.8).

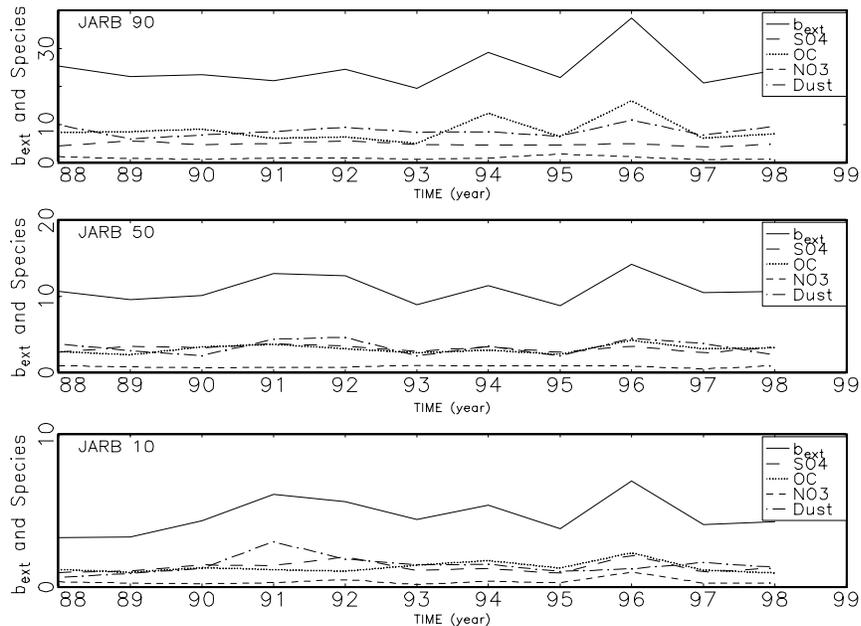


Figure 5.12 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Jarbidge Wilderness Area. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in 1/Mm and time is in years.

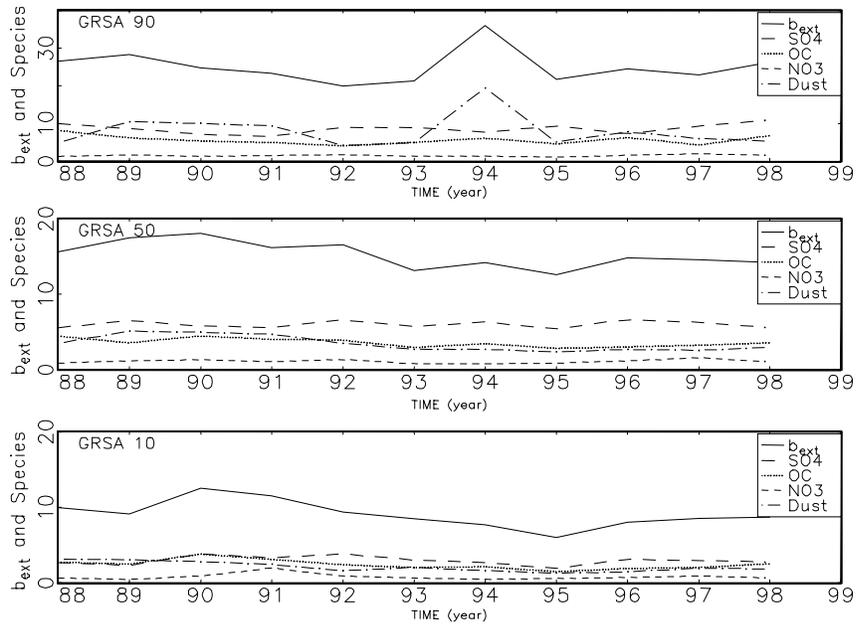


Figure 5.13 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Great Sand Dunes National Monument. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in 1/Mm and time is in years.

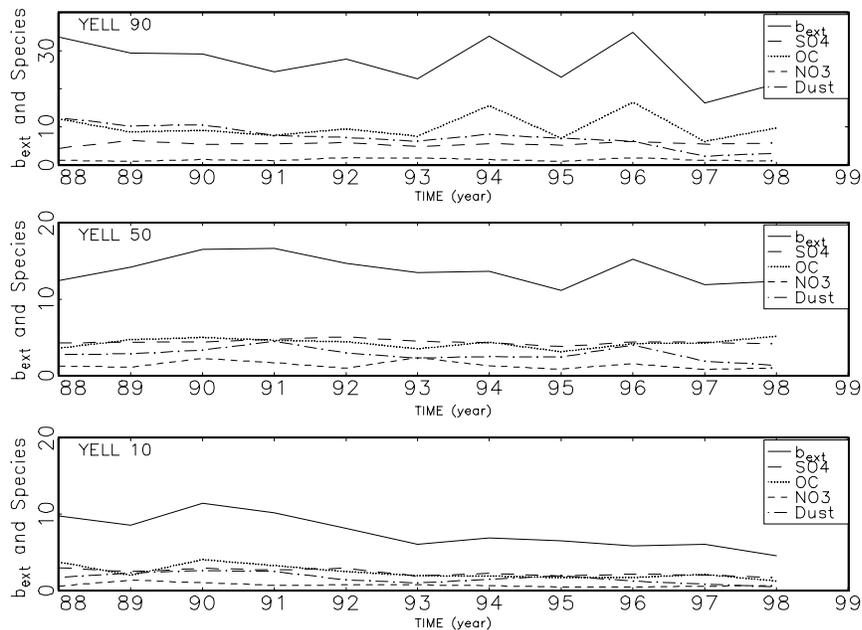


Figure 5.14 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Yellowstone National Park. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in 1/Mm and time is in years.

Colorado Plateau: Trends on the Colorado Plateau are mixed in that three sites show trends in increasing haziness, while two sites show visibility getting better. Bryce Canyon and Mesa Verde National Parks and Bandelier National Monument all show statistically significant increasing haziness in visibility and not all for the same reason. Sulfates are increasing at Bandelier, nitrates at Mesa Verde, and organics at Bryce Canyon (see Figures 5.15, 5.16, and 5.17). (Nitrates are actually decreasing at Bryce Canyon). Fine soil is increasing at Bandelier and Mesa Verde, while coarse mass is decreasing at Bryce Canyon and Bandelier. Two sites, Canyonlands and Petrified Forest National Parks show improvement in visibility. Sulfates, nitrates, and coarse mass concentrations have decreased at Canyonlands, while organics and coarse mass have gone down at Petrified Forest.

Sonoran Desert: Chiricahua National Monument shows an increase in haziness, while Tonto National Monument does not. Chiricahua shows significantly increasing trends in sulfates, nitrates, and fine soil (see Figure 5.18), while Tonto shows an increase in fine soil concentration.

West Texas: Big Bend National Park shows a significant increase in haziness primarily due to an increase in sulfates (see Figure 5.19). Nitrates, fine soil and coarse mass also show statistically significant increases. At Guadalupe Mountains National Monument, no trend is detected in visibility, however, nitrates and fine soil were shown to be increasing, while organics are decreasing.

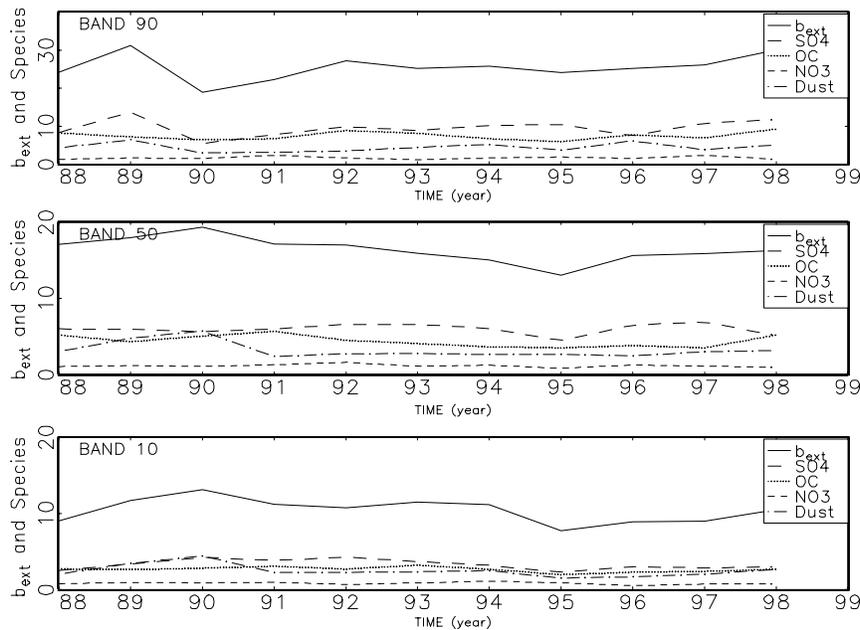


Figure 5.15 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Bandelier National Monument. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in 1/Mm and time is in years.

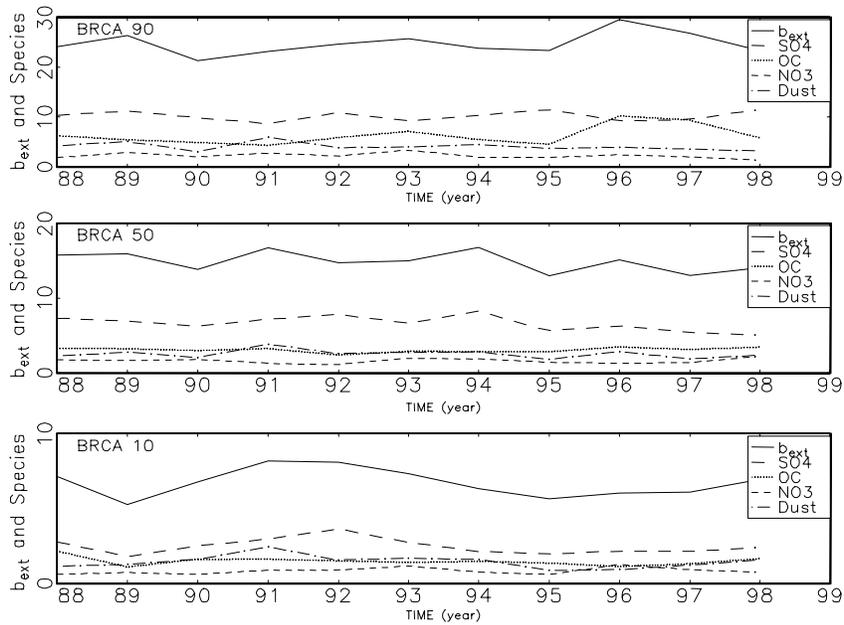


Figure 5.16 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Bryce Canyon National Park. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in $1/Mm$ and time is in years.

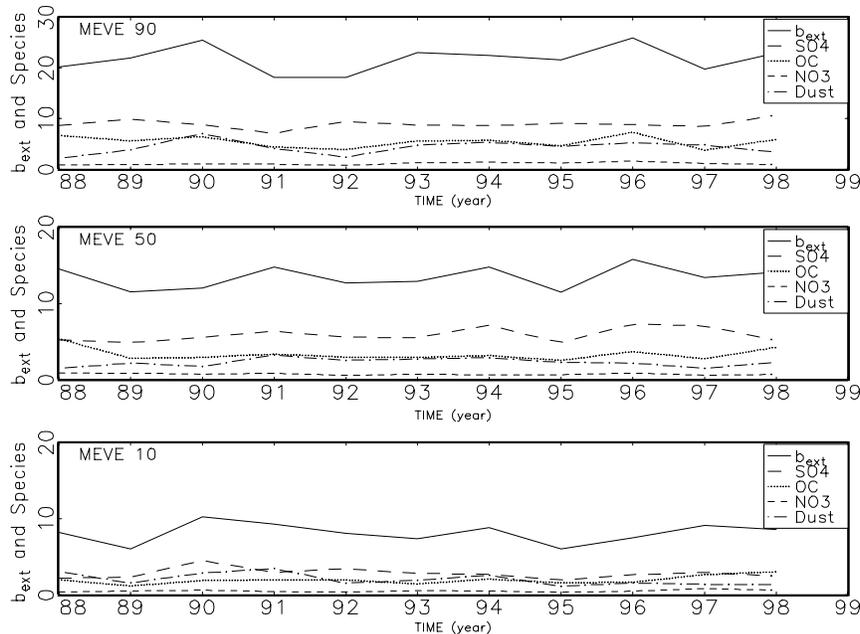


Figure 5.17 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Mesa Verde National Park. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in $1/Mm$ and time is in years.

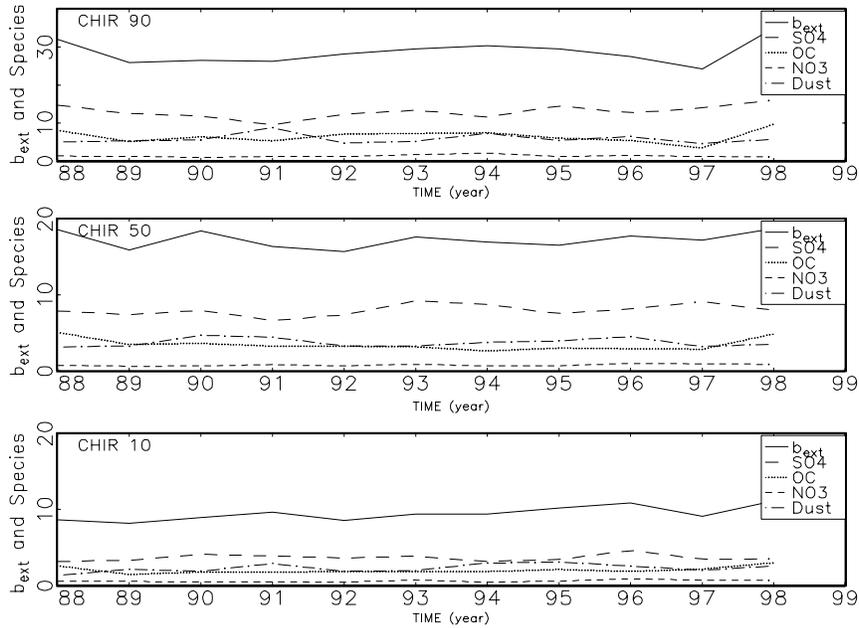


Figure 5.18 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Chiricahua National Monument. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in 1/Mm and time is in years.

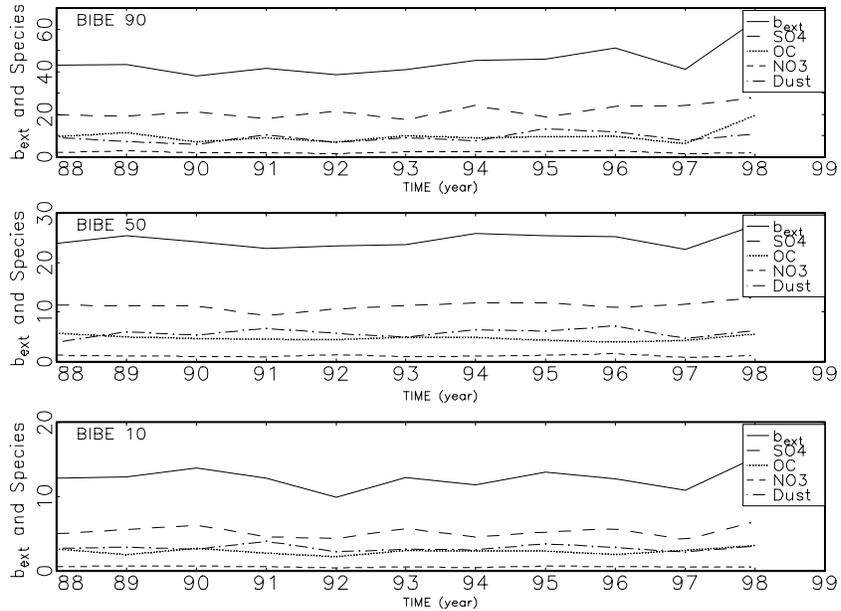


Figure 5.19 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Big Bend National Park. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in 1/Mm and time is in years.

Appalachian Mountains: Great Smoky Mountains National Park shows a significantly increasing haziness in visibility due to an increasing trend in sulfate concentration (see Figure 5.20). Nitrates have actually decreased, while all other species have remained the same. Shenandoah National Park on the other hand, did not show a change in visibility and sulfates have not changed in a statistically significant way.

At the remaining monitoring sites, visibility has not changed or improved. The good news is that at all western California monitoring sites, visibility has improved at a statistically significant rate primarily because of decreases in nitrate concentrations (see Figures 5.4 and 5.7). Also at most of these sites, organics and sulfates have decreased significantly. The sites along the Sierra range in California and southern Oregon have not shown a change in visibility. Glacier National Park has shown a decrease in haziness primarily because of a decrease in sulfate concentration. Acadia National Park has shown a trend in decreasing haziness because of reductions in nitrate and organic concentrations.

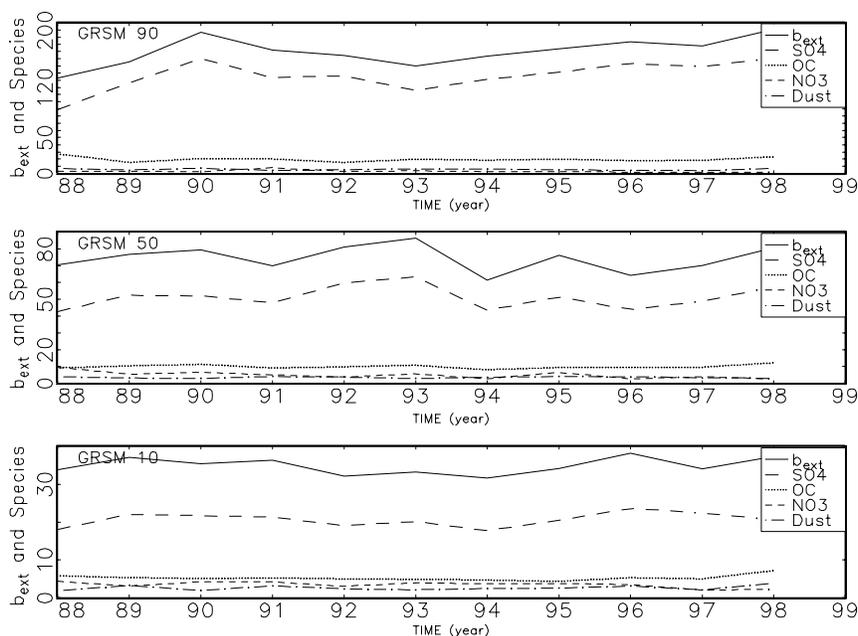


Figure 5.20 Temporal plot of reconstructed extinction and extinction of constituent species for the group 90, 50, and 10 categories for Great Smoky Mountains National Park. The solid line corresponds to reconstructed extinction, the dashed line to sulfate scattering, the dotted line to organic scattering, the small dashed line to nitrate scattering, and the dot-dashed line to soil scattering. Units are in 1/Mm and time is in years.

5.3 SEASONAL TRENDS IN FINE MASS AND EXTINCTION

Figure 5.21 is a map with bar plots showing annual and seasonal reconstructed fine mass and the contribution of each species for the 20 monitoring regions, excluding Washington, D.C., in the IMPROVE Network. (See Appendix E for the same plots but for each site by month instead of season.) The summer months have the highest fine mass loadings at 19 of the 20 monitoring regions with two regions having nearly identical mass loadings in two seasons. In the Pacific

Coastal Mountain region, fine mass concentrations are nearly the same in the summer and autumn seasons, while the West Texas fine mass loadings are nearly the same in spring and summer. The summer months are averages across June, July, and August, and at most sites east of the Mississippi it is August that has the highest mass loadings because sulfates are highest during that month. East of the Mississippi sulfates make up about 60-70% of the fine mass in all seasons.

At most sites in four of the western regions, Cascade Mountains, Central Rocky Mountains, Colorado Plateau, Great Basin, Seirra-Humboldt, Sonoran Desert, and Wasatch, sulfate concentrations are highest during the August-September timeframe, although fine mass concentrations are somewhat evenly split between sulfates, carbon, and soil/dust mass concentrations.

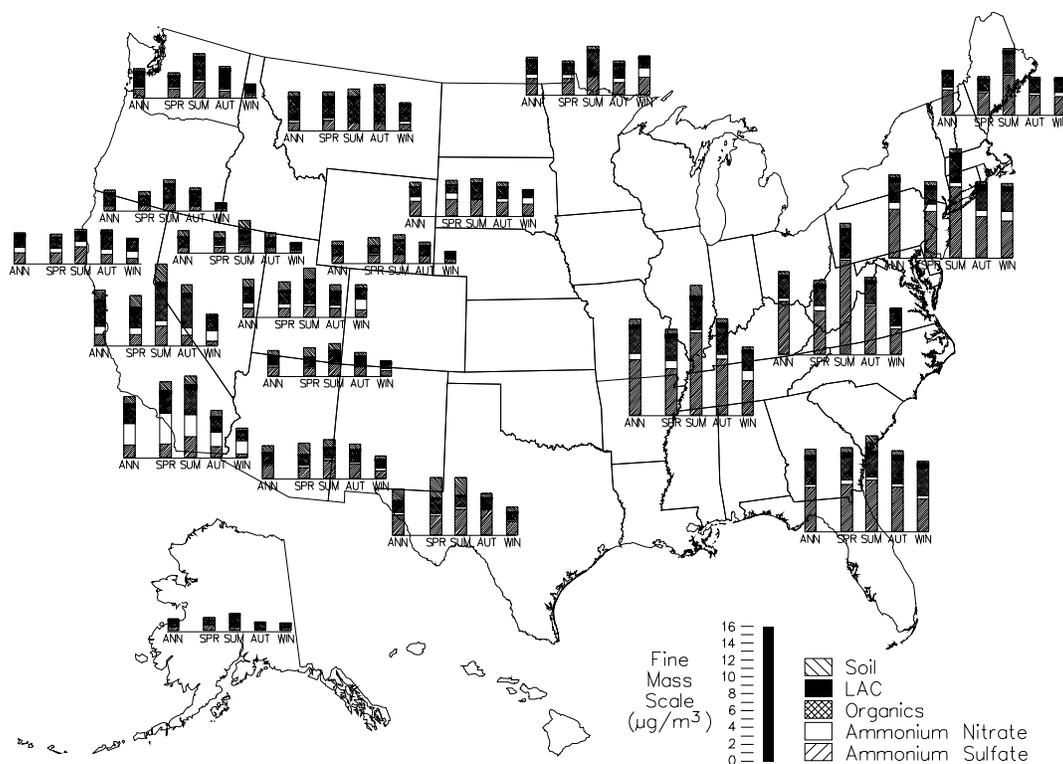


Figure 5.21 Summary plot of reconstructed fine mass and the fractional contribution of each species for the 20 monitoring regions in the IMPROVE network (Washington, D.C. is not shown).

At many sites in seven regions in the west, Cascade Mountains, Central Rocky Mountains, Colorado Plateau, Great Basin, Sierra-Nevada, Sierra-Humboldt, and Wasatch regions, August has the highest fine mass concentration because organic mass concentrations are elevated. These regions show increased trends in organic mass concentration

Even though the average summer fine mass concentrations are highest at most western United States sites, the month with the highest fine mass loading is May, and it also is primarily associated with elevated carbon mass concentrations. The sites are Weminuche, Bryce Canyon, Mesa Verde,

Petrified Forest, Chiricahua, Tonto, and Big Bend. Notice that these sites are a subset of those listed in the previous paragraph.

In the Northern Rocky Mountain region, fine mass loadings are greatest during the autumn season again primarily because of increased organic mass concentration

Figure 5.22 is a summary plot of reconstructed light extinction and the contribution of each species for the 20 monitoring regions, excluding Washington, D.C. The addition of the effect of water on hygroscopic aerosols and the addition of coarse mass changes the seasonal trends somewhat. At 13 of the 20 monitoring regions, summer extinction is the highest with the largest difference between seasons being in the eastern United States where sulfates, in combination with high relative humidity, make summer substantially hazier than any other season. Notice that sulfates, on a relative basis contribute significantly more, because of high relative humidity, to extinction than to fine mass. West Texas, Sonoran Desert, Colorado Plateau, Great Basin, Sierra-Humboldt, Sierra-Nevada, Pacific Coastal Mountains, and Cascade Mountain regions also have, on the average, the highest extinction during the summer months, however, the differences between seasons tend to not be as pronounced. Three of the regions, Southern California, Central Rocky Mountains, and Northern Great Plains, have the highest extinction during the spring season. In Southern California, the springtime high is driven by increased nitrate extinction. Two regions, Cascade Mountains and Boundary Waters, winter has the highest extinction and again it is driven by nitrates, while in the Northern Rocky Mountains region spring is the season with greatest extinction.



Figure 5.22 Summary plot of reconstructed light extinction and the fractional contribution of each species for the 20 monitoring regions in the IMPROVE network (Washington, D.C. is not shown).

5.4 DIURNAL TRENDS IN RELATIVE HUMIDITY AND SCATTERING AND EXTINCTION

One of the fundamental differences between the aerosol and optical measurements in the IMPROVE network is the sampling frequency. While the aerosol measurements are made twice weekly, the optical, temperature, and relative humidity (RH) measurements are made hourly. So, while the aerosol data are usually analyzed on a seasonal or annual basis, the optical data can be analyzed with respect to hour of day, or day of week. Diurnal patterns in optical and RH data are shown for all sites in Appendix F; data for a few sites are discussed in detail below.

5.4.1 Most Common Patterns

At many IMPROVE sites there are diurnal patterns in RH and b_{ext} or b_{scat} that are what would be expected simply based on average meteorology. On average, RH is higher at night, lower during midday, and higher during the winter than during the summer. This is due to the temperature dependence of RH. Warm air is able to hold more water than cool air, so for a constant amount of moisture in the atmosphere, RH (the ratio of actual moisture in the air to the total amount possible) rises and falls inversely with temperature.

Also, as expected based on RH alone, light extinction (b_{ext}) measured by the transmissometer or scattering (b_{scat}) measured by the nephelometer are often either in phase with RH or relatively independent of time of day. This is due to the RH dependence of scattering by hygroscopic aerosols such as sulfates and nitrates. Because the relationship between scattering and RH is nonlinear, small changes in RH can cause very large changes in light scattering when the RH is high (i.e., 70% or higher), but will cause relatively smaller changes when RH is low. The greater the fraction of light scattering due to hygroscopic aerosols, the more sensitive the light scattering will be to changes in RH. See Chapter 2 for details of reconstructed fine particle mass at each site and Chapter 3 for reconstructed light extinction. There are other factors that confound the relationship between RH and scattering, however, such as diurnal or seasonal differences in mean transport of pollutants to the site, atmospheric stability, precipitation, mixing heights, and/or rates of chemical processes.

Each site is unique, but patterns in RH and b_{ext} at Petrified Forest, Guadalupe Mountains, Great Basin, Badlands and Big Bend National Parks, and Jarbidge Wilderness Area are similar to those shown in Figure 5.23 for Pinnacles National Monument. Even though relative humidity is highest during the winter months, winter has the lowest extinction coefficient. The highest scattering or extinction is usually during the summer, lowest during the winter and scattering or extinction is somewhat, but not dramatically, higher at night than during the day. However, it is pointed out that at Pinnacles National Monument extinction during the nighttime hours is greater during the autumn season than the summer months.

Another group of sites, Canyonlands, Chiricahua, Bandelier, and Grand Canyon (both Hopi Point and below the rim) have similar patterns in measured RH, but have a different diurnal pattern in measured scattering or extinction. The graphs for data collected at Grand Canyon National Park (Hopi Point) are shown in Figure 5.24. At these sites, the highest scattering occurs during midday and lower hourly means are measured at night and with very little relative

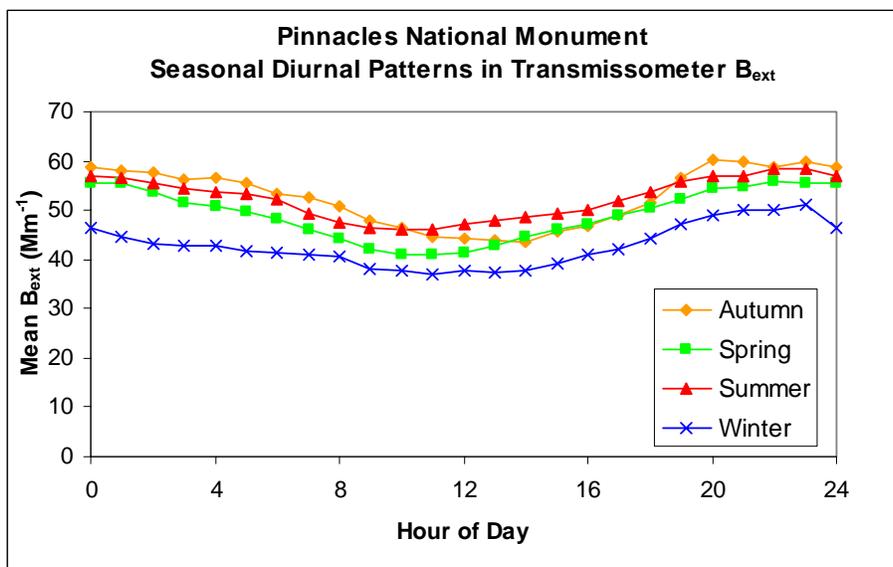
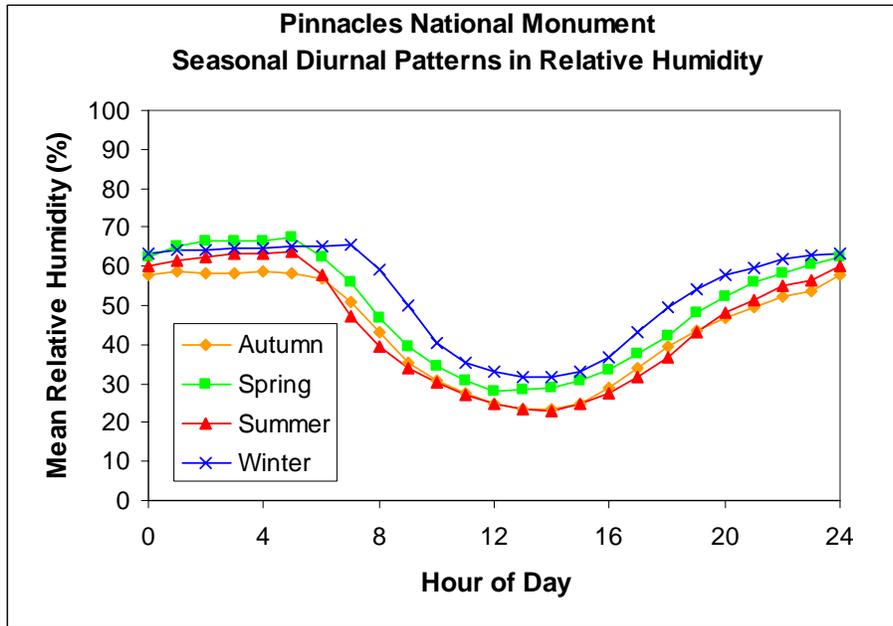


Figure 5.23 Diurnal patterns by season for RH and b_{ext} measured at Pinnacles National Monument from 1988 to August 1993.

humidity dependence. This is because the relative humidity tends to vary between 20 and 50% where there is very little particle growth and therefore little dependence on scattering as a function of relative humidity. At these sites, the transmissometer is located in such a manner as to measure air in or over canyons, where the diurnal particulate concentrations may be at least partially dependent on the height of the mixed layer. Higher mixing heights that occur during midday allow low-level aerosol concentrations to be mixed up to the elevation of the monitoring site. Note that at Grand Canyon during the winter, b_{ext} is much lower than during the warmer

seasons and there is virtually no diurnal variation in b_{ext} during the winter. This could well be because the top of the mixed layer only rarely reaches the transmissometer site path at Hopi Point during the winter. Also the in-canyon transmissometer at Grand Canyon has a similar diurnal pattern as the rim instrument but is about 30% higher indicating that the in-canyon haze is greater than on the rim.

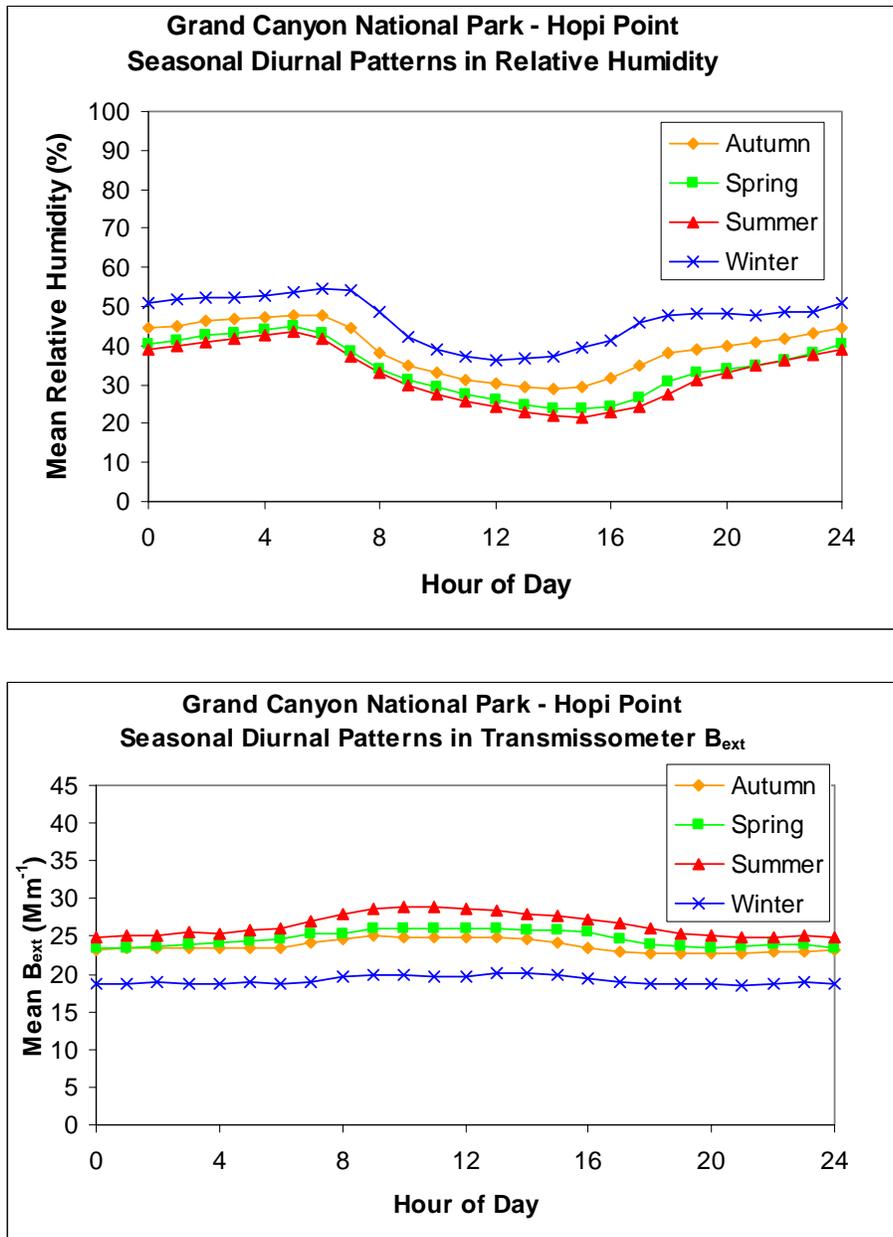


Figure 5.24 Diurnal patterns by season for RH and b_{ext} measured at Grand Canyon National Park from 1986 to August 1997.

Some sites have unique or distinct patterns that may be linked to nearby source regions (i.e., a city or group of cities) or local meteorology. Some of these are discussed in more detail in the following subsections.

5.4.1.1 Gila Cliff Dwelling National Monument/Gila Wilderness Area, New Mexico

Figure 5.25 shows the hourly average b_{scat} and RH values at Gila Wilderness Area. The diurnal differences in b_{scat} are very pronounced in the summer and almost nonexistent in the winter. In the summer, hourly average b_{scat} peaks at 5:00 a.m., with values almost twice those measured during the afternoon hours. Although RH also peaks near 5:00 a.m., the average RH is too low to account for the large change in b_{scat} . The peak in b_{scat} is an increase in particulate concentrations that occurs somewhat regularly during summer mornings. Spring and autumn exhibit similar but less pronounced patterns. Winter has the highest average RH and a strong diurnal pattern in RH, but almost no diurnal pattern in b_{scat} . Again these patterns are consistent with mixing of low elevational aerosol concentrations up to the elevation of the monitoring site.

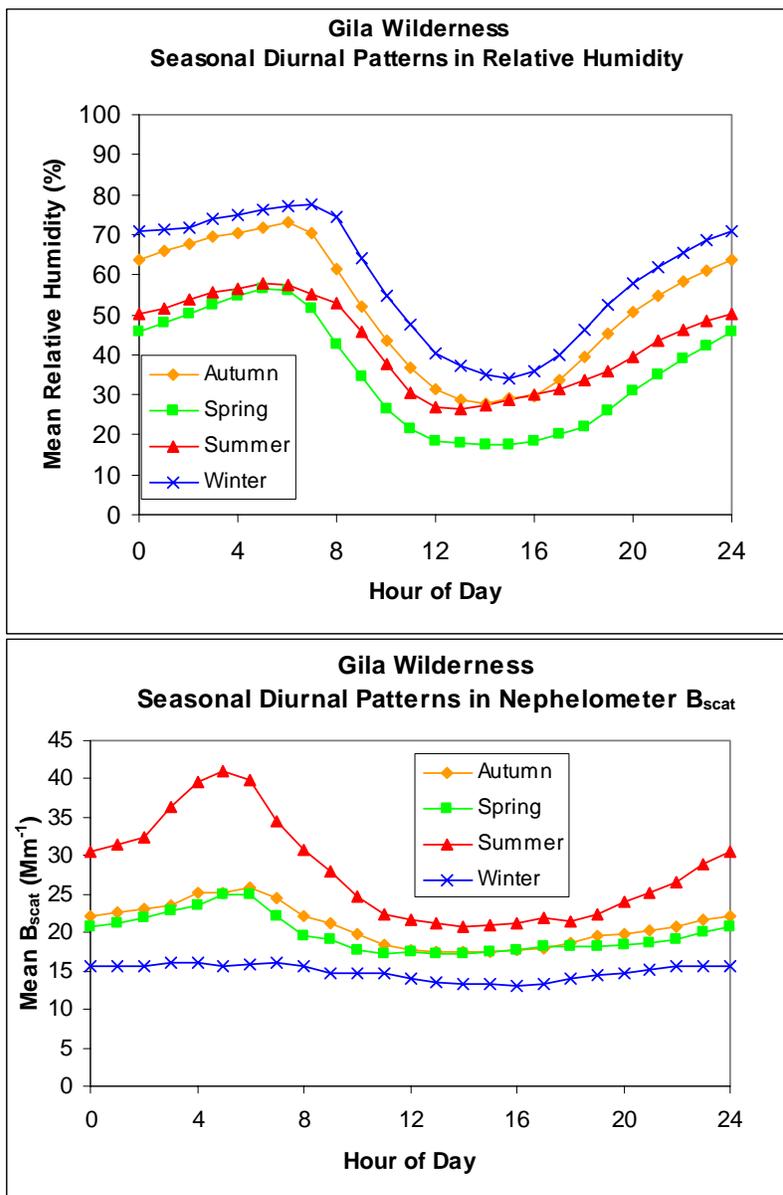


Figure 5.25 Diurnal patterns by season for RH and b_{scat} measured at Gila Wilderness from 1994 to August 1997.

The reconstructed extinction at Gila Wilderness is typical for sites in the Southwest. The haziest days occur in the summer with episodes dominated by organics and sulfates. The best visibility occurs in the winter.

5.4.1.2 Lone Peak Wilderness Area, Utah

Lone Peak Wilderness Area is located near the urban area of Provo and Salt Lake City, Utah. Winter weather in this area often alternates between periods of stagnation of several days or longer duration exacerbated by the nearby Wasatch Mountains to the east and Oquirrah Mountains to the west, interspersed with periodic winter storms bringing snow and/or rain that washes out any particulates in the atmosphere. Sites at high elevation, such as the nephelometer site in Lone Peak Wilderness, may often be above this stagnant surface layer.

Perhaps not surprisingly then, the worst episodes of impaired visibility at this site occur in the winter, with reconstructed extinction showing that these days are dominated by nitrates (see Chapter 3). And the periods with the best visibility also occur during the winter, probably either immediately following a cleansing winter storm or on days when the nephelometer site is above the surface layer of the atmosphere. During winter, the maximum hourly average b_{scat} occurs between 10:00 a.m. and 6:00 p.m., with the highest averages being more than twice the values during the remainder of the day. This suggests transport from the nearby urban areas during the afternoon when the mixing height is greatest. During spring, summer, and autumn, b_{scat} peaks between 10:00 a.m. and noon, tapers off throughout the day, then peaks again between 8:00 p.m. and 9:00 p.m. The second daily peak is most pronounced in the summer. These are shown in Figure 5.26.

5.4.1.3 San Gorgonio Wilderness Area, California

San Gorgonio Wilderness Area is located in a pass in the mountains east of the Los Angeles urban area. The diurnal pattern in regional meteorology, affected by the different responses of ocean, coast, and mountains to the daily heating cycle, is such that the urban air mass is often transported eastward through the mountain passes in the afternoon. The highest extinction days at San Gorgonio generally occur in the spring and summer with reconstructed extinction analysis showing episodes of high extinction that are dominated by nitrates (see Chapter 3). The best visibility at San Gorgonio occurs during the winter, with autumn falling between winter and spring/summer.

Although the diurnal pattern in RH at San Gorgonio is fairly typical of many sites, the diurnal pattern in b_{ext} is unique in the IMPROVE network. As shown in Figure 5.27, hourly average b_{ext} begins to rise at roughly 8:00 a.m., though the mean RH is relatively unchanged from previous hours. Average b_{ext} continues to rise throughout the day, peaking between 5:00 p.m. and 6:00 p.m. depending on the season, then drops rapidly, several hours before RH drops in the morning. This pattern suggests that the site at San Gorgonio is less affected by the Los Angeles urban area at night than during midday. This could be due to either diurnal changes in the height of the mixed layer, shifts in wind direction or a combination of these factors.

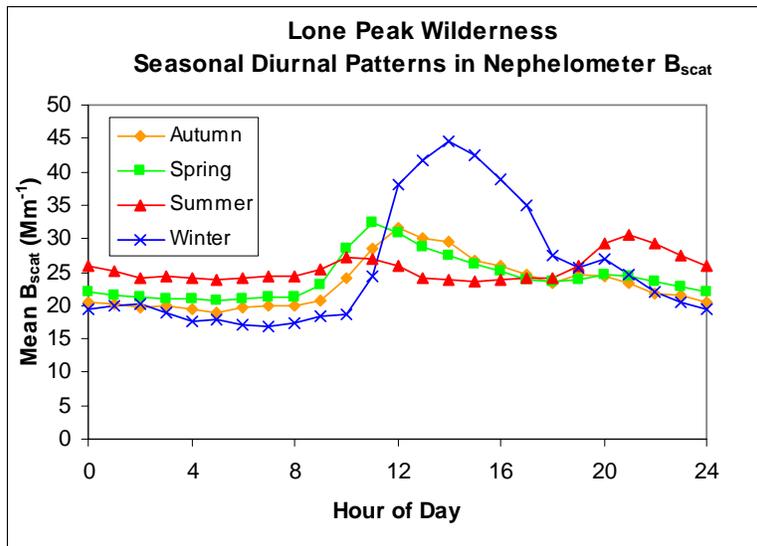
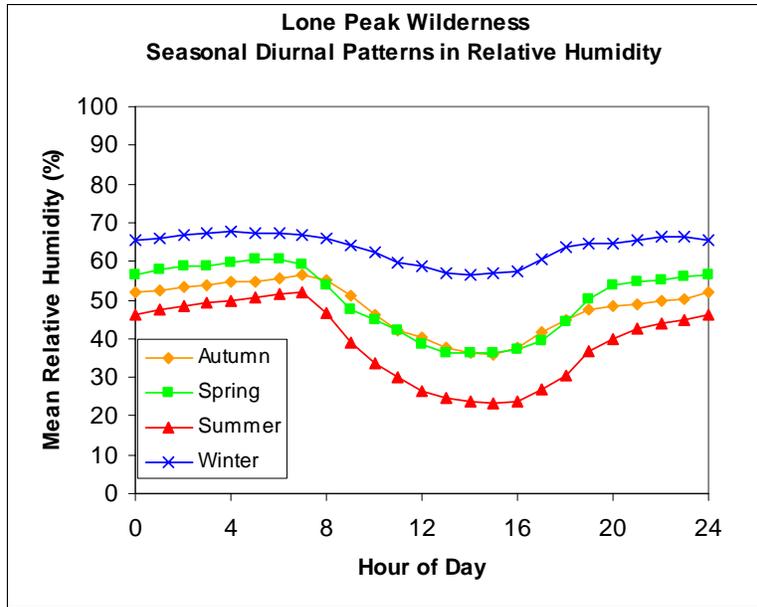


Figure 5.26 Diurnal patterns by season for RH and b_{scat} measured at Lone Peak Wilderness from 1993 to August 1997.

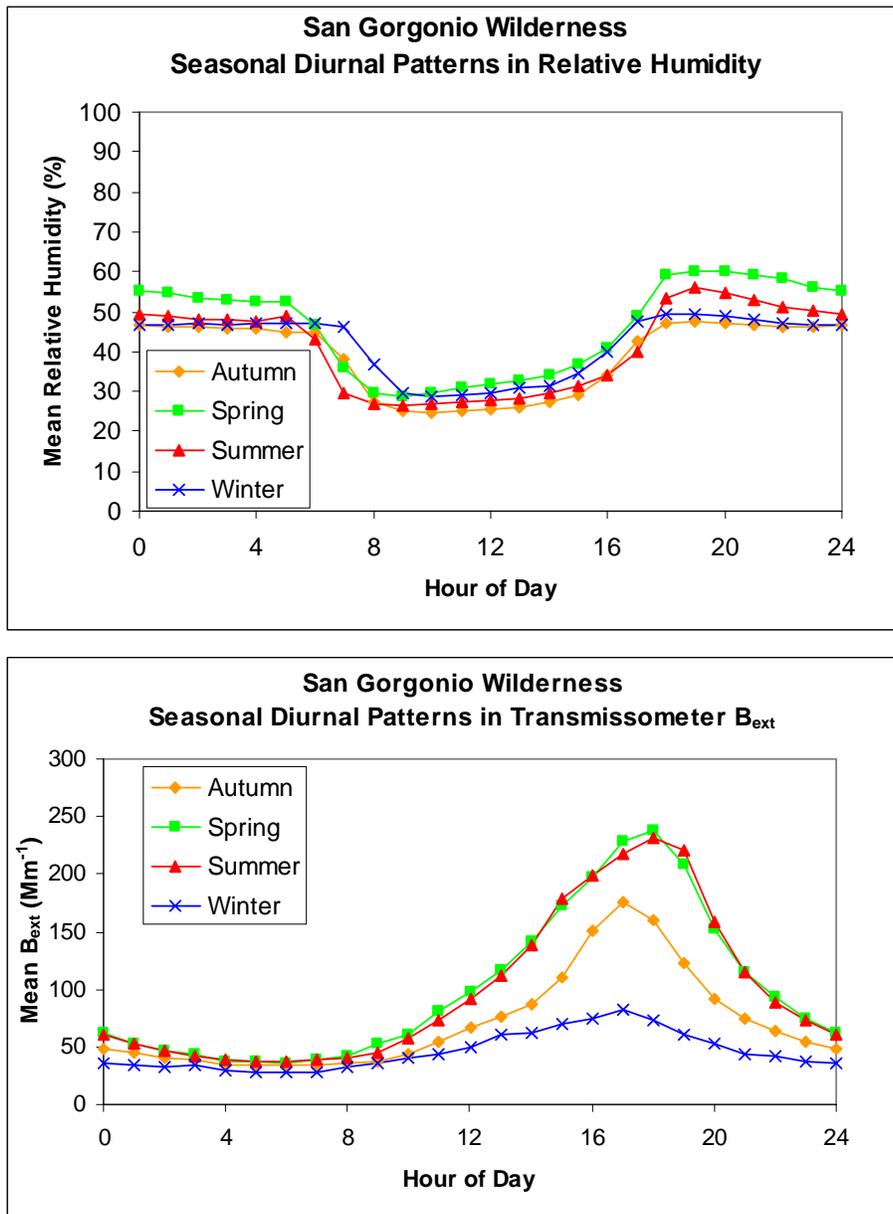


Figure 5.27 Diurnal patterns by season for RH and b_{ext} measured at San Gorgonio Wilderness from 1989 to August 1997.

5.4.1.4 Yosemite National Park, California

The transmissometer at Yosemite National Park is located on Turtle Back Dome west of the entrance to the main valley. The diurnal patterns in the b_{ext} and RH are shown in Figure 5.28. While the RH pattern is typical of many sites, the daily pattern in b_{ext} seems to be driven by a combination of RH and mixing height. Peaks in b_{ext} during all seasons tend to occur during mid-afternoon, though the time of the maximum hourly average varies by season, occurring slightly earlier in the day during warmer seasons. Mid-afternoon is the time of day when the mixing

height is likely to be high enough to allow haze from lower elevations to mix up as high as the site. As at San Gorgonio, some diurnal differences in pollutant concentrations may also be due to changes in wind direction driven partially by the complex terrain.

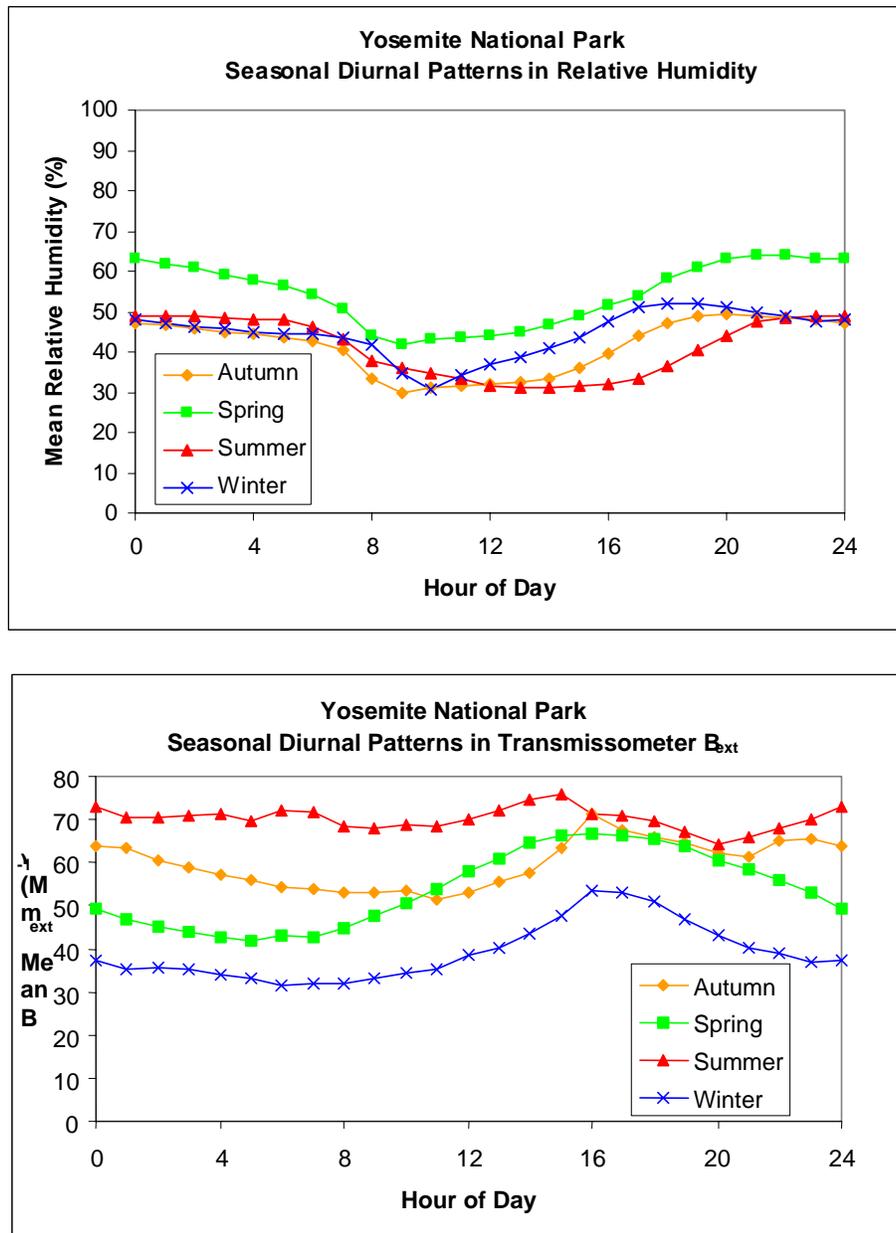


Figure 5.28 Diurnal patterns by season for RH and b_{ext} measured at Yosemite National Park from 1988 to August 1997.

5.4.1.5 Alpine Lake Wilderness Area at Snoqualmie Pass, Washington

The nephelometer is located on a ridge top at a ski area just east of Seattle. There are two interesting features in the diurnal b_{scat} pattern as shown in Figure 5.29. First is the rise in scattering occurring during mid-afternoon, beginning by noon and peaking by 9 p.m. during the

summer, and an hour or two earlier during the cooler seasons. This may be due to transport of haze from Seattle at the time of day when the mixing height is high enough to allow it. The hourly average RH is always relatively high, so slight changes in RH may also cause larger changes in scattering at this site as compared to drier areas. The second feature of interest in b_{scat} is the mid-morning peak occurring during winter only. This could be due to local traffic associated with the ski area.

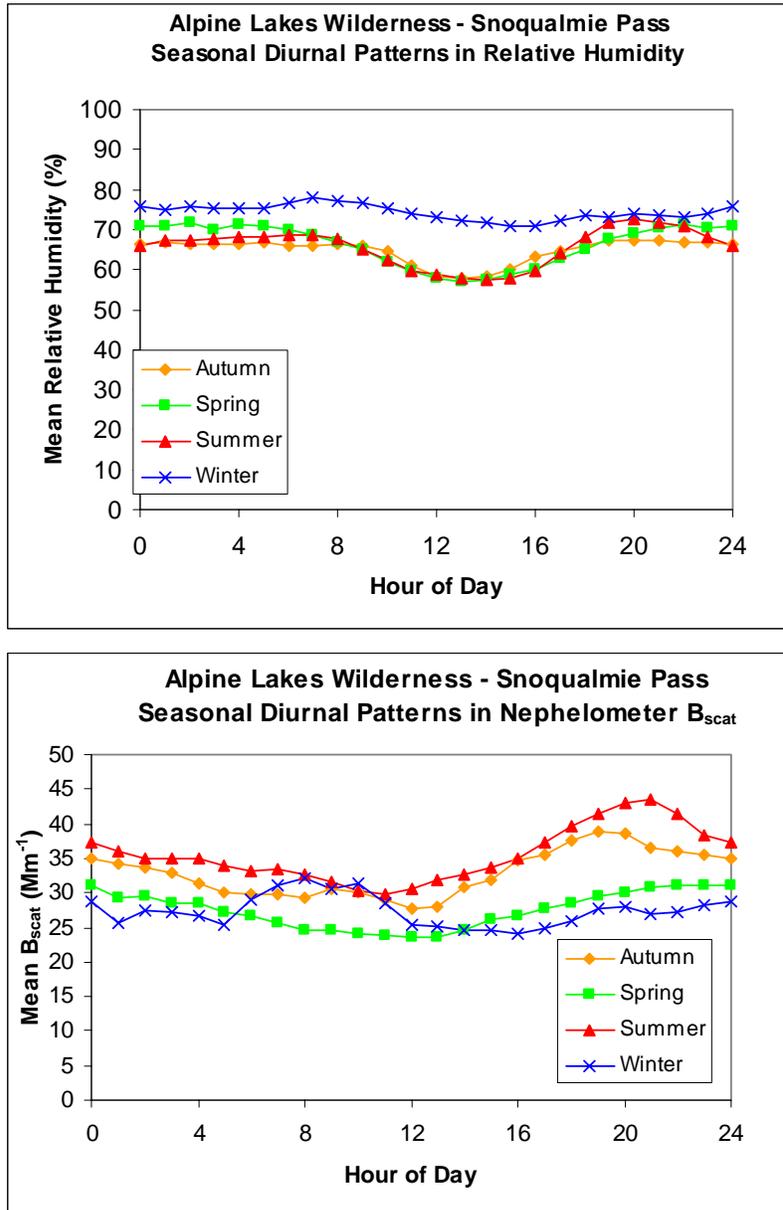


Figure 5.29 Diurnal patterns by season for RH and b_{scat} measured at Snoqualmie Pass from 1993 to August 1997.

5.4.1.6 Great Smoky Mountains National Park, Tennessee

Data for Great Smoky Mountains National Park are shown in Figure 5.30. Data at this site have features common to other sites in the eastern United States, such as Acadia National Park, Shining Rock Wilderness Area, Dolly Sods Wilderness Area, and Shenandoah National Park. The most dramatic property is that the hourly mean b_{scat} measured during the summer is more than twice as high as during the remaining seasons of the year. RH is high during all seasons, and the hourly means are nearly always above 70% during the summer. This is in the range of RH where small increases in RH cause large increases in scattering due to hygroscopic aerosols such as sulfates and nitrates. The largest fraction of the scattering at most eastern United States sites is due to sulfates. (See Chapters 2 and 3.) The diurnal pattern in mean scattering during the

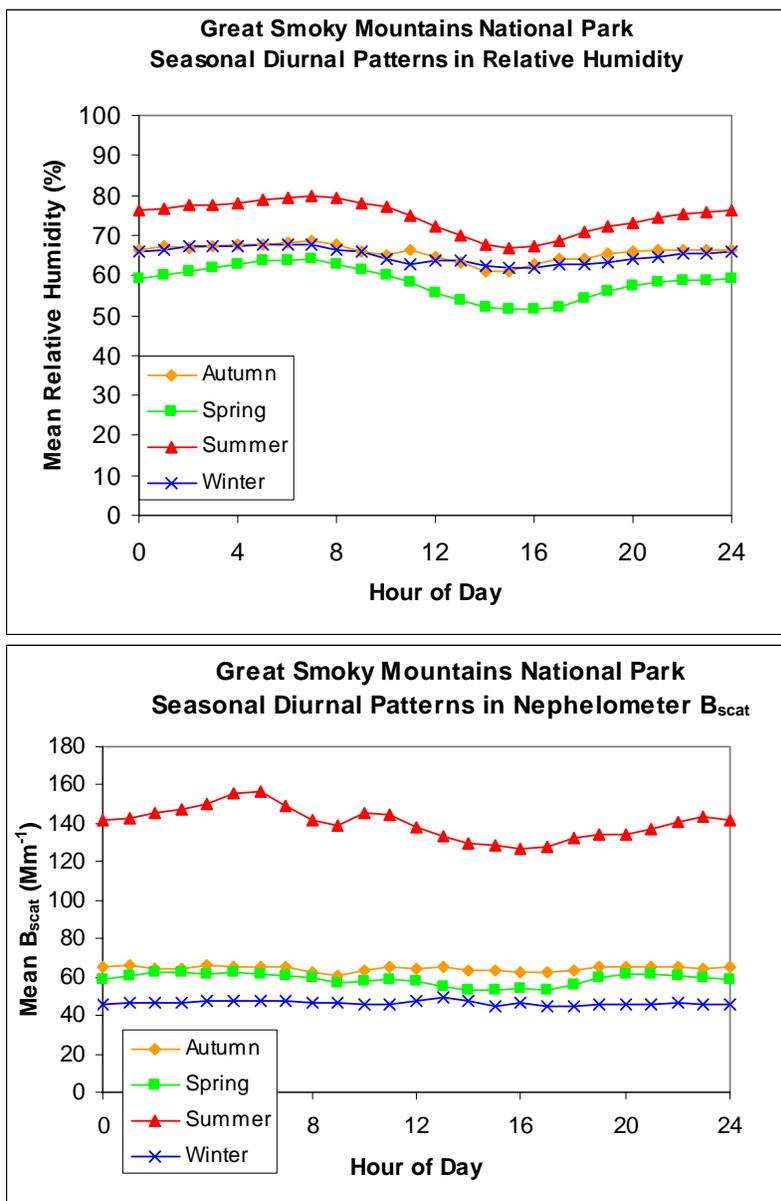


Figure 5.30 Diurnal patterns by season for RH and b_{scat} measured at Great Smoky Mountains National Park from 1993 to August 1997.

summer matches fairly closely the diurnal pattern in the RH, with a minimum in the late afternoon and higher values at night. Scattering during the remaining seasons is not dependent on time of day.

5.4.1.7 Boundary Waters Canoe Area, Minnesota

Graphs for this site are shown in Figure 5.31. This site is located in a very remote flat area of lakes and forest in northern Minnesota. Contrary to most sites in the IMPROVE Network, the highest scattering here occurs during the winter rather than during the summer. Lowest b_{scat} is during spring and fall with summer falling in between. RH is quite high on average, being

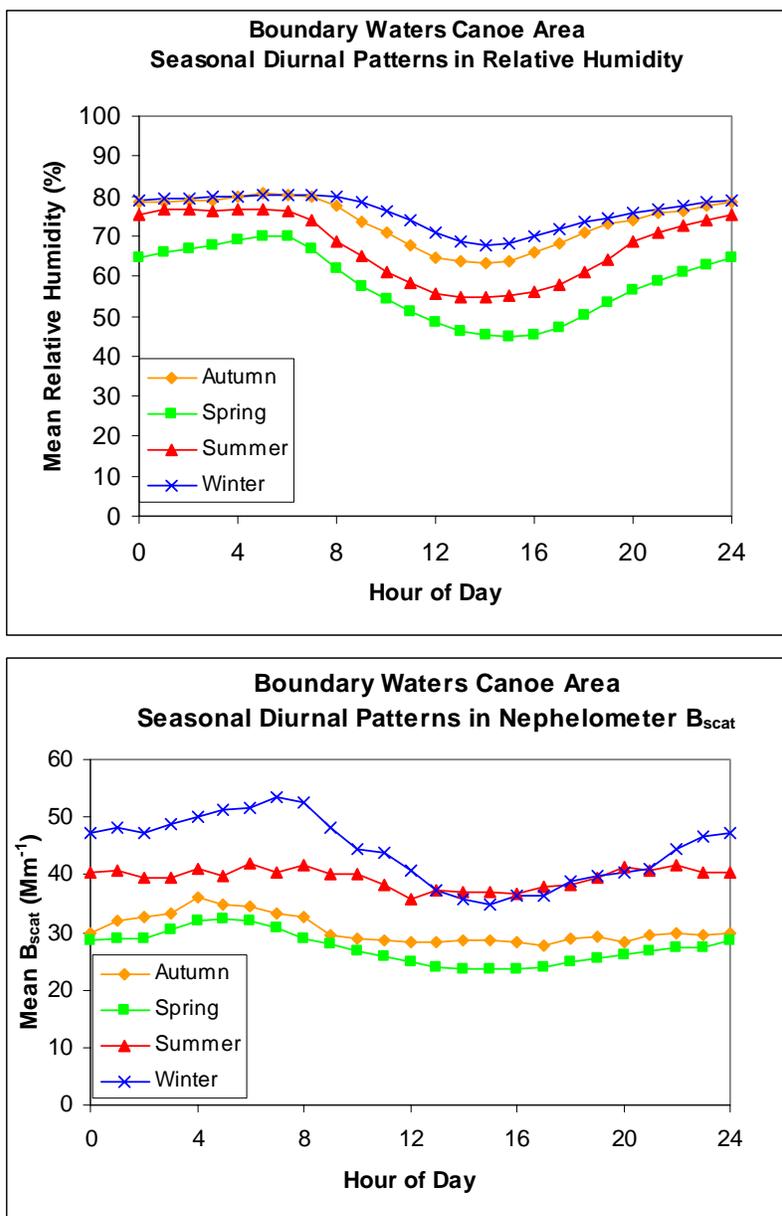


Figure 5.31 Diurnal patterns by season for RH and b_{scat} measured at Boundary Waters Canoe Area from 1993 to August 1997.

highest during the winter and lowest during the spring, although the nighttime averages for winter and fall are nearly identical, especially at night. It's possible that the high scattering measured from approximately 10 p.m. to 8 a.m. during the winter is associated with icy fog.

Diurnal and seasonal patterns in measured b_{scat} and b_{ext} are similar for many sites. A common pattern is highest scattering or extinction during the summer, lowest during the winter with scattering or extinction being somewhat higher at night. Usually, the differences between different hours of the day are not as large as the differences between seasons. In some cases, however, the average extinction varies by up to a factor of 5 from one time of day to another largely because of changes in relative humidity and the associated growth of hygroscopic aerosols. RH is typically driven mostly by an inverse relationship to average temperature. There are some sites that have unique diurnal or seasonal patterns in average b_{scat} or b_{ext} . In many cases, especially when the site is near a large urban area, there is evidence that these average values are dependent on mixing height. Higher mixing heights allow emissions from local sources to reach the monitoring site.

5.5 REFERENCES

Theil, H., A rank-invariant method of linear and polynomial regression analysis (I-III), *Proc. Kon. Ned. Akad. V. Wetensch. A.*, (53), 1950