Western North Carolina and Surrounding Area Air Quality Annual Trends Supplement

1987-2000

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Public sources of data:
ozone data:
http://www.epa.gov/aqspubl1/annual_summary.html
sulfate and nitrate data:
http://nadp.sws.uiuc.edu/
reconstructed visibility data:
http://vista.cira.colostate.edu/IMPROVE/Data/IMPROVE/IMPLoctable_Data.asp

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Abstract—This work supplements a comprehensive study of air quality trends in Western NC and adjoining areas of TN and VA published in March, 1999, and an update to that published in November, 2000. The N.C. Division of Air Quality statistically tested ambient ozone concentrations, reconstructed visibility metrics, and ion concentrations in acid precipitation at monitoring stations in Western NC and Eastern TN beginning in various years (as available) through 2000 for evidence of annual trends. We detected no overall trends in ozone concentrations in the region, although some concentration measures are increasing at four sites. We could not detect trends in summer or winter season visibility. We found decreasing concentrations of the sulfate ion (SO_4^{2}) in acid precipitation (but no trend in the corresponding deposition rates).

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I. Introduction

This report is a limited trends analysis for ozone and acid precipitation data in the Western North Carolina region, including some adjoining areas of Tennessee. (A map of this region is shown in Figure 1.) It is a supplement to Cornelius (1999) and Anonymous (2000), updating most of their coverage through 2001. Section 2 describes the monitoring sites examined in this study, and Section 3 describes the study methods. We summarize regional ozone trends in Section 4 of this report and regional trends of acid precipitation constituents in Section 5. In Section 6, we summarize haze and visual range statistics derived from the particulate matter sampled at IMPROVE monitors. In Section 7, we report the individual study sites in detail. We discuss the overall results in Section 8, and we list implications of those findings in Section 9.

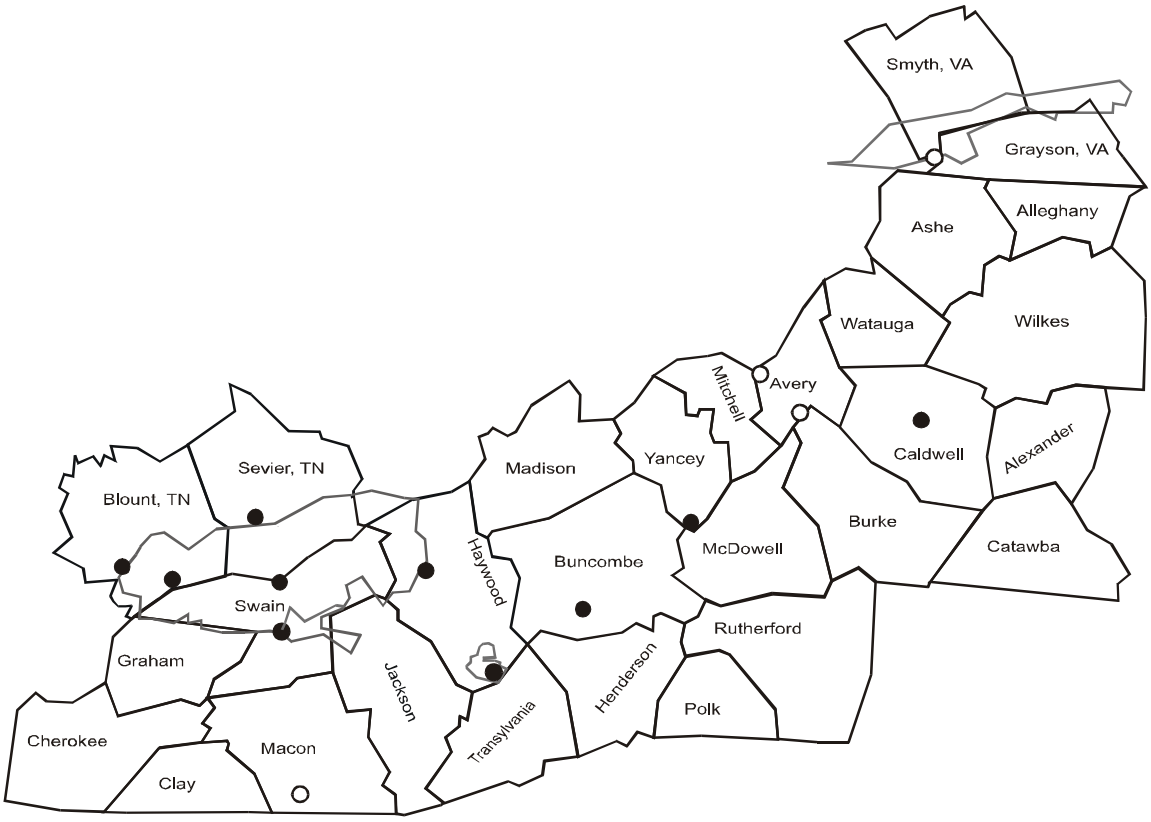

Figure 1. Western NC Study Region, Including Adjoining Area of TN, With Ozone Monitor Locations and Boundaries of the Great Smoky Mountains National Park and Shining Rock Wilderness Area. Open circles mark discontinued monitors that were analyzed in an earlier report.

2. Study Sites

We evaluate 6 ozone monitors in North Carolina from Lenoir (Caldwell County) west to the Tennessee border and four Tennessee ozone monitors in Great Smoky Mountains National Park. We also evaluate NADP/NTN acid precipitation data from two of the North Carolina sites, a Tennessee site, and a Virginia site. One of the NC NADP/NTN sites is essentially co-located with an ozone monitor in this study. We obtained "reconstructed" visibility coefficient data for the Great Smoky Mountains National Park and Shining Rock Wilderness Area from the IMPROVE Network database; these data are also presented as co-located with ozone monitors in this study.

We use ozone data from 1987 through 2000 only (some sites are not active for all 14 of these years), and acid precipitation data for 1987 through 2000. For some acid precipitation analyses, we use the entire available series from 1978 through 2000. These are fewer sites than were used in Cornelius (1999), because subsequent

judgements made by the custodians of the ozone data have caused some of the monitors to be withdrawn from availability for analysis.

3. Methods

Distributions of the first and second maximum one-hour ozone concentrations across the region for each available year are graphed as boxplots and time series. For those boxplots depicting successive year distributions at several sites, a "trend line" calculated using a variable-span smoother function in S-Plus® has been overlaid on the same graph.

The distributions of annual mean concentrations of SO_4^2 in the region are graphed as boxplots with a "trend line" calculated using a variable-span smoother function in S-Plus®.

Deciview haze coefficients have been algorithmically estimated and stored in the IMPROVE database. We analyzed these for two monitors in the region, and we calculated and analyzed the corresponding standard visual range values. We blocked these data by quarters of a December-November year and made time series graphs of each quarter.

In addition to these graphs, we have applied the Mann-Kendall nonparametric trend test to the concentration data and the medians of the winter and summer visibility coefficients. In those cases where we applied a trend test, we also estimated the overall (total) change per year in concentration by fitting a linear least squares regression to the data, and we estimated the average percent change by fitting the same type of regression to the logarithms of the concentrations.

Our individual site analyses (Section 7) contain graphical presentations of time series and trend lines for each pollutant summary available at each site. (This is similar to the regional summaries, except there are no boxplots.) We show the first and second maximum 1-hour averages in one graph and the first and fourth 8-hour ozone averages in another graph. Visibility coefficient graphs are boxplot representations of the quarterly distributions, with reference lines indicating the 5^{th}, 50^{th}, and 95^{th} percentiles of the entire data series (all seasons and years pooled).

4. Regional Ozone Trends

Table 1 gives a listing of 1-hour ozone maximums for sites and years. In addition to first and second maximum concentrations, it gives two more maximums, effective sample sizes (valid hours) and the number of valid sampling days. Table 2 gives 8-hour ozone maximum statistics in the same format, excluding a column for the number of valid hours of sampling.

Table 3 recapitulates the first maximum 1-hour averages in a two-way layout that allows site values to be compared for the same year. Table 4 treats the second maximum 1-hour averages in the same way. Table 5 gives the first maximum 8-hour averages, and Table 6 gives the *fourth* maximum 8-hour averages in the same two-way layout.

Figure 2 gives annual distributions of first maximum 1-hour ozone concentrations for all sites, as boxplots. A reference line is drawn for the NAAQS that indicates nonattainment if the *second* maximum exceeds it. This variable shows highly significant statistical evidence of a trend (P = 0.0015). There was an average annual change of 0.0006 ppm (0.57 percent).

In Figure 3, distributions for all (available) years of the first maximum ozone concentrations for each individual location are shown. In Figure 4, distributions for all (available) years of the first maximum ozone concentrations for the selected sites in each state are shown.

Figure 5 gives annual distributions of second maximums for all sites, as boxplots. A reference line is drawn for the NAAQS that indicates nonattainment if the second maximum exceeds it. This variable shows highly significant statistical evidence of a trend (P = 0.0003). There was an average annual change of 0.0007 ppm (0.71 percent).

Table 1. One-hour Ozone Statistics From Western N.C. and Adjoining Great Smoky Mountains National Park Ozone Monitors, 1987-2000.

AIRS	SITE	STATE	year	max1h1 (ppm)	max1h2 (ppm)	max1h3 (ppm)	max1h4 (ppm)	valid days	county
370210029	Fairview-Bent Creek	NC	1987	0.097	0.086	0.086	0.085	204	BUNCOMBE
370210029	Fairview-Bent Creek	NC	1988	0.118	0.110	0.106	0.104	123	BUNCOMBE
470090101	Look Rock	TN	1988	0.112	0.103	0.093	0.089	87	BLOUNT
471550101	Cove Mtn	TN	1988	0.109	0.103	0.097	0.095	58	SEVIER
370210030	Fairview-Bent Creek	NC	1989	0.087	0.079	0.078	0.078	208	BUNCOMBE
370270003	Lenoir	NC	1989	0.092	0.090	0.089	0.088	209	CALDWELL
470090101	Look Rock	TN	1989	0.098	0.097	0.093	0.089	205	BLOUNT
471550101	Cove Mtn	TN	1989	0.093	0.088	0.087	0.085	122	SEVIER
370210030	Fairview-Bent Creek	NC	1990	0.097	0.091	0.087	0.086	208	BUNCOMBE
470090101	Look Rock	TN	1990	0.108	0.107	0.106	0.097	174	BLOUNT
471550101	Cove Mtn	TN	1990	0.102	0.101	0.098	0.091	139	SEVIER
370210030	Fairview-Bent Creek	NC	1991	0.089	0.079	0.077	0.075	210	BUNCOMBE
370270003	Lenoir	NC	1991	0.096	0.093	0.085	0.084	209	CALDWELL
470090101	Look Rock	TN	1991	0.097	0.096	0.091	0.089	190	BLOUNT
471550101	Cove Mtn	TN	1991	0.101	0.098	0.093	0.092	187	SEVIER
370210030	Fairview-Bent Creek	NC	1992	0.087	0.083	0.080	0.078	209	BUNCOMBE
371990003	Mt. Mitchell	NC	1992	0.096	0.090	0.088	0.088	168	YANCEY
470090101	Look Rock	TN	1992	0.098	0.096	0.095	0.094	203	BLOUNT
471550101	Cove Mtn	TN	1992	0.089	0.083	0.081	0.080	115	SEVIER
370210030	Fairview-Bent Creek	NC	1993	0.099	0.079	0.078	0.076	209	BUNCOMBE
370270003	Lenoir	NC	1993	0.095	0.088	0.087	0.087	206	CALDWELL
370870034	Pisgah-Frying Pan Mtn	NC	1993	0.092	0.087	0.082	0.076	90	HAYWOOD
371990003	Mt. Mitchell	NC	1993	0.102	0.097	0.096	0.093	158	YANCEY
470090101	Look Rock	TN	1993	0.107	0.104	0.101	0.093	185	BLOUNT
471550101	Cove Mtn	TN	1993	0.113	0.099	0.099	0.098	193	SEVIER
471550102	Clingmans Dome	TN	1993	0.082	0.081	0.080	0.079	173	SEVIER
370210030	Fairview-Bent Creek	NC	1994	0.090	0.084	0.082	0.080	214	BUNCOMBE
370870035	Pisgah-Frying Pan Mtn	NC	1994	0.078	0.077	0.075	0.074	115	HAYWOOD
371990003	Mt. Mitchell	NC	1994	0.093	0.092	0.090	0.089	167	YANCEY
470090101	Look Rock	TN	1994	0.116	0.106	0.106	0.104	194	BLOUNT
470090102	Cades Cove	TN	1994	0.111	0.100	0.098	0.092	172	BLOUNT
471550101	Cove Mtn	TN	1994	0.120	0.110	0.106	0.101	208	SEVIER
471550102	Clingmans Dome	TN	1994	0.102	0.102	0.101	0.097	177	SEVIER

AIRS	SITE	STATE	year	max1h1 (ppm)	max1h2 (ppm)	max1h3 (ppm)	max1h4 (ppm)	valid days	county
370210030	Fairview-Bent Creek	NC	1995	0.089	0.085	0.085	0.085	212	BUNCOMBE
370270003	Lenoir	NC	1995	0.100	0.095	0.092	0.091	211	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	1995	0.101	0.095	0.094	0.092	192	HAYWOOD
370870036	Purchase Knob	NC	1995	0.107	0.107	0.101	0.094	133	HAYWOOD
371730002	Bryson City	NC	1995	0.081	0.077	0.076	0.075	201	SWAIN
371990003	Mt. Mitchell	NC	1995	0.127	0.111	0.108	0.103	170	YANCEY
470090101	Look Rock	TN	1995	0.123	0.120	0.116	0.107	147	BLOUNT
470090102	Cades Cove	TN	1995	0.107	0.101	0.097	0.097	208	BLOUNT
471550101	Cove Mtn	TN	1995	0.118	0.111	0.109	0.104	199	SEVIER
471550102	Clingmans Dome	TN	1995	0.107	0.105	0.100	0.097	194	SEVIER
370210030	Fairview-Bent Creek	NC	1996	0.085	0.084	0.083	0.081	207	BUNCOMBE
370870035	Pisgah-Frying Pan Mtn	NC	1996	0.101	0.095	0.095	0.094	189	HAYWOOD
370870036	Purchase Knob	NC	1996	0.092	0.092	0.090	0.090	171	HAYWOOD
371730002	Bryson City	NC	1996	0.076	0.075	0.072	0.070	172	SWAIN
371990003	Mt. Mitchell	NC	1996	0.094	0.090	0.086	0.085	126	YANCEY
470090101	Look Rock	TN	1996	0.106	0.102	0.100	0.100	202	BLOUNT
470090102	Cades Cove	TN	1996	0.093	0.093	0.088	0.087	211	BLOUNT
471550101	Cove Mtn	TN	1996	0.111	0.107	0.100	0.100	205	SEVIER
471550102	Clingmans Dome	TN	1996	0.106	0.102	0.095	0.095	178	SEVIER
370210030	Fairview-Bent Creek	NC	1997	0.093	0.090	0.086	0.083	209	BUNCOMBE
370270003	Lenoir	NC	1997	0.099	0.097	0.097	0.091	213	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	1997	0.094	0.089	0.089	0.086	194	HAYWOOD
370870036	Purchase Knob	NC	1997	0.109	0.106	0.103	0.097	211	HAYWOOD
371730002	Bryson City	NC	1997	0.086	0.081	0.078	0.077	209	SWAIN
371990003	Mt. Mitchell	NC	1997	0.085	0.085	0.084	0.083	212	YANCEY
470090101	Look Rock	TN	1997	0.117	0.115	0.115	0.110	194	BLOUNT
470090102	Cades Cove	TN	1997	0.102	0.099	0.099	0.095	213	BLOUNT
471550101	Cove Mtn	TN	1997	0.120	0.106	0.105	0.105	203	SEVIER
471550102	Clingmans Dome	TN	1997	0.111	0.110	0.109	0.099	189	SEVIER
370210030	Fairview-Bent Creek	NC	1998	0.127	0.114	0.111	0.108	211	BUNCOMBE
370270003	Lenoir	NC	1998	0.122	0.114	0.111	0.109	211	CALDWELL

AIRS	SITE	STATE	year	max1h1 (ppm)	max1h2 (ppm)	max1h3 (ppm)	max1h4 (ppm)	valid days	county
370870035	Pisgah-Frying Pan Mtn	NC	1998	0.116	0.109	0.107	0.106	176	HAYWOOD
370870036	Purchase Knob	NC	1998	0.115	0.100	0.099	0.097	204	HAYWOOD
371730002	Bryson City	NC	1998	0.092	0.090	0.087	0.087	209	SWAIN
371990003	Mt. Mitchell	NC	1998	0.096	0.083	0.074	0.073	73	YANCEY
470090101	Look Rock	TN	1998	0.135	0.120	0.119	0.118	242	BLOUNT
470090102	Cades Cove	TN	1998	0.106	0.101	0.100	0.097	211	BLOUNT
471550101	Cove Mtn	TN	1998	0.124	0.120	0.119	0.115	231	SEVIER
471550102	Clingmans Dome	TN	1998	0.119	0.116	0.115	0.114	180	SEVIER
370210030	Fairview-Bent Creek	NC	1999	0.115	0.099	0.097	0.094	211	BUNCOMBE
370270003	Lenoir	NC	1999	0.117	0.115	0.110	0.107	214	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	1999	0.110	0.107	0.104	0.104	211	HAYWOOD
370870036	Purchase Knob	NC	1999	0.105	0.103	0.102	0.099	214	HAYWOOD
371730002	Bryson City	NC	1999	0.100	0.091	0.086	0.084	208	SWAIN
371990003	Mt. Mitchell	NC	1999	0.109	0.104	0.101	0.097	178	YANCEY
470090101	Look Rock	TN	1999	0.125	0.123	0.117	0.117	244	BLOUNT
470090101	Look Rock	TN	1999	0.131	0.121	0.121	0.118	237	BLOUNT
470090102	Cades Cove	TN	1999	0.116	0.102	0.101	0.100	181	BLOUNT
471550101	Cove Mtn	TN	1999	0.127	0.114	0.113	0.112	231	SEVIER
471550102	Clingmans Dome	TN	1999	0.116	0.113	0.109	0.107	177	SEVIER
370210030	Fairview-Bent Creek	NC	2000	0.108	0.107	0.106	0.102	213	BUNCOMBE
370270003	Lenoir	NC	2000	0.099	0.099	0.096	0.095	202	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	2000	0.098	0.093	0.092	0.090	182	HAYWOOD
370870036	Purchase Knob	NC	2000	0.104	0.102	0.092	0.092	214	HAYWOOD
371730002	Bryson City	NC	2000	0.086	0.082	0.082	0.080	211	SWAIN
371990003	Mt. Mitchell	NC	2000	0.111	0.107	0.102	0.102	181	YANCEY
470090101	Look Rock	TN	2000	0.111	0.108	0.102	0.100	238	BLOUNT
470090102	Cades Cove	TN	2000	0.098	0.097	0.092	0.089	238	BLOUNT
471550101	Cove Mtn	TN	2000	0.115	0.112	0.110	0.101	239	SEVIER
471550102	Clingmans Dome	TN	2000	0.128	0.116	0.109	0.108	179	SEVIER
370210030	Fairview-Bent Creek	NC	2001	0.097	0.091	0.087	0.086	118	BUNCOMBE
370270003	Lenoir	NC	2001	0.105	0.097	0.094	0.094	120	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	2001	0.092	0.091	0.090	0.089	105	HAYWOOD

AIRS	SITE	STATE	year	max1h1 (ppm)	max1h2 (ppm)	max1h3 (ppm)	max1h4 (ppm)	valid days	county
370870036	Purchase Knob	NC	2001	0.093	0.093	0.092	0.088	115	HAYWOOD
371730002	Bryson City	NC	2001	0.084	0.082	0.078	0.078	122	SWAIN
371990003	Mt. Mitchell	NC	2001	0.094	0.090	0.090	0.090	102	YANCEY
470090101	Look Rock	TN	2001	0.096	0.093	0.089	0.088	87	BLOUNT
470090102	Cades Cove	TN	2001	0.093	0.088	0.087	0.083	91	BLOUNT
471550101	Cove Mtn	TN	2001	0.095	0.092	0.091	0.090	91	SEVIER
471550102	Clingmans Dome	TN	2001	0.097	0.097	0.094	0.091	31	SEVIER

Table 2. Eight-hour Ozone Statistics From Western N.C. and Adjoining Great Smoky Mountains National Park Ozone Monitors, 1987-2000.

AIRS	SITE	STATE	year	max8h1 (ppm)	max8h2 (ppm)	max8h3 (ppm)	max8h4 (ppm)	valid days	county
370210029	Fairview-Bent Creek	NC	1987	0.090	0.081	0.077	0.076	204	BUNCOMBE
370210029	Fairview-Bent Creek	NC	1988	0.103	0.097	0.093	0.093	123	BUNCOMBE
470090101	Look Rock	TN	1988	0.107	0.098	0.090	0.078	76	BLOUNT
471550101	Cove Mtn	TN	1988	0.100	0.099	0.092	0.088	56	SEVIER
370210030	Fairview-Bent Creek	NC	1989	0.083	0.080	0.075	0.072	207	BUNCOMBE
370270003	Lenoir	NC	1989	0.081	0.079	0.077	0.075	210	CALDWELL
470090101	Look Rock	TN	1989	0.088	0.086	0.086	0.086	206	BLOUNT
471550101	Cove Mtn	TN	1989	0.084	0.082	0.081	0.081	113	SEVIER
370210030	Fairview-Bent Creek	NC	1990	0.081	0.077	0.076	0.073	207	BUNCOMBE
470090101	Look Rock	TN	1990	0.096	0.094	0.093	0.092	175	BLOUNT
471550101	Cove Mtn	TN	1990	0.094	0.094	0.087	0.087	130	SEVIER
370210030	Fairview-Bent Creek	NC	1991	0.068	0.065	0.064	0.063	211	BUNCOMBE
370270003	Lenoir	NC	1991	0.091	0.079	0.076	0.075	213	CALDWELL
470090101	Look Rock	TN	1991	0.086	0.086	0.081	0.081	192	BLOUNT
471550101	Cove Mtn	TN	1991	0.086	0.086	0.083	0.082	186	SEVIER
370210030	Fairview-Bent Creek	NC	1992	0.071	0.065	0.065	0.064	211	BUNCOMBE
371990003	Mt. Mitchell	NC	1992	0.086	0.085	0.085	0.085	172	YANCEY
470090101	Look Rock	TN	1992	0.094	0.094	0.091	0.088	202	BLOUNT
471550101	Cove Mtn	TN	1992	0.079	0.078	0.077	0.075	115	SEVIER
370210030	Fairview-Bent Creek	NC	1993	0.073	0.067	0.066	0.066	212	BUNCOMBE
370270003	Lenoir	NC	1993	0.082	0.079	0.077	0.076	212	CALDWELL
370870034	Pisgah-Frying Pan Mtn	NC	1993	0.078	0.078	0.071	0.070	90	HAYWOOD
371990003	Mt. Mitchell	NC	1993	0.092	0.090	0.086	0.086	160	YANCEY
470090101	Look Rock	TN	1993	0.100	0.097	0.094	0.091	187	BLOUNT
471550101	Cove Mtn	TN	1993	0.100	0.099	0.091	0.091	194	SEVIER
471550102	Clingmans Dome	TN	1993	NA	NA	NA	NA	NA	SEVIER
370210030	Fairview-Bent Creek	NC	1994	0.079	0.075	0.071	0.069	214	BUNCOMBE
370870035	Pisgah-Frying Pan Mtn	NC	1994	0.071	0.069	0.067	0.066	116	HAYWOOD
371990003	Mt. Mitchell	NC	1994	0.090	0.088	0.079	0.079	175	YANCEY
470090101	Look Rock	TN	1994	0.109	0.102	0.096	0.093	193	BLOUNT
470090102	Cades Cove	TN	1994	0.083	0.083	0.081	0.077	205	BLOUNT
471550101	Cove Mtn	TN	1994	0.111	0.108	0.097	0.088	206	SEVIER
471550102	Clingmans Dome	TN	1994	0.097	0.097	0.090	0.076	179	SEVIER

AIRS	SITE	STATE	year	max8h1 (ppm)	max8h2 (ppm)	max8h3 (ppm)	max8h4 (ppm)	valid days	county
370210030	Fairview-Bent Creek	NC	1995	0.078	0.077	0.076	0.076	214	BUNCOMBE
370270003	Lenoir	NC	1995	0.092	0.083	0.080	0.079	214	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	1995	0.087	0.087	0.086	0.085	116	HAYWOOD
370870036	Purchase Knob	NC	1995	0.103	0.095	0.092	0.085	139	HAYWOOD
371730002	Bryson City	NC	1995	0.070	0.069	0.068	0.067	205	SWAIN
371990003	Mt. Mitchell	NC	1995	0.105	0.098	0.092	0.090	174	YANCEY
470090101	Look Rock	TN	1995	0.109	0.103	0.102	0.101	146	BLOUNT
470090102	Cades Cove	TN	1995	0.084	0.082	0.078	0.076	211	BLOUNT
471550101	Cove Mtn	TN	1995	0.108	0.103	0.100	0.097	200	SEVIER
471550102	Clingmans Dome	TN	1995	0.097	0.095	0.089	0.089	191	SEVIER
370210030	Fairview-Bent Creek	NC	1996	0.078	0.077	0.076	0.076	210	BUNCOMBE
370870035	Pisgah-Frying Pan Mtn	NC	1996	0.093	0.092	0.088	0.088	197	HAYWOOD
370870036	Purchase Knob	NC	1996	0.088	0.083	0.082	0.079	184	HAYWOOD
371730002	Bryson City	NC	1996	0.065	0.065	0.065	0.063	175	SWAIN
371990003	Mt. Mitchell	NC	1996	0.083	0.082	0.080	0.078	133	YANCEY
470090101	Look Rock	TN	1996	0.090	0.089	0.089	0.088	199	BLOUNT
470090102	Cades Cove	TN	1996	0.079	0.076	0.076	0.075	122	BLOUNT
471550101	Cove Mtn	TN	1996	0.094	0.093	0.092	0.092	199	SEVIER
471550102	Clingmans Dome	TN	1996	0.094	0.089	0.089	0.088	177	SEVIER
370210030	Fairview-Bent Creek	NC	1997	0.078	0.078	0.076	0.075	210	BUNCOMBE
370270003	Lenoir	NC	1997	0.085	0.084	0.082	0.079	214	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	1997	0.087	0.087	0.085	0.085	195	HAYWOOD
370870036	Purchase Knob	NC	1997	0.094	0.093	0.089	0.087	213	HAYWOOD
371730002	Bryson City	NC	1997	0.079	0.071	0.071	0.070	208	SWAIN
371990003	Mt. Mitchell	NC	1997	0.081	0.078	0.076	0.075	214	YANCEY
470090101	Look Rock	TN	1997	0.111	0.108	0.100	0.098	187	BLOUNT
470090102	Cades Cove	TN	1997	0.084	0.079	0.079	0.077	211	BLOUNT
471550101	Cove Mtn	TN	1997	0.104	0.097	0.095	0.095	193	SEVIER
471550102	Clingmans Dome	TN	1997	0.097	0.096	0.090	0.089	181	SEVIER
370210030	Fairview-Bent Creek	NC	1998	0.103	0.098	0.095	0.090	213	BUNCOMBE
370270003	Lenoir	NC	1998	0.109	0.101	0.101	0.098	212	CALDWELL
370870035	Pisgah-	NC	1998	0.108	0.106	0.104	0.102	178	HAYWOOD

AIRS	SITE	STATE	year	max8h1 (ppm)	max8h2 (ppm)	max8h3 (ppm)	max8h4 (ppm)	valid days	county
	Frying Pan Mtn								
370870036	Purchase Knob	NC	1998	0.102	0.098	0.093	0.092	205	HAYWOOD
371730002	Bryson City	NC	1998	0.086	0.083	0.080	0.078	208	SWAIN
371990003	Mt. Mitchell	NC	1998	0.084	0.070	0.069	0.069	71	YANCEY
470090101	Look Rock	TN	1998	0.122	0.116	0.112	0.110	212	BLOUNT
470090102	Cades Cove	TN	1998	0.090	0.088	0.086	0.086	208	BLOUNT
471550101	Cove Mtn	TN	1998	0.111	0.110	0.107	0.106	197	SEVIER
471550102	Clingmans Dome	TN	1998	0.113	0.112	0.106	0.106	179	SEVIER
370210030	Fairview-Bent Creek	NC	1999	0.089	0.085	0.084	0.084	210	BUNCOMBE
370270003	Lenoir	NC	1999	0.103	0.097	0.096	0.094	214	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	1999	0.098	0.098	0.097	0.096	211	HAYWOOD
370870036	Purchase Knob	NC	1999	0.100	0.097	0.096	0.093	214	HAYWOOD
371730002	Bryson City	NC	1999	0.082	0.077	0.077	0.076	206	SWAIN
371990003	Mt. Mitchell	NC	1999	0.099	0.098	0.094	0.094	172	YANCEY
470090101	Look Rock	TN	1999	0.110	0.102	0.099	0.092	121	BLOUNT
470090101	Look Rock	TN	1999	0.121	0.111	0.106	0.104	175	BLOUNT
470090102	Cades Cove	TN	1999	0.083	0.081	0.079	0.077	87	BLOUNT
471550101	Cove Mtn	TN	1999	0.105	0.096	0.094	0.094	96	SEVIER
471550102	Clingmans Dome	TN	1999	0.105	0.104	0.091	0.089	91	SEVIER
370210030	Fairview-Bent Creek	NC	2000	0.097	0.095	0.094	0.090	169	BUNCOMBE
370270003	Lenoir	NC	2000	0.092	0.090	0.089	0.085	206	CALDWELL
370870035	Pisgah-Frying Pan Mtn	NC	2000	0.091	0.089	0.087	0.085	85	HAYWOOD
370870036	Purchase Knob	NC	2000	0.095	0.089	0.087	0.087	144	HAYWOOD
371730002	Bryson City	NC	2000	0.076	0.075	0.075	0.074	197	SWAIN
371990003	Mt. Mitchell	NC	2000	0.093	0.088	0.088	0.087	181	YANCEY
470090101	Look Rock	TN	2000	0.099	0.097	0.096	0.093	214	BLOUNT
470090102	Cades Cove	TN	2000	0.092	0.085	0.081	0.081	214	BLOUNT
471550101	Cove Mtn	TN	2000	0.110	0.104	0.099	0.096	214	SEVIER
471550102	Clingmans Dome	TN	2000	0.111	0.109	0.101	0.100	184	SEVIER

Table 3. First Maximum 1-Hour Ozone Concentrations in Western NC, 1987-2000

year	Bryson City	Cades Cove TN	Cling-mans Dome TN	Cove Mtn TN	Fair-view-Bent Creek	Lenoir	Look Rock TN	Mt. Mitchell	Pis-gah-Frying Pan Mtn	Purch-ase Knob
1987	NA	NA	NA	NA	0.097	NA	NA	NA	NA	NA
1988	NA	NA	NA	0.109	0.118	NA	0.112	NA	NA	NA
1989	NA	NA	NA	0.093	0.087	0.092	0.098	NA	NA	NA
1990	NA	NA	NA	0.102	0.097	NA	0.108	NA	NA	NA
1991	NA	NA	NA	0.101	0.089	0.096	0.097	NA	NA	NA
1992	NA	NA	NA	0.089	0.087	NA	0.098	0.096	NA	NA
1993	NA	NA	0.082	0.113	0.099	0.095	0.107	0.102	0.092	NA
1994	NA	0.111	0.102	0.120	0.090	NA	0.116	0.093	0.078	NA
1995	0.081	0.107	0.107	0.118	0.089	0.100	0.123	0.127	0.101	0.107
1996	0.076	0.093	0.106	0.111	0.085	NA	0.106	0.094	0.101	0.092
1997	0.086	0.102	0.111	0.120	0.093	0.099	0.117	0.085	0.094	0.109
1998	0.092	0.106	0.119	0.124	0.127	0.122	0.135	0.096	0.116	0.115
1999	0.100	0.116	0.116	0.127	0.115	0.117	0.128	0.109	0.110	0.105
2000	0.086	0.098	0.128	0.115	0.108	0.099	0.111	0.111	0.098	0.104

Table 4. Second Maximum 1-Hour Ozone Concentrations in Western NC, 1987-2000

year	Bryson City	Cades Cove TN	Cling-mans Dome TN	Cove Mtn TN	Fair-view-Bent Creek	Lenoir	Look Rock TN	Mt. Mitchell	Pis-gah-Frying Pan Mtn	Purch-ase Knob
1987	NA	NA	NA	NA	0.086	NA	NA	NA	NA	NA
1988	NA	NA	NA	0.103	0.110	NA	0.103	NA	NA	NA
1989	NA	NA	NA	0.088	0.079	0.090	0.097	NA	NA	NA
1990	NA	NA	NA	0.101	0.091	NA	0.107	NA	NA	NA
1991	NA	NA	NA	0.098	0.079	0.093	0.096	NA	NA	NA
1992	NA	NA	NA	0.083	0.083	NA	0.096	0.090	NA	NA
1993	NA	NA	0.081	0.099	0.079	0.088	0.104	0.097	0.087	NA
1994	NA	0.100	0.102	0.110	0.084	NA	0.106	0.092	0.077	NA
1995	0.077	0.101	0.105	0.111	0.085	0.095	0.120	0.111	0.095	0.107
1996	0.075	0.093	0.102	0.107	0.084	NA	0.102	0.090	0.095	0.092
1997	0.081	0.099	0.110	0.106	0.090	0.097	0.115	0.085	0.089	0.106
1998	0.090	0.101	0.116	0.120	0.114	0.114	0.120	0.083	0.109	0.100
1999	0.091	0.102	0.113	0.114	0.099	0.115	0.122	0.104	0.107	0.103
2000	0.082	0.097	0.116	0.112	0.107	0.099	0.108	0.107	0.093	0.102

Table 5. First Maximum 8-Hour Ozone Concentrations in Western NC, 1987-2000

year	Bryson City	Cades Cove TN	Cling-mans Dome TN	Cove Mtn TN	Fair-view-Bent Creek	Lenoir	Look Rock TN	Mt. Mitchell	Pis-gah-Frying Pan Mtn	Purch-ase Knob
1987	NA	NA	NA	NA	0.090	NA	NA	NA	NA	NA
1988	NA	NA	NA	0.100	0.103	NA	0.1070	NA	NA	NA
1989	NA	NA	NA	0.084	0.083	0.081	0.0880	NA	NA	NA
1990	NA	NA	NA	0.094	0.081	NA	0.0960	NA	NA	NA
1991	NA	NA	NA	0.086	0.068	0.091	0.0860	NA	NA	NA
1992	NA	NA	NA	0.079	0.071	NA	0.0940	0.086	NA	NA
1993	NA	NA	NA	0.100	0.073	0.082	0.1000	0.092	0.078	NA
1994	NA	0.083	0.097	0.111	0.079	NA	0.1090	0.090	0.071	NA
1995	0.070	0.084	0.097	0.108	0.078	0.092	0.1090	0.105	0.087	0.103
1996	0.065	0.079	0.094	0.094	0.078	NA	0.0900	0.083	0.093	0.088
1997	0.079	0.084	0.097	0.104	0.078	0.085	0.1110	0.081	0.087	0.094
1998	0.086	0.090	0.113	0.111	0.103	0.109	0.1220	0.084	0.108	0.102
1999	0.082	0.083	0.105	0.105	0.089	0.103	0.1155	0.099	0.098	0.100
2000	0.076	0.092	0.111	0.110	0.097	0.092	0.0990	0.093	0.091	0.095

Table 6. Fourth Maximum 8-Hour Ozone Concentrations in Western NC, 1987-2000

year	Bryson City	Cades Cove TN	Cling-mans Dome TN	Cove Mtn TN	Fair-view-Bent Creek	Lenoir	Look Rock TN	Mt. Mitchell	Pis-gah-Frying Pan Mtn	Purch-ase Knob
1987	NA	NA	NA	NA	0.076	NA	NA	NA	NA	NA
1988	NA	NA	NA	0.088	0.093	NA	0.078	NA	NA	NA
1989	NA	NA	NA	0.081	0.072	0.075	0.086	NA	NA	NA
1990	NA	NA	NA	0.087	0.073	NA	0.092	NA	NA	NA
1991	NA	NA	NA	0.082	0.063	0.075	0.081	NA	NA	NA
1992	NA	NA	NA	0.075	0.064	NA	0.088	0.085	NA	NA
1993	NA	NA	NA	0.091	0.066	0.076	0.091	0.086	0.070	NA
1994	NA	0.077	0.076	0.088	0.069	NA	0.093	0.079	0.066	NA
1995	0.067	0.076	0.089	0.097	0.076	0.079	0.101	0.090	0.085	0.085
1996	0.063	0.075	0.088	0.092	0.076	NA	0.088	0.078	0.088	0.079
1997	0.070	0.077	0.089	0.095	0.075	0.079	0.098	0.075	0.085	0.087
1998	0.078	0.086	0.106	0.106	0.090	0.098	0.110	0.069	0.102	0.092
1999	0.076	0.077	0.089	0.094	0.084	0.094	0.098	0.094	0.096	0.093
2000	0.074	0.081	0.100	0.096	0.090	0.085	0.093	0.087	0.085	0.087

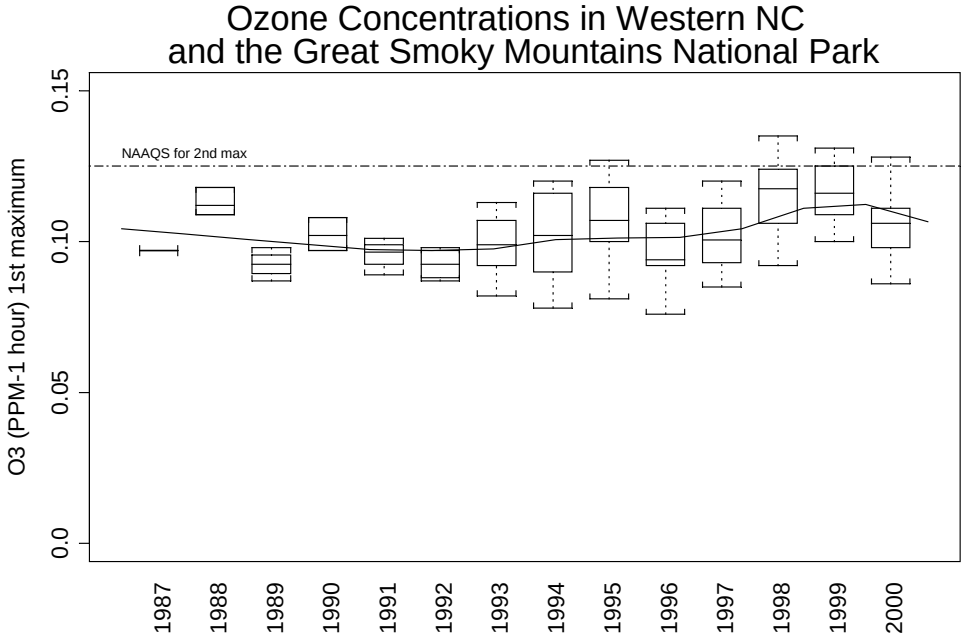

Figure 2. Annual Maximum 1-Hour Ozone Concentrations: 10 Locations Represented By 12 Sites.

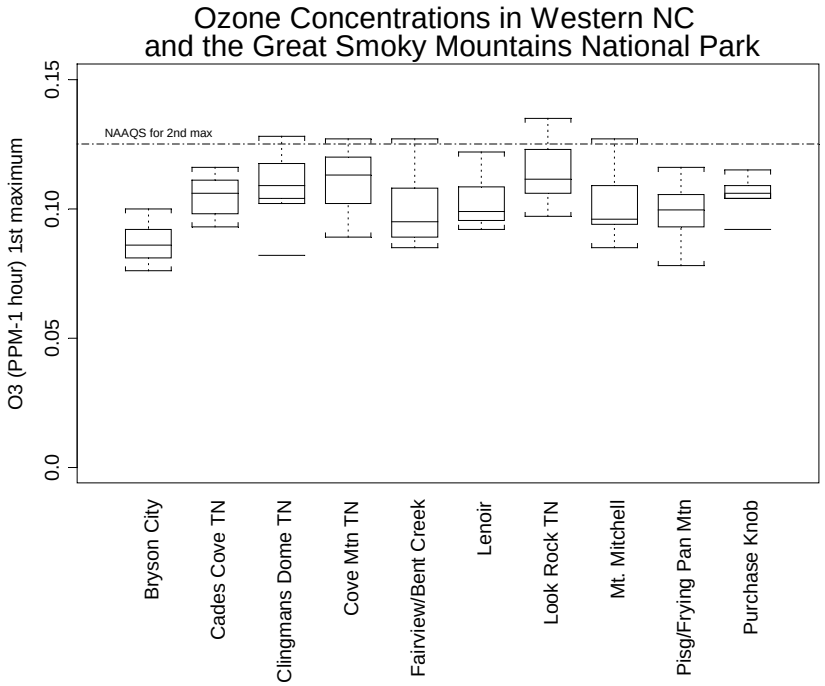

Figure 3. Annual Maximum 1-Hour Ozone Concentrations: Each Location, All Years

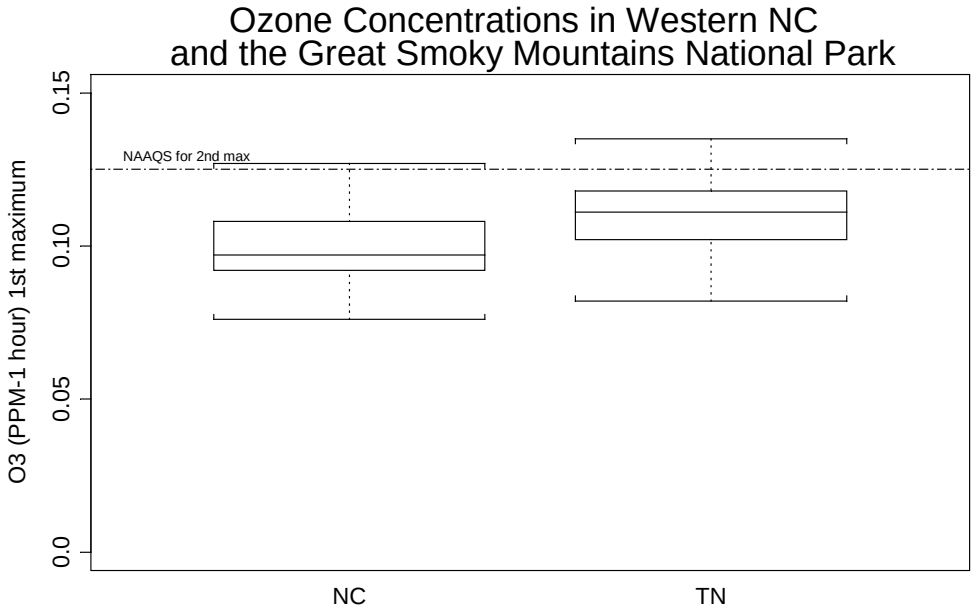

Figure 4. Maximum 1-Hour Ozone Concentrations by State, for All Years

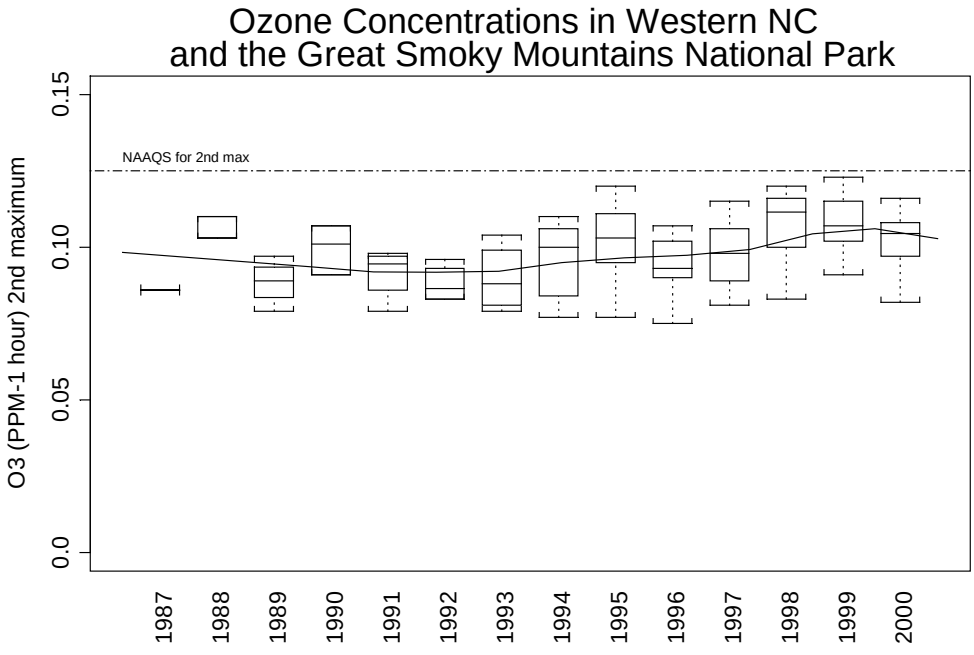

Figure 5. Annual Second Maximum 1-Hour Ozone Concentrations: 10 Locations Represented by 12 Sites

In Figure 6, distributions of the second maximum ozone concentrations for each individual location are shown for all (available) years. In Figure 7, distributions of the second maximum concentrations for the selected sites in each state are shown for all (available) years.

Figure 8 gives annual distributions of first maximum 8-hour ozone concentrations for all sites, as boxplots. A reference line is drawn for the NAAQS that indicates nonattainment if the *fourth* maximum exceeds it. This variable shows significant statistical evidence of a trend (P = 0.028). There was an average annual change of 0.0008 ppm (0.87 percent).

In Figure 9, distributions for all (available) years of the first maximums for each individual location are shown. In Figure 10, distributions for all (available) years of the first maximums for the selected sites in each state are shown.

Figure 11 gives annual distributions of fourth maximum 8-hour ozone concentrations for all sites, as boxplots. A reference line is drawn for the NAAQS that indicates nonattainment if the fourth maximum exceeds it. This variable shows statistical evidence of a trend (P = 0.0023). There was an average annual change of 0.0010 ppm (1.15 percent).

In Figure 12, distributions for all (available) years of the fourth maximums for each individual location are shown. In Figure 13, distributions for all (available) years of the fourth maximums for the selected sites in each state are shown.

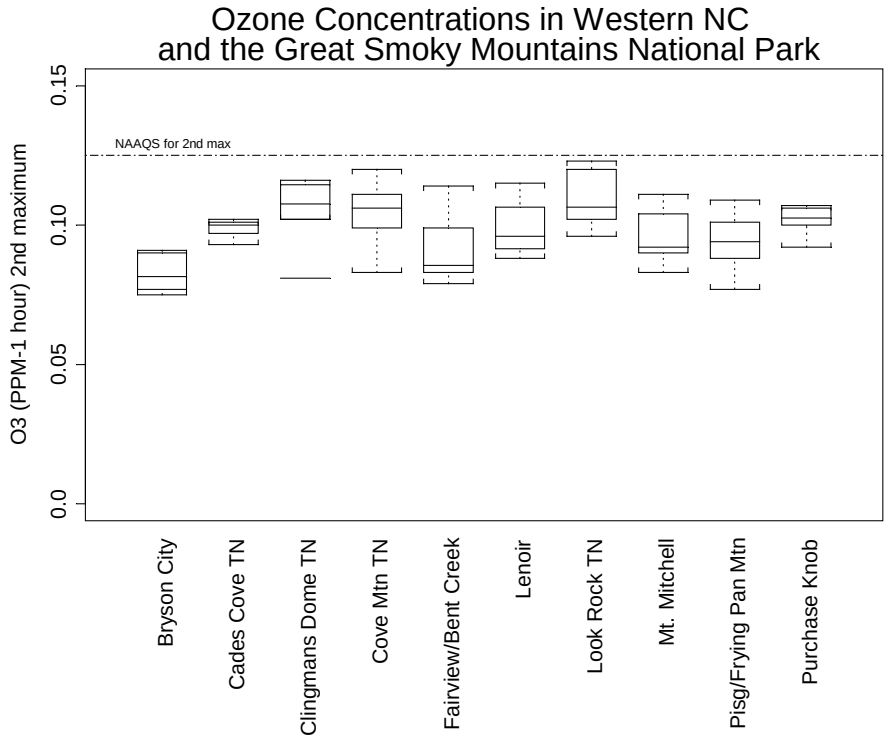

Figure 6. Second Maximum 1-Hour Ozone Concentrations: Each Location, All Years

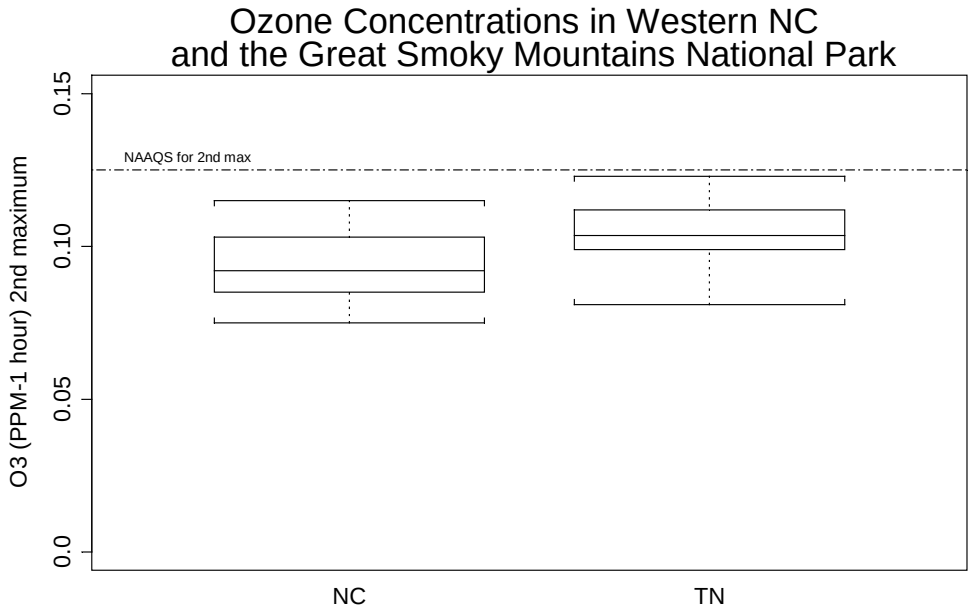

Figure 7. Second Maximum 1-Hour Ozone Concentrations: Grouped by State, All Years

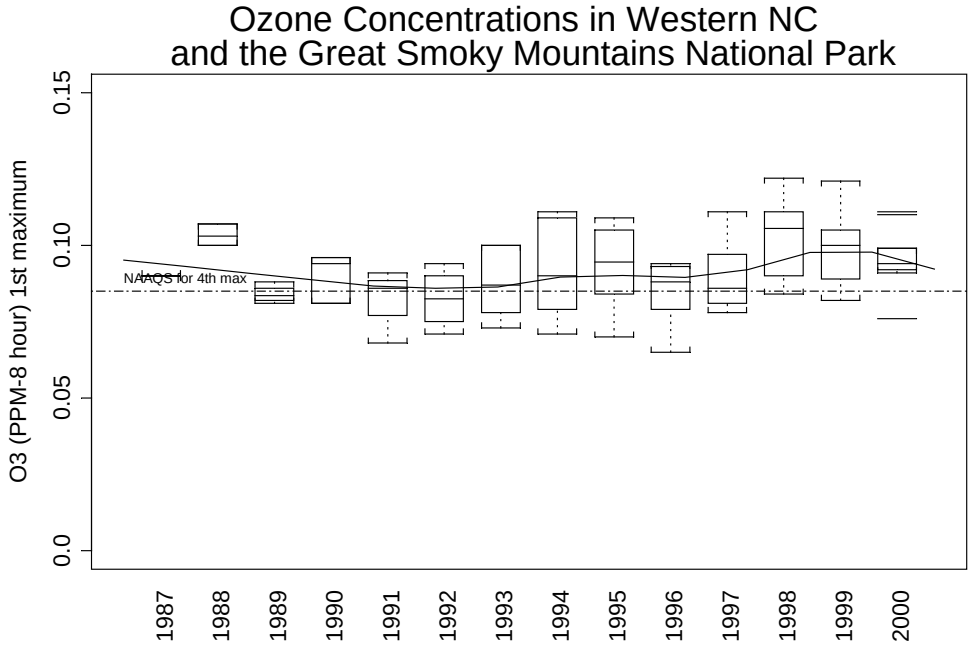

Figure 8. Annual Maximum 8-Hour Ozone Concentrations: 10 Locations Represented by 12 Sites

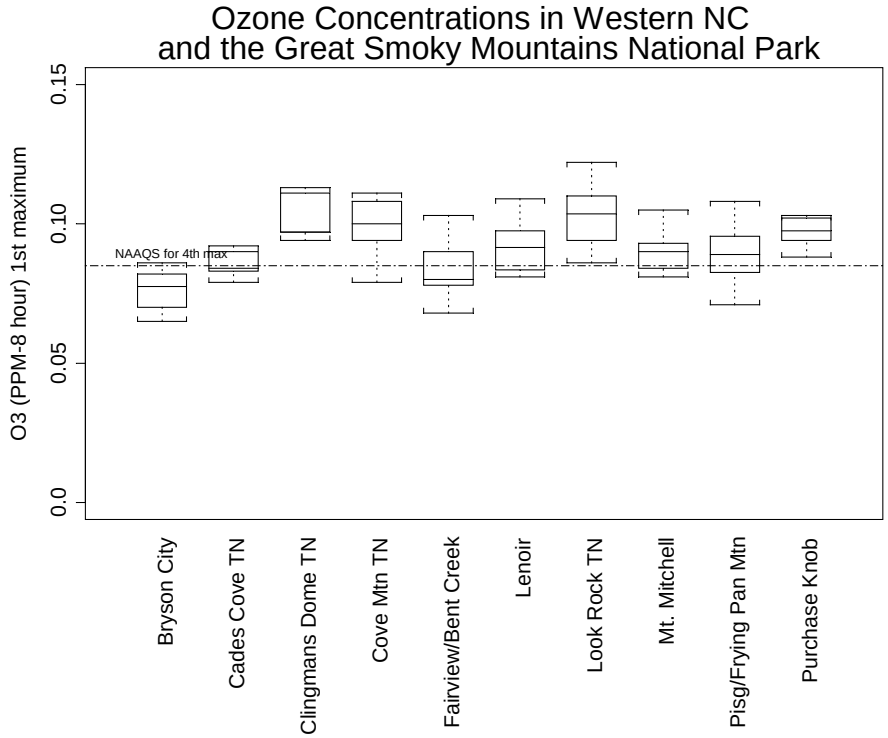

Figure 9. Maximum 8-Hour Ozone Concentrations, At Each Location, For All Years

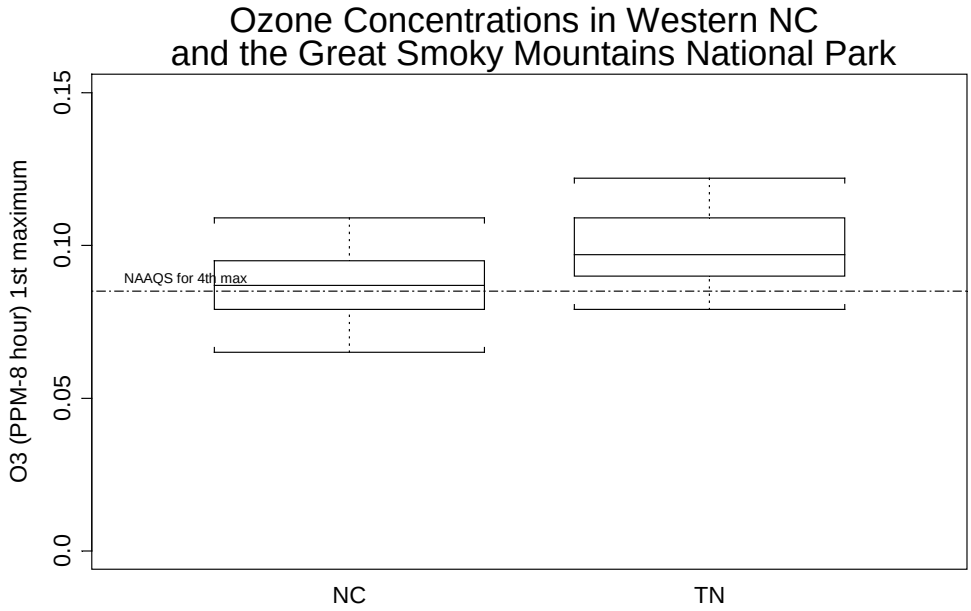

Figure 10. Maximum 8-Hour Ozone Concentrations, By State, For All Years

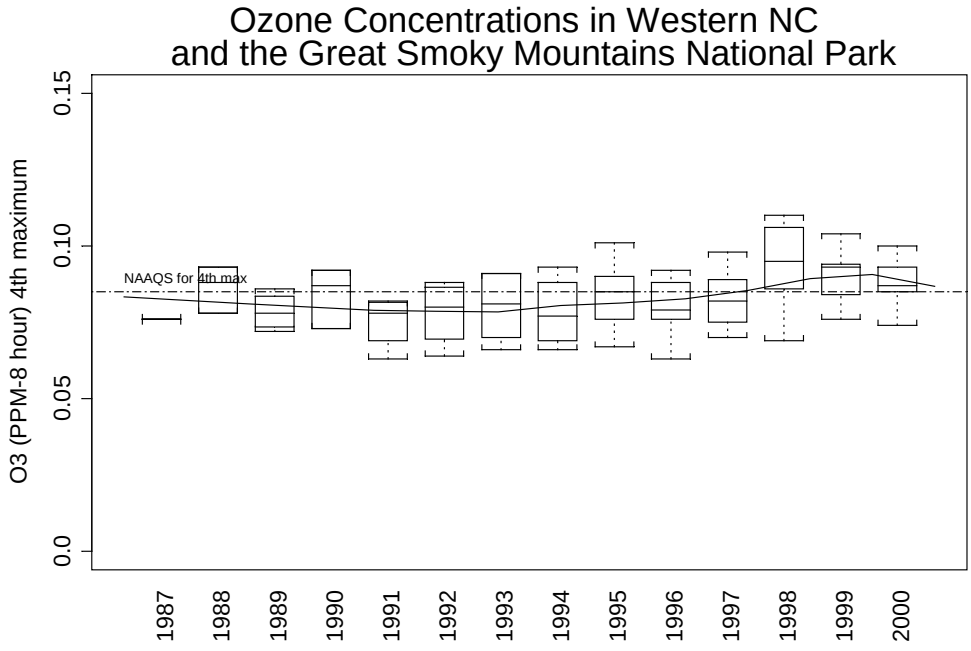

Figure 11. Annual Fourth Maximum 8-Hour Ozone Concentrations: 10 Locations Represented by 12 Sites

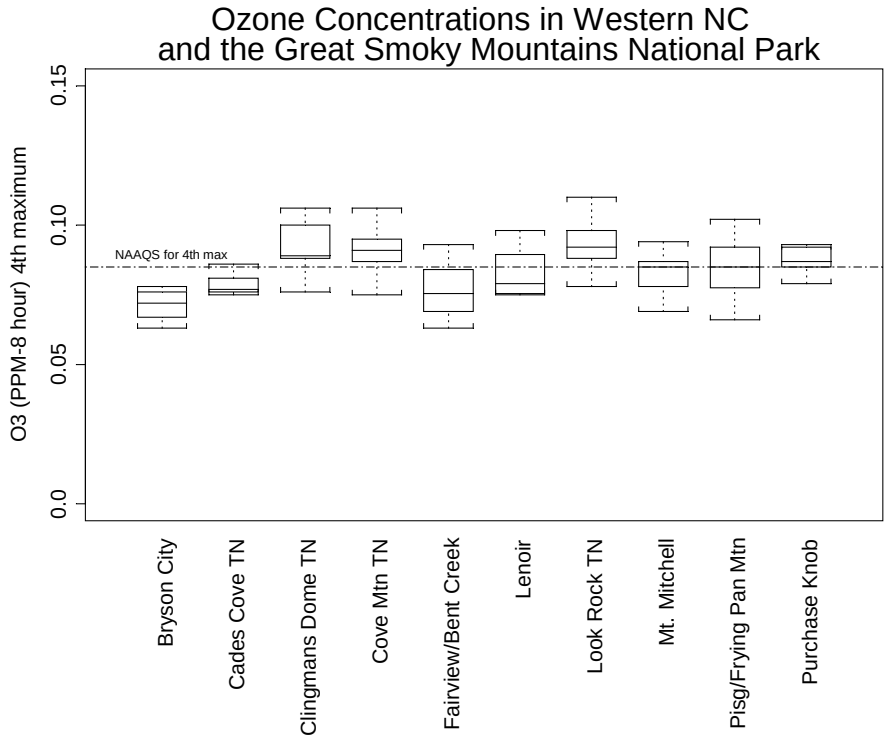

Figure 12. Fourth Maximum 8-Hour Ozone Concentrations, For Each Location, All Years

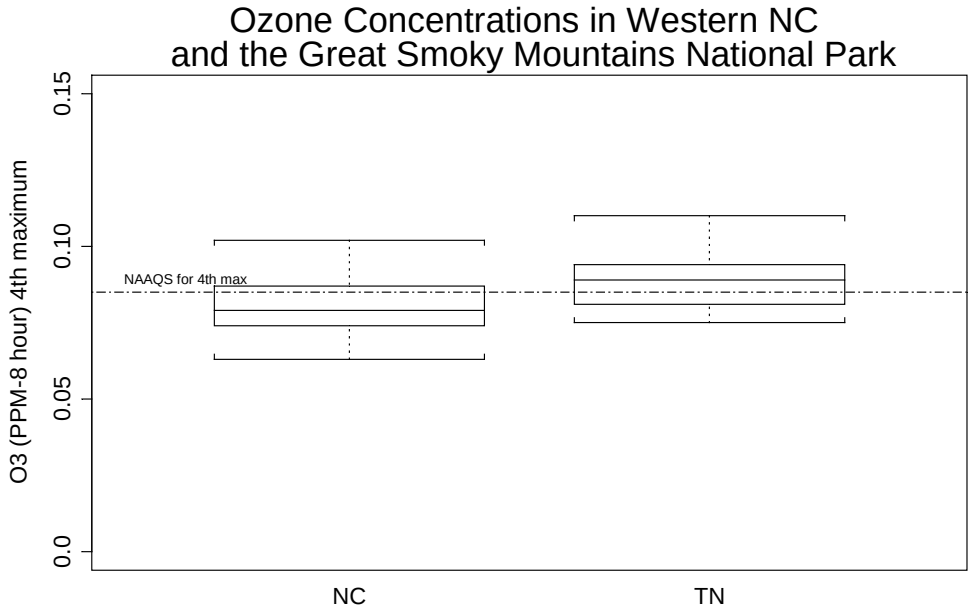

Figure 13. Fourth Maximum 8-Hour Ozone Concentrations, By State, All Years

5. Regional Acid Precipitation Trends

Recently, Seilkop (1992) analyzed trends in precipitation chemistry data from these NADP/NTN monitoring sites for the time period from 1979 through 1990. He found no significant change in precipitation acidity for any of the North Carolina or adjacent South Carolina, Tennessee and Virginia sites. Likewise, Seilkop (1992) found no general evidence of trends in nitrate and ammonium concentrations, except at one site in the sandhills (Jordan Creek, NC36) and one in the southern coastal region (Clinton, NC35).

For sulfate, Seilkop (1992) did find weak evidence of decreasing concentrations over time at Coweeta (NC25) and at one Piedmont region site (NC34). He stated that the concentration at Coweeta was decreasing about 2 percent per year, but he found that the statistical evidence was inconclusive for this being a real trend, as opposed to random variation. Cornelius (1999) reported highly significant evidence of a trend through 1997 (also finding the rate to average about 2 percent per year, for the 8 years longer duration).

Sulfate ion concentration distributions and trends for 1978 through 2000 are shown in Figure 14 for the NADP/NTN sites we examined. There was an average annual change of -0.208 mg/l (-1.42 percent), which is very highly significant evidence of a trend ($P < .0001$). The graph suggests that the decreasing trend may have ended in about 1994, leveling off thereafter. In Section 7, the trend will be addressed at each separate component site.

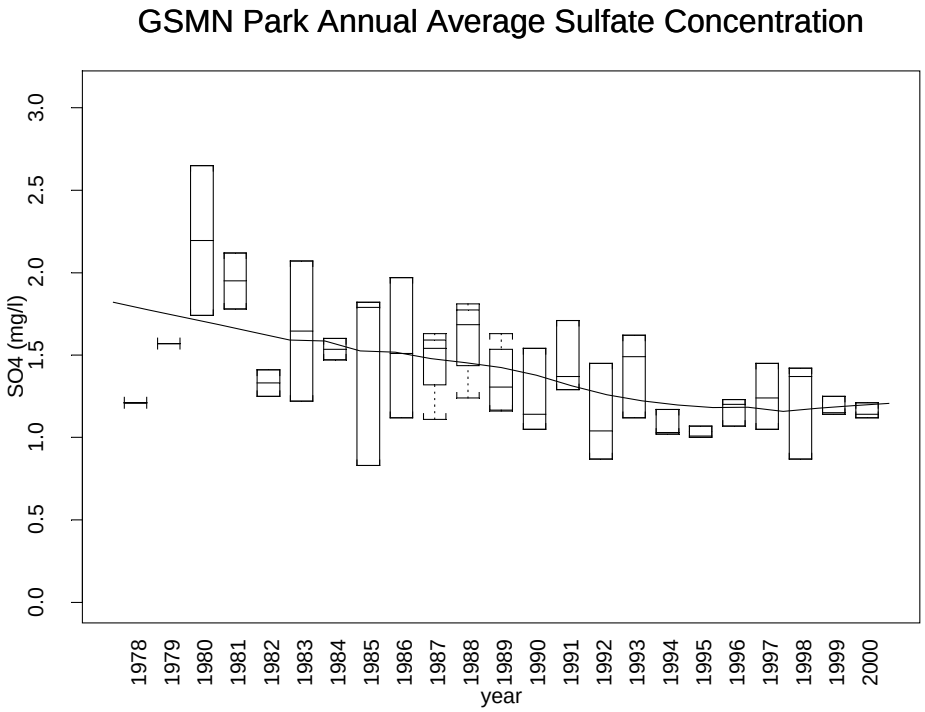

Figure 14. Sulfate Ion Concentration Distributions in Western North Carolina and Surrounding Area (Four NADP Locations).

In 1999, a reviewer for the National Park Service commented to us that nitrate deposition at Elkmont (TN11) appeared to be increasing annually. Cornelius (1999) verified that there was an average annual change of about 0.18 kg/ha nitrate (1.4 percent) through 1997, along with statistically significant evidence of a trend. With the data available through 2000, the apparent annual change now averages 0.12 kg/ha nitrate (1.0 percent), but this can be attributable to random variations rather than a definitive trend, since the statistical test is unable to detect a significant nonzero change ($P = 0.13$). Annual nitrate ion deposition totals for 1981 through 2000 are shown as a time series graph in Figure 15.

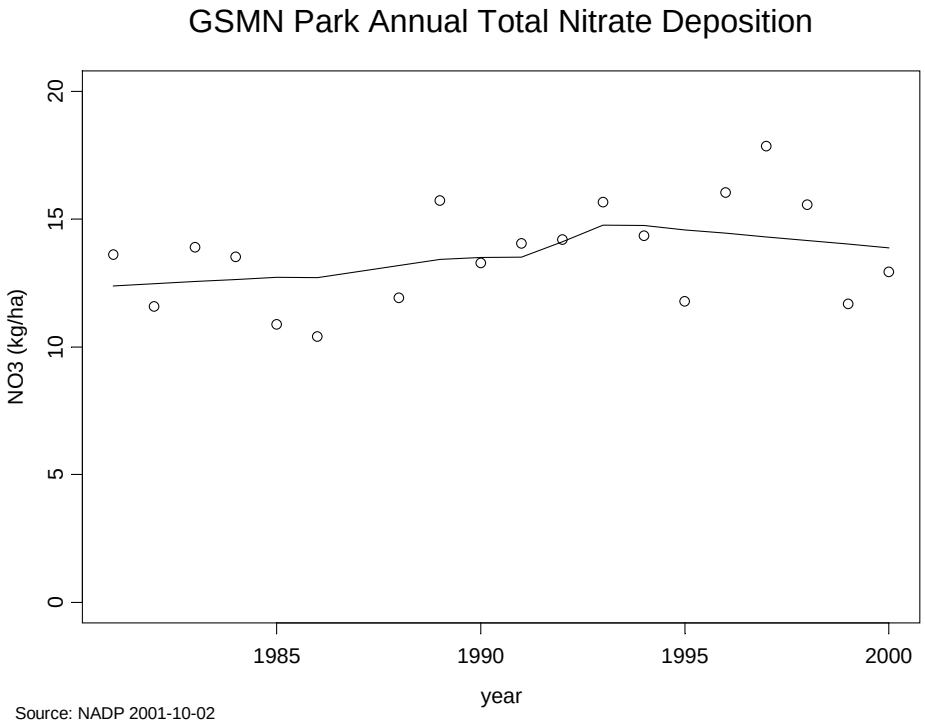

Figure 15. Nitrate Ion Depositions at Elkmont, TN.

6. Visibility Trends

Cahill, Eldred and Wakabayashi (1996) demonstrated trends in sulfur concentrations at the Great Smoky Mountains National Park IMPROVE monitor from 1984 through 1995. Summer average concentrations increased 4.4 percent per year from 1984 to 1990 and decreased 3.8 percent per year from 1990 to 1995. Sulfur particles account for about 50 to 70 percent of annual average light extinction in this park and at Shenandoah National Park (US Environmental Protection Agency [USEPA] 1998). Sulfur is measured in two places on IMPROVE monitors, sometimes inconsistently; Cahill et all (1996) stated that no successful study of the differences has been reported. Generally, about half of the fine particle mass in the Eastern U.S. is ammonium sulfate, which has a high light scattering efficiency, especially in the presence of high humidity (Anon. 1994).

Long term visibility trends based upon airport data have been interpreted to suggest 80 percent decrease in summer visibility and 40 percent decrease in winter visibility from 1948 to the 1990s in Great Smoky Mountains National Park (Jim Renfro *pers. comm.*) or 50 percent decrease in summer visibility and no significant change in winter visibility from the 1950s to the 1970s for the mid-Atlantic states, Maryland, Virginia, and North Carolina (Irving *n.d.*)

The *National Air Quality and Emissions Trends Report, 1998* summarized 1989-1998 light extinction trends for 3 Eastern U.S. Class I sites (one of which is in this study) and 1992-1998 trends for 10 sites. The haziest days were unchanged from 1989 to 1998 and degraded by 4 percent from 1992 to 1998; the “best” days improved over the 10 years but not over the 1992

to 1998 period. The "middle" days showed more than 10 percent improvement from 1989 to 1998 and about 5 percent improvement for 1992 to 1998. [USEPA 2000, p. 96].

Visibility data for the two IMPROVE monitors representing Western N.C. is shown as haze coefficients (deciviews) in Table 7 (Great Smoky Mountain National Park) and Table 8 (Shining Rock Wilderness) and as Standard Visual Ranges (km) in Table 9 (Great Smoky Mountain National Park) and Table 10 (Shining Rock Wilderness). Each of these tables shows the 10th percentile, median and 90th percentile value for each quarter of data (quarters based on a December to November year). For haze coefficients, small numbers signify better visibility than do large numbers; however, Standard Visual Range numbers are directly proportional to distances from which standardized features can be seen. The 10th percentile of haziness can be interpreted as an average value for the 20 percent of days with the best visibility, the median is an average value for the "middle" 20 percent – or generally *all* of the days, and the 90th percentile can be interpreted as an average value for the 20 percent of days with the worst visibility. Similarly, for Standard Visual Ranges, the 10th percentile can be interpreted as an average for the 20 percent of days with the *worst* visibility and the 90th percentile as an average for the 20 percent of days with the *best* visibility.

The statistical evidence for trends in all of these measures is inconclusive, although fall, winter and spring visibility may be improving slowly. Summer visibility is always poorer than that in other seasons.

Table 7. Great Smoky Mountains National Park: Deciviews of Haziness

Season	percentiles		
	p10	p50	p90
1988 MAR-MAY	15.64	20.40	24.90
1988 JUN-AUG	19.91	24.11	31.73
1988 SEP-NOV	16.22	20.22	23.66
1989 DEC-FEB	11.35	16.47	19.77
1989 MAR-MAY	18.16	22.42	26.19
1989 JUN-AUG	20.81	26.40	32.80
1989 SEP-NOV	16.20	21.97	29.79
1990 DEC-FEB	13.61	17.96	21.62
1990 MAR-MAY	17.22	21.29	25.60
1990 JUN-AUG	21.14	31.06	34.73
1990 SEP-NOV	16.05	20.09	25.83
1991 DEC-FEB	11.80	16.54	20.89
1991 MAR-MAY	16.26	20.48	25.66
1991 JUN-AUG	21.29	25.93	32.56
1991 SEP-NOV	16.42	19.32	23.46
1992 DEC-FEB	13.02	17.84	22.37
1992 MAR-MAY	19.23	21.54	26.11
1992 JUN-AUG	23.46	28.26	32.67
1992 SEP-NOV	13.30	21.10	28.42
1993 DEC-FEB	13.23	17.58	22.08
1993 MAR-MAY	15.14	20.97	26.70
1993 JUN-AUG	25.34	29.17	32.86
1993 SEP-NOV	15.43	22.86	26.02
1994 DEC-FEB	13.02	15.87	19.54
1994 MAR-MAY	14.04	20.98	27.83

Season	percentiles		
	p10	p50	p90
1994 JUN-AUG	17.49	26.49	35.26
1994 SEP-NOV	13.88	20.77	28.49
1995 DEC-FEB	13.68	16.04	20.67
1995 MAR-MAY	15.16	21.23	26.32
1995 JUN-AUG	19.23	27.58	34.26
1995 SEP-NOV	13.23	19.29	28.18
1996 DEC-FEB	15.60	18.64	20.73
1996 MAR-MAY	16.51	19.01	25.86
1996 JUN-AUG	22.09	30.31	33.00
1996 SEP-NOV	15.63	21.26	25.92
1997 DEC-FEB	14.63	18.63	21.40
1997 MAR-MAY	15.91	18.07	22.33
1997 JUN-AUG	21.18	27.64	31.49
1997 SEP-NOV	16.86	21.98	32.15
1998 DEC-FEB	13.04	18.64	22.18
1998 MAR-MAY	14.16	21.83	29.99
1998 JUN-AUG	22.51	28.63	33.86
1998 SEP-NOV	15.39	22.63	31.00
1999 DEC-FEB	14.49	18.31	22.00
1999 MAR-MAY	16.20	20.75	26.64
1999 JUN-AUG	23.83	29.33	33.02
1999 SEP-NOV	16.18	23.58	27.77
2000 DEC-FEB	13.16	18.55	21.80

Table 8. Shining Rock Wilderness: Deciviews of Haziness

Season	percentiles		
	p10	p50	p90
1994 JUN-AUG	14.90	25.75	33.06
1994 SEP-NOV	10.93	16.07	25.68
1995 DEC-FEB	8.81	12.02	16.51
1995 MAR-MAY	11.09	19.34	24.03
1995 JUN-AUG	18.17	26.04	33.65
1995 SEP-NOV	13.13	19.73	28.19
1996 DEC-FEB	8.70	13.91	16.25
1996 MAR-MAY	13.18	17.86	22.52
1996 JUN-AUG	18.75	27.99	33.37
1996 SEP-NOV	9.14	16.65	25.19
1997 DEC-FEB	9.85	13.68	17.91
1997 MAR-MAY	12.39	17.03	21.11
1997 JUN-AUG	13.97	24.91	30.07
1997 SEP-NOV	12.86	18.43	31.04
1998 DEC-FEB	10.64	13.05	15.85
1998 MAR-MAY	10.01	19.58	29.38
1998 JUN-AUG	19.98	26.40	33.34
1998 SEP-NOV	9.86	20.94	29.56
1999 DEC-FEB	8.56	12.36	18.63
1999 MAR-MAY	12.98	18.41	25.36
1999 JUN-AUG	24.19	26.28	32.85
1999 SEP-NOV	8.65	20.18	25.96
2000 DEC-FEB	9.46	13.28	19.34

Table 9. Great Smoky Mountains National Park: Standard Visual Ranges

Season	percentiles		
	p10	p50	p90
1988 MAR-MAY	32.43	50.85	81.86
1988 JUN-AUG	16.47	35.09	54.39
1988 SEP-NOV	36.69	51.76	77.33
1989 DEC-FEB	54.19	75.74	125.62
1989 MAR-MAY	28.48	41.56	63.61
1989 JUN-AUG	14.72	27.89	48.84
1989 SEP-NOV	19.88	43.45	77.38
1990 DEC-FEB	45.09	64.92	100.28
1990 MAR-MAY	30.23	46.58	69.91
1990 JUN-AUG	12.13	17.50	47.76
1990 SEP-NOV	29.78	52.45	78.81
1991 DEC-FEB	48.41	74.76	120.14
1991 MAR-MAY	30.05	50.44	76.98
1991 JUN-AUG	15.07	29.26	46.70
1991 SEP-NOV	38.02	56.69	75.83
1992 DEC-FEB	41.77	65.78	106.50
1992 MAR-MAY	28.75	45.40	57.13
1992 JUN-AUG	14.91	23.17	37.48
1992 SEP-NOV	22.80	47.39	103.50
1993 DEC-FEB	42.98	67.42	104.11
1993 MAR-MAY	27.07	48.03	85.99
1993 JUN-AUG	14.63	21.15	31.05
1993 SEP-NOV	28.99	39.74	83.85
1994 DEC-FEB	55.41	80.03	106.30
1994 MAR-MAY	24.19	48.04	96.08
1994 JUN-AUG	11.50	27.65	67.98
1994 SEP-NOV	22.70	49.02	97.85
1995 DEC-FEB	49.57	78.60	99.68
1995 MAR-MAY	28.17	46.81	85.92
1995 JUN-AUG	12.74	24.80	57.21
1995 SEP-NOV	23.35	56.82	104.17
1996 DEC-FEB	49.20	60.63	82.16
1996 MAR-MAY	29.44	58.43	75.02
1996 JUN-AUG	14.45	18.88	43.17
1996 SEP-NOV	29.27	46.64	81.94
1997 DEC-FEB	46.00	60.66	90.52
1997 MAR-MAY	41.98	64.20	79.63
1997 JUN-AUG	16.77	24.65	47.04
1997 SEP-NOV	15.71	43.42	72.41
1998 DEC-FEB	42.56	60.68	106.22
1998 MAR-MAY	19.50	44.09	95.07
1998 JUN-AUG	13.24	22.32	41.24
1998 SEP-NOV	17.67	40.89	83.94
1999 DEC-FEB	43.32	62.66	91.81
1999 MAR-MAY	27.49	49.12	77.62
1999 JUN-AUG	14.40	20.82	36.26
1999 SEP-NOV	24.34	37.09	77.61
2000 DEC-FEB	44.26	61.20	105.02

Table 10. Shining Rock Wilderness: Standard Visual Ranges

Season	percentiles		
	p10	p50	p90
1994 JUN-AUG	14.34	29.77	88.09
1994 SEP-NOV	29.98	78.39	131.03
1995 DEC-FEB	75.26	117.52	162.07
1995 MAR-MAY	35.40	56.54	129.31
1995 JUN-AUG	13.57	28.93	63.56
1995 SEP-NOV	23.55	55.62	105.27
1996 DEC-FEB	77.00	97.34	163.74
1996 MAR-MAY	41.12	65.57	104.69
1996 JUN-AUG	13.90	23.81	60.03
1996 SEP-NOV	31.49	74.69	156.79
1997 DEC-FEB	65.22	99.69	146.31
1997 MAR-MAY	47.42	71.19	113.36
1997 JUN-AUG	19.35	32.38	96.99
1997 SEP-NOV	17.57	61.96	108.07
1998 DEC-FEB	80.10	106.01	134.98
1998 MAR-MAY	20.70	55.37	143.88
1998 JUN-AUG	13.94	27.90	53.02
1998 SEP-NOV	20.34	48.17	145.92
1999 DEC-FEB	60.69	113.64	166.13
1999 MAR-MAY	31.00	62.02	106.82
1999 JUN-AUG	14.65	28.29	34.96
1999 SEP-NOV	29.69	51.95	165.05
2000 DEC-FEB	56.54	103.59	151.83

We show and discuss the individual graphical summaries of these two sites in Section 7 under their local site names (Look Rock and Frying Pan Mountain B which we have grouped with Mt. Pisgah).

7. Individual Site Trends

For the 10 monitors updated in this report, we show annual distributions of 1-hour and 8-hour concentrations, beginning with Figure 16 through Figure 42, and we describe the indicated trend for the years that valid data are available. We summarize statistical tests of the ozone trends for 1-hour and 8-hour concentrations in Table 11.

The monitors at Clingman's Dome, Cove Mountain and Look Rock have statistically significant increasing trends for 1-hour concentrations. Cove Mountain, Look Rock and Lenoir have significant increasing trends for 8-hour concentrations. At the remaining sites, the evidence of trend is too weak to declare statistically significant.

Table 11. Annual Trends at Ozone Monitors in Western NC, 1987-2000.

Site	max1h1		max1h2	
	Annual change (ppm)	p-value	Annual change (ppm)	p-value
Bryson City	0.0010	0.13	0.0010	0.09
Cades Cove TN	-0.0022	0.65	-0.0005	0.76
Clingmans Dome TN	0.0066	0.003	0.0050	0.006
Cove Mtn TN	0.0005	0.009	0.0008	0.010
Fairview-Bent Creek	0.0008	0.51	0.0016	0.11
Lenoir	0.0006	0.06	0.0008	0.013
Look Rock TN	-0.0001	0.02	0.0004	0.008
Mt. Mitchell	0.0019	0.46	0.0021	0.92
Pisgah-Frying Pan Mtn	0.0009	0.17	0.0009	0.17
Purchase Knob	-0.0006	0.85	-0.0010	0.57
	max8h1		max8h4	
	Annual change (ppm)	p-value	Annual change (ppm)	p-value
Bryson City	0.0012	0.35	0.0014	0.19
Cades Cove TN	0.0015	0.17	0.0007	0.21
Clingmans Dome TN	0.0023	0.12	0.0040	0.06
Cove Mtn TN	0.0008	0.03	0.0007	0.006
Fairview-Bent Creek	0.0005	0.78	0.0011	0.14
Lenoir	0.0010	0.06	0.0009	0.012
Look Rock TN	-0.0007	0.03	0.0012	0.005
Mt. Mitchell	0.0009	0.84	0.0003	0.83
Pisgah-Frying Pan Mtn	0.0019	0.06	0.0021	0.10
Purchase Knob	-0.0016	0.85	0.0004	0.13

For the three sulfate monitors in the NADP network with updated data, we show the annual mean sulfate concentrations in Figure 24, Figure 25 and Figure 34, and we describe the indicated trend. In one case (Mt. Mitchell), an ozone and a sulfate monitor are identified as being at the same location. Annual mean sulfate ion concentrations have statistically significant decreasing trends at Coweeta and Elkmont. At Mt. Mitchell, annual mean sulfate ion concentrations may be increasing; however, the evidence of trend is too weak to declare statistically significant.

We discuss the visibility data from the two IMPROVE monitors with the monitors of Look Rock (Figure 32) and Pisgah (Figure 40).

Bryson City

Ozone concentrations for Bryson City from 1995 to 2000 are shown in Figure 16 (1-hour concentrations) and Figure 17 (8-hour concentrations). Tests for trend are not statistically significant for the maximum 1-hour concentration (P = 0.13), second maximum 1-hour concentration (P = 0.09), maximum 8-hour concentration (P = 0.35) and fourth maximum 8-hour concentration (P = 0.19).

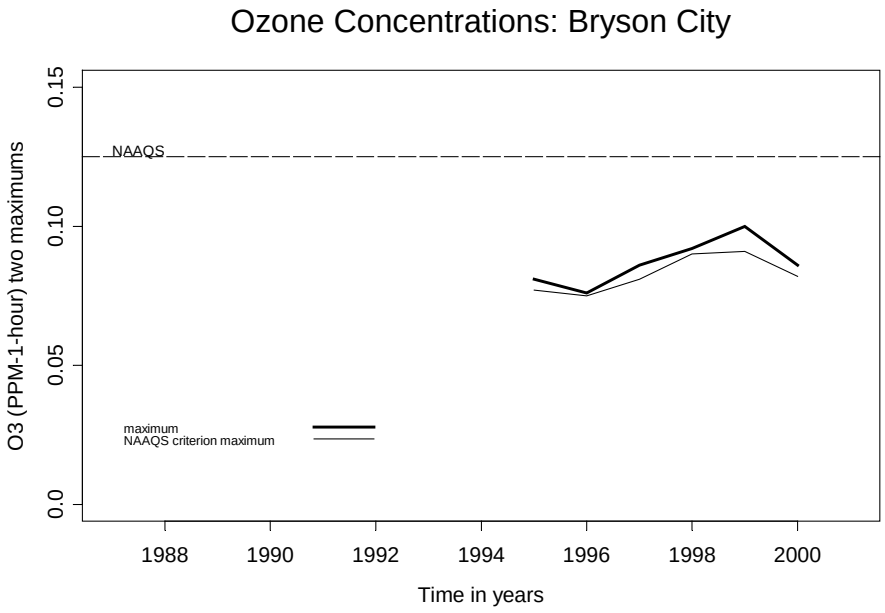

Figure 16. Bryson City, NC: 1-Hour Ozone Maximum Concentrations.

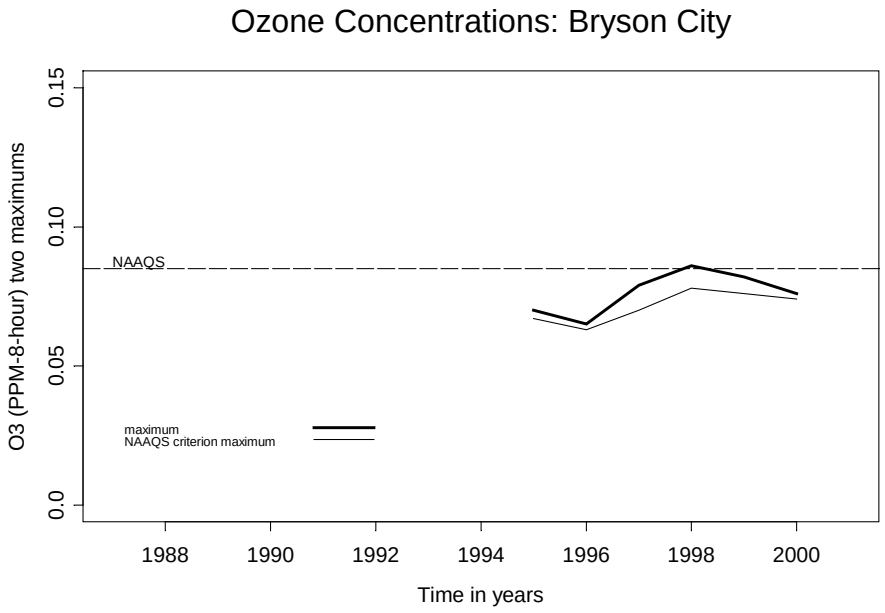

Figure 17. Bryson City, NC: 8-Hour Ozone Maximum Concentrations

Cades Cove TN

Ozone concentrations for Cades Cove from 1994 to 2000 are shown in Figure 18 (1-hour concentrations) and Figure 19 (8-hour concentrations). Tests for trend are not statistically significant for the maximum 1-hour concentration (P = 0.65), second maximum 1-hour concentration (P=0.76), maximum 8-hour concentration (P = 0.17), and fourth maximum 8-hour concentration (P = 0.21).

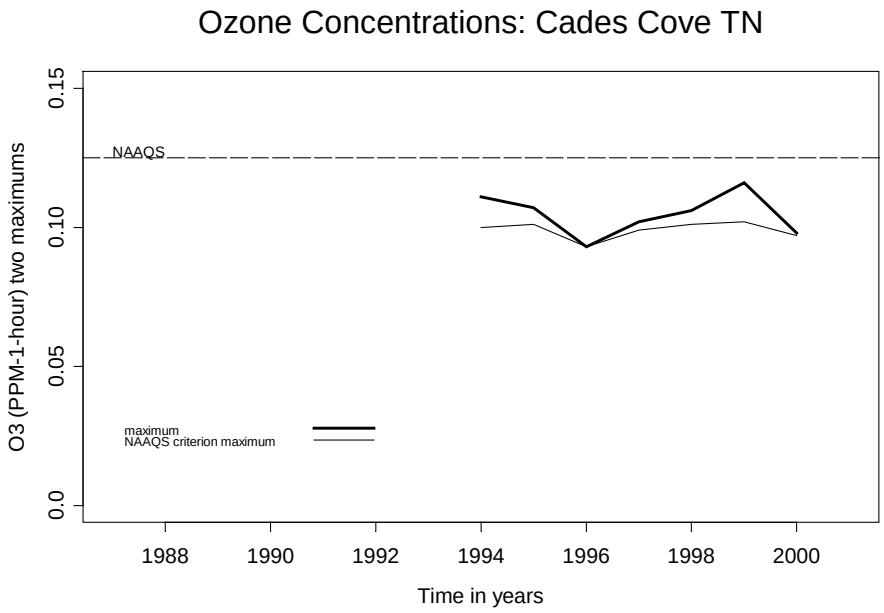

Figure 18. Cades Cove, TN: 1-Hour Ozone Maximums

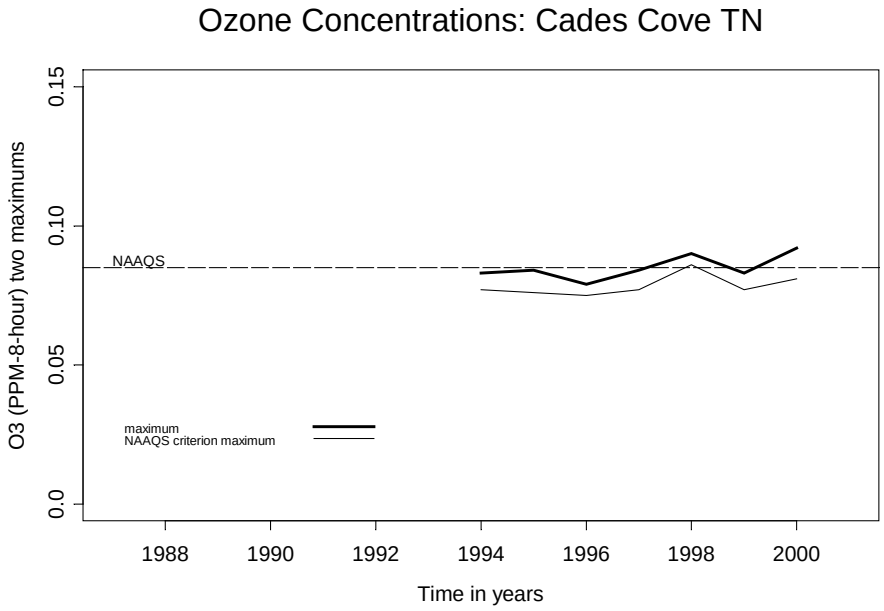

Figure 19. Cades Cove, TN: 8-Hour Ozone Maximum Concentrations

Clingmans Dome TN

Ozone concentrations for Clingmans Dome from 1993 to 2000 are shown in Figure 20 (1-hour concentrations) and Figure 21 (8-hour concentrations). The maximum 1-hour average is increasing by an average of 0.0066 ppm per year (P =0.003), and the second maximum 1-hour average is increasing by an average of 0.0050 ppm per year (P =0.006). Tests for trend are not statistically significant for the maximum 8-hour concentration (P =.12) and fourth maximum 8-hour concentration (P = 0.06).

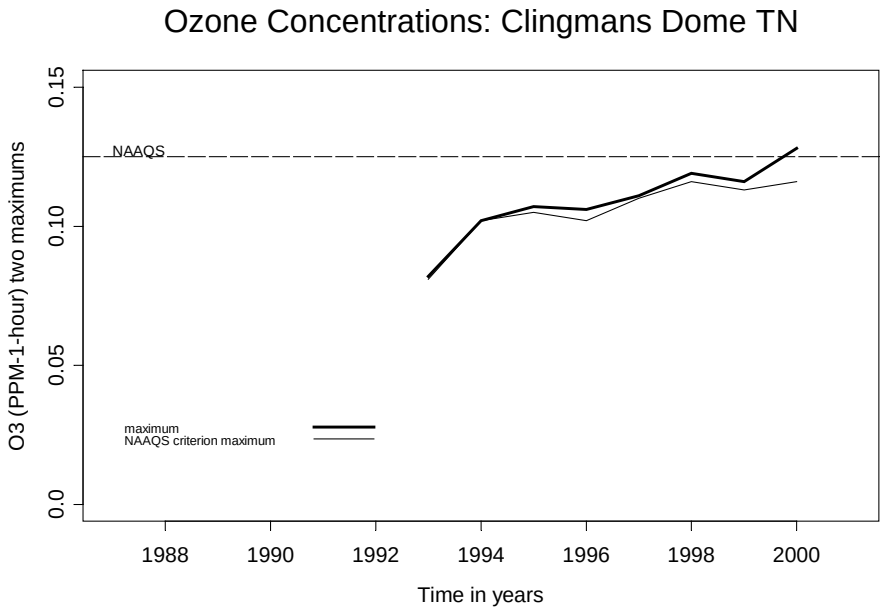

Figure 20. Clingmans Dome, TN: 1-Hour Ozone Maximum Concentrations

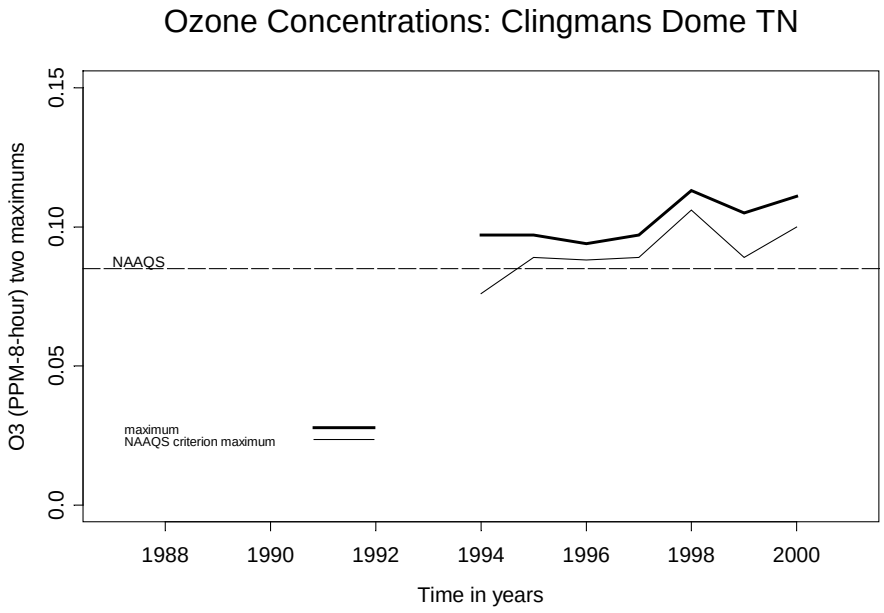

Figure 21. Clingmans Dome, TN: 8-Hour Ozone Maximum Concentrations

Cove Mountain TN

Ozone concentrations for Cove Mountain from 1988 to 2000 are shown in Figure 22 (1-hour concentrations) and Figure 23 (8-hour concentrations). Maximum ozone concentrations have been approximately constant. The maximum 1-hour average is increasing by an average of 0.0005 ppm per year (P = 0.0086), and the second maximum 1-hour average is increasing by an average of 0.00075 ppm per year (P = 0.010). The maximum 8-hour average is increasing by an average of 0.00083 pm per year (P = 0.03), and the fourth maximum 8-hour average is increasing by an average of 0.00067 ppm per year (P = 0.006).

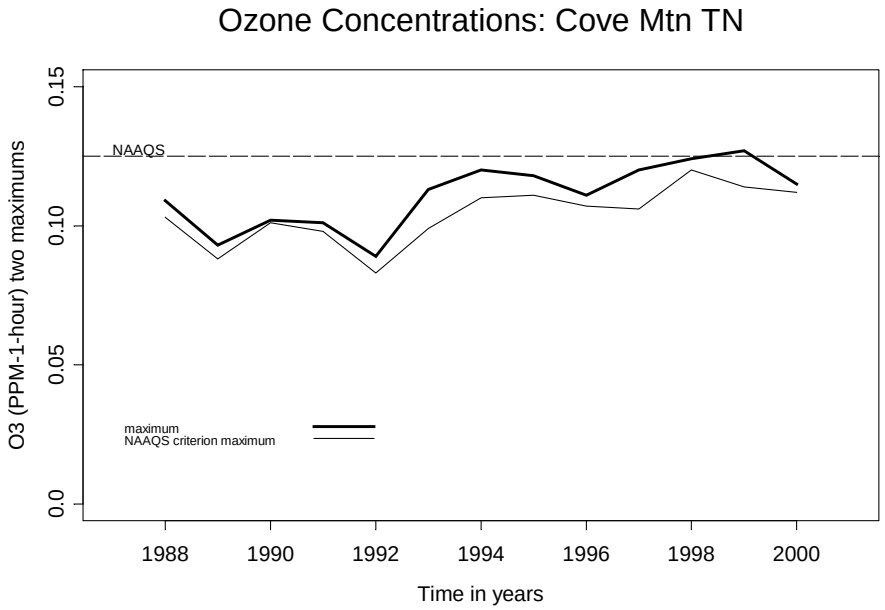

Figure 22. Cove Mtn, TN: 1-Hour Ozone Maximum Concentrations

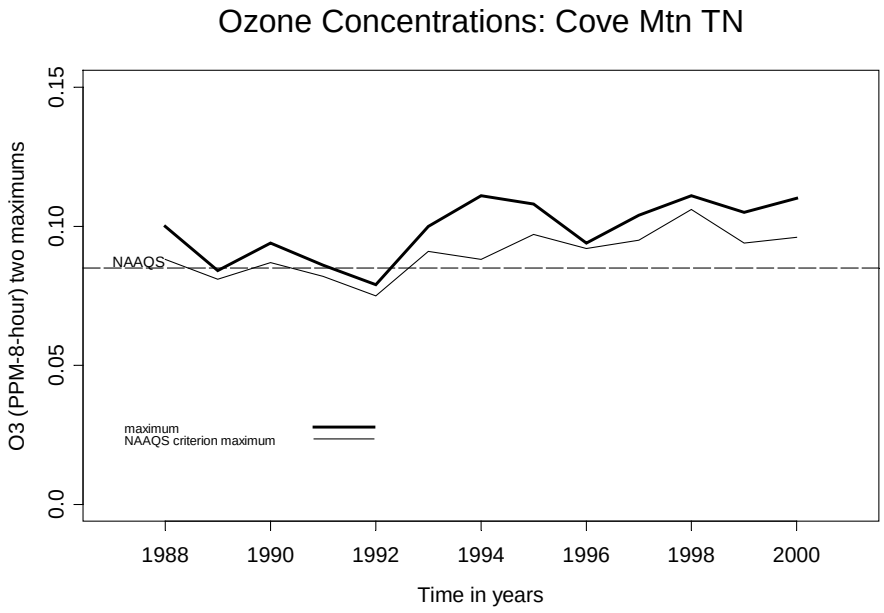

Figure 23. Cove Mtn, TN: 8-Hour Ozone Maximum Concentrations

Coweeta

NADP sulfate concentration distributions for Coweeta from 1978 to 2000 are shown in Figure 24. Sulfate concentrations have decreased by an average of 0.0195 mg/l per year (about 1.3 percent annual decreases). This trend is highly statistically significant (P = 0.0005).

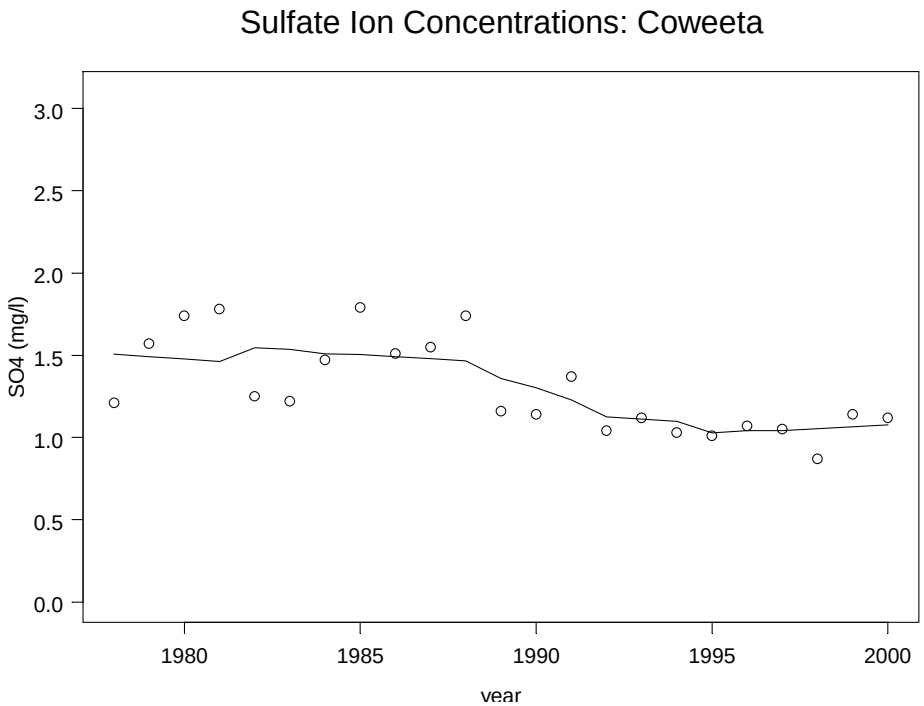

Figure 24. Coweeta, NC: NADP Mean Annual Sulfate Ion Concentration.

Elkmont

NADP sulfate concentration distributions for Elkmont from 1980 to 2000 are shown in Figure 25. Sulfate concentrations have decreased by an average of 0.0463 mg/l per year (about 2.1 percent annual decreases). This trend is highly statistically significant (P = 0.0005).

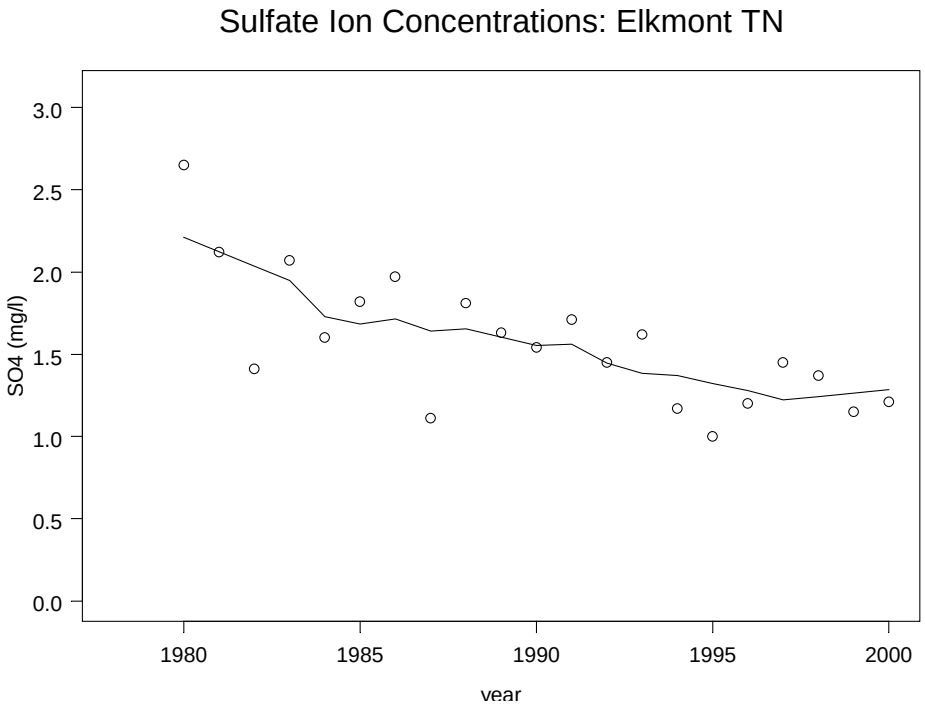

Figure 25. Elkmont, TN: NADP Mean Annual Sulfate Ion Concentration.

Fairview and Bent Creek

Ozone concentrations for Fairview from 1987 to 1988 and Bent Creek from 1989 to 2000 are shown in Figure 26 (1-hour concentrations) and Figure 27. Maximum ozone concentrations have been approximately constant, except for slightly higher than average concentrations in 1987, 1988 and 1998. It can not be determined whether the 1987-88 concentrations are higher because of a time trend or because of a difference between the Fairview and Bent Creek sites. Although the higher years are noted, there are no statistically significant trends for maximum 1-hour ozone concentration (P = 0.51), second maximum 1-hour concentration (P = 0.11), maximum 8-hour concentration (P = 0.78) and fourth maximum 8-hour concentration (P = 0.14).

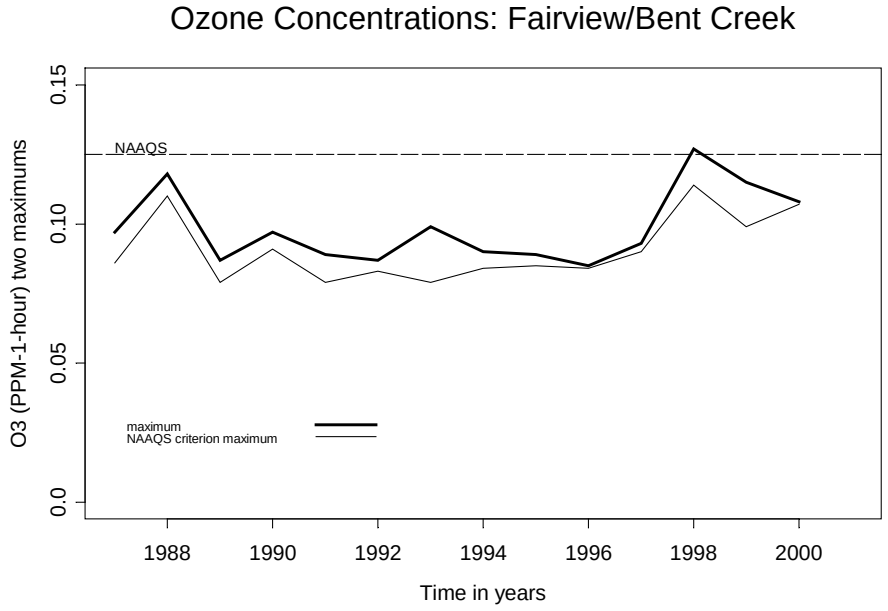

Figure 26. Fairview-Bent Creek, NC: 1-Hour Ozone Maximum Concentrations.

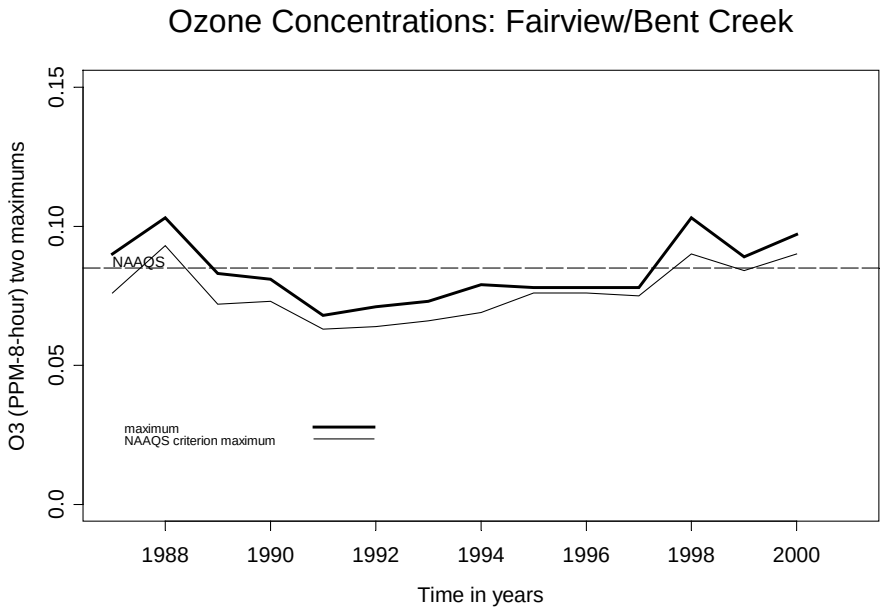

Figure 27. Fairview-Bent Creek, NC: 8-Hour Ozone Maximum Concentrations

Lenoir

Ozone concentrations for Lenoir from 1989 to 2000 are shown in Figure 28 (1-hour concentrations) and Figure 29 (8-hour concentrations). This site was not monitored in the even numbered years from 1990 through 1996, making the characterization of trends problematic, although trend tests are statistically significant for the second maximum 1-hour concentration (P = 0.0008) and fourth maximum 8-hour concentration (P = 0.012). The trend tests for the maximum 1-hour concentration and maximum 8-hour concentration are not significant (both P = 0.062). It seems misleading to suggest average annual increases, because the years prior to 1998 appear to be nearly constant, followed by a marked increase in 1998 to 2000.

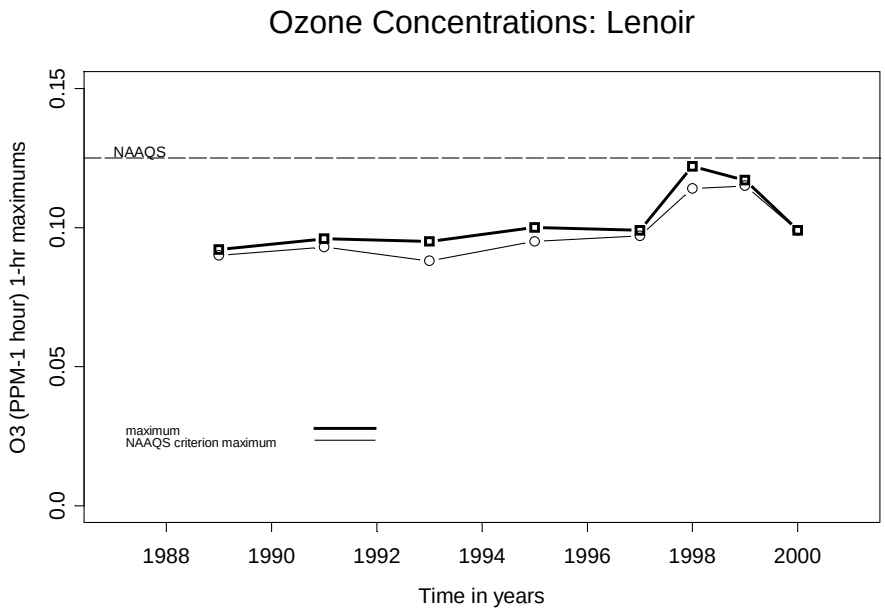

Figure 28. Lenoir, NC: 1-Hour Ozone Maximum Concentrations.

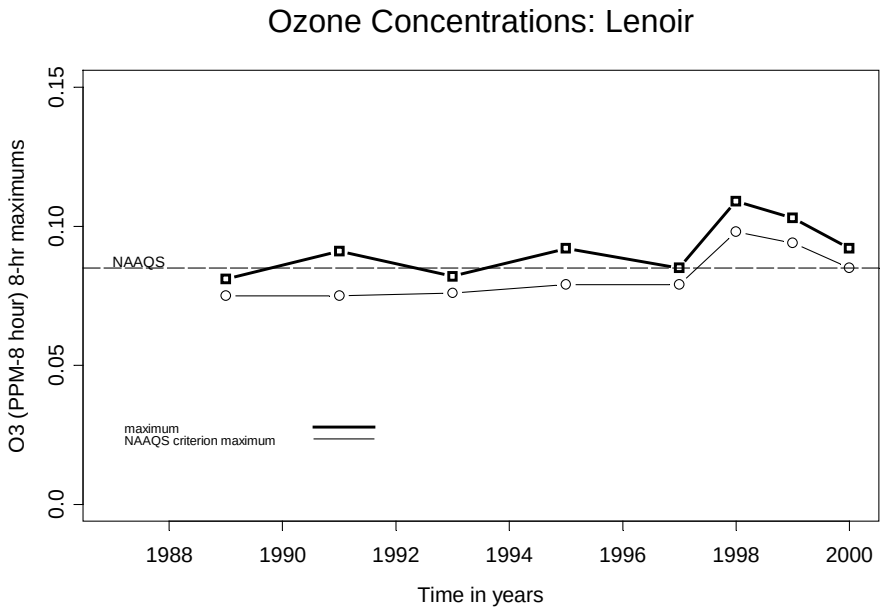

Figure 29. Lenoir, NC: 8-Hour Ozone Maximum Concentrations

Look Rock TN

Ozone concentrations for Look Rock from 1988 to 2000 are shown in Figure 30 (1-hour concentrations) and Figure 31 (8-hour concentrations). The maximum 1-hour average is *decreasing* by an average of 0.00008 ppm per year (P = 0.024), and the second maximum 1-hour average is increasing by an average of 0.0004 ppm per year (P = 0.008). The maximum 8-hour average is *decreasing* by an average of 0.00067 ppm per year (P = 0.0012), and the fourth maximum 8-hour average is increasing by an average of 0.0013 ppm per year (P = 0.0050)

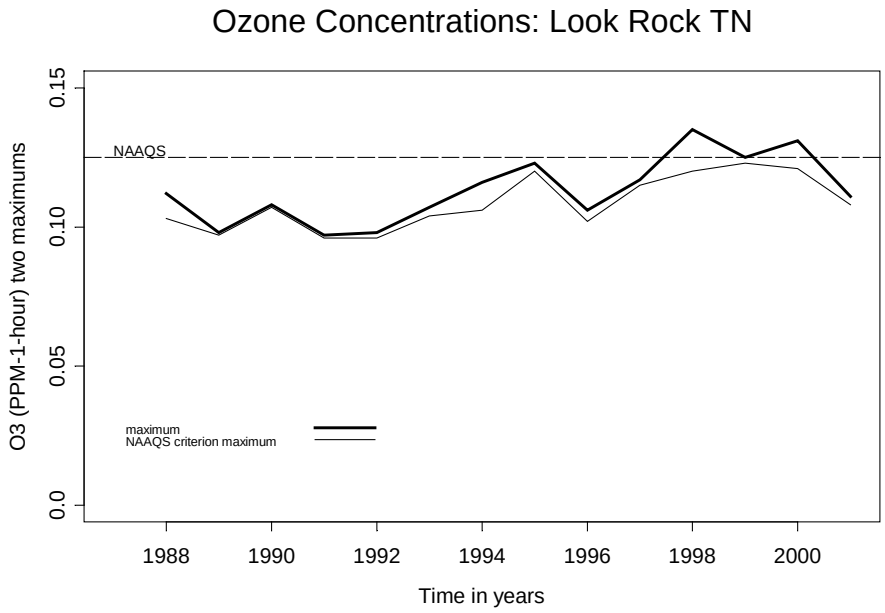

Figure 30. Look Rock, TN: 1-Hour Ozone Maximum Concentrations

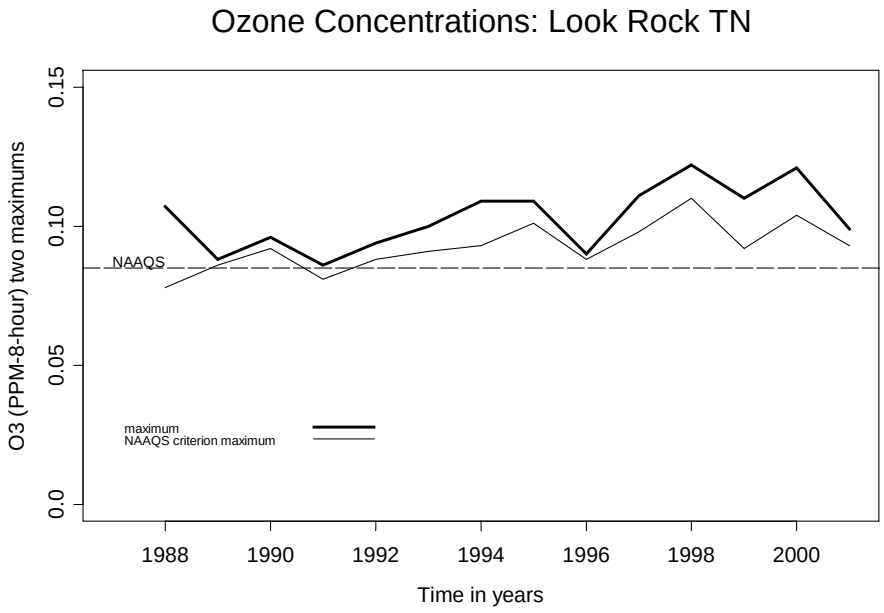

Figure 31. Look Rock, TN: 8-Hour Ozone Maximum Concentrations

Seasonal haze distributions for the IMPROVE monitor near Look Rock are shown in Figure 32, and corresponding standard visual range distributions are shown in Figure 33. We applied the trend test to the median haze coefficients of each year separately for the summer and winter data quarters. There was no statistically significant trend for summer ($P = 0.13$) or winter ($P = 0.07$). (Identical results would obtain if standard visual range medians were tested by the same method.)

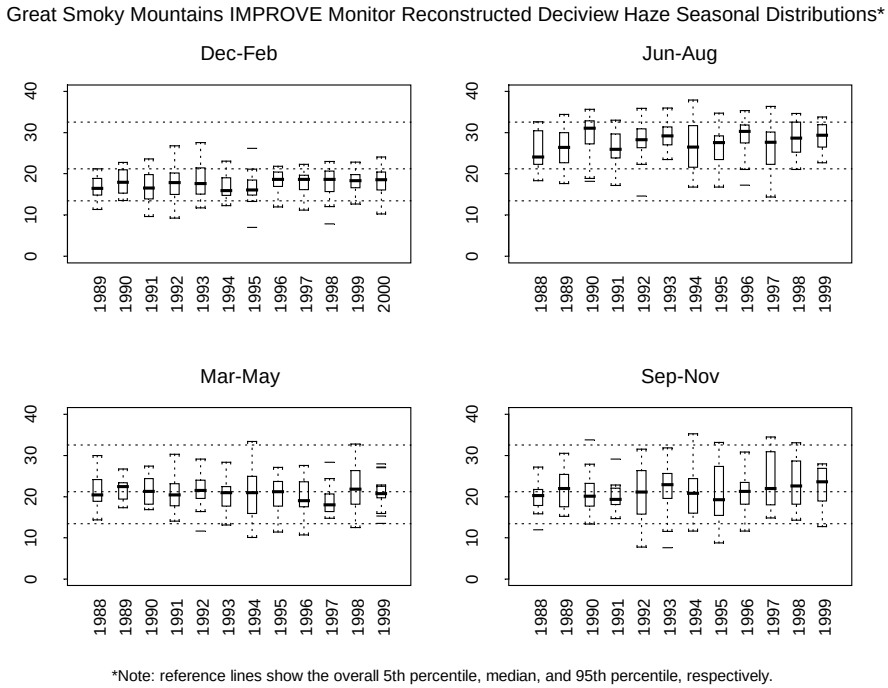

Figure 32. Great Smoky Mountains National Park: Seasonal Haze Distributions.

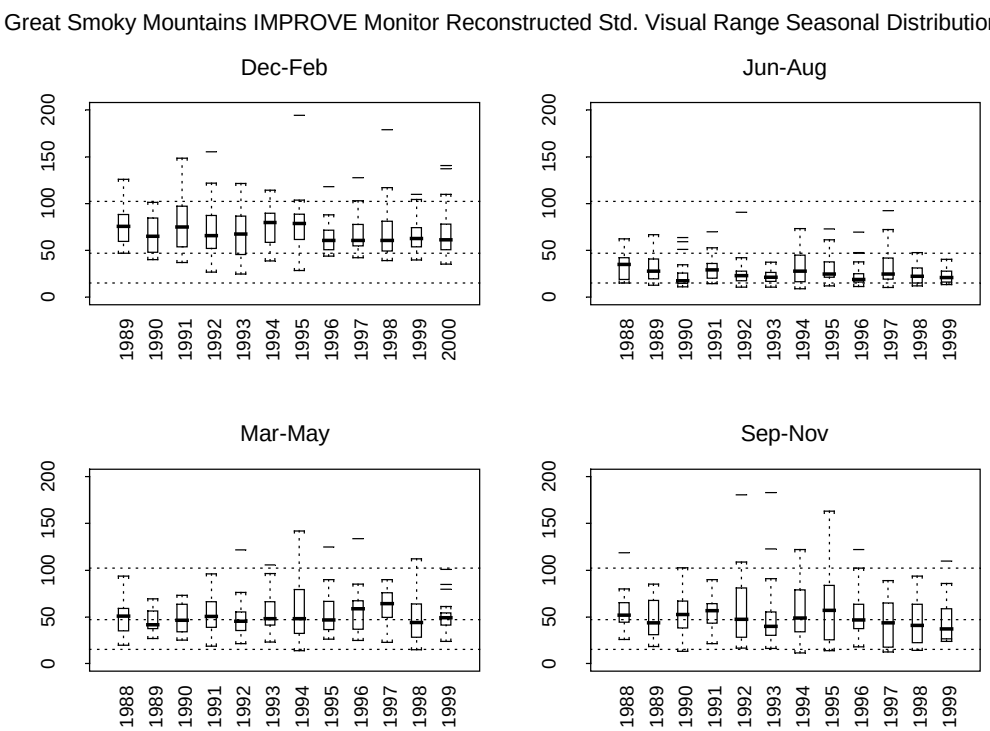

Figure 33. Great Smoky Mountains National Park: Seasonal Standard Visibility Range Distributions.

Mount Mitchell

Ozone concentrations for Mt. Mitchell from 1995 to 2000 are shown in Figure 34 (1-hour concentrations) and Figure 35 (8-hour concentrations). Tests for trend are not statistically significant for the maximum 1-hour concentration (P = 0.46), second maximum 1-hour concentration (P=0.92), maximum 8-hour concentration (P = 0.84), and fourth maximum 8-hour concentration (P = 0.84).

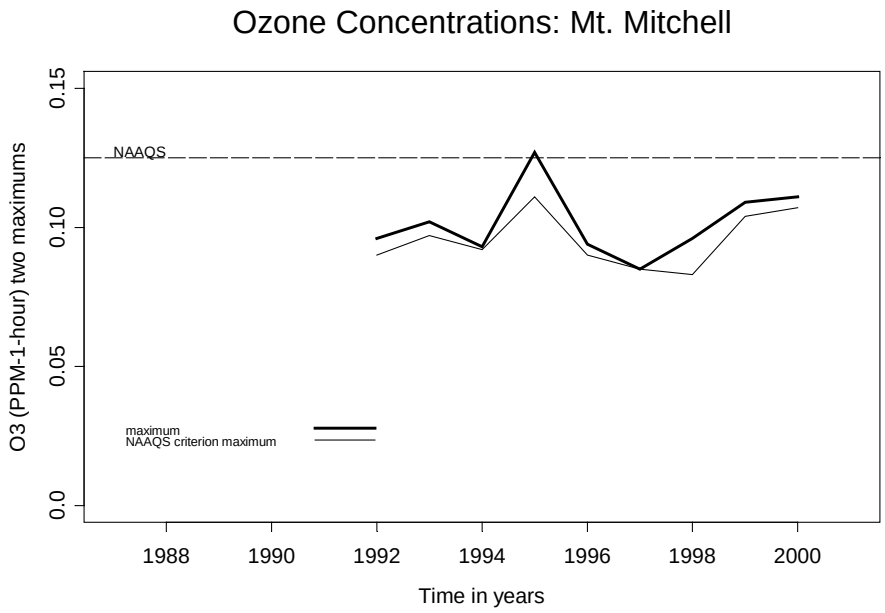

Figure 34. Mt. Mitchell, NC: 1-Hour Ozone Maximum Concentrations

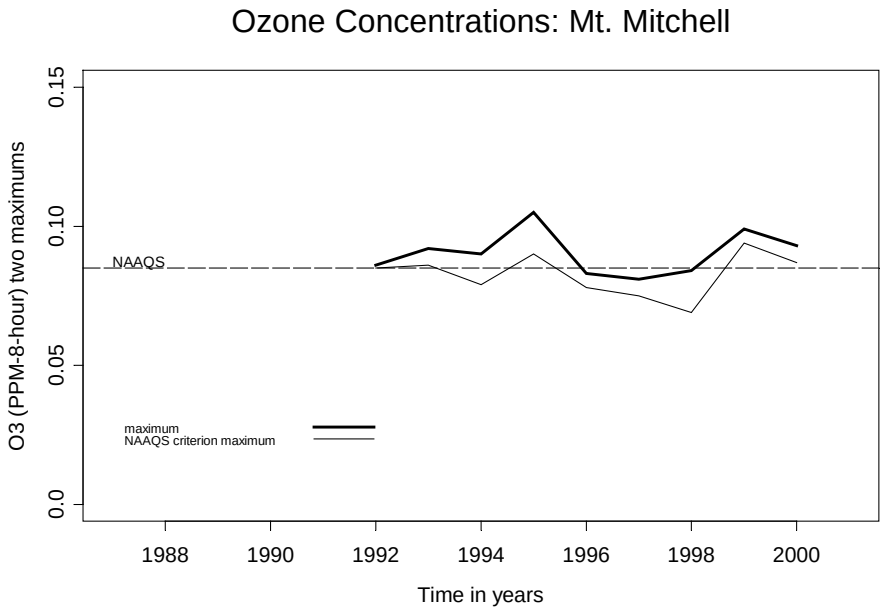

Figure 35. Mt. Mitchell, NC: 8-Hour Ozone Maximum Concentrations

NADP sulfate concentration distributions for Mt. Mitchell from 1985 to 2000 are shown in Figure 36. Sulfate concentrations have **increased** by an average of 0.0123 mg/l per year (about 1.1 percent annually); however, this is not a statistically significant trend (P = 0.39).

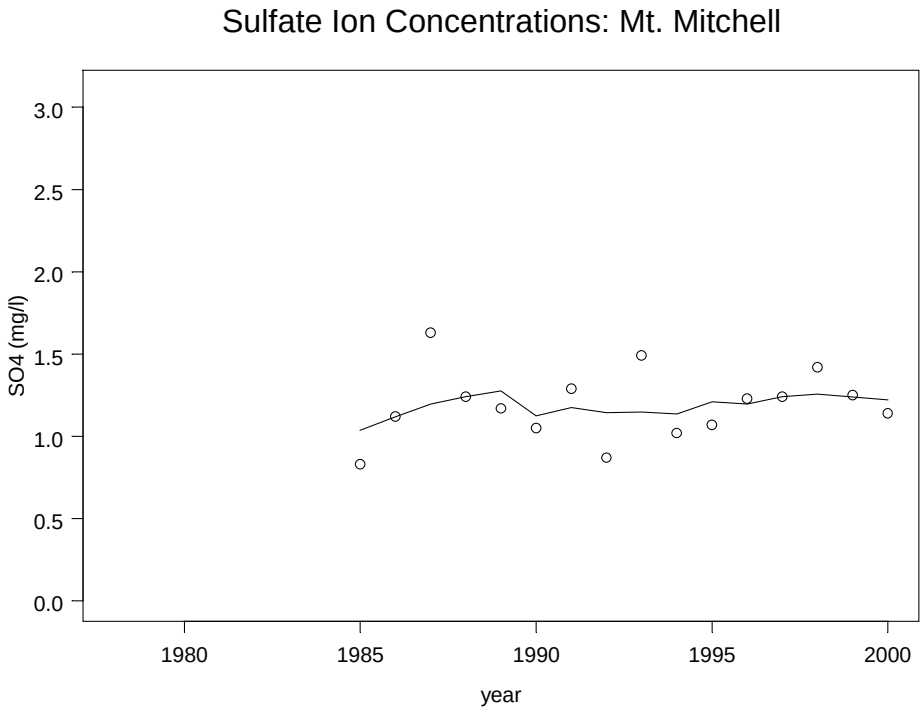

Figure 36. Mt. Mitchell, NC: NADP Mean Annual Sulfate Ion Concentration.

Mount Pisgah and Frying Pan Mountain

Ozone concentrations for Mt. Pisgah in 1993 and Frying Pain Mountain from 1994 to 2000 are shown in Figure 37 (1-hour concentrations) and Figure 38 (8-hour concentrations). Tests for trend are not statistically significant for the maximum 1-hour concentration (P = 0.17), second maximum 1-hour concentration (P=0.17), maximum 8-hour concentration (P = 0.06) and fourth maximum 8-hour average (P = 0.10).

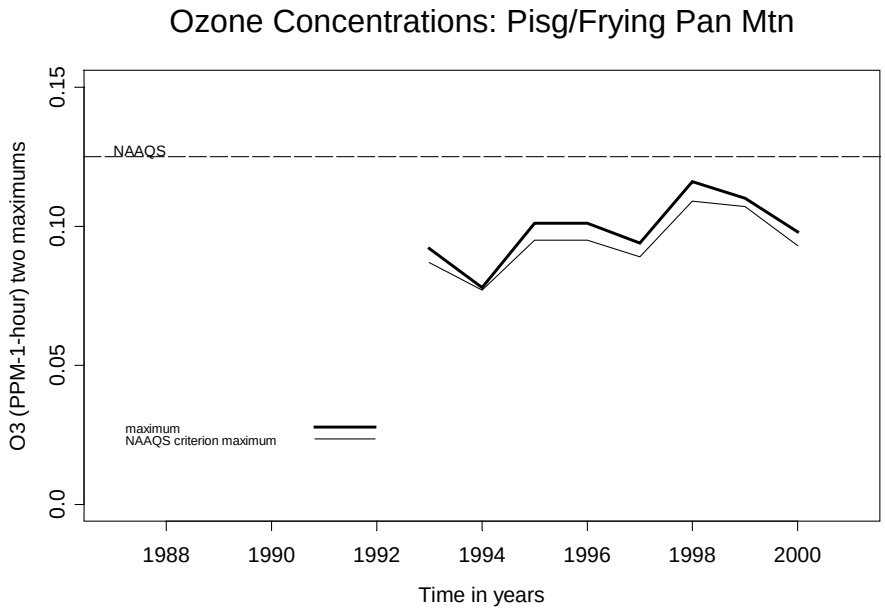

Figure 37. Pisgah-Frying Pan Mtn, NC: 1-Hour Ozone Maximum Concentrations

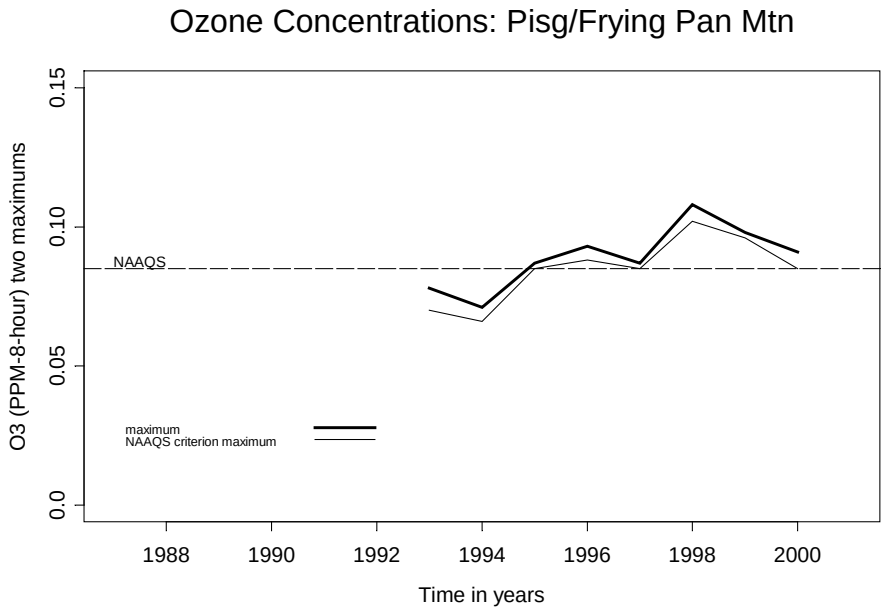

Figure 38. Pisgah-Frying Pan Mtn, NC: 8-Hour Ozone Maximum Concentrations

Seasonal haze distributions for the IMPROVE monitor near Frying Pan Mountain are shown in Figure 39, and corresponding standard visual range distributions are shown

in Figure 40. We applied the trend test to the median haze coefficients of each year separately for the summer and winter data quarters. There was no statistically significant trend for summer ($P = 0.85$) or winter ($P = 0.57$). (Identical results would obtain if standard visual range medians were tested by the same method.)

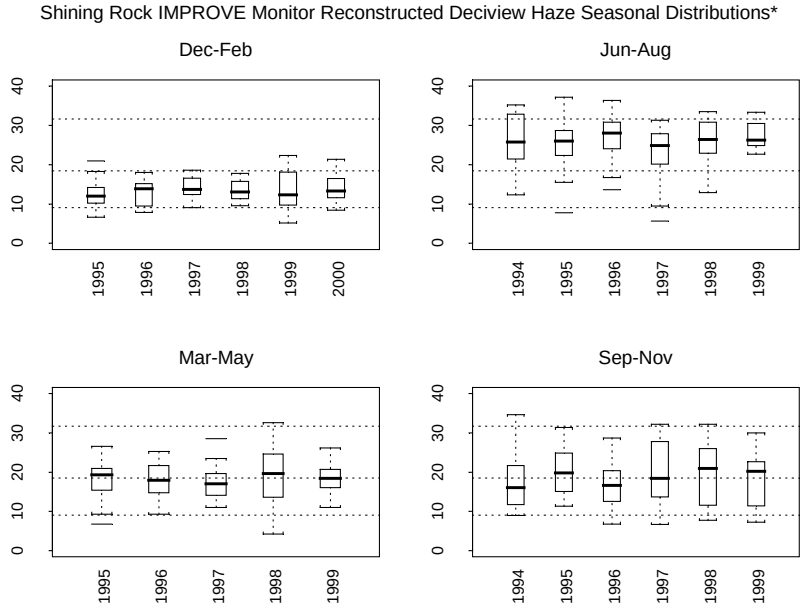

Figure 39. Shining Rock National Wilderness: Seasonal Haze Distributions.

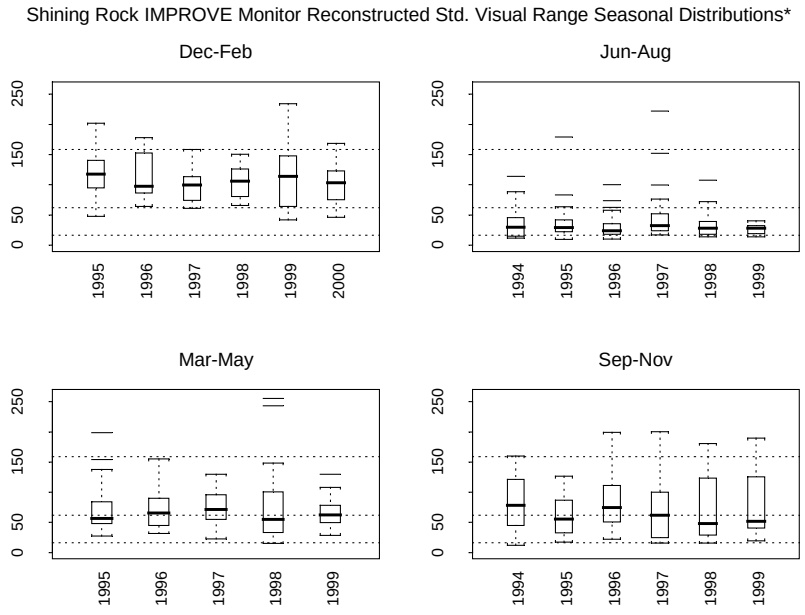

Figure 40. Shining Rock National Wilderness: Seasonal Standard Visibility Range Distributions.

Purchase Knob

Ozone concentrations for Purchase Knob from 1995 to 2000 are shown in Figure 41 (1-hour concentrations) and Figure 42 (8-hour concentrations). Tests for trend are not statistically significant for the maximum 1-hour concentration (P = 0.85), second maximum 1-hour concentration (P=0.57), maximum 8-hour concentration (P = 0.85) and fourth maximum 8-hour average (P = 0.13).

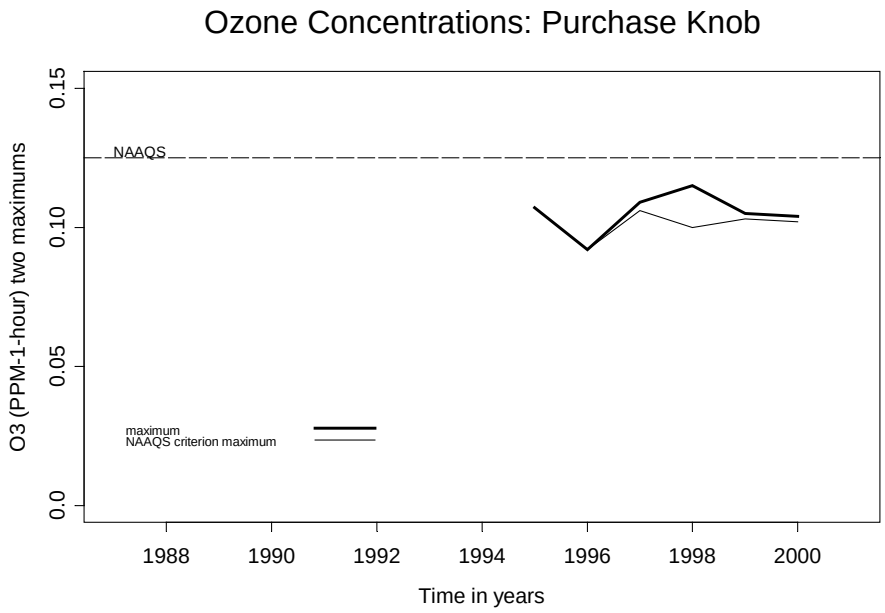

Figure 41. Purchase Knob, NC: 1-Hour Ozone Maximum Concentrations

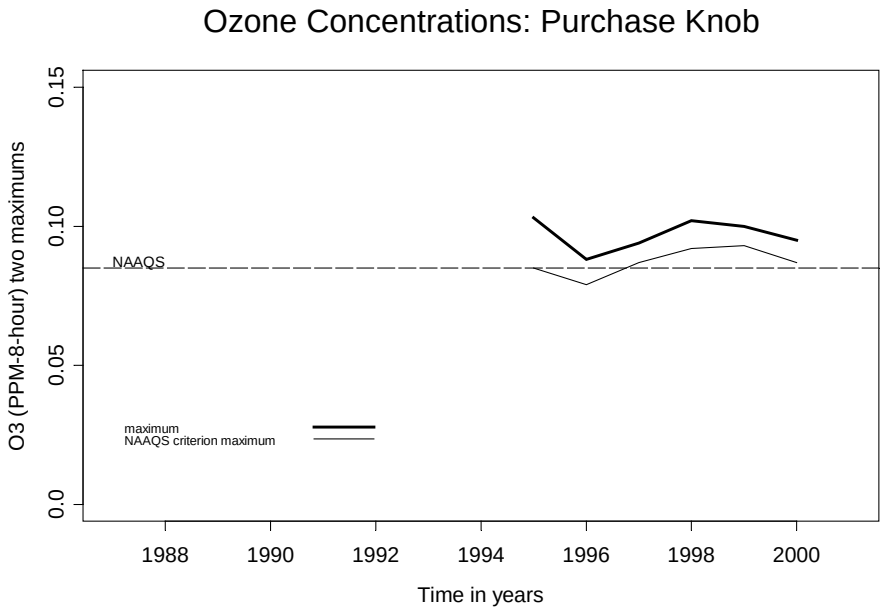

Figure 42. Purchase Knob, NC: 8-Hour Ozone Maximum Concentrations

8. Discussion

Regional average trends for first and second maximum 1-hour, fourth maximum 8-hour ozone concentrations were statistically significant, although the first maximum 8-hour ozone concentration trend was not statistically significant. For Western NC and the surrounding area, there are one or more detectable increasing time trends in the most extreme ozone concentrations at four of 10 sites, and mixed (less definitive) results at the remaining six sites. In 1988 and again in 1998, unusual conditions created exceptionally high ozone concentrations at various sites, confounding the statistical trend tests. (A high concentration leading an increasing trend would tend to mask that trend. A high concentration following a series of unchanging values may result in a spurious significant trend result.)

Except in 1988, 1998 and 1999, there have been no validated violations of the National Ambient Air Quality Standards for ozone (using the 1-hour standard then in effect) in Western NC and the surrounding area. One exceedance (not regarded as a "violation") occurred at Mount Mitchell in 1995. Unusual meteorological conditions may be responsible for the exceptional concentrations observed in 1988, 1998 and 1999.

Concentrations of the sulfate ion component of acid rain have been decreasing over time at two of the three stations where this has been monitored long enough to

statistically detect any trend. At Mt. Mitchell, sulfate concentrations may be increasing, but this remains a statistically inconclusive observation.

9. Research and Management Implications

The data analyzed here are of limited value in making decisions about future monitoring or controls seeking to limit ozone production. More detailed analyses are possible, including review of 1-hour or 8-hour concentrations other than the maximums. Statistically modeling the one-hour concentrations as a function of calendar time, altitude, and diurnal variation (and meteorological data, if available) might be useful.

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