ANALYSIS OF PARTICULATE AND VISIBILITY-RELATED DATA WITHIN THE LADCO REGION

Prepared for

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March 5, 2004

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1.0 INTRODUCTION

This document describes visibility analysis work performed by Air Resource Specialists, Inc. (ARS), for the Lake Michigan Air Directors Consortium (LADCO) in partial fulfillment of the scope of work defined in the ARS quote number VIS090602-01. All comments regarding this document should be directed to Joe Adlhoch: jadlhoch@air-resource.com.

1.1 PROJECT OBJECTIVES

LADCO contracted with ARS to perform analyses on collected particulate matter (PM) and particle scattering (b_{sp}) data at selected monitoring sites for the 2002 monitoring year. Specific objectives covered in this report include:

- Spatial and temporal characterization of the contribution of chemical species to PM and light extinction across four specified LADCO monitoring sites during periods of high, medium, and low extinction.
- Comparison between two methods for incorporating relative humidity (RH) in estimates of aerosol extinction.
- Comparison between particle scattering estimated from speciated PM and measured by nephelometers.
- Investigation of meteorological back trajectories for periods of high and low extinction.

Section 2 describes the site specifications and instruments used. Section 3 presents analysis methods and results.

2.0 SITE SPECIFICATIONS

This section describes the specifications, instruments, and data collection responsibilities for all selected sites. Analysis methods and results are discussed in Section 3.

2.1 SITE LOCATIONS AND INSTRUMENTATION

The four sites selected by LADCO for analysis are shown in Figure 2-1. Table 2-1 presents a listing of the particulate and visibility-related instrumentation, sampling frequencies, and periods of operation for the 2002 monitoring year. Speciated $PM_{2.5}$ is collected at each site. Three of the sites employ the IMPROVE Version II samplers as part of the IMPROVE network, and two of the sites employ the Met One SASS samplers as part of the EPA STN network. At Seney the IMPROVE and Met One samplers are collocated, providing a comparison between networks. Three of the sites monitor ambient particle scattering (b_{sp}) with the Optec ambient nephelometer as well as ambient relative humidity for validation purposes. The Bondville site monitors dry particle scattering with the TSI temperature controlled, multi-wavelength nephelometer, and these data were taken from the NOAA Climate Monitoring and Diagnostics Laboratory (CMDL) data archive Web site (CMDL, 2004). Relative humidity measurements for Bondville were taken from the USDA UV-B Radiation Monitoring Network (Bondville site) data archive Web site (USDA, 2003).

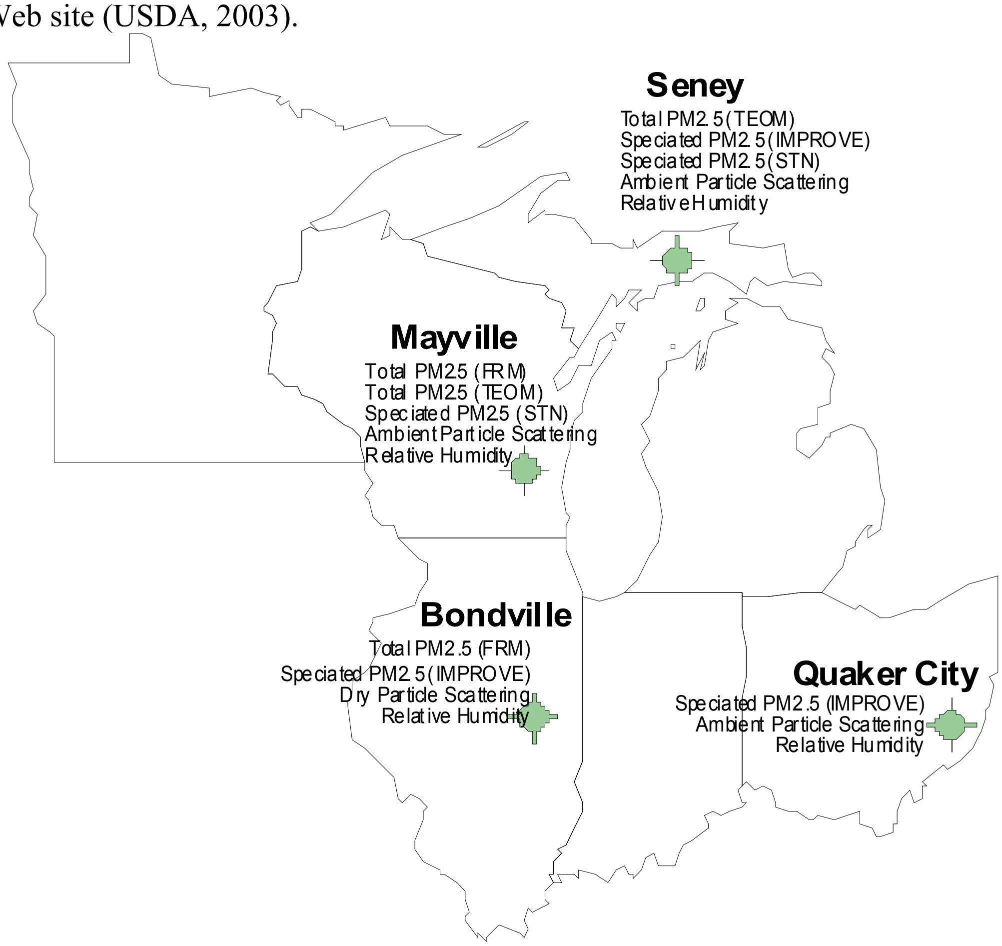


Figure 2-1. Site Location Map Including Particulate and Visibility Instruments.

Table 2-1

Particulate and Visibility-Related Instrumentation Specifications By Site for the 2002 Monitoring Year

Quaker City, OH

Parameters	Manufacturer/Model	Collected by IMPROVE	Collected by EPA-STN	Collected by ARS	Collected by Other	Collection Frequency	Operational Period
Total and Speciated PM2.5	IMPROVE Version II sampler	X				1/3 days	1/01/02 – 12/31/02
Ambient Particle Scattering	OPTEC NGN-2			X		Hourly	1/01/02 – 12/31/02
Relative Humidity	Rotronics MP101A			X		Hourly	1/01/02 – 12/31/02

Bondville, IL

Parameters	Manufacturer/Model	Collected by IMPROVE	Collected by EPA-STN	Collected by ARS	Collected by Other	Collection Frequency	Operational Period
Total PM2.5	Anderson RAAS 2.5-100				X	1/6 days	1/01/02 – 12/31/02
Total and Speciated PM2.5	IMPROVE Version II sampler	X				1/3 days	1/01/02 – 12/31/02
Dry Particle Scattering[1]	TSI 3563				X	Hourly	1/01/02 – 12/31/02
Relative Humidity	Vaisala HMP35A				X	Hourly	1/01/02 – 12/31/02

Mayville, WI

Parameters	Manufacturer/Model	Collected by IMPROVE	Collected by EPA-STN	Collected by ARS	Collected by Other	Collection Frequency	Operational Period
Total PM2.5	TEOM 50 Degree C				X	Hourly	1/01-3/04, 10/29-12/31/02
	TEOM 30 Degree C				X	Hourly	3/04/02-10/29/02
	R&P 2025 PM2.5 Sequential				X	1/3 days	1/01/02 – 10/31/02
	Sampler					Daily	11/01/02 – 12/31/02
Total and Speciated PM2.5	Met One SASS sampler		X			2/3 days	1/01/02 – 12/31/02
Ambient Particle Scattering	OPTEC NGN-2			X		Hourly	1/01/02 – 12/31/02
Relative Humidity	Rotronics MP101A			X		Hourly	1/01/02 – 12/31/02

Seney, MI

Parameters	Manufacturer/Model	Collected by IMPROVE	Collected by EPA-STN	Collected by ARS	Collected by Other	Collection Frequency	Operational Period
Total PM2.5	TEOM 50 Degree C				X	Hourly	1/01/02 – 12/31/02
Total and Speciated PM2.5	MetOne SASS sampler		X			2/3 days[2]	1/01/02 – 12/31/02
	IMPROVE Version II Sampler	X				1/3 days	1/01/02 – 12/31/02
Ambient Particle Scattering	OPTEC NGN-2			X		Hourly	1/01/02 – 12/31/02
Relative Humidity	Rotronics MP101A			X		Hourly	1/01/02 – 12/31/02

[1] The TSI nephelometer is operated with a heater to keep the sample chamber relative humidity at or below 40%.

[2] The STN sampler operates during the 2 of 3 days in which the IMPROVE sampler does not operate. In addition, the STN sampler also operates approximately 1 day per month on the IMPROVE schedule.

3.0 ANALYSIS METHODS AND RESULTS

ARS investigated the mass data collected at the four LADCO sites by several monitoring networks to characterize the spatial and temporal patterns of major mass species, and contributions of mass to visibility, as measured by total light extinction. Table 3-1 presents data collection statistics by site for the parameters used in this analysis.

3.1 SPECIATED AEROSOL DATA

3.1.1 IMPROVE Network

The Interagency Monitoring of Protected Visual Environments (IMPROVE) Program operates a nation-wide speciated aerosol monitoring network which expanded significantly beginning in 2000 in response to the EPA's Regional Haze Rule. IMPROVE monitoring consists of 24-hour integrated filter samples every three days. Each monitoring location operates 4 samplers, designated Module A through D. Module A utilizes a Teflon filter for $PM_{2.5}$ gravimetric and elemental analysis. Module B utilizes a nylon filter preceded by a carbonate denuder for $PM_{2.5}$ ion analysis. Module C utilizes a quartz filter for $PM_{2.5}$ carbon analysis. A backup quartz filter is used on a small fraction of samples across the network to determine the extent of adsorbed organic gases. The median carbon mass measured on the backup filters is subtracted from the sample filters. Module D utilizes a Teflon filter for PM_{10} gravimetric analysis. The elements and species required for estimating light extinction are listed in Table 3-2. Note that quantities in brackets (e.g., [S]) denote the mass concentration of those quantities.

Over the past decade the IMPROVE program has developed a method for estimating light extinction from speciated aerosol and relative humidity data (CIRA, 2000). Each species is assigned a constant dry mass extinction (scattering or absorption) efficiency. Since size distribution data is not collected with each sample, an average or typical extinction efficiency is applied to all sites nationwide. IMPROVE makes the assumption that all sulfur present and all sulfate ion present can be explained as ammonium sulfate. In reality, there are other forms of particulate sulfate, and the mix of sulfate types affects both the total sulfate mass and its contribution to extinction. IMPROVE makes the assumption that all nitrate ions present can be explained as ammonium nitrate. Some nitrate collected at coastal sites may be in the form of sodium nitrate, though the percentage on a given sample or on average is not currently known.

Table 3-1

Data Collection Statistics By Site
For the 2002 Monitoring Year

Quaker City, OH

Parameters	Manufacturer/Model	Collection Frequency	Number Possible	Number Valid	Percent Valid
Total and Speciated PM2.5	IMPROVE Version II sampler	1/3 days	122	119	97.5%
Ambient Particle Scattering[1]	OPTEC NGN-2	Hourly	8760	5992	68.4%
Relative Humidity	Rotronics MP101A	Hourly	8760	8691	99.2%

Bondville, IL

Parameters	Manufacturer/Model	Collection Frequency	Number Possible	Number Valid	Percent Valid
Total PM2.5	Anderson RAAS2.5-100	1/6 days	61	59	96.7%
Total and Speciated PM2.5	IMPROVE Version II sampler	1/3 days	122	119	97.5%
Dry Particle Scattering	TSI 3563	Hourly	8760	8350	95.3%
Relative Humidity	Vaisala HMP 35A	Hourly	8760	8439	96.3%

Mayville, WI

Parameters	Manufacturer/Model	Collection Frequency	Number Possible	Number Valid	Percent Valid
Total PM2.5	TEOM	Hourly	8760	8099	92.5%
	R&P 2025 PM2.5 Sequential Sampler	1/3 days & Daily	166	161	97.0%
Total and Speciated PM2.5	Met One SASS sampler	2/3 days	122	119	97.5%
Ambient Particle Scattering[1]	OPTEC NGN-2	Hourly	8760	5594	63.8%
Relative Humidity	Rotronics MP101A	Hourly	8760	8437	96.3%

Seney, MI

Parameters	Manufacturer/Model	Collection Frequency	Number Possible	Number Valid	Percent Valid
Total PM2.5	TEOM 50 Degree C	Hourly	8760	6162	70.3%
Total and Speciated PM2.5	MetOne SASS sampler	2/3 days	254	246	96.8%
	IMPROVE Version II Sampler	1/3 days	122	120	98.4%
Ambient Particle Scattering[1]	OPTEC NGN-2	Hourly	8760	5579	63.6%
Relative Humidity	Rotronics MP101A	Hourly	8760	8594	98.1%

[1]The number valid shown for ambient particle scattering is actually the number of filtered hours remaining after weather and other interferences are flagged.

Table 3-2

Aerosol Elements and Species
Used to Estimate Light Extinction from IMPROVE Data
(IMPROVE Protocol)

Species	Composite Mass Equation *	Comment
Ammonium Sulfate $[(NH_4)_2SO_4]$	4.125[S, elemental sulfur] -or- $1.375[SO_4^{=}$, sulfate ion]	[S] is derived from the Teflon filter (A module). $[SO_4^{=}]$ is derived from the nylon filter (B module).
Ammonium Nitrate $[(NH_4)NO_3]$	$1.29[NO_3^{-}]$	$[NO_3^{-}]$ is derived from the nylon filter (B module).
Organic Mass [various organic carbon compounds]	1.4[OC, organic carbon]	[OC] is derived from the quartz filter (C module).
Elemental Carbon	1.0[EC, elemental carbon]	[EC] is derived from the quartz filter (C module).
Soil	2.20[Al] + 2.49[Si] + 1.63[Ca] + 2.42[Fe] + 1.94[Ti]	Soil elements are derived from the Teflon filter (A module).
Coarse Mass	$[PM_{10}] - [PM_{2.5}]$	$[PM_{10}]$ is derived from the D module Teflon filter. $[PM_{2.5}]$ is derived from the A module Teflon filter.

* Quantities in brackets (e.g., [S]) denote the mass concentration of those quantities.

Sulfate and nitrate species are known to be hygroscopic and thus their contribution to extinction is enhanced above certain values of relative humidity (RH). As the RH increases, IMPROVE assumes an increase in scattering by these species based on the work of Tang (Tang, 1996). While some organic mass is believed to be hygroscopic as well, there is no consensus on what percentage of organic mass to apply the f(RH) curve to. IMPROVE does not treat organic mass as hygroscopic. EPA Regional Haze guidance and current IMPROVE protocol for calculating extinction call for the use of a monthly value of f(RH) (EPA, 2001). This approach removes much of the short-term variability of RH effects. It also allows calculation of extinction at sites which do not routinely monitor RH or have incidents of RH sensor failure. Science Applications International Corporation (SAIC) has compiled hourly RH data from across the country for the EPA and generated a grid overlay of monthly averaged f(RH) for the entire U.S. In their 2002 analysis, RH values above 95% were set to 95%, so the f(RH) curve levels off at that value. Figure 3-1 presents the EPA f(RH) curve used by SAIC. Monthly f(RH) values from the latest SAIC HazeCalc software were used in this analysis (SAIC, 2003).

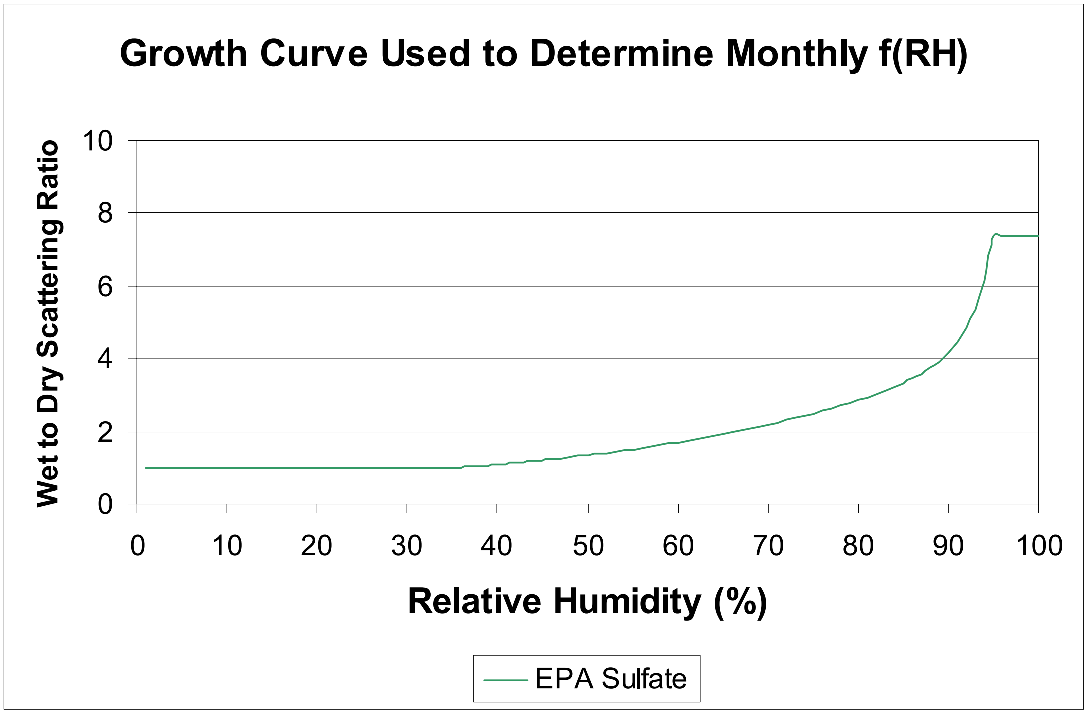


Figure 3-1. Growth Curve Used by EPA to Determine Monthly f(RH).

The equation used by IMPROVE/Regional Haze guidance to reconstruct extinction (b_{ext}) is (CIRA, 2000; EPA, 2001):

$$
\begin{aligned}
b_{ext} = \; & 3 \times f(RH) \times [\text{ammonium sulfate}] \\
& + 3 \times f(RH) \times [\text{ammonium nitrate}] \\
& + 4 \times [\text{organic mass}] \\
& + 10 \times [\text{elemental carbon}] \\
& + 1 \times [\text{soil}] \\
& + 0.6 \times [\text{coarse mass}] \\
& + 10 \quad (\text{Rayleigh scattering at 5000 ft})
\end{aligned}
$$

where: b_{ext} is expressed in inverse megameters (Mm^{-1})
Dry extinction efficiencies (leading numbers) are expressed as m^2/g
f(RH) values are taken from the curve in Figure 2-4
Species mass concentrations are expressed in $\mu g/m^3$
Rayleigh (gaseous) scattering is assumed to be 10 Mm^{-1}

IMPROVE speciated aerosol data can be obtained on the IMPROVE Web site (IMPROVE, 2003) or the VIEWS Web site (VIEWS, 2003).

3.1.2 EPA Speciation Trends Network

The EPA Speciation Trends Network (STN) developed out of changes to the 1997 National Ambient Air Quality Standards for $PM_{2.5}$ (EPA, 1999b). The network operates several models of aerosol speciation sampler, each with multiple filters which can be analyzed for sulfate, nitrate, organic carbon, elemental carbon, and soil mass. The IMPROVE methodology for calculating extinction was used for STN data.

The most significant difference between the IMPROVE and EPA STN methodologies is in their respective analyses of carbon mass. Both methods heat the sample in a series of temperature steps, first in a 100% helium atmosphere, to evolve particulate carbon to gaseous form, then in a 98% helium, 2% oxygen atmosphere to burn off the remaining original carbon and the carbon pyrolized during the first stage. Carbon detected during the 100% helium atmosphere, and a portion detected once oxygen is introduced is interpreted as organic carbon. The remaining carbon is interpreted as elemental carbon. Both methods employ different temperature steps and different methods for determining the split between organic carbon (OC) and elemental carbon (EC). IMPROVE monitors the reflectance of the sample filter to define the split (Thermal Optical Reflectance or TOR); EPA STN monitors the transmittance of the sample filter (Thermal Optical Transmittance or TOT). The point of division between OC and EC is a working definition, and neither method is universally accepted as "correct."

The result of these differences is that the total carbon measurement (TC = OC + EC) can agree between the TOR and TOT methods, but since the point of division between OC and EC is different, TOR analysis tends to yield lower OC and higher EC than TOT analysis. Since EC is generally the smaller of the two fractions, it shows the largest percentage difference between the methods. The EPA analyzed samples using the TOR and TOT methods for a set of 20 filters from both Phoenix and Philadelphia during their 1999 Four Cities study. The total carbon collected on the filters ranged from approximately 5 to 42 $\mu g/m^3$. EC, OC, and TC for both cities yielded similar slopes and intercepts and high R^2 values. Combining the data yielded the following results (EPA, 2001):

$$\text{TOR OC} = \text{TOT OC} \times 0.91 + 0.00, \quad R^2 = 0.98$$
$$\text{TOR EC} = \text{TOT EC} \times 1.97 - 0.22, \quad R^2 = 0.93$$
$$\text{TOR TC} = \text{TOT TC} \times 1.11 - 0.07, \quad R^2 = 0.99$$

Another difference in carbon analysis methodology is that IMPROVE utilizes a backup filter on a small fraction of samples to determine the extent of adsorbed organic gases. The median carbon mass measured on the backup filters is subtracted from the sample filters. No such procedure is followed with STN data.

ARS compared IMPROVE speciated mass data with data from collocated EPA STN samplers from several available locations. The results of these comparisons are presented in Section 3.2.3. STN speciated aerosol data can be obtained from EPA Aerometric Information Retrieval System (AIRS) database.

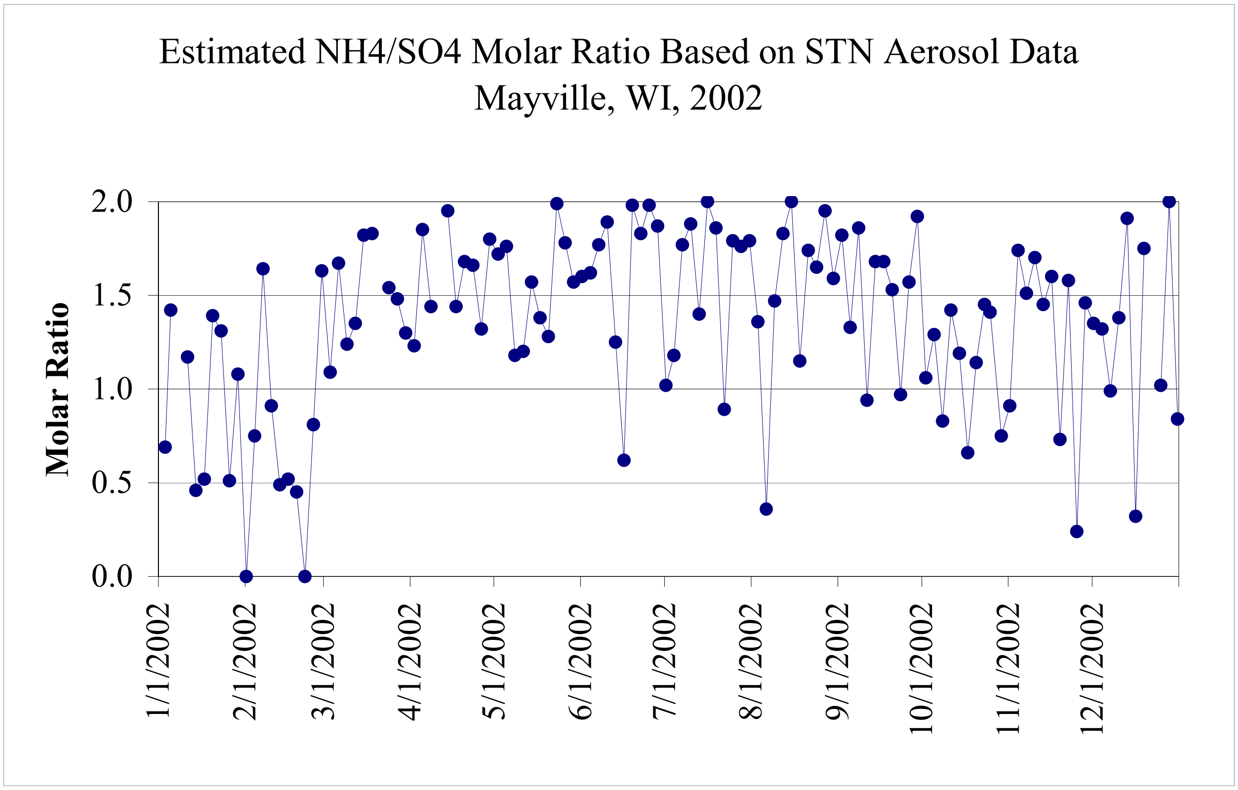
3.1.3 Alternate Calculation Method – Using Daily f(RH)

The full analysis of IMPROVE and STN speciated data incorporated a monthly relative humidity enhancement factor, f(RH), for ammonium sulfate and ammonium nitrate scattering. This is the method for calculating extinction described in EPA's Regional Haze Guidance Document. The purpose of using a monthly value is to minimize the variability in extinction due to fluctuating RH. This is arguably not the method to use to calculate the "best estimate" of extinction on a given day. The Alternate 1 method calculation of extinction uses all the same equations for species' masses and extinctions, but replaces the monthly f(RH) for ammonium sulfate and ammonium nitrate with a daily f(RH). Daily f(RH) values are calculated as the average of individual hourly f(RH) values using on-site RH measurements. A minimum of 16 valid RH measurements were required to constitute a valid daily f(RH) for this analysis. The f(RH) values were taken from the EPA growth curve shown in Figure 3-1.

A second alternate method for calculating aerosol extinction involves a more complex sulfate chemistry model than the IMPROVE assumption that all sulfate is in the form of ammonium sulfate. Sulfate may exist in any of several forms, from sulfuric acid (ammonium to sulfate molar ratio of 0.0) to ammonium sulfate (ammonium to sulfate molar ratio of 2.0), each of which is characterized by varying abilities to absorb water and, thus, varying scattering efficiencies. The combination of sulfate types is determined by the availability of ammonium. While ammonium preferentially reacts with sulfate, it also reacts with nitrate (governed to a large degree by temperature and RH). The equilibrium calculations required to determine the apportionment of ammonium to sulfate and nitrate for each filter sample are not trivial, but can be estimated by assuming that the measured nitrate ion can be explained by ammonium nitrate, and subtracting the corresponding mass of ammonium from the total ammonium before apportioning it to various forms of sulfate. IMPROVE does not analyze filters for ammonium at any of the LADCO sites. STN does analyze for ammonium at Mayville and Seney.

Figure 3-2 presents a timeline of the ammonium to sulfate molar ratio for these sites in 2002. Using this alternate method to calculate extinction, the largest differences from the IMPROVE method will occur when the molar ratio is less than 1.0. Both of the sites show low molar ratios in the first quarter. Seney shows many days throughout the year with a molar ratio of 0.0. The STN nitrate mass is substantially higher than the IMPROVE nitrate mass on some common sampling days (see Figure 3-8) although on average only modestly higher (see Table 3-4). This may be driving the molar ratios (at least mathematically) because the measured ammonium is first reduced to account for assumed ammonium nitrate, leaving less to pair up with sulfate. Ammonium is difficult to analyze from filters due to its volatility (dependent on sampling temperature fluctuations and handling) and the reported measurements may be lower than the true ambient levels.

This alternative method for calculating aerosol extinction was not performed for this report. However, when this method was applied to speciated $PM_{2.5}$ monitoring data within the southeastern U.S., ARS found no significant change in urban areas, but an overall increase in extinction at rural and wilderness sites of approximately 8%. This is roughly the magnitude of change that could be expected at LADCO sites if this alternate method were applied.



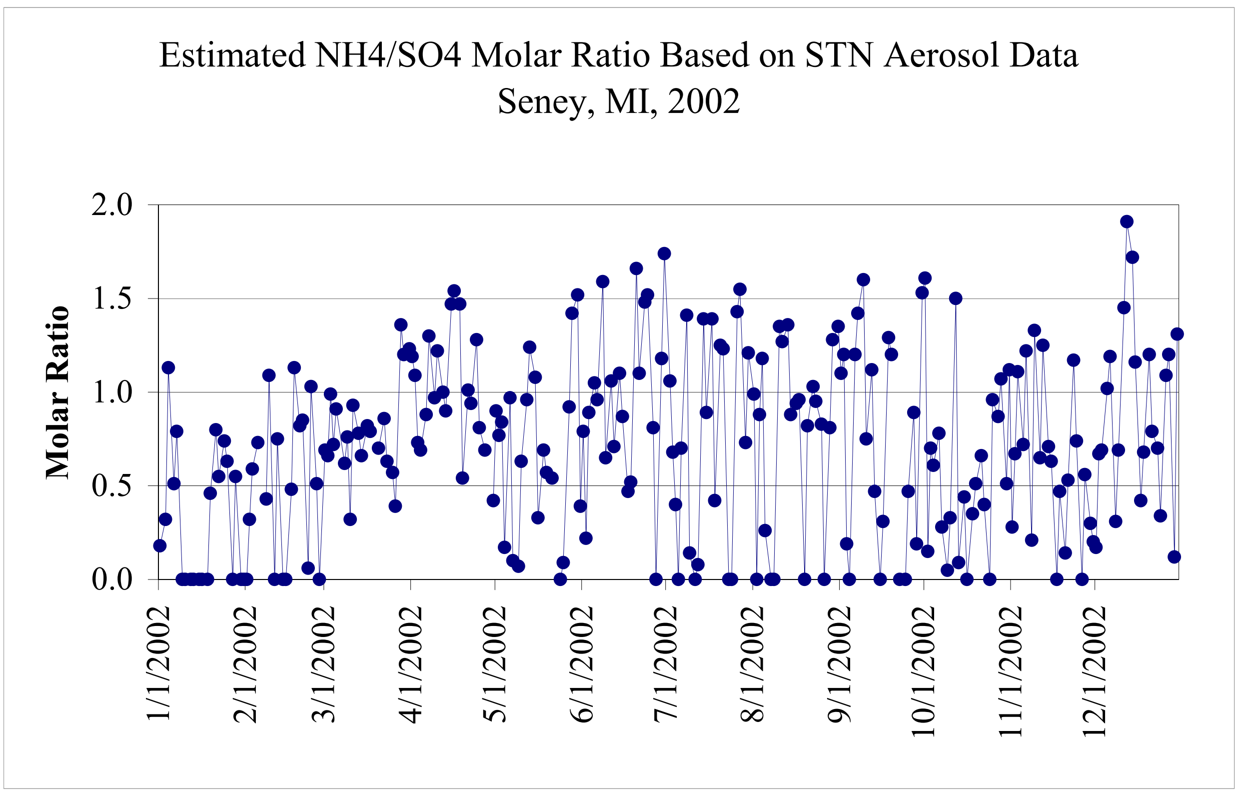


Figure 3-2. Timeline of Estimated Ammonium (NH_4) to Sulfate (SO_4) Molar Ratios Based on STN Aerosol Data for Mayville, WI, and Seney, MI, 2002.

3.1.4 Categorization of High, Medium, and Low Extinction Days

Extinction was calculated only for those days that had a complete data record (all mass species, and a minimum sixteen RH measurements, if required). Once calculated, site-specific daily extinction values were ranked from lowest to highest and assigned to one of 4 bins: the 5% highest, 20% highest (includes 5% highest), 60% middle, and 20% lowest extinction days. Extinction and mass contributions by each species were averaged within bins. Estimated extinction and mass budgets for each bin for all four LADCO sites were generated in this way.

3.1.5 Visibility Metrics

Throughout this report visibility results are presented in terms of light extinction due to particulates in the atmosphere. There are, however, other metrics used to quantify visibility conditions. The three most common metrics are:

- **Extinction** – Extinction is a measure of the fraction of light lost per unit length along a sight path due to scattering and absorption by gases and particles. Throughout this report extinction will be expressed in inverse Megameters (Mm^{-1}).
- **Visual Range** – Visual range is the greatest distance a large black object can be seen on the horizon. Extinction can be converted to visual range in miles using the equation:

$$\text{Visual Range} = \{(3912) / (\text{Extinction in } Mm^{-1})\} / 1.61$$

- **Deciview** – The deciview index was designed to be linear with respect to human perception of visibility. A one deciview change is approximately equivalent to a 10% change in extinction, whether visibility is good or poor. Extinction can be converted to deciview using the equation:

$$\text{Deciview} = 10 \times \ln \{(\text{Extinction in } Mm^{-1}) / 10\}$$

An increase in extinction or deciview is equivalent to a decrease in visual range. Therefore, improved visibility is associated with decreasing extinction, decreasing deciview, and increasing visual range.

3.2 AEROSOL EXTINCTION AND MASS SUMMARIES

3.2.1 Aerosol Extinction and Mass by Species

Daily estimated total extinction and mass was calculated for all IMPROVE and STN samplers as described above. Appendix A contains year 2002 timelines of IMPROVE and STN extinction and fine mass by individual species. Two extinction timelines are included for each site/sampler type, one using the recommended EPA monthly f(RH), one using a daily f(RH). The f(RH) values used are included in the timelines. Note that the STN data sets do not include coarse mass. These timelines provide the following information at a glance:

- The difference in daily extinction estimates using monthly and daily f(RH) values.

- Each species relative contribution to extinction and total fine mass. Ammonium sulfate can be seen as the dominant species for most sites on most days. A high correlation between sulfate and extinction is suggested in the timelines. Mayville is the exception, where ammonium nitrate is often dominant. At those sites measuring coarse mass, the coarse mass contribution to extinction exceeds that of soil by a significant amount.
- The seasonality of species extinction. Quaker City exhibits the most seasonality in extinction with highest values in the 3rd quarter. For all sites the contribution from ammonium sulfate is generally greatest during the warmer months and the contribution from ammonium nitrate is greatest during the cooler months.
- Occasional spikes in species extinction, particularly organic mass, soil, and coarse mass.
- Periods of missing data.

Site-specific daily total extinction values calculated using monthly f(RH) were ranked from lowest to highest and assigned to one of 4 extinction bins. Figures 3-3 through 3-6 present extinction and fine mass budgets for each bin in absolute and percentage terms. Tables 3-3 and 3-4 present a listing of absolute species extinction and mass. Also included in Table 3-3 are visual range (VR) and deciview (DV) values calculated from the total extinction. Similar figures and tables created with extinction calculated using daily f(RH) are presented in Appendix B for reference.

The amount of information contained within these graphs is large, and many observations could be made with regard to the differences between networks and extinction bins. This discussion will highlight major points.

Ammonium sulfate is shown to be the largest contributor to extinction in all extinction categories at Bondville, Seney, and Quaker City, and low extinction days at Mayville. Ammonium nitrate dominates the Mayville extinction budget on high extinction days. Depending on the site and extinction category, ammonium nitrate or organic mass is the second largest contributor to extinction. Elemental carbon and coarse mass generally contribute less than 10% to total extinction. While soil contributes up to about 10% to fine mass, its contribution to extinction is negligible.

Other important site-specific results include:

- Quaker City exhibits the highest ammonium sulfate of all sites in all categories. This result is not unexpected due to the site's proximity to power generation in the Ohio River Valley and regions further south. The low ammonium nitrate at Quaker City on high extinction days is likely due to their occurrence generally in the warmer months, and the fact that the sulfate-nitrate-ammonium chemistry may be ammonia-limited.
- Seney exhibits the lowest total extinction in all categories. The IMPROVE extinction is some what lower than the STN extinction, due mainly to the difference in reported organic mass for both networks.

- Mayville ammonium nitrate is very high, particularly on the dirtiest days. This may be due, in part, to the availability of ammonia (from agricultural/livestock activities) and the relatively lower sulfate, allowing ammonium nitrate to form in its place.
- The difference between extinction budgets based on monthly or daily f(RH) values is due in part to differing resultant contribution by sulfate and nitrate, and by a different binning of days into extinction categories.

3.2.2 Extinction Correlations between Sites

LADCO is a large and diverse geographic region. Pairs or clusters of monitoring sites can experience local or regional events together. ARS investigated the site-to-site correlations between total and species extinction for all site pairs. Appendix C contains the results of these comparisons in graphical format with site pair R^2 values indicated. No strong correlations were found, indicating that often local influences are significant enough to mask regional influences. The most meaningful correlations, while not high, were generally found for the Seney/Mayville and Mayvill/Bondville site pairings, for total, ammonium sulfate, and organic mass extinction. Soil extinction correlations between some site pairs were relatively high, but these were driven by a few large values.

3.2.3 Comparison of EPA STN and Improve Speciated Mass

To better understand the comparability of IMPROVE data with EPA STN data, ARS compiled and compared data from four (4) collocated sites across the country (Phoenix, AZ; Puget Sound, WA; Mingo, MO; and Seney, MI). The combined results of these comparisons are presented in Figure 3-7, and individually in Appendix D. A comparison for Seney alone for all of 2002 presented in Figure 3-8.

Sulfate was strongly correlated and reasonably equivalent in comparisons between networks at all four sites. Nitrate was well correlated at all sites, with IMPROVE nitrate significantly higher than STN nitrate at Puget Sound and significantly lower than STN nitrate at Seney. Seney showed significantly lower nitrate mass and poorer correlation between networks than the other three sites.

Organic and total carbon were both strongly correlated at Seney in 2002, but a positive bias of approximately 1 $\mu g/m^3$ can be seen in the STN data. Nearly all samples showed higher organic and total carbon at STN sites. A similar trend can be seen at Phoenix and Puget Sound. The Mingo comparison appears to contain two populations, with the dominant population also showing this trend. Elemental carbon is generally higher in the IMPROVE samples at Mingo and Seney, and fairly equal between networks at Phoenix and Puget Sound. These differences in mass measurements are likely a combination of analysis differences, instrument differences, and field operations differences. The differences shown here between carbon mass in both networks does not agree at all sites with the earlier comparisons taken from the 1999 Four Cities Study. Carbon comparisons appear to be somewhat site-specific between networks.

Soil was systematically lower at the STN sites than IMPROVE sites. Soil mass differences generally do not have significant effects on visibility calculations, especially in the LADCO region.

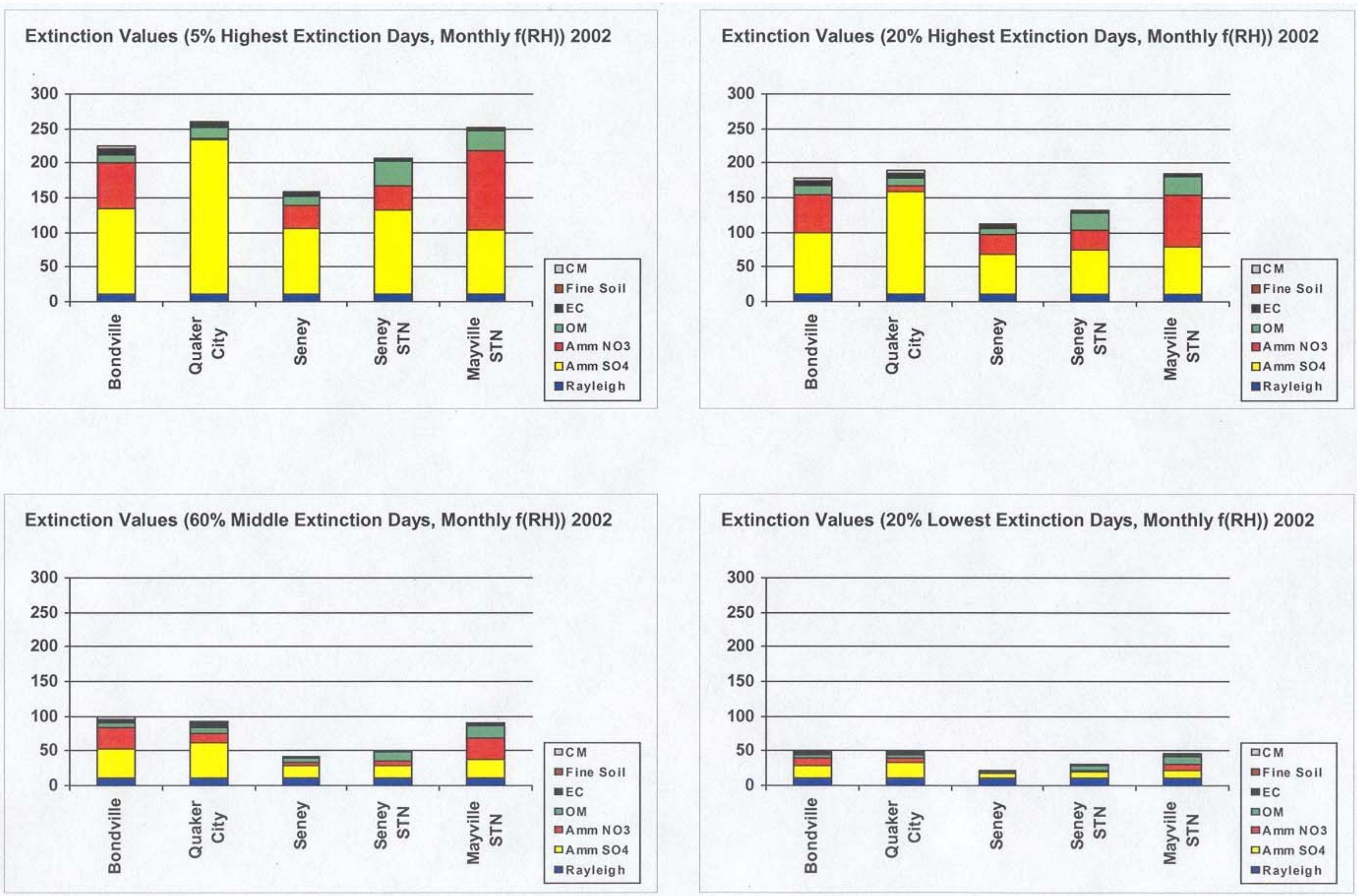


Figure 3-3. Absolute Extinction Values (in Mm^{-1}) for Each Extinction Category, Using Monthly f(RH) Values, for 2002

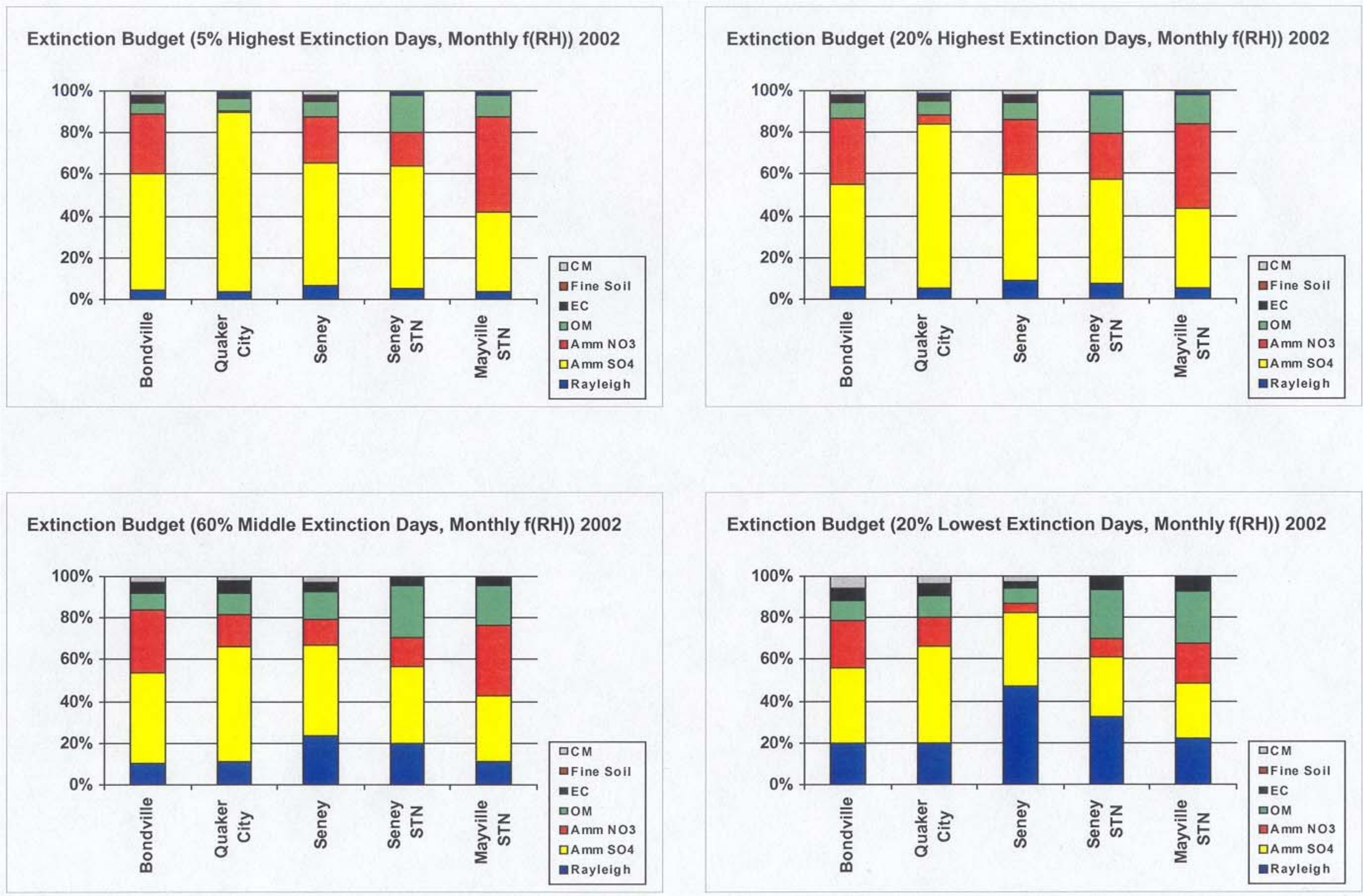


Figure 3-4. Percentage Extinction Values for Each Extinction Category, Using Monthly f(RH) Values, for 2002

Table 3-3

Extinction Budgets by Extinction Category (Using Monthly f(RH))
Presented in Figure 3-3

Site	Network	Amm SO4	Amm NO3	OM	EC	Fine Soil	CM	Rayleigh	Total Ext	DV	VR
5 % Highest Extinction											
Bondville	IMPROVE	124.9	65.3	11.8	6.0	2.2	4.4	10.0	224.7	31.1	17
Quaker City	IMPROVE	224.5	2.3	14.7	6.1	1.3	2.1	10.0	261.0	32.6	15
Seney	IMPROVE	95.1	34.9	11.3	4.3	1.1	3.1	10.0	159.8	27.7	24
Seney STN	STN	122.8	33.9	36.5	3.6	0.4	N/A	10.0	207.2	30.3	19
Mayville STN	STN	94.5	114.8	27.0	4.1	0.5	N/A	10.0	251.0	32.2	16
20% Highest Extinction											
Bondville	IMPROVE	88.4	56.3	12.3	5.9	1.1	4.0	10.0	177.9	28.8	22
Quaker City	IMPROVE	148.9	7.7	12.5	5.7	1.5	2.8	10.0	189.0	29.4	21
Seney	IMPROVE	57.6	29.7	9.2	3.7	0.6	2.4	10.0	113.2	24.3	35
Seney STN	STN	65.5	29.2	23.7	2.8	0.3	N/A	10.0	131.5	25.8	30
Mayville STN	STN	69.9	75.6	25.5	3.9	0.5	N/A	10.0	185.3	29.2	21
60% Middle Extinction											
Bondville	IMPROVE	43.1	30.0	7.9	4.2	0.7	3.2	10.0	99.0	22.9	40
Quaker City	IMPROVE	50.7	14.6	9.4	4.7	0.5	2.2	10.0	92.1	22.2	42
Seney	IMPROVE	18.4	5.2	5.5	1.7	0.2	1.3	10.0	42.2	14.4	93
Seney STN	STN	18.4	7.2	12.6	2.1	0.2	N/A	10.0	50.5	16.2	77
Mayville STN	STN	28.6	30.0	17.5	3.4	0.4	N/A	10.0	89.9	22.0	44
20% Lowest Extinction											
Bondville	IMPROVE	18.1	11.6	5.0	2.6	0.3	3.0	10.0	50.6	16.2	77
Quaker City	IMPROVE	23.0	7.0	5.2	2.8	0.2	1.7	10.0	49.9	16.1	78
Seney	IMPROVE	7.5	0.9	1.6	0.6	0.1	0.6	10.0	21.3	7.6	183
Seney STN	STN	8.8	2.9	7.2	1.9	0.1	N/A	10.0	30.9	11.3	127
Mayville STN	STN	12.0	8.7	11.4	2.9	0.3	N/A	10.0	45.3	15.1	86

Figure 3-5. Absolute Fine Mass Values (in μg/m^3) for Each Extinction Category, Using Monthly f(RH) Values, for 2002

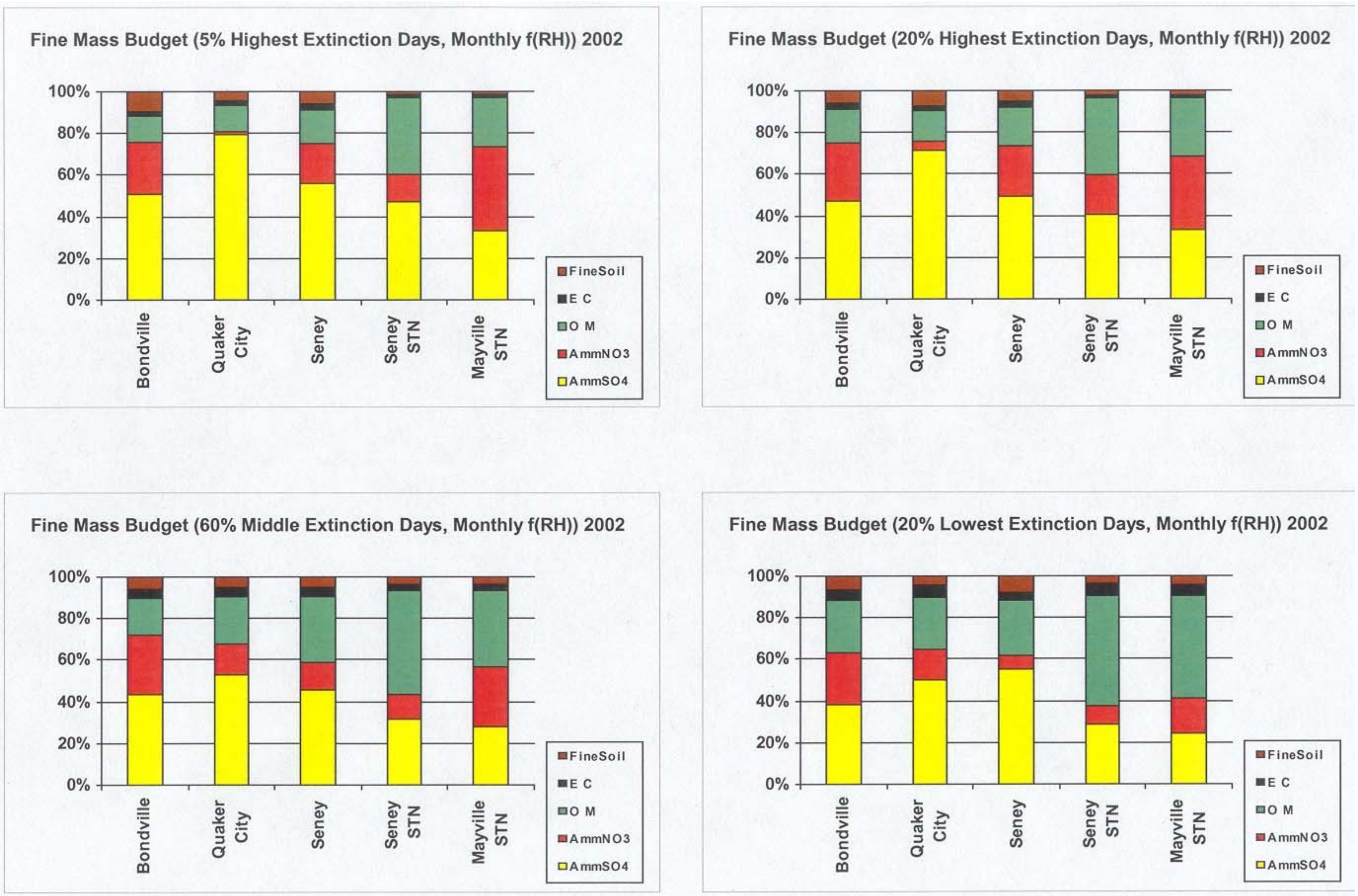


Figure 3-6. Percentage Fine Mass Values for Each Extinction Category, Using Monthly f(RH) Values, for 2002

Table 3-4

Fine Mass Budgets by Extinction Category (Using Monthly f(RH))
Presented in Figure 3-5

Site	Network	Amm SO4	Amm NO3	OM	EC	Fine Soil
5% Highest Extinction						
Bondville	IMPROVE	12.1	5.9	3.0	0.6	2.2
Quaker City	IMPROVE	22.9	0.2	3.7	0.6	1.3
Seney	IMPROVE	9.7	3.4	2.8	0.4	1.1
Seney STN	STN	11.8	3.3	9.1	0.4	0.4
Mayville STN	STN	9.8	11.8	6.8	0.4	0.5
20% Highest Extinction						
Bondville	IMPROVE	8.8	5.3	3.1	0.6	1.1
Quaker City	IMPROVE	15.2	0.8	3.1	0.6	1.5
Seney	IMPROVE	6.0	3.0	2.3	0.4	0.6
Seney STN	STN	6.5	3.0	5.9	0.3	0.3
Mayville STN	STN	7.6	8.2	6.4	0.4	0.5
60% Middle Extinction						
Bondville	IMPROVE	4.7	3.1	2.0	0.4	0.7
Quaker City	IMPROVE	5.5	1.6	2.4	0.5	0.5
Seney	IMPROVE	2.0	0.6	1.4	0.2	0.2
Seney STN	STN	2.0	0.8	3.1	0.2	0.2
Mayville STN	STN	3.3	3.4	4.4	0.3	0.4
20% Lowest Extinction						
Bondville	IMPROVE	1.9	1.2	1.2	0.3	0.3
Quaker City	IMPROVE	2.6	0.8	1.3	0.3	0.2
Seney	IMPROVE	0.8	0.1	0.4	0.1	0.1
Seney STN	STN	1.0	0.3	1.8	0.2	0.1
Mayville STN	STN	1.4	1.0	2.8	0.3	0.3

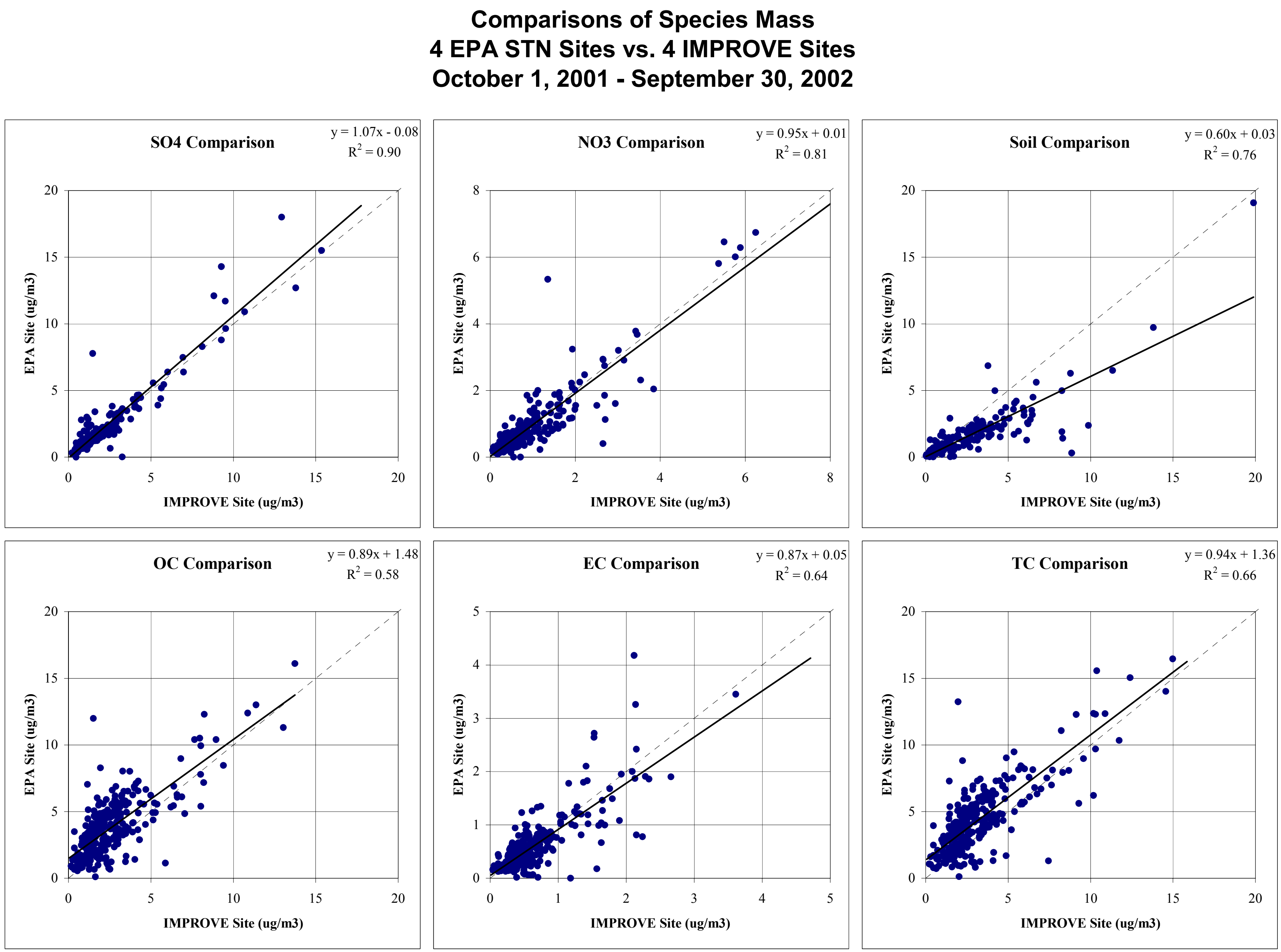


Figure 3-7. 1 Year of Species Mass Comparisons Between 4 Sets of Collocated IMPROVE and EPA STN Sites.

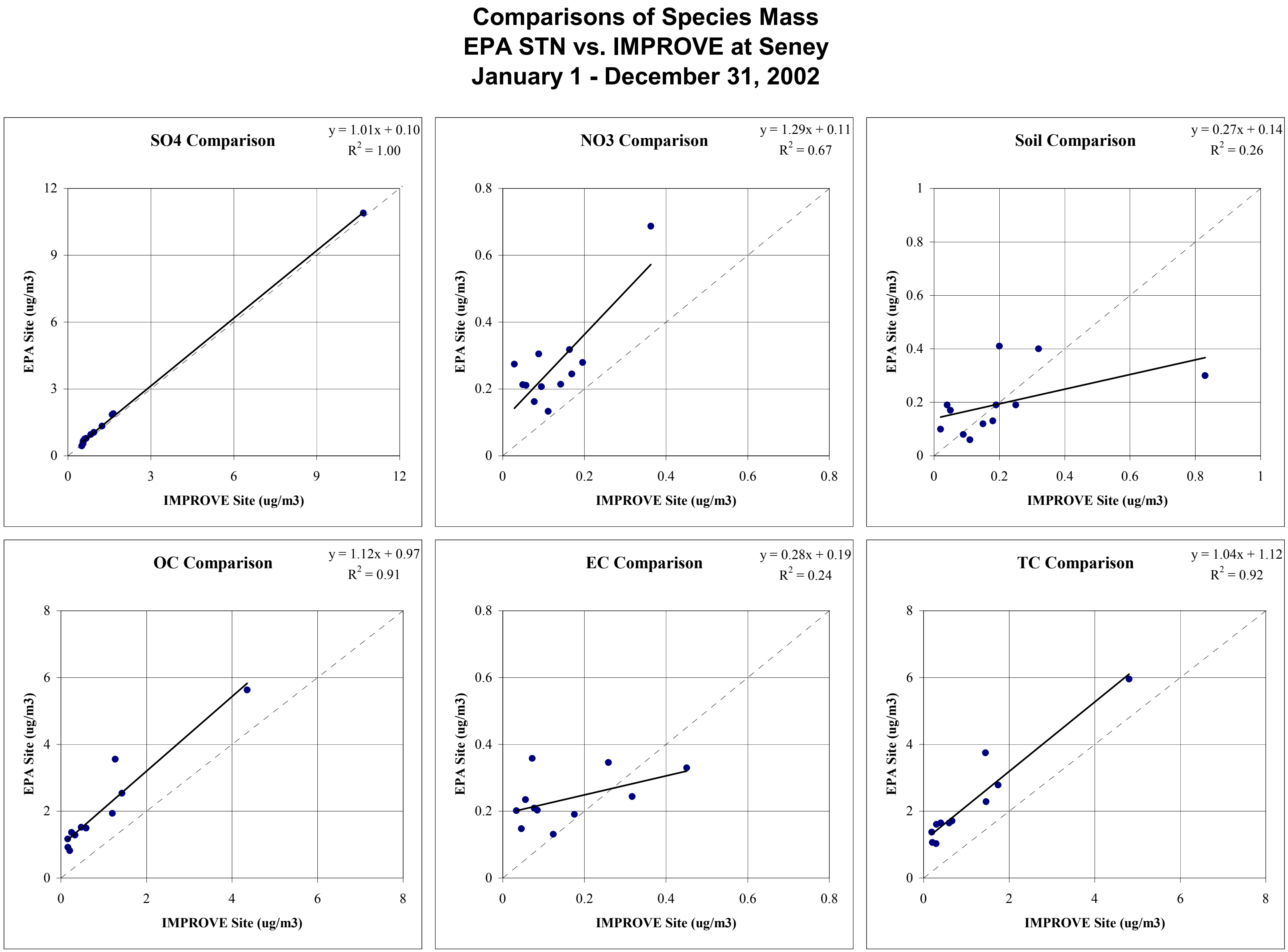


Figure 3-8. Species Mass Comparisons Between Collocated IMPROVE and EPA STN Data Collected at Seney in 2002.

3.3 NEPHELOMETER DATA SUMMARIES

3.3.1 Nephelometer Particle Scattering Data

Two types of nephelometers are operated at the LADCO sites. Many IMPROVE sites across the country employ an ambient nephelometer in conjunction with aerosol monitoring. Heated nephelometers are employed at some special study sites to monitor scattering by dry particulates.

Ambient Nephelometers

Ambient nephelometers are operated at three of the four LADCO sites in conjunction with aerosol monitoring. The ambient nephelometers used measure light scattering (at 550 nm) of aerosols with minimal changes to the sample aerosol temperature and humidity. This information allows comparison between estimated aerosol scattering (aerosol extinction minus the contributions of elemental carbon absorption and Rayleigh scattering) and direct measurements of particle scattering.

The ambient nephelometer scattering data is collected every five minutes and processed into hourly averages. The hourly averages are screened to identify periods of data which are not representative of particle scattering (e.g., weather events, insects or other objects in the measurement chamber, etc.). The screening algorithms flag otherwise valid hourly data if any of the following parameters are above specified thresholds: the ambient relative humidity; the absolute change in data from hour to hour; the standard deviation over the mean of the twelve 5-minute values which make an hourly average; the measured particle scattering above the maximum allowable value. Data not flagged by the screening algorithms are commonly called "filtered" nephelometer data (ARS, 1994). The "unfiltered" nephelometer data set contains all of the filtered data plus that data believed to be associated with weather effects and other interferences. While unfiltered data are summarized in this report as a hypothetical upper bound on valid data, it is generally accepted that filtered data are most appropriate to use for comparisons with aerosol data.

To compare ambient nephelometer and aerosol scattering data it is important to treat the data in as similar a manner as possible. For this analysis, the aerosol scattering used was derived from the Alternate Calculation method described above. All sulfate was assumed to be in the form of ammonium sulfate. Hourly RH measurements collected at the aerosol sampling sites were used to calculate aerosol scattering. In addition, only those hourly RH measurements which corresponded with filtered nephelometer data were used. A minimum of sixteen valid hourly RH measurements were required to calculate aerosol scattering for a given day. Likewise, a minimum of sixteen filtered hourly nephelometer measurements were required to represent a given day. The cutoff RH for nephelometer filtering was set to 95%.

Heated Nephelometers

Dry particle scattering is measured at the Bondville site with a heated nephelometer. The heater is activated to keep the sample air relative humidity no greater than approximately 40%.

The purpose of this type of measurement is to determine the scattering characteristics of the sampled aerosol essentially uninfluenced by water uptake. Unfortunately no valid sampling chamber RH was available with this data, so it is not known how well this condition was met.

The heated nephelometer data is reported as hourly averages of dry particle scattering at multiple wavelengths. For best comparison with ambient nephelometer data, only the data collected for the 550 nm wavelength scattering was used in this report. Since the sample chamber is not directly exposed to ambient conditions, no filtering of the data (as is done with the ambient nephelometer data) was performed.

Data comparisons between nephelometer dry particle scattering and estimated aerosol dry particle scattering (ignoring RH effects) were performed. A minimum of 16 valid hourly scattering valves were required to calculate a daily value.

3.3.2 Nephelometer Data Summaries

Appendix E presents quarterly nephelometer data summaries for all sites. Note that Quaker City, Seney, and Mayville operated ambient nephelometers, and those data were processed according to IMPROVE protocol (ARS, 1994) and filtered for weather and other interferences. The appropriate standard operating procedures and technical instructions can be obtained on the IMPROVE Web site (IMPROVE, 2003) or the VIEWS Web site (VIEWS, 2003). Bondville operated a heated nephelometer and those data were not processed or filtered according to IMPROVE protocol. Bondville quarterly summaries are included in Appendix D for reference.

Site-specific daily nephelometer scattering values were calculated and assigned to one of 4 bins: the 5% highest, 20% highest, 60% middle, and 20% lowest values. Daily scattering was averaged within those bins and the results are presented in Table 3-5. It is important to note that the days included in these bins do not necessarily correlate with the days included in similar bins for the aerosol extinction summaries.

Table 3-5

Nephelometer Summaries by Scattering Category

Site	Nephelometer	Particle Scattering, b_{sp} (Mm^{-1})
		5% Highest
Bondville	Dry	140.8
Quaker City	Ambient	166.1
Seney	Ambient	148.5
Mayville	Ambient	178.6
		20% Highest
Bondville	Dry	105.7
Quaker City	Ambient	118.1
Seney	Ambient	85.5
Mayville	Ambient	122.6
		60% Middle
Bondville	Dry	47.9
Quaker City	Ambient	49.5
Seney	Ambient	21.3
Mayville	Ambient	43.7
		20% Lowest
Bondville	Dry	19.3
Quaker City	Ambient	22.8
Seney	Ambient	7.3
Mayville	Ambient	17.6

3.3.3 Comparison of Aerosol and Nephelometer Light Scattering

ARS computed daily estimated aerosol scattering and measured nephelometer scattering as described above. Figures 3-9 through 3-12 present comparisons of 2002 daily aerosol and nephelometer scattering for all data, and individual quarters for Quaker City, Seney, and Mayville. Figure 3-13 presents the same comparisons for Bondville. Note that dry aerosol and dry nephelometer scattering is presented for Bondville. Differences between daily estimated and measured scattering may occur due to the following reasons:

- Differences between assumed and actual aerosol characteristics (size, scattering efficiency, acidity, hygroscopicity, etc.).
- Uncertainty about the sample chamber relative humidity at Bondville.
- Nephelometer measurement error (e.g., weather or other interference not caught by screening algorithms; systematic bias in measurement from one instrument to another).
- Aerosol sample measurement or analysis error (e.g., variable sample flow which affects particle size cut point; contamination of filter sample).
- Instrument uncertainty associated with the aerosol sample or nephelometer measurement.

A high degree of correlation was found at all sites for 2002, with seasonal variations at each site. The most favorable comparison was at Seney, between IMPROVE aerosol scattering and measured nephelometer scattering, where the difference between methods was often within $\pm$ 10Mm^{-1}. The comparison between Seney STN aerosol scattering and nephelometer scattering also showed high R^2 values, but the STN aerosol scattering exhibited a positive bias, due to the higher organic mass reported with STN methodology. A similar bias can be seen in the Mayville STN comparison throughout most of the year. The least favorable comparison was at Bondville, where dry aerosol scattering was compared to dry nephelometer scattering. The large difference between aerosol and nephelometer scattering (with nephelometer scattering often significantly higher) may be related to the sampling chamber RH, which is not known with certainty.

The time of year with the most favorable slope is not the same at all sites. Quaker City shows the best agreement between aerosol and nephelometer scattering in quarter 3 (slope = 0.73), Seney in quarter 2 for both networks (IMPROVE slope = 0.97, STN slope = 1.02), Mayville in quarter 1 (slope = 1.05), and Bondville in quarter 1 (slope = 0.63). The largest differences between aerosol and nephelometer scattering generally occur during quarter 3 at all sites, with Mayville showing some large differences in quarter 4 as well.

There is a tendency for high ambient nephelometer scattering to be higher than the corresponding IMPROVE aerosol scattering. While somewhat less pronounced in the figures, it is also common for low IMPROVE aerosol scattering to be higher than the corresponding ambient nephelometer scattering. This phenomenon has been noted elsewhere in the IMPROVE network. During the Southeastern Aerosol and Visibility Study (SEAVS) in 1995, estimated aerosol scattering was compared to measured nephelometer scattering (Malm *et al.* 1997). A linear regression of aerosol scattering (based on the IMPROVE algorithm with on-site measured RH) and measured scattering yielded a slope of 1.28, implying the measured scattering was approximately 28% higher than aerosol scattering. When collocated size distribution data, combined with sulfate acidity were used to refine the aerosol scattering estimates, agreement between estimated and measured values improved, yielding a regression slope of 0.89.

Size distribution data can be collected with or without regard to species. Several particle size counters on the market can be used to gather non-speciated size distribution data, but it is difficult to apply this information to a complex mixture of aerosol types. Given specific days in which the collected aerosol is dominated by a single species, it is possible to refine the extinction equation with regard to that species on that day using the particle size distribution. However, for most days this is not the case. Speciated particle size information can be obtained from multi-stage impacting samplers and the appropriate filter media (the MOUDI sampler is well characterized for this). Not all species can be separated from the sample (e.g., organic and elemental carbon), so again, this information alone can aid in refining the extinction equation, but does not solve the problem completely. During intensive special studies, numerous instruments to monitor size and chemistry of aerosols have yielded enough information to very accurately estimate scattering and extinction by collected aerosol. It is not practical or cost effective to routinely measure particle size distributions and the necessary chemistry in the IMPROVE or STN networks. The IMPROVE algorithm for calculating aerosol scattering (extinction) assumes a “typical” size distribution for each species. As can be seen from this analysis and earlier work, that assumption is not always correct, particularly on the dirtiest days and the very cleanest days.

Even with these discrepancies, measured scattering does correlate well with aerosol scattering on a 24-hour basis. In addition to serving as a check on the IMPROVE extinction equation, nephelometers complement filter-based aerosol sampling because they operate continuously, not on a 1 in 3 or 1 in 6 schedule. Figures 3-14 through 3-17 present timelines of 24-hour aerosol and nephelometer scattering for each site. The nephelometer scattering can be seen to agree well in general with aerosol scattering at all sites. The largest discrepancies occur at the Bondville site, where dry scattering was monitored.

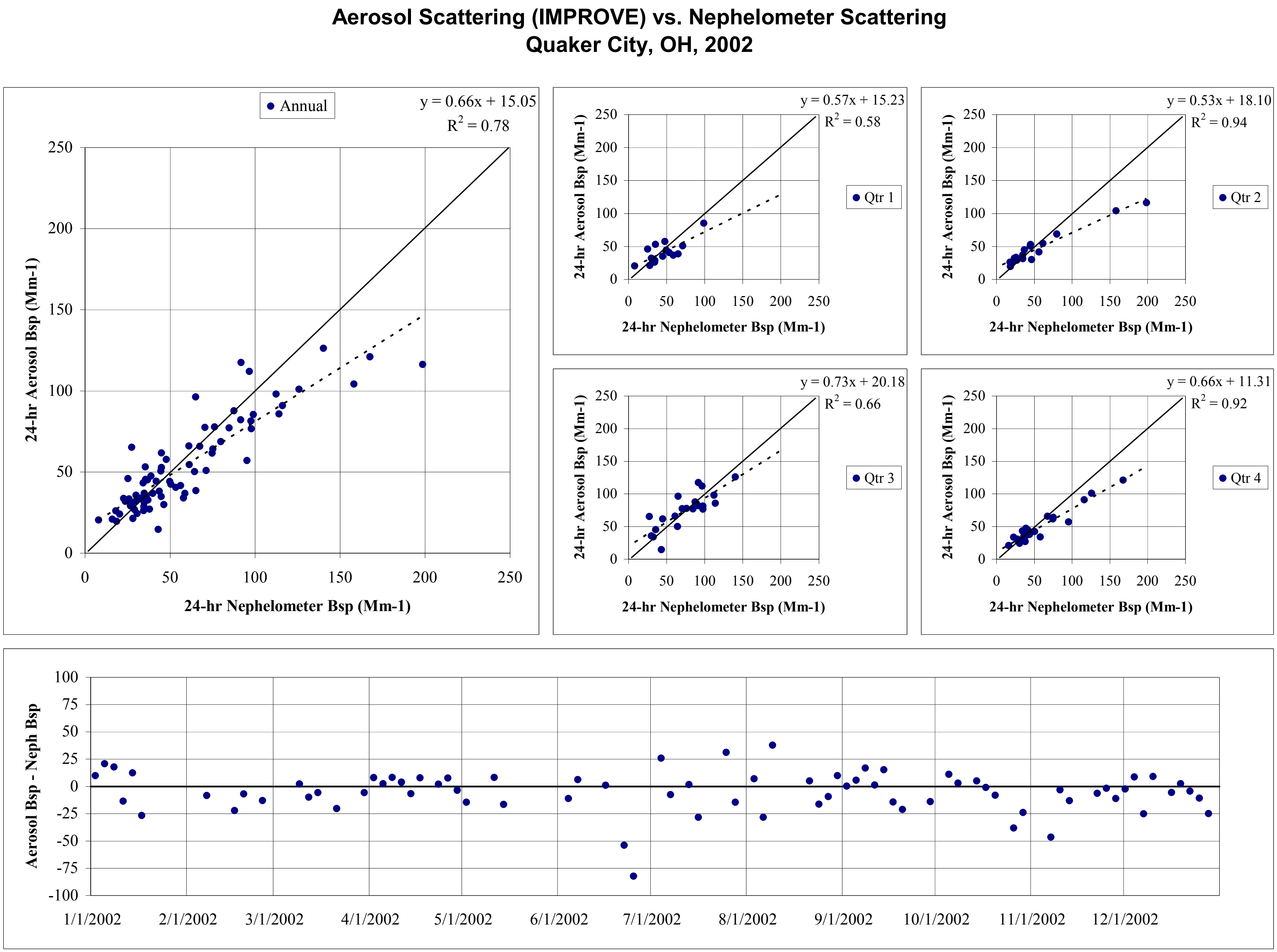


Figure 3-9. Comparison between Aerosol Scattering (IMPROVE) and Nephelometer Scattering, Quaker City, OH, 2002.

Aerosol Scattering (IMPROVE) vs. Nephelometer Scattering
Seney, MI, 2002

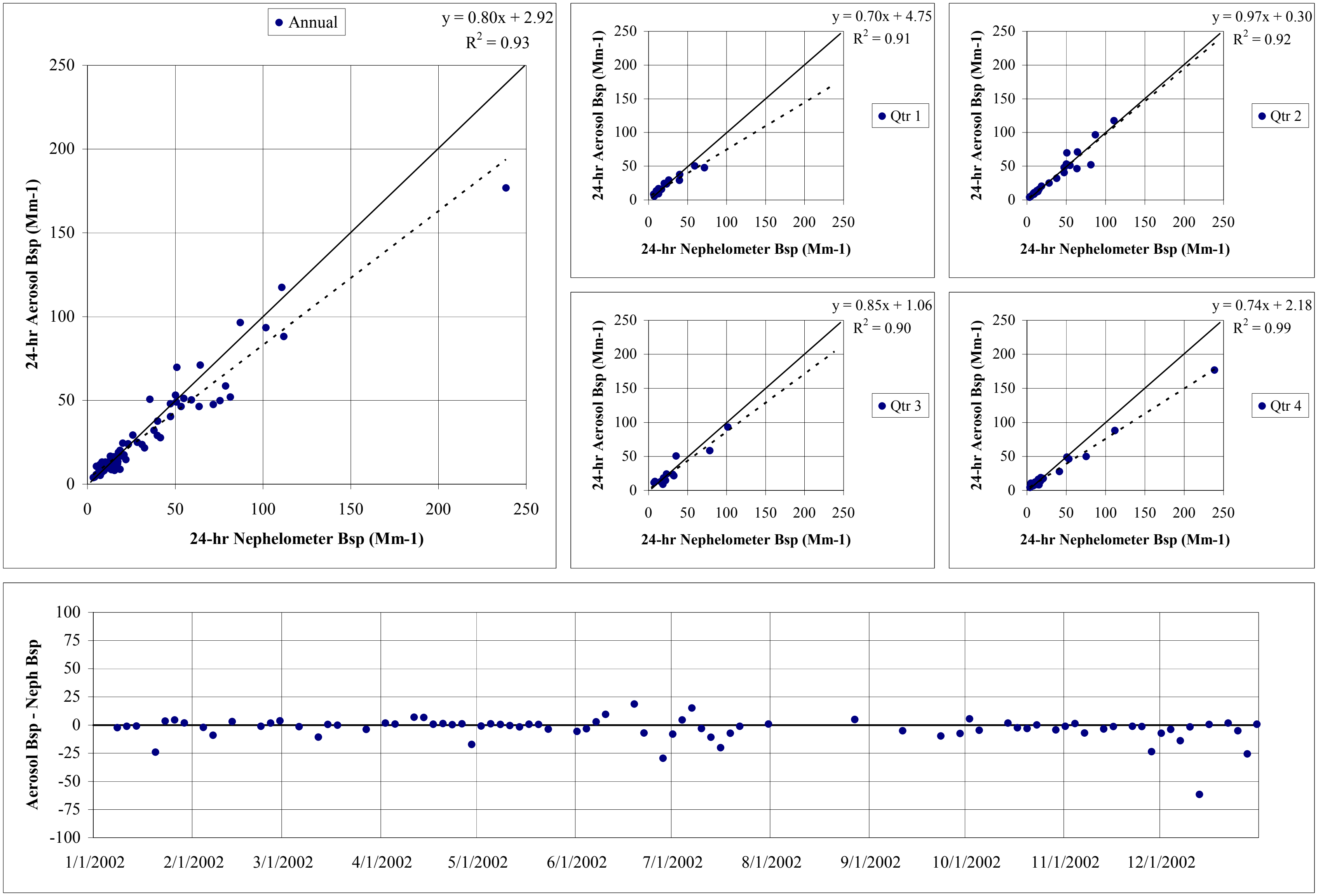


Figure 3-10. Comparison Between Aerosol Scattering (IMPROVE) and Nephelometer Scattering, Seney, MI, 2002.

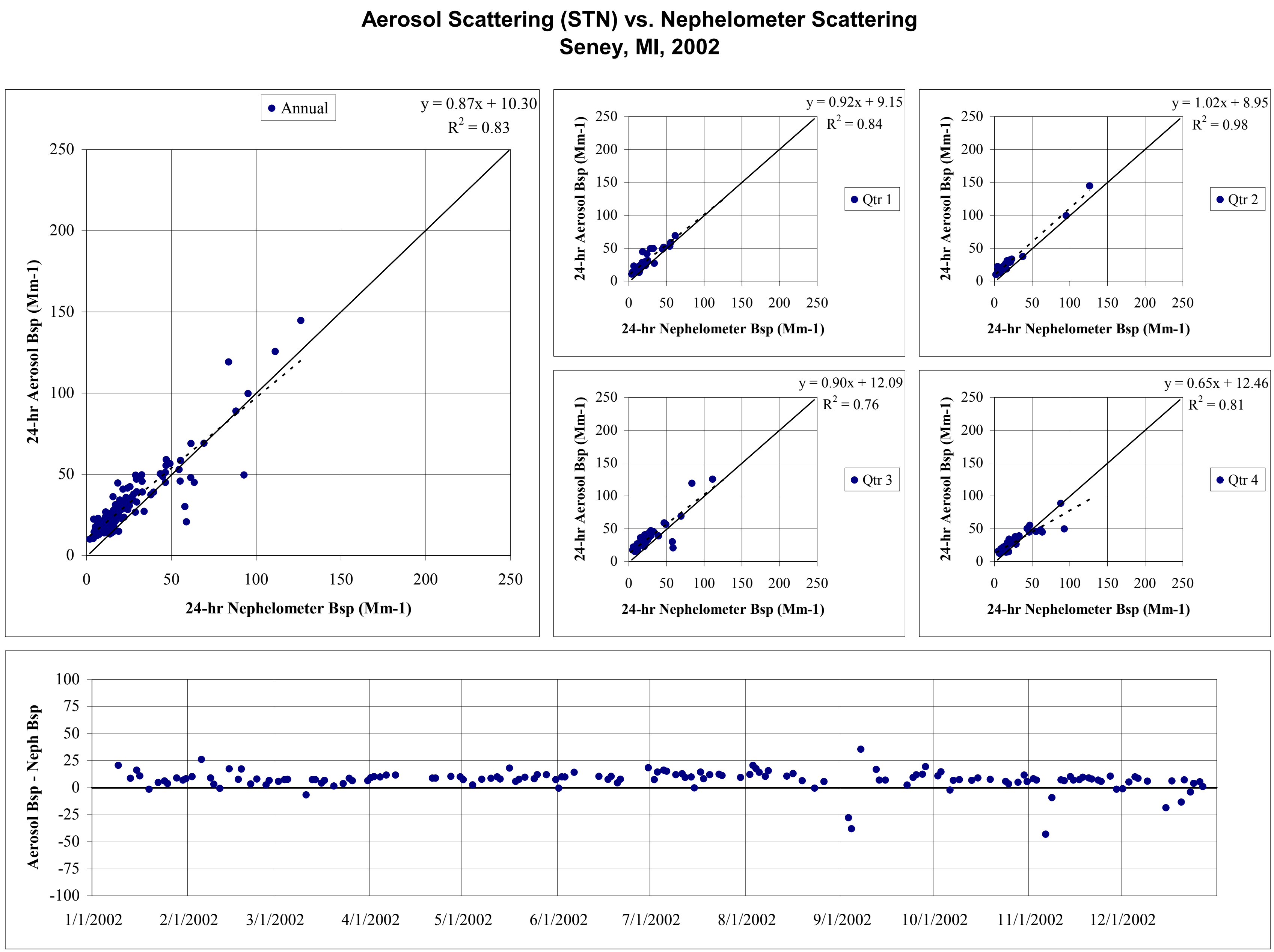


Figure 3-11. Comparison Between Aerosol Scattering (STN) and Nephelometer Scattering, Seney, MI, 2002.

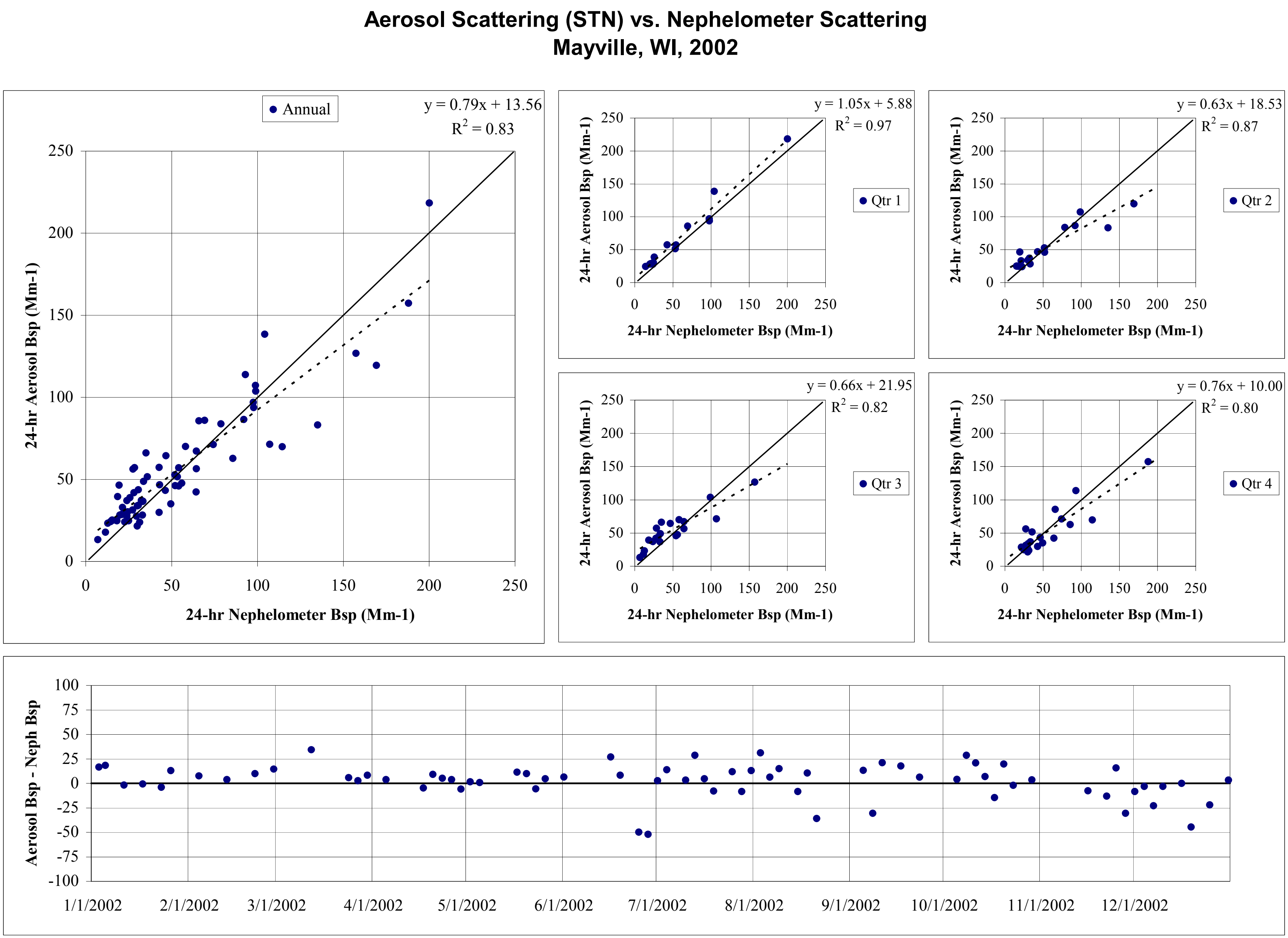


Figure 3-12. Comparison Between Aerosol Scattering (STN) and Nephelometer Scattering, Mayville, WI, 2002.

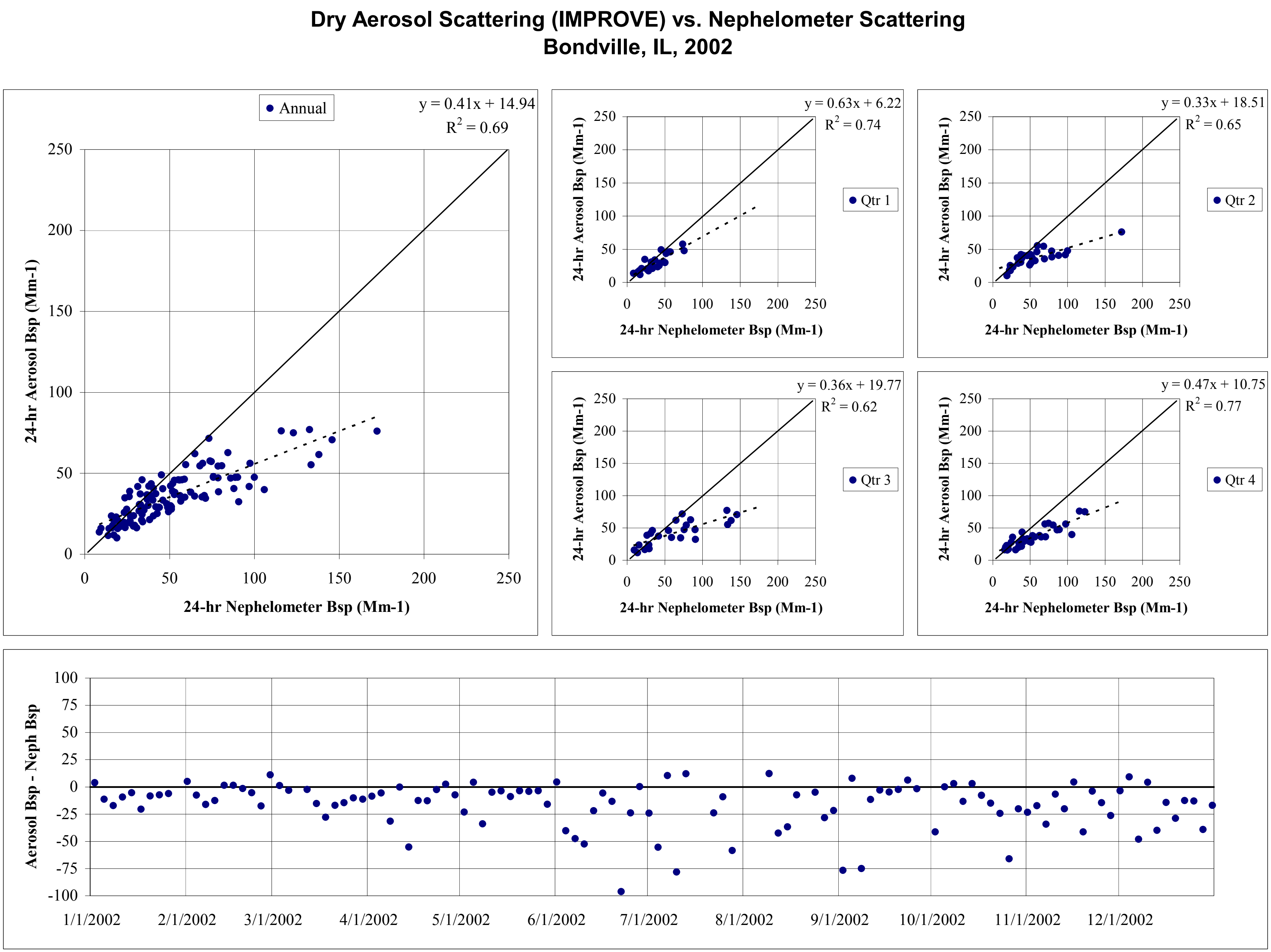


Figure 3-13. Comparison Between Dry Aerosol Scattering (IMPROVE) and Dry Nephelometer Scattering, Bondville, IL, 2002.

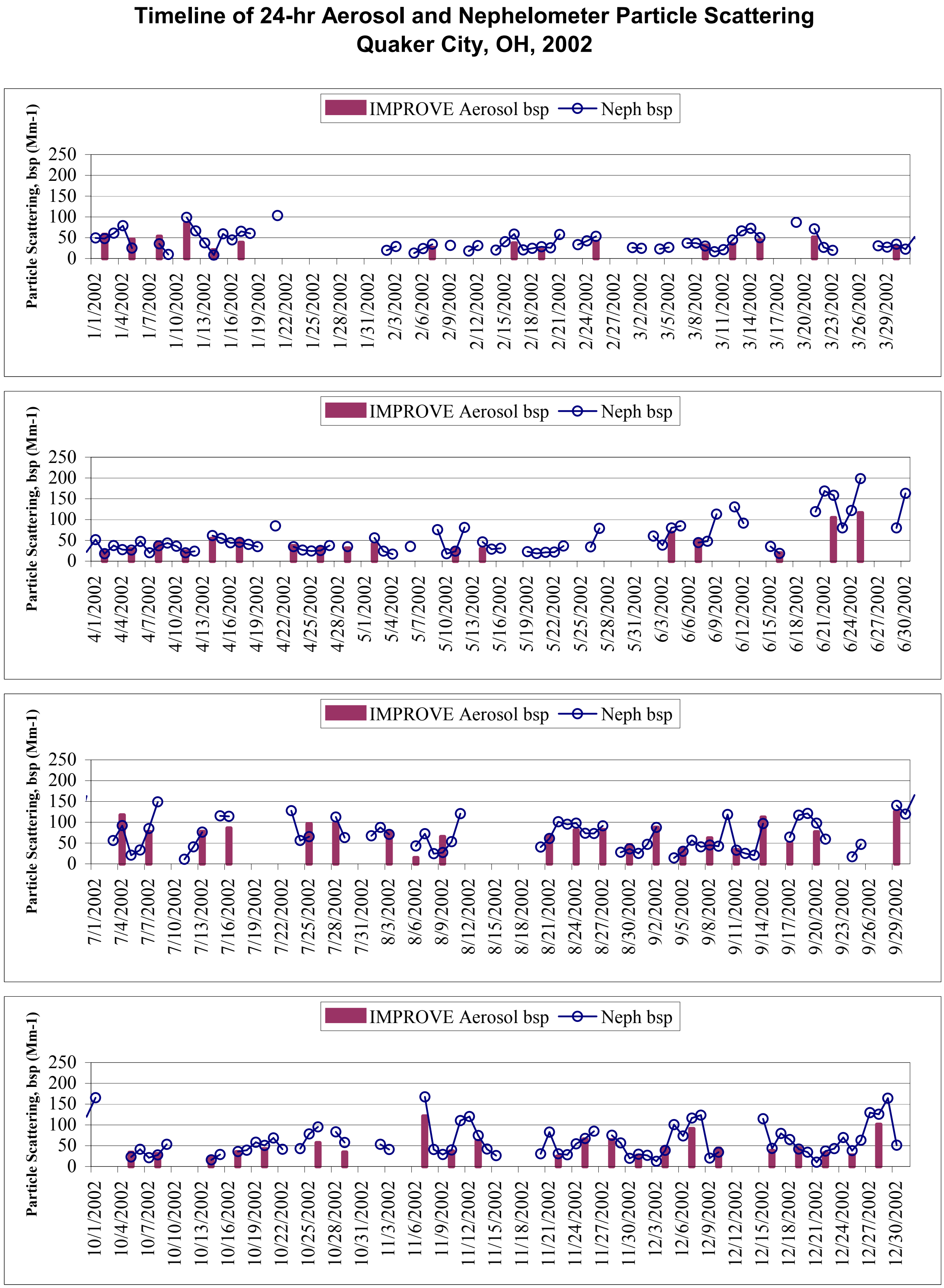


Figure 3-14. Timeline of 24-hr Aerosol (IMPROVE) and Nephelometer Particle Scattering, Quaker City, OH, 2002.

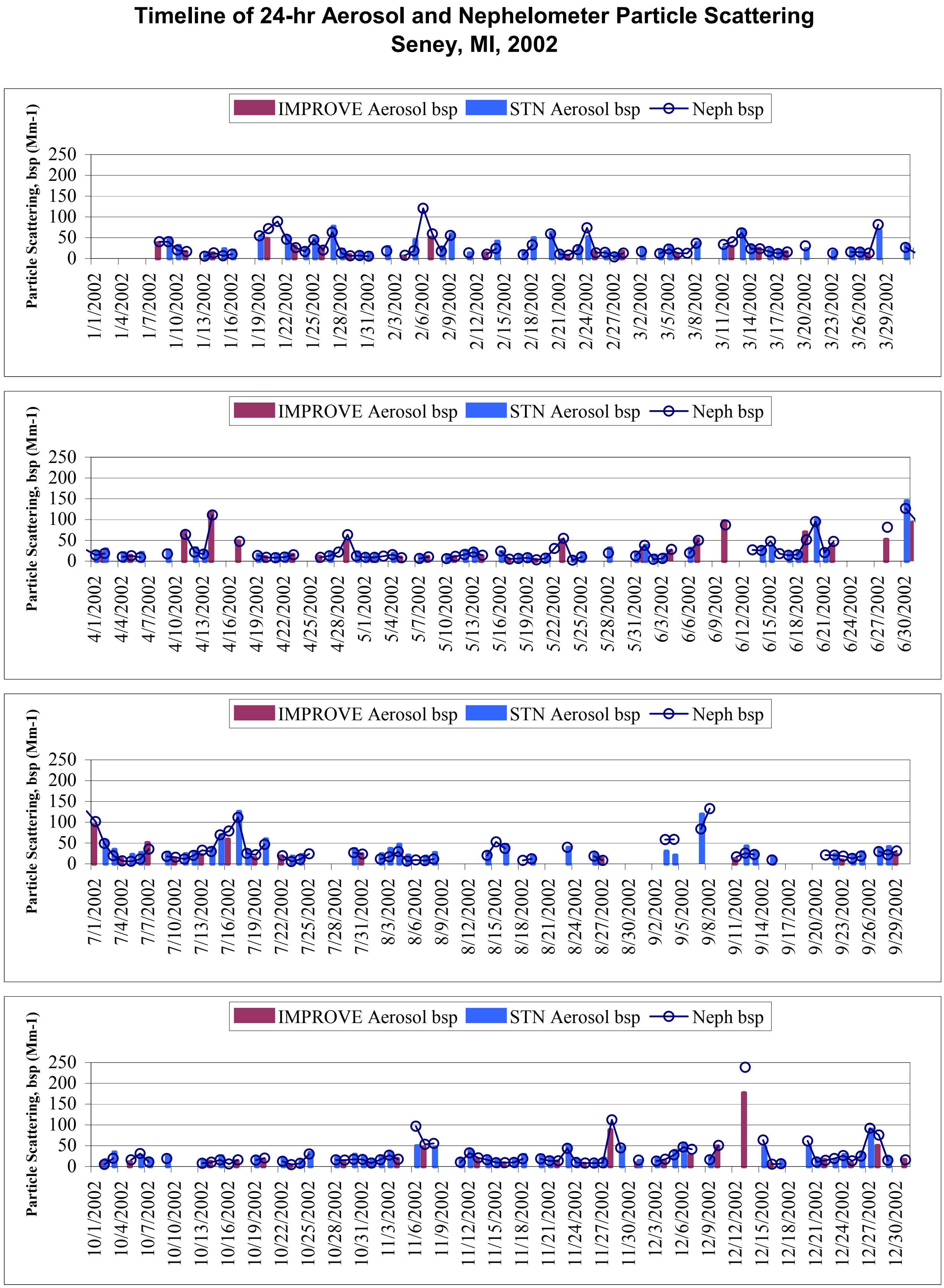


Figure 3-15. Timeline of 24-hr Aerosol (IMPROVE and STN) and Nephelometer Particle Scattering, Seney, MI, 2002.

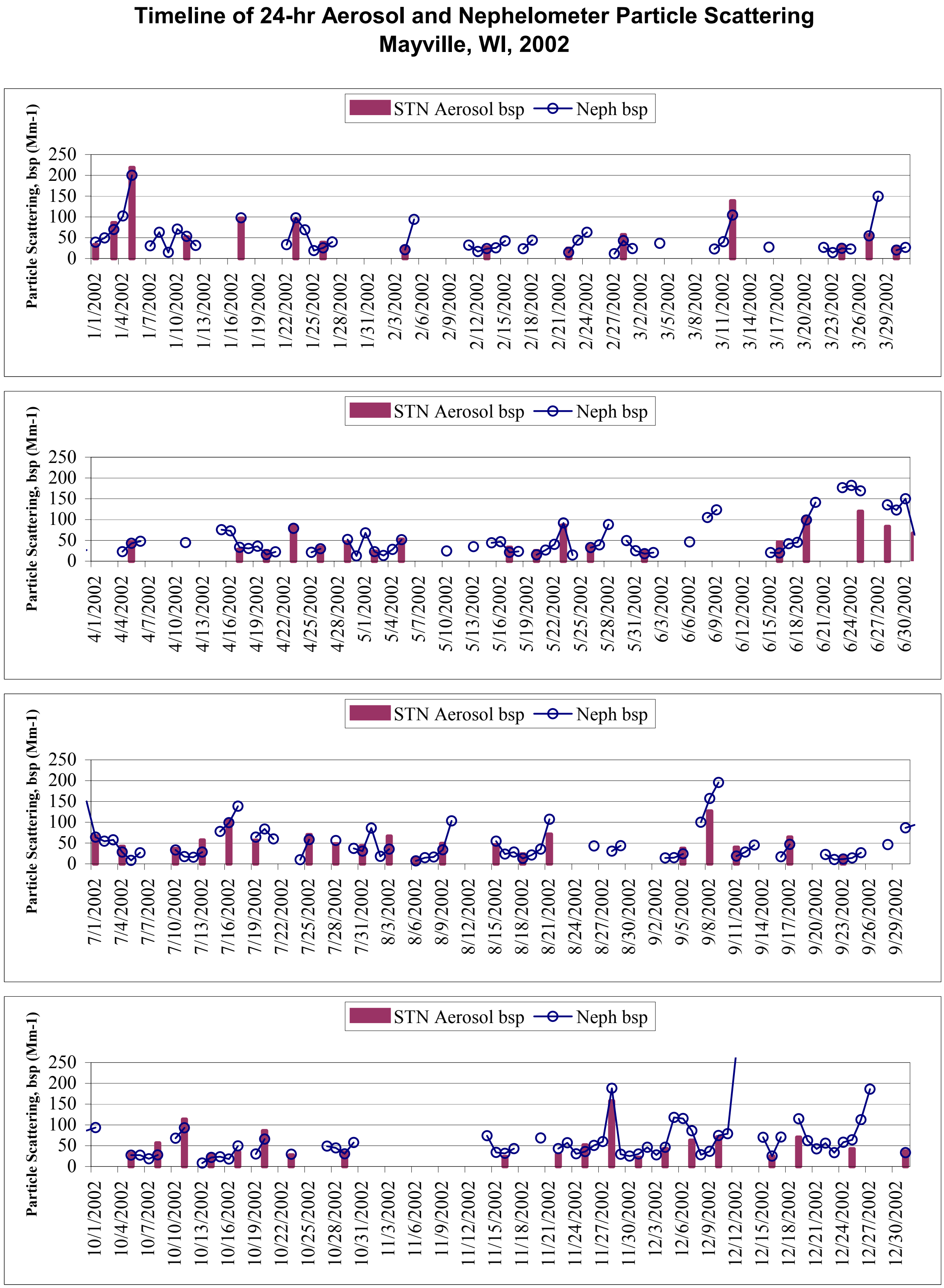


Figure 3-16. Timeline of 24-hr Aerosol (STN) and Nephelometer Particle Scattering, Mayville, WI, 2002.

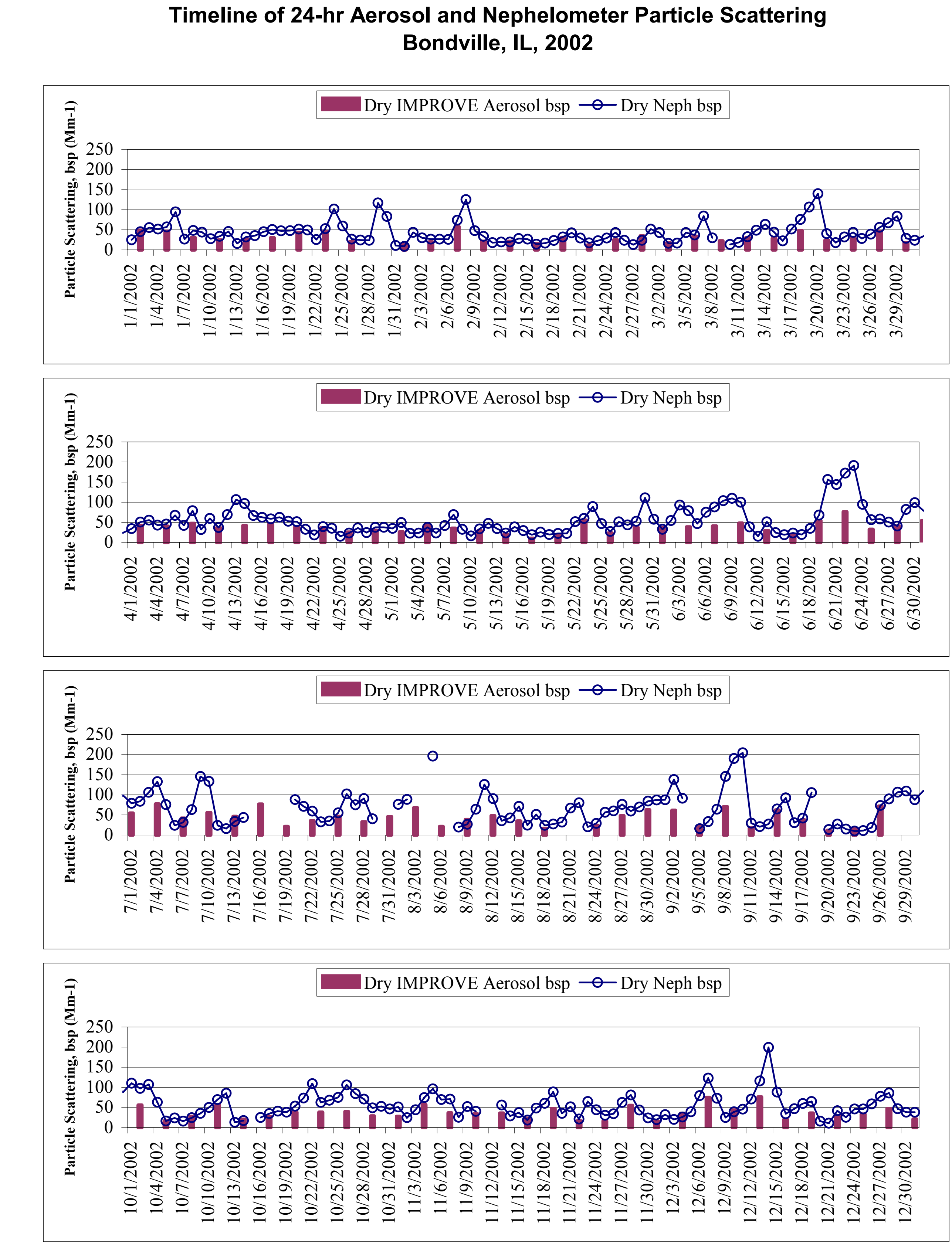


Figure 3-17. Timeline of 24-hr Dry Aerosol (IMPROVE) and Dry Nephelometer Particle Scattering, Bondville, IL, 2002.

3.3.4 Comparison of $PM_{2.5}$ Mass and Nephelometer Scattering

ARS compared nephelometer scattering directly with total $PM_{2.5}$ mass collected with selected instruments at three sites. The $PM_{2.5}$ mass data were compiled from the AIRS database and include data from FRM and TEOM samplers. The relationship between fine mass and scattering is influenced by a number of factors, including:

- The lack of information about each species mass contribution.
- The lack of information about RH effects.
- The lack of information about coarse mass.
- Some $PM_{2.5}$ (elemental carbon) absorbs rather than scatters light.
- Particle loss from volatilization during filter handling (FRM, IMPROVE, STN samplers).
- Particle loss from volatilization during sample heating (TEOM samplers).

Even given these problems, some reasonable correlations exist between total $PM_{2.5}$ and light scattering at LADCO sites.

Figure 3-18 presents three scattering to mass comparisons for Mayville: daily nephelometer scattering and daily FRM, STN, and TEOM $PM_{2.5}$ mass. The comparisons between scattering vs. both FRM and STN mass are similar and well correlated (slope ~6-6.5, R^2 ~0.8). The TEOM mass relationship is poorer and appears to contain more than one population. The fourth graph in the figure shows the relationship between FRM and TEOM mass at this site based roughly on the winter period (Jan, Feb, Nov, Dec), when the instrument was heated to 50°C, and the summer period when it was heated to 30°C. Individually these winter/summer relationships are quite good, but quite different.

Figure 3-19 presents daily and hourly scattering to TEOM mass comparisons for Mayville. The daily summer comparison is most favorable and similar to the FRM and STN mass comparisons. The hourly comparisons are not favorable.

Figure 3-20 presents two scattering to mass comparisons for Seney: daily nephelometer scattering vs. daily STN and TEOM $PM_{2.5}$ mass. The STN comparison is not as good as what was seen at Mayville, although it is reasonably correlated (R^2 ~0.7). The TEOM comparison, while not as dramatic, is similar to what was seen at Mayville. The third graph in the figure shows the relationship between STN and TEOM mass based on the same winter/summer periods described for Mayville. One major difference here is that the Seney TEOM operated at 50°C throughout the year.

Figure 3-21 presents daily and hourly scattering to TEOM mass comparisons for Seney. As was seen at Mayville, the daily comparisons are more favorable than the hourly comparisons. (Note that two periods of Seney TEOM data were invalidated and not included in these graphs. On both occasions, the instrument appeared to have been taken off line for maintenance for the 1200 hour and upon start up yielded values very high in comparison with the days' previous values. It is believed that the mass during these periods, 2/25/02 and 12/24/02, from 1300 through 1900, while reported as valid to AIRS, are likely erroneous.)

Figure 3-22 presents a comparison between daily nephelometer scattering and IMPROVE $PM_{2.5}$ mass at Quaker City. This comparison shows a lower correlation (R^2 ~0.6) than the previous sites between scattering and filter-based mass. This is perhaps due to more variability in the composition of collected mass. No continuous mass instrument operated at this site during 2002, so no comparison between hourly scattering and mass can be made.

Figure 3-23 presents a comparison between daily dry nephelometer scattering and FRM and IMPROVE PM2.5 mass at Bondville. This comparison shows a correlation (R^2 ~0.6) similar to Quaker City between scattering and FRM mass, but somewhat higher (R^2 ~0.7) for IMPROVE mass. There is good agreement between mass measurements from both networks (R^2 = 0.95), with the IMPROVE mass approximately 12% lower than FRM mass. No continuous mass data were analyzed for Bondville for this report.

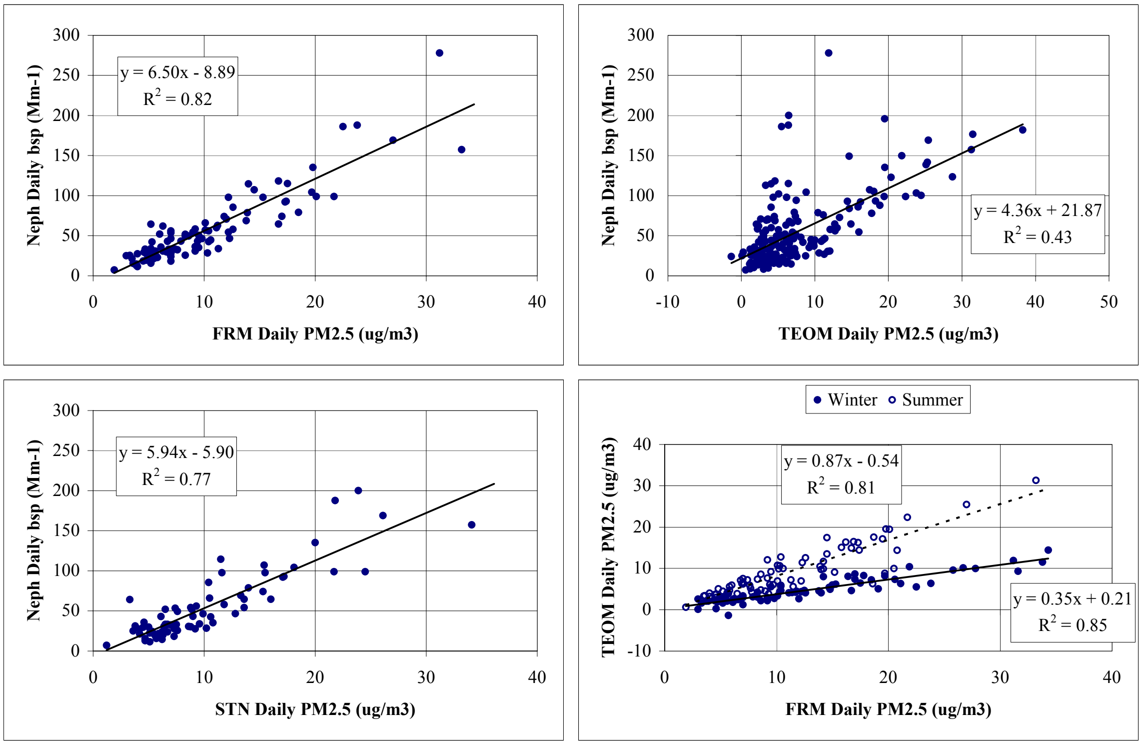


Figure 3-18. Comparisons Between Daily Nephelometer Scattering and Total $PM_{2.5}$ Mass at Mayville, WI.

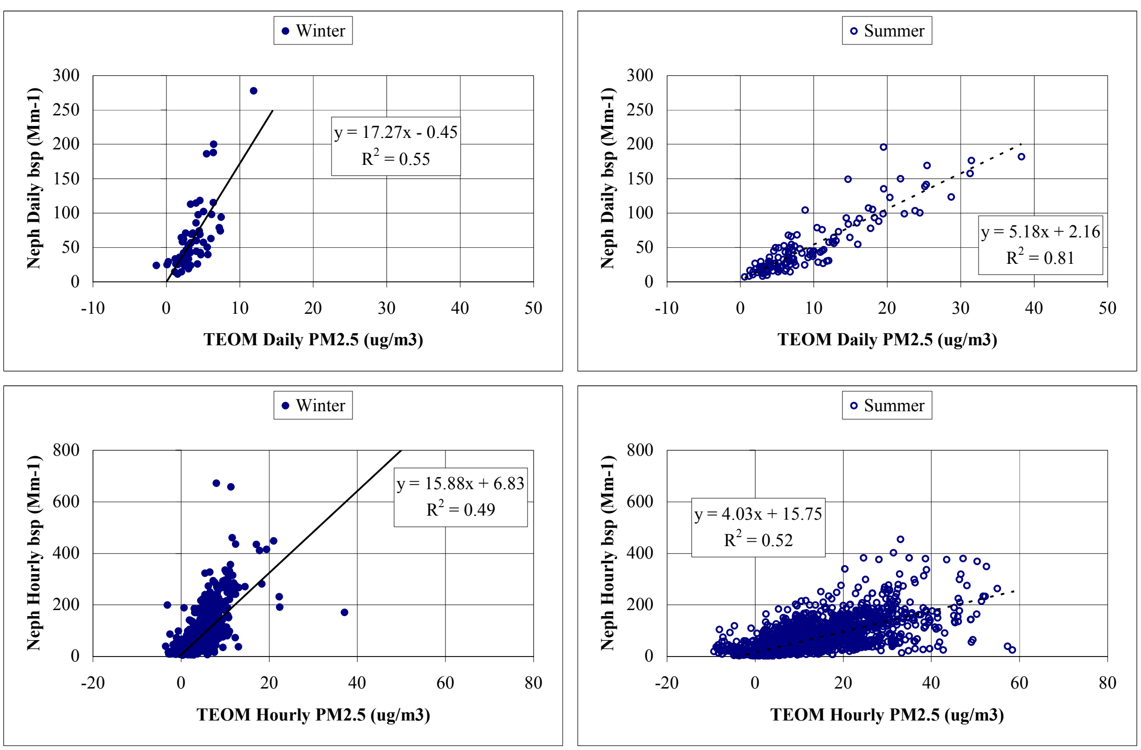


Figure 3-19. Comparisons Between Daily and Hourly Nephelometer Scattering and TEOM $PM_{2.5}$ Mass at Mayville, WI.

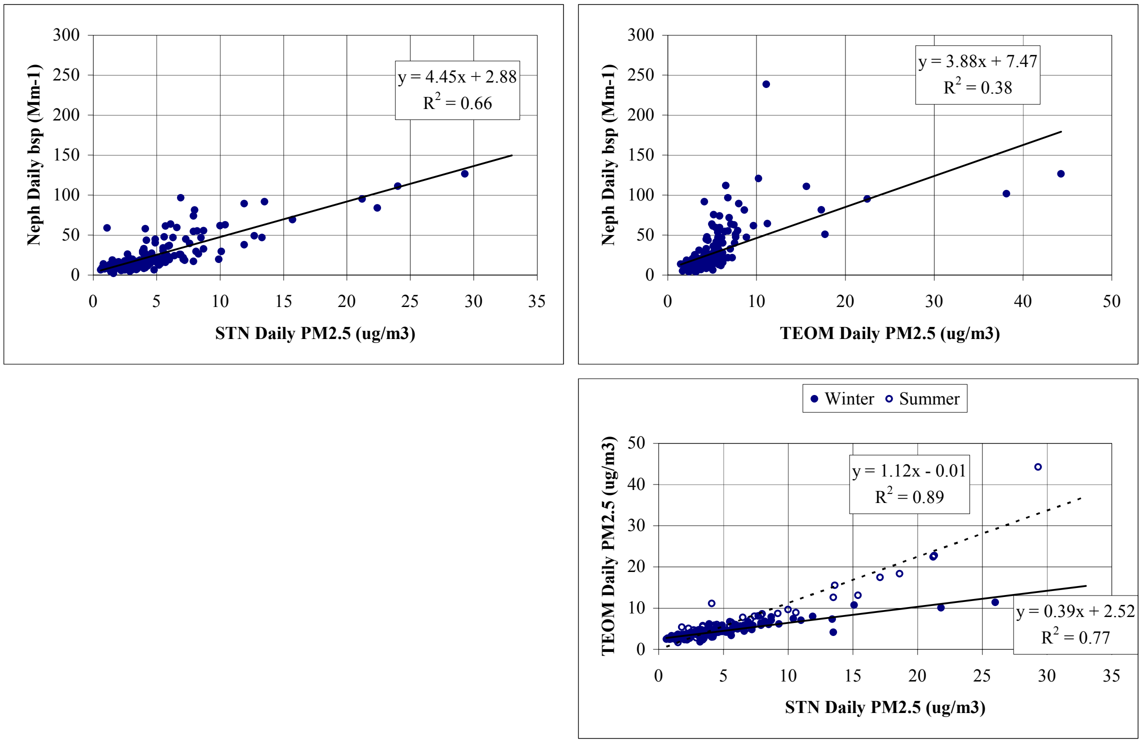


Figure 3-20. Comparisons Between Daily Nephelometer Scattering and Total $PM_{2.5}$ Mass at Seney, MI.

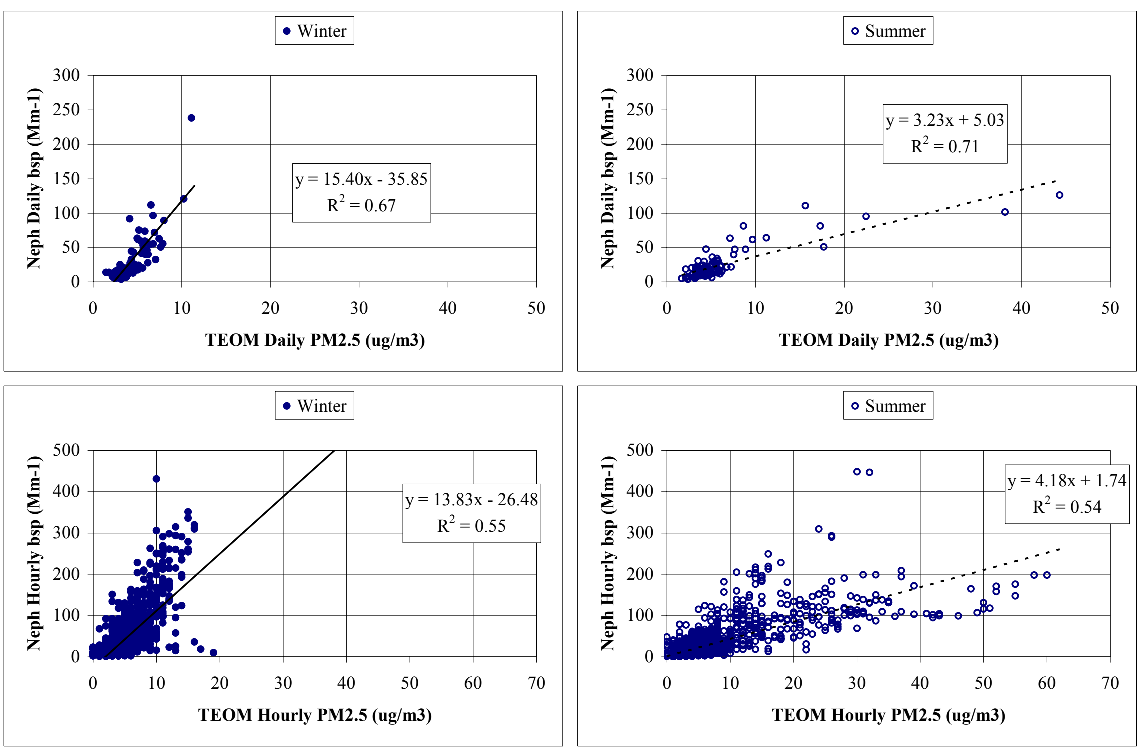


Figure 3-21. Comparisons Between Daily and Hourly Nephelometer Scattering and TEOM $PM_{2.5}$ Mass at Seney, MI.

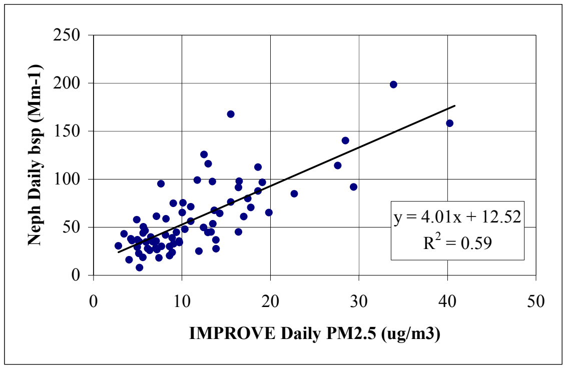


Figure 3-22. Comparison Between Daily Nephelometer Scattering and Total $PM_{2.5}$ Mass at Quaker City, OH.

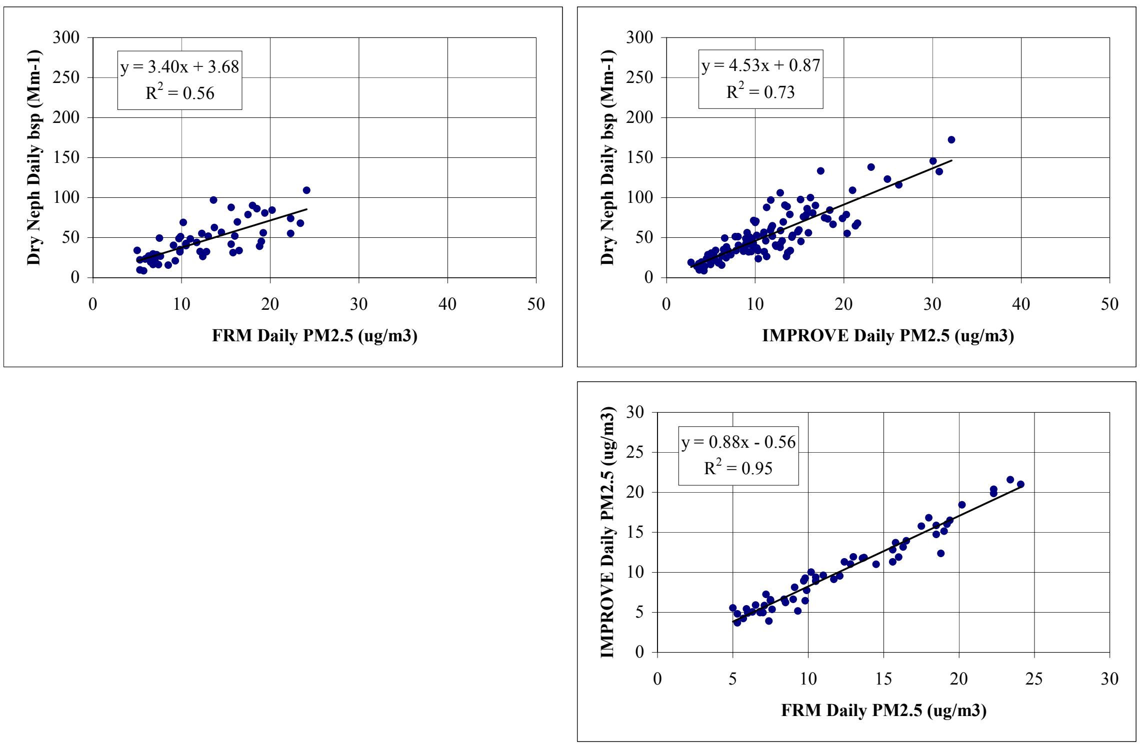


Figure 3-23. Comparisons Between Daily Dry Nephelometer Scattering and Total $PM_{2.5}$ Mass at Bondville, IL.

3.4 METEOROLOGICAL BACK TRAJECTORY ANALYSIS

The National Oceanic and Atmospheric Administration (NOAA) has developed the Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model for particle dispersion and deposition. HYSPLIT can be run to generate forward or backward trajectories using several available meteorological data archives. The data archives used in this analysis were the National Weather Service's National Centers for Environmental Prediction Eta Data Assimilation System (EDAS) Archive. Detailed information regarding the dispersion model and these data sets can be found on NOAA's Web site. Model trajectories were run from a downloadable version of the model software. Additional assistance was provided by Kristi Gebhart of the Cooperative Institute for Research in the Atmosphere (CIRA), in Fort Collins, CO.

HYSPLIT requires user inputs related to physical or analytical assumptions which affect the model output. The adopted set of parameters for back trajectories included a duration of 72 hours (3 days), actual vertical motion measurements, 100m end height, and 1200 EST end time. Model runs which were less than 60 hours in length, either due to missing meteorological data or due to trajectories leaving the model domain were not accepted. For Seney and Mayville, this threshold was lowered to 48 hours because of these sites' proximity to the northern boundary of the EDAS domain. Many back-trajectories for the 20% lowest extinction days crossed the northern domain boundary in less than 60 hours.

ARS generated back trajectories for the 20% highest and 20% lowest aerosol extinction days (using monthly f(RH) values) for all four LADCO sites. Due in large part to the inexact nature of back trajectories, the analysis performed for this report focused on general patterns of large sets of trajectories. The exact starting point of each trajectory cannot be known with a high degree of confidence when relying strictly on the HYSPLIT model.

Figures 3-24 through 3-28 present pairs of trajectory maps for each site for 2002. Note that each trajectory is made up of hourly dots, and is tagged with its associated sample (or end) date. Closely spaced dots indicate slow moving air parcels, widely spaced dots indicate fast moving air parcels. Since these are back trajectories, air movement is from the date tag toward the monitoring site. Often high extinction day trajectories are slow moving and originate within or close to the LADCO states. By contrast, low extinction day trajectories are often much faster moving and often originate well outside of the LADCO region.

To summarize these back trajectories, ARS tallied the number of valid trajectory origins in 4 zones, illustrated in Figure 3-29. The zones were defined as:

1. The LADCO zone, containing the LADCO states plus a buffer of approximately 100 miles. The buffer zone is not a constant width around the LADCO states, but allows for a practical boundary.
2. The Eastern zone, encompassing the remaining states east of the Mississippi and the most heavily populated portion of eastern Canada.
3. The Western zone, encompassing the remaining states west of the Mississippi and northern Mexico.
4. The Northern zone, encompassing the remainder of Canada.

Table 3-6 summarizes the range of extinction and zones of origin of the trajectories. The results from this analysis must be viewed in terms of general patterns or trends rather than specific numerical values. It is also important to note that a trajectory originating in an area believed to have relatively clean air (e.g., northern Canada) may pass through an area containing high levels of pollution prior to arriving at a particular monitoring site.

Low extinction day trajectories often originate outside the LADCO zone, especially from the Northern zone, and are often faster moving than the high extinction day trajectories. High extinction day trajectories often originate within the LADCO zone, and are often slower moving than the low extinction day trajectories, indicating more stagnant meteorological conditions in the region. The site-specific percentages are significantly influenced by geography, as well as local and regional air quality.

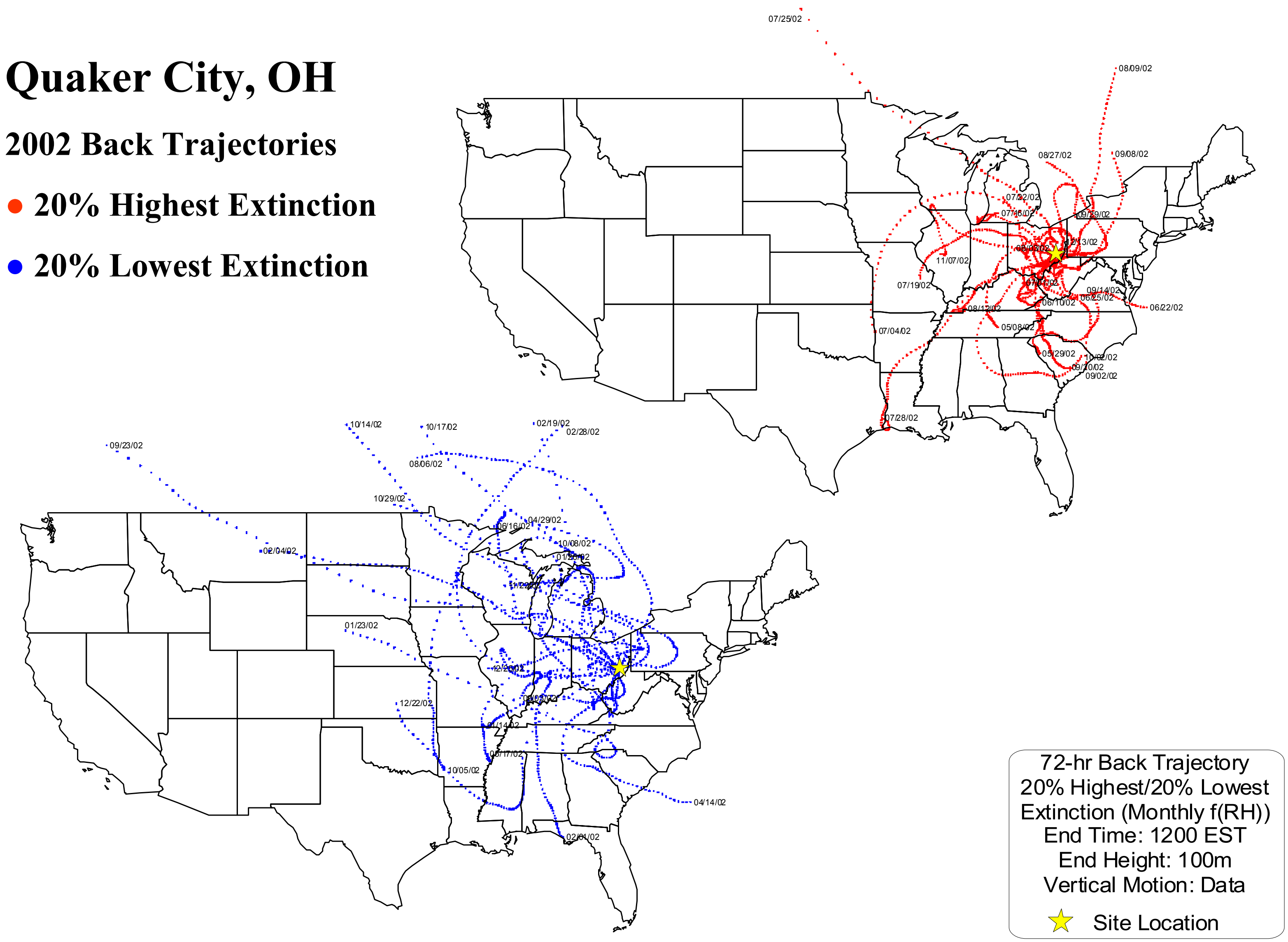


Figure 3-24. Back Trajectories for the 20% Highest and 20% Lowest Extinction Days at Quaker City, OH, for 2002.

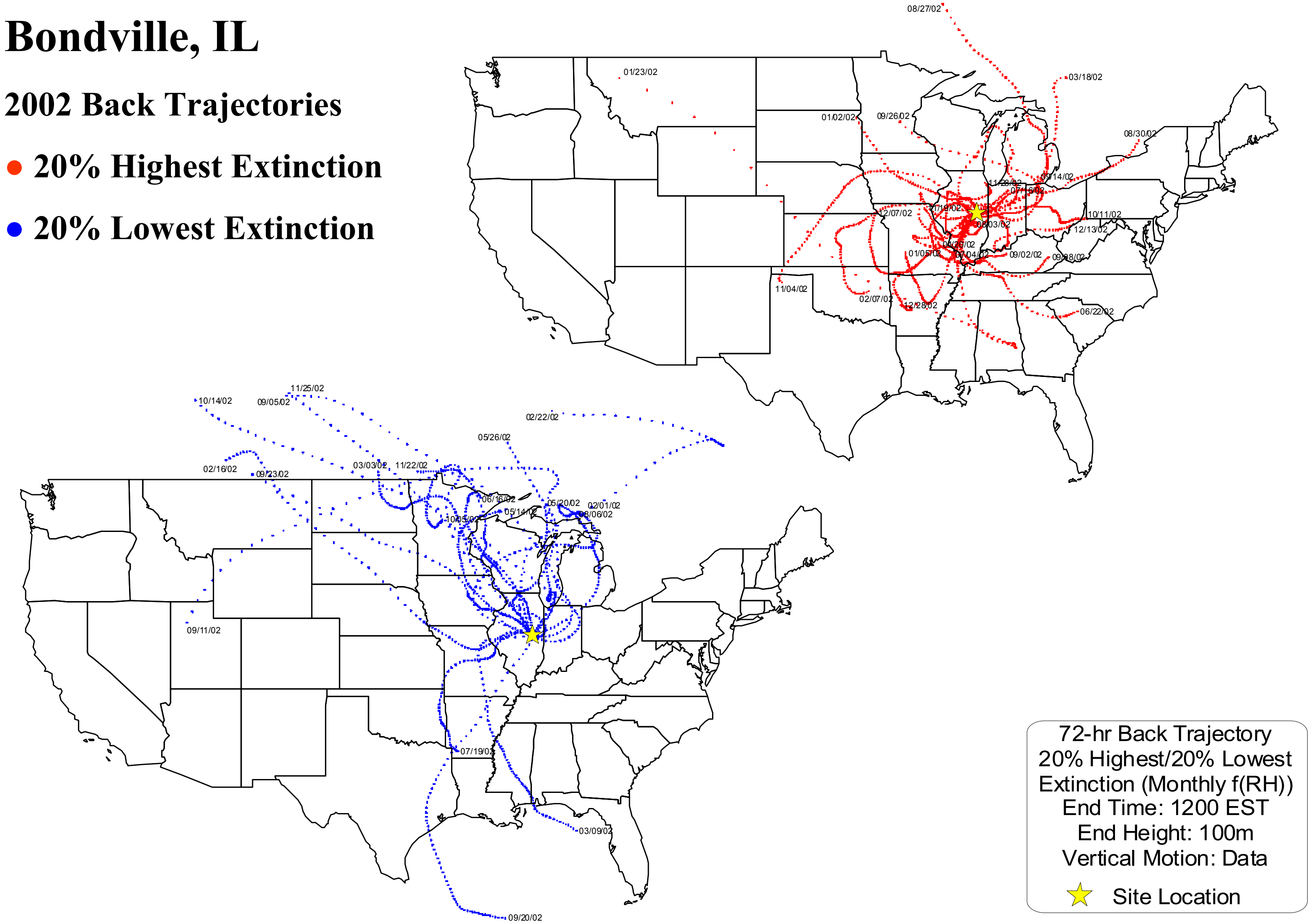


Figure 3-25. Back Trajectories for the 20% Highest and 20% Lowest Extinction Days at Bondville, IL, for 2002.

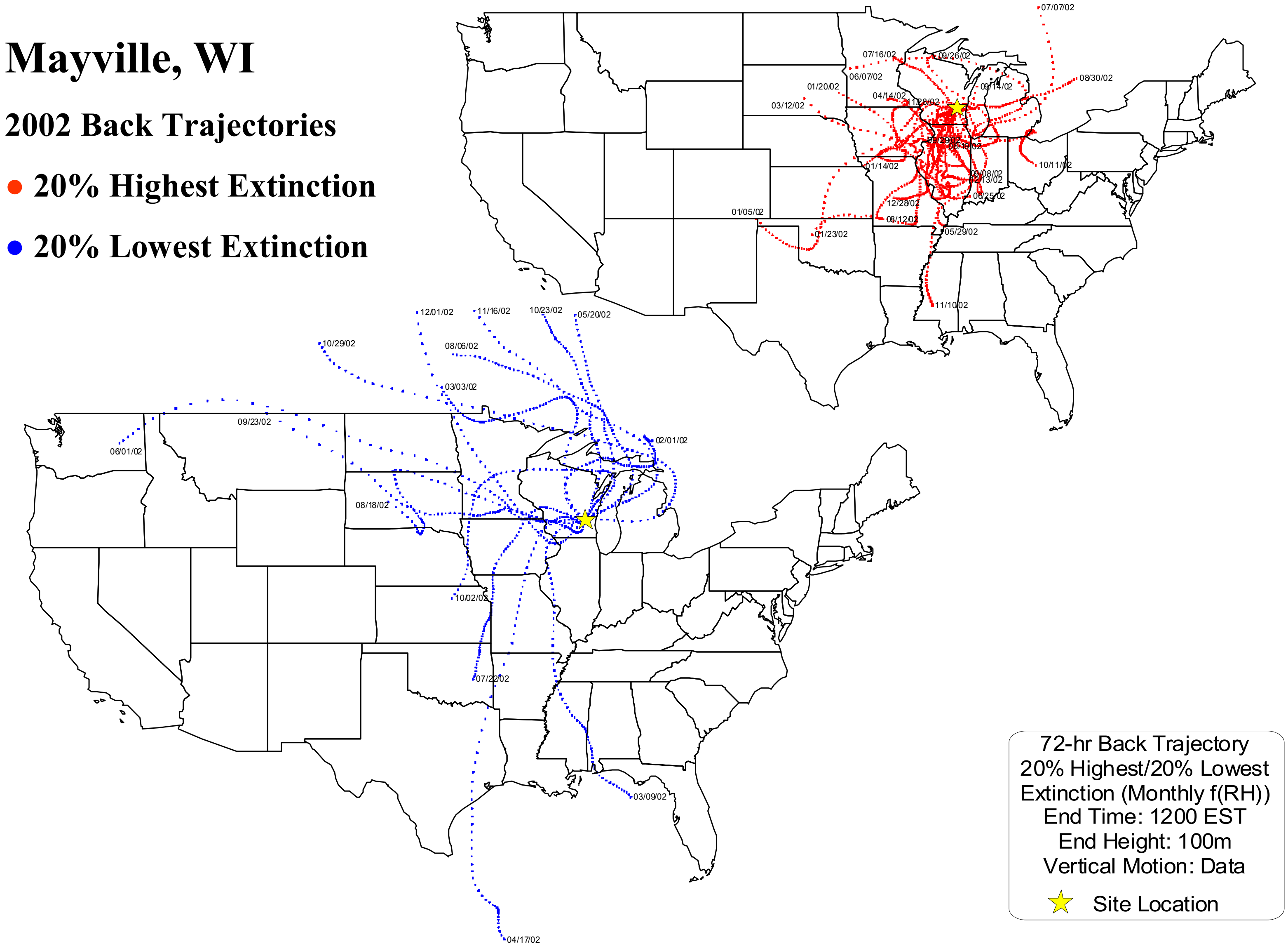


Figure 3-26. Back Trajectories for the 20% Highest and 20% Lowest Extinction Days at Mayville, WI, for 2002.

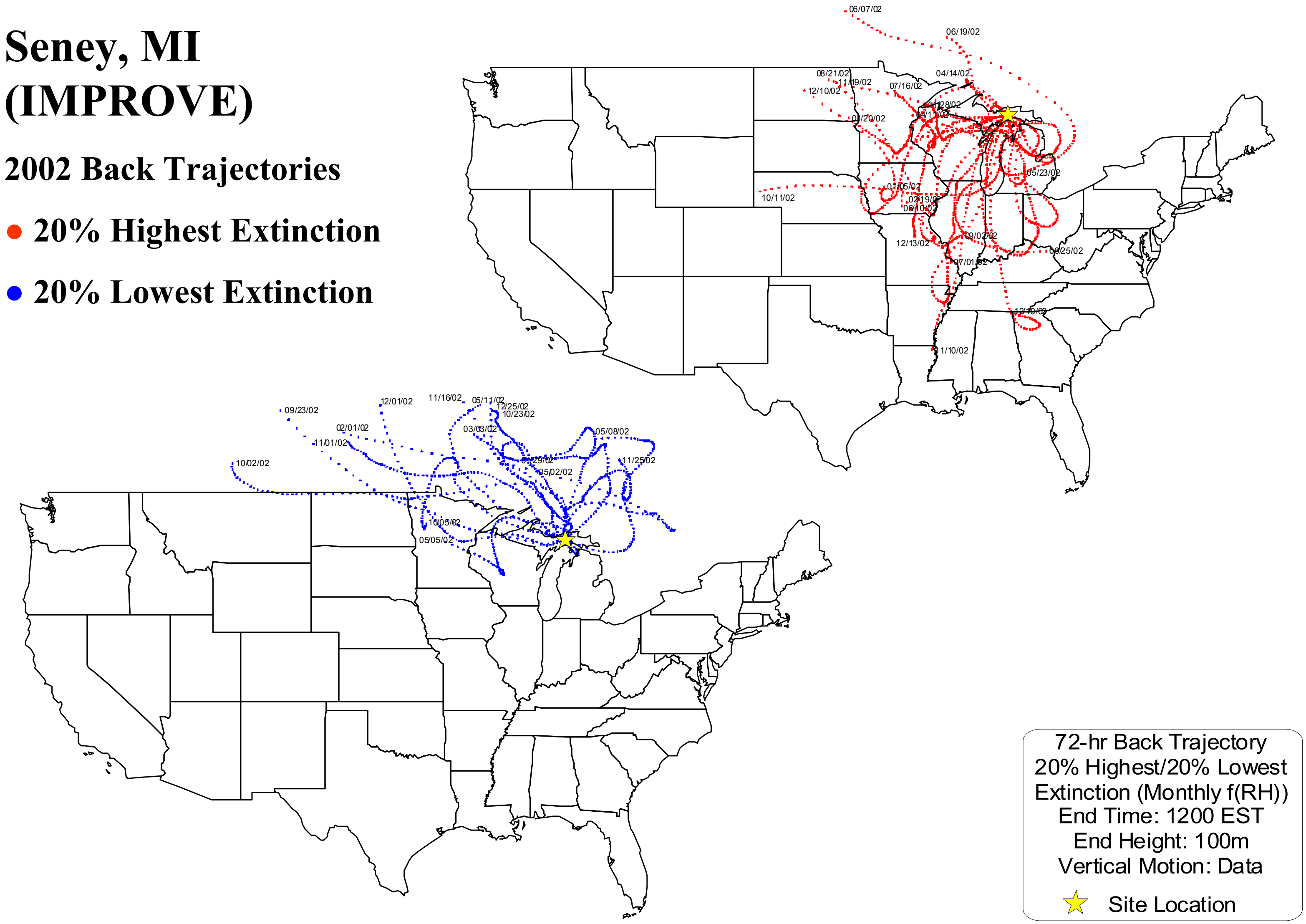


Figure 3-27. Back Trajectories for the 20% Highest and 20% Lowest (IMPROVE) Extinction Days at Seney, MI, for 2002.

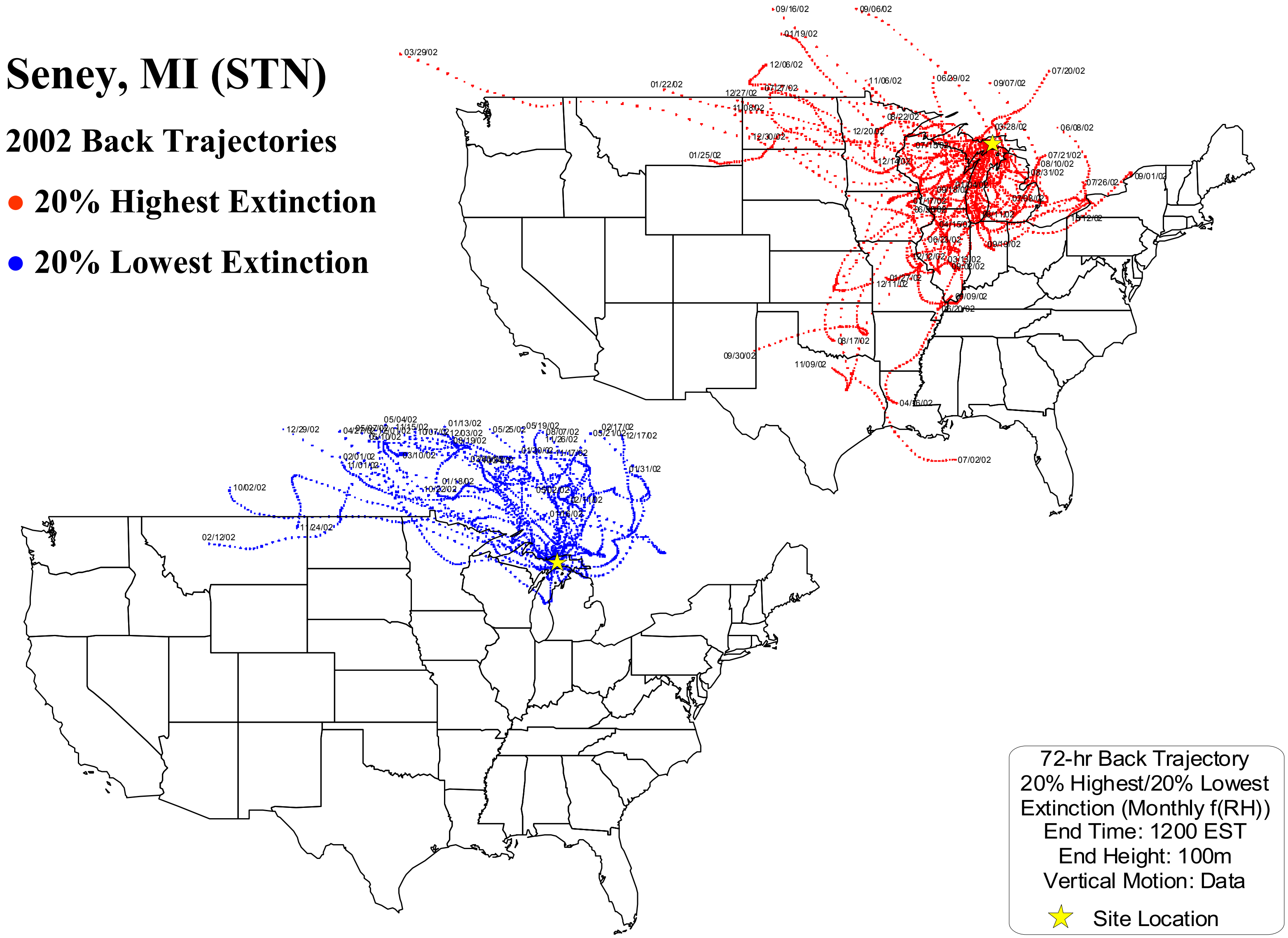


Figure 3-28. Back Trajectories for the 20% Highest and 20% Lowest (STN) Extinction Days at Seney, MI, for 2002.

Back Trajectory Start Zones

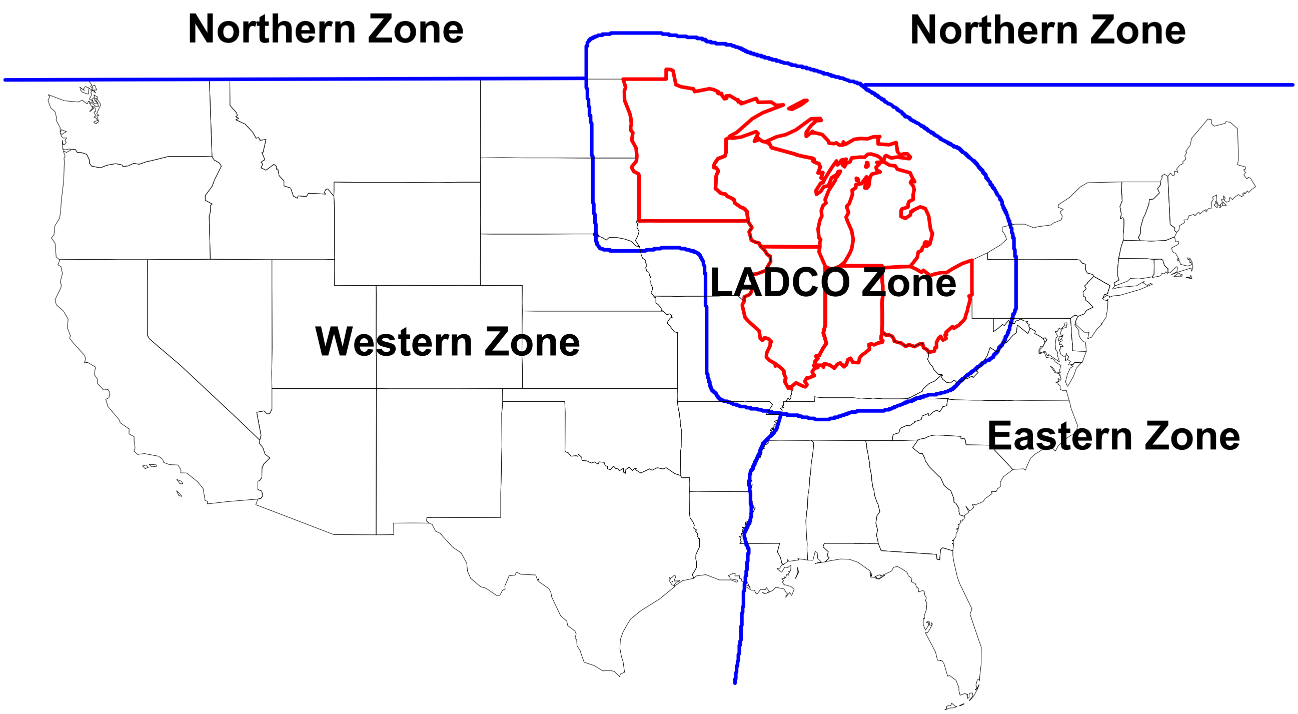


Figure 3-29. Definition of Zones for Back Trajectory Analysis.

Table 3-6

Summary of 72-hr Back Trajectory Patterns
Based on 20% Highest and 20% Lowest Extinction Days
2002

Site	Based on 20% Lowest Extinction Days					Based on 20% Highest Extinction Days				
	Range of Extinction	LADCO Zone	Eastern Zone	Western Zone	Northern Zone	Range of Extinction	LADCO Zone	Eastern Zone	Western Zone	Northern Zone
Mayville	26 - 53	13	7	**40**	**40**	138 - 305	**61**	9	26	4
Bondville	32 - 64	**37**	11	11	**42**	140 - 267	**57**	13	26	4
Quaker City	35 - 58	**41**	9	23	27	140 - 293	**42**	**42**	8	8
Seney	15 - 25	13	0	0	***87***	81 - 206	***67***	5	19	10
Seney (STN)	23 - 36	6	0	6	***88***	82 - 300	**50**	8	21	21

KEY

67% - 100%
34% - 66%
0% - 33%

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