Comparison of Particle Light Scattering and Fine Particulate Matter Mass in Central California

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ABSTRACT
Particle light scattering (Bsp) from nephelometers and fine particulate matter (PM$_{2.5}$) mass determined by filter samplers are compared for summer and winter at 35 locations in and around California’s San Joaquin Valley from December 2, 1999 to February 3, 2001. The relationship is described using particle mass scattering efficiency ($\sigma_{sp}$) derived from linear regression of Bsp on PM$_{2.5}$ that can be applied to estimated PM$_{2.5}$ from nephelometer data within the 24-hr filter sampling periods and between the every-6th-day sampling frequency. An average of $\sigma_{sp} = 4.9 \text{ m}^2 / \text{g}$ was found for all of the sites and seasons; however, $\sigma_{sp}$ averaged by site type and season provided better PM$_{2.5}$ estimates. On average, the $\sigma_{sp}$ was lower in summer than winter, consistent with lower relative humidities, lower fractions of hygroscopic ammonium nitrate, and higher contributions from fugitive dust. Winter average $\sigma_{sp}$ were similar at non-source-dominated sites, ranging from 4.8 m$^2$/g to 5.9 m$^2$/g. The $\sigma_{sp}$ was 2.3 m$^2$/g at the roadside, 3.7 m$^2$/g at a dairy farm, and 4.1 m$^2$/g in the Kern County oilfields. Comparison of Bsp from nephelometers with and without a PM$_{2.5}$ inlet at the Fresno Super-site showed that coarse particles contributed minor amounts to light scattering. This was confirmed by poorer correlations between Bsp and coarse particulate matter measured during a fall sampling period.

INTRODUCTION
Nephelometers$^{1-3}$ quantify the light scattered by particles by drawing them into an enclosed chamber, shining a bright light through the particle cloud, and measuring the amount of light scattered from its original direction. This particle light scattering (Bsp, in units of inverse megameters [Mm$^{-1}$]) is often correlated with mass concentrations of suspended particulate matter (PM, in units of $\mu$g/m$^3$). Using the relationship $B_{sp} = \sigma_{sp} \times PM$, where $\sigma_{sp}$ is the particle mass scattering efficiency (m$^2$/g), several researchers have derived empirical relationships between Bsp and PM that enable one to be estimated by measuring the other.$^{4-12}$ The value of $\sigma_{sp}$ varies with particle size distribution, particle composition, and relative humidity (RH).$^{13}$ so it must be derived for different seasons, monitoring locations, and even for different samples. In addition, $\sigma_{sp}$ is most consistent and physically meaningful when it is applied to the fine particulate matter (PM$_{2.5}$) size fraction under dry conditions. Most PM$_{2.5}$ particles have diameters comparable to the wavelength ($\lambda$) of the incident light, resulting in high $\sigma_{sp}$. Particles larger than 2.5 $\mu$m tend to scatter light less uniformly than smaller particles, and for most nephelometers a portion of the forward-scattered signal is truncated.$^{14-21}$ For these reasons, nephelometer Bsp is most accurately used as a surrogate for PM$_{2.5}$ mass concentrations, rather than for larger size fractions.

Nephelometers were deployed along with 24-hr PM$_{2.5}$ filter samplers during the California Regional PM$_{10}$/PM$_{2.5}$ Air Quality Study (CRPAQS) to (1) determine $\sigma_{sp}$ and its variability with location and season; (2) understand how PM$_{2.5}$ changes during the 24-hr filter sampling period; (3) evaluate PM$_{2.5}$ levels on days between the every-6th-day filter sampling frequency at most sites; and (4) estimate PM$_{2.5}$ levels at sites that did not have collocated PM$_{2.5}$ filter measurements. The combination of inexpensive nephelometers$^{24-25}$ and filter samplers$^{26}$ that can be located on rooftops and power poles provides the possibility of obtaining large amounts of spatial and temporal information at minimal cost. The methods illustrated here can be applied in a wide variety of locations.

In this study, relationships between Bsp and PM$_{2.5}$ mass are derived for 35 monitoring sites in central California. A predictability function is developed that can be used to estimate PM$_{2.5}$ mass from Bsp. Differences caused by site type, sampling location, sampling period, and ambient PM$_{2.5}$ levels are examined to determine when and where Bsp can be used as a surrogate for PM$_{2.5}$ mass.

IMPLICATIONS
Relatively inexpensive and portable nephelometers and PM$_{2.5}$ samplers can be used to deploy a large spatial air-monitoring network. Relationships between Bsp and PM$_{2.5}$ can be reliably established, but these differ by site type and sampling period. Nephelometers should not be used in the absence of some collocated PM$_{2.5}$ filter sampling at the same or similar measurement sites.
Fine particle light scattering ($B_{sp}$) measured with PM$_{2.5}$ size-selective inlets is compared with total $B_{sp}$ to evaluate the contribution from coarse particle scattering. Different nephelometers and filter sampling methods for $B_{sp}$ and PM$_{2.5}$ mass are also compared.

**METHODS**

At the CRPAQS sites shown in Figure 1, Radiance Research (Seattle, WA) M903 nephelometers ($\lambda = 530$ nm) were collocated with Desert Research Institute (DRI; Reno, NV) PM$_{2.5}$ sequential filter samplers (SFS) at five anchor sites (Bethel Island [BTI], Sierra Nevada Foothills [SNFH], Fresno Supersite$^{27}$ [FSF], Angiola [ANGI], and Bakersfield [BAC]). These were also collocated with Airmetrics (Eugene, OR) battery-powered PM$_{2.5}$ MiniVol filter samplers at 30 satellite sites (Table 1). Most sites were located within California’s San Joaquin Valley (SJV) except for the Bodega Bay (BODG), San Francisco (SFA), Olanchar (OLW), China Lake (CHL), Tehachapi Pass (TEH2), and Edwards (EDW) sites. Table 1 summarizes locations (longitude, latitude), elevations, filter sampler types, site classifications and characterizations, and sampling periods.

Air was drawn into the nephelometer through an annular inlet (capped inlet tube with a 0.5-cm annulus) with a smart heater. The smart heater consists of a tube wrapped with heating tape that only applies heat when the RH at the outlet exceeds 72%. This heating reduces the enhancement of $B_{sp}$ caused by water uptake of hygroscopic particles under high RH, while minimizing the evaporation of volatile material such as secondary ammonium nitrate ($\text{NH}_4\text{NO}_3$)$^{23,24}$.

The 24-hr (midnight-to-midnight) filter samples were collected every 6th day over a 14-month period (December 2, 1999, to February 3, 2001). The 24-hr SFS samples were taken at the FSF, ANGI, and BAC sites, starting on December 2, 1999, and at the BTI and SNFH sites, starting on December 2, 2000. Winter intensive operating periods (December 15, 2000 to February 3, 2001) included 5-times-per-day sampling for 15 days at the five anchor sites and 24-hr samples for 13 days at 25 satellite sites. The $B_{sp}$ data were averaged over the 24-hr sampling periods for comparison.

At FSF, Radiance nephelometers with and without a PM$_{2.5}$ size-selective inlet were collocated to determine the extent to which coarse particles affect $B_{sp}$. An Optec NGN-2 ambient temperature low-truncation nephelometer (Lowell, MI, $\lambda = 550$ nm) measured total $B_{sp}$, including the portion caused by hygroscopicity and coarse particles. Non-integrating nephelometers included the TSI DustTrak (DT8520; Shoreview, MN, $\lambda = 780$ nm) and the GreenTek photometer (GT640A; Atlanta, GA, $\lambda = 780$ nm). These measure forward scattering at longer wavelengths and are more sensitive to coarse particles than integrating nephelometers that measure side-scatter at shorter wavelengths. Although the DustTrak and GreenTek units measure light scattering, they internally apply a $\sigma_{sp}$ and give mass per unit volume outputs. Hourly average PM$_{2.5}$ and PM$_{10}$ were measured at FSF with Met One (Grants Pass, OR) beta attenuation monitors (BAMs) without water vapor denuders and Rupprecht & Patashnick (Albany, NY) tapered element oscillating microbalances (TEOMs) operated at 50 °C. Also at FSF, PM$_{2.5}$ filter samples were taken with SFS, MiniVol, and Federal Reference Method (FRM; RAAS 100; Anderson Instruments, Smyrna, GA) samplers.

Nonweighted least-squares regression of $B_{sp}$ on PM$_{2.5}$ mass was used to estimate $\sigma_{sp}$ as the regression slope. A multiple linear regression was conducted when $B_{sp}$, PM$_{2.5}$, and PM$_{10} - $PM$_{2.5}$ mass were available.

Figure 1. CRPAQS monitoring sites (5 anchor sites [ ] and 30 satellite sites [*]) with collocated Radiance Research M903 nephelometer and PM$_{2.5}$ filter samplers (Map not to scale).
RESULTS AND DISCUSSION

Spatial Variability of Light Scattering, PM$_{2.5}$ Mass, and Scattering Efficiencies

Comparisons of daily average $B_{sp}$ and PM$_{2.5}$ mass grouped by site characteristics and season (winter and summer) are summarized in Table 2. As shown in Figure 2a, the 24-hr winter average $B_{sp}$ varied by a factor of 21, from 14 Mm$^{-1}$ at the OLW site to 299–303 Mm$^{-1}$ at the Bakersfield residential (BRES), Edison (EDI), and Visalia (VCS) sites. The 24-hr winter average PM$_{2.5}$ mass varied by a factor of 46, from 1.3 $\mu$g/m$^3$ at the CHL site to 60.5 $\mu$g/m$^3$ at the Frem-3425 First Street (FRES) site. Winter average PM$_{2.5}$ concentrations at urban sites (e.g., BRES, 53.9 $\mu$g/m$^3$; FRES, 57.4 $\mu$g/m$^3$; FREM, 60.5 $\mu$g/m$^3$) were twice the wintertime all-site average (28.9 $\mu$g/m$^3$). The lowest $B_{sp}$ and PM$_{2.5}$ averages occurred at OLW (14 Mm$^{-1}$, 3.3 $\mu$g/m$^3$), CHL (15 Mm$^{-1}$, 1.3 $\mu$g/m$^3$), and EDW (26 Mm$^{-1}$, 5.4 $\mu$g/m$^3$); these were desert sites outside of the SJV.

The spatial variability of $\alpha_{sp}$ for the winter sampling period is shown in Figure 3. The desert sites, OLW, CHL,
and EDW, yielded low \( \sigma_{SP} \) of 0.1, 0.1, and 1.8 m²/g, respectively. The OLW and CHL values are not accurate owing to the higher measurement uncertainties at the low concentration levels. According to the site characteristics shown in Table 2, average wintertime \( \sigma_{SP} \) are 4.8 m²/g for background sites, 5.2 m²/g for interbasin transport sites, 5.6 m²/g for community exposure sites, and 5.9 m²/g for intrabasin gradient sites. With the exception of \( \sigma_{SP} \) at residential sites (5.1 m²/g) where home heating is believed to be a nearby source, lower \( \sigma_{SP} \) were determined at sites near sources, including motor vehicle (2.3 m²/g), dairy farm (3.7 m²/g), and oilfield (4.1 m²/g). Most of the values are higher than the Interagency Monitoring of Protected Visual Environments (IMPROVE) dry chemical scattering efficiencies, indicating that the samples retain some liquid water, probably associated with \( \text{NH}_4\text{NO}_3 \), ammonium sulfate \( [\text{NH}_4\text{SO}_4] \), and possibly with some of the organic material. The RH set point
on the nephelometer smart heater should probably have been set at a level lower than 72% to remove more of the particle liquid water. Different amounts of liquid water probably cause some of the scatter observed in the Bsp/PM2.5 comparisons.

Seasonal Differences for Light Scattering, PM2.5 Mass, and Scattering Efficiencies

Particle compositions and size distributions in the SJV have a distinct seasonal pattern. Chow et al. showed that PM10–2.5 dominates high PM10 levels during summer in the SJV, whereas PM2.5 constitutes most of the high PM10 concentrations during winter. During winter, shallow surface layers form under cold conditions and enhance the accumulation of carbon particles from fresh emissions and secondary NH₄NO₃. Coarse particles in the SJV are suppressed by periodic precipitation and fog. During CRPAQS, elevated PM2.5 concentrations in winter accounted for more than 50% of the annual PM2.5 level inside the SJV. That contribution was more pronounced in urban areas where fresh carbon emissions from vehicle exhaust and home heating can accumulate.

Figures 2a and 2b also show that average Bsp and PM2.5 mass were higher during winter than summer. In summer, the dairy farm (FEDL) site had the highest PM2.5 (27.9 µg/m³). Elevated PM2.5 levels at the FEDL site were also found during winter (38.6 µg/m³) and occurred throughout the year. These high levels were not reflected at nearby monitors, indicating that the zone of influence for this source was small.

Figure 2. Average Bsp and PM2.5 mass concentration at CRPAQS sites in (a) winter (February 2000, December 2000, and January 2001) and (b) summer (June 2000 to August 2000). See Table 1 for site codes.
Winter and summer $\sigma_{sp}$ as a function of PM$_{2.5}$ mass is shown in Figure 4. The average $\sigma_{sp}$ was 2.6 m$^2$/g in summer and 4.6 m$^2$/g in winter, consistent with differences in particle composition, particle size, and RH that affect $\sigma_{sp}$. Suspended dust events are more common during summer, owing to drier conditions and more agricultural activity. Higher summertime $\sigma_{sp}$ at the OLW and CHL sites is influenced by the outflow of PM$_{2.5}$ from the SJV and from the South Coast Air Basin that provides a larger fraction of PM$_{2.5}$ than during winter, when such outflow is suppressed.\(^{35,36}\)

Daily average $\sigma_{sp}$ and PM$_{2.5}$ at the regional-scale ANGI and urban-scale BAC sites in winter and summer are shown in Figures 5a and 5b, respectively. Both sites display a similar seasonal dependence of $\sigma_{sp}$ on PM$_{2.5}$ (i.e., higher scattering efficiency and correlation during winter...
than during summer). Summertime $\sigma_{sp}$ varied widely from 0.7 m$^2$/g to 5.9 m$^2$/g at ANGI and from 1.3 m$^2$/g to 6.5 m$^2$/g at BAC. Wintertime relationships are much more consistent.

When an all-site and both-season average of $\sigma_{sp} = 4.9$ m$^2$/g is used to estimate PM$_{2.5}$ mass from $B_{sp}$, the slope between the estimated and measured PM$_{2.5}$ mass deviates from a 1:1 line, especially during the summer.

**Figure 5.** Daily average $B_{sp}$ and PM$_{2.5}$ mass at the (a) ANGI and (b) BAC sites during winter and summer.
This average $B_{sp}$ does not accurately estimate $PM_{2.5}$ mass everywhere all the time. Figures 6a and 6b compare $PM_{2.5}$ estimated from $B_{sp}$ with the measured $PM_{2.5}$ mass at different types of sites in winter and summer, respectively, showing closer agreement when site-type and seasonal $\sigma_{sp}$ values are used. Community exposure and interbasin gradient/transport sites, as well as source-dominated home heating and oilfield sites, show correlations exceeding 0.9 during winter. Correlations are low during summer, with the
exception of the desert sites, indicating that \( B_{sp} \) is a less reliable estimator of PM\(_{2.5} \) during that season.

\( B_{sp} \) was compared with PM\(_{10} \) mass for a neighborhood-scale study centered on the Corcoran (COP) site from October 10, 2000, to November 14, 2000, to determine how well \( B_{sp} \) in the area is related to PM\(_{10} \). \( B_{sp} \) and PM\(_{10} \) were not as well correlated (\( r = 0.66 \)) and yielded smaller \( \sigma_{sp} \) (2.6 m\(^2/\text{g}\)) than those found for \( B_{sp} \) and PM\(_{2.5} \) (\( r = 0.89, 4.5 \text{ m}^2/\text{g} \)). This reflects the lower scattering efficiency expected for the coarse particles. IMPROVE estimates a coarse particle mass scattering efficiency (\( \sigma_{spc} \)) of 0.6 m\(^2/\text{g}\).\(^{13}\)

**Light Scattering and PM Comparisons at FSF**

\( B_{sp} \) derived from the Fresno PM\(_{2.5} \) nephelometer and \( B_{sp} \) from other instruments are compared with PM\(_{2.5} \) mass from different instruments in Table 3. The correlations between hourly averaged \( B_{sp} \) and PM\(_{2.5} \) are higher during winter (\( r = 0.97 \)) than during summer (\( r = 0.85 \)) with 2-fold higher PM\(_{2.5} \) \( \sigma_{sp} \) during winter (4.3 m\(^2/\text{g}\)) than during summer (1.8 m\(^2/\text{g}\)), as shown in Figure 7. \( B_{sp} \) and PM\(_{2.5} \) measured with the Radiance nephelometers were highly correlated (Table 3), with a higher regression slope in winter than summer (1.04 versus 0.98). Coarse particles appear to have a small effect on the \( B_{sp} \) measurement.

Results from a multiple linear regression with \( B_{sp} \) as the dependent variable and PM\(_{2.5} \) and PM\(_{10-2.5} \) concentrations as the independent variables,\(^{11}\) \( 1 \)-hr average data were used for comparisons, except for the FRM filter mass (24-hr average). The average value was calculated over the collocated sampling period for each instrument.

### Table 3. Comparison of particle light scattering and PM\(_{2.5} \) at the FSF for data acquired between September 1, 2000, and August 31, 2001.

<table>
<thead>
<tr>
<th>Observables</th>
<th>Measurement methods</th>
<th>( y )</th>
<th>( x )</th>
<th>( y )</th>
<th>( x )</th>
<th>Slope ± Standard Error (m(^2/\text{g}))</th>
<th>Intercept ± Standard Error (m(^2/\text{g}))</th>
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</thead>
<tbody>
<tr>
<td>Wintera</td>
<td>( B_{sp} ) PM(_{2.5} ) Radiance nephelometer TSP ( \times ) BAM</td>
<td>334.7 ± 233.4</td>
<td>70.0 ± 47.6</td>
<td>0.96</td>
<td>1524</td>
<td>4.50 ± 0.03</td>
<td>10.51 ± 2.69</td>
</tr>
<tr>
<td>Summerb</td>
<td>( B_{sp} ) PM(_{2.5} ) Radiance nephelometer TSP ( \times ) BAM</td>
<td>334.7 ± 233.4</td>
<td>27.7 ± 24.4</td>
<td>0.88</td>
<td>1546</td>
<td>8.79 ± 0.12</td>
<td>103.58 ± 4.31</td>
</tr>
<tr>
<td>Winter</td>
<td>( B_{sp} ) PM(_{2.5} ) Radiance nephelometer TSP ( \times ) TEOM</td>
<td>334.7 ± 233.4</td>
<td>82.7 ± 61.3</td>
<td>0.96</td>
<td>1097</td>
<td>2.14 ± 0.02</td>
<td>-8.71 ± 2.29</td>
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<tr>
<td>Winter</td>
<td>( B_{sp} ) PM(_{2.5} ) Radiance nephelometer TSP ( \times ) TEOM</td>
<td>334.7 ± 233.4</td>
<td>84.1 ± 54.7</td>
<td>0.82</td>
<td>798</td>
<td>2.66 ± 0.07</td>
<td>85.22 ± 6.54</td>
</tr>
<tr>
<td>Winter</td>
<td>( B_{sp} ) PM(_{2.5} ) Radiance nephelometer TSP ( \times ) GreenTek</td>
<td>334.7 ± 233.4</td>
<td>7.7 ± 7.6</td>
<td>0.79</td>
<td>1777</td>
<td>2.24 ± 0.04</td>
<td>6.79 ± 0.46</td>
</tr>
<tr>
<td>Winter</td>
<td>( B_{sp} ) PM(_{2.5} ) Radiance nephelometer TSP ( \times ) FRM filter</td>
<td>334.7 ± 200.1</td>
<td>78.0 ± 47.2</td>
<td>0.97</td>
<td>10</td>
<td>4.80 ± 0.45</td>
<td>-0.05 ± 0.40</td>
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<tr>
<td>Summer</td>
<td>( B_{sp} ) PM(_{2.5} ) Radiance nephelometer TSP ( \times ) FRM filter</td>
<td>334.7 ± 200.1</td>
<td>8.5 ± 2.1</td>
<td>0.92</td>
<td>12</td>
<td>3.48 ± 0.44</td>
<td>-9.87 ± 4.00</td>
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<td>( B_{sp} ) PM(_{2.5} ) Radiance nephelometer TSP ( \times ) FRM filter</td>
<td>334.7 ± 200.1</td>
<td>38.9 ± 16.7</td>
<td>0.97</td>
<td>1527</td>
<td>5.43 ± 0.03</td>
<td>13.13 ± 2.69</td>
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<td>Winter</td>
<td>( B_{sp} ) PM(<em>{2.5} ) Radiance nephelometer TSP ( \times ) PM(</em>{10-2.5} ) BAM</td>
<td>334.7 ± 233.4</td>
<td>58.4 ± 34.5</td>
<td>0.96</td>
<td>1527</td>
<td>4.54 ± 0.03</td>
<td>12.13 ± 2.69</td>
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<tr>
<td>Summer</td>
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<td>6.79 ± 0.46</td>
</tr>
</tbody>
</table>

\( a \) Winter (December 2000 to February 2001); \( b \) Summer (June 2001 to August 2001); \( \times \) \( B_{sp} \) from a Radiance Research M903 Nephelometer (Seattle, WA) without a size-selective inlet, presumably measuring total suspended particles (TSP, particles with aerodynamic diameters < 30 \( \mu \text{m} \)) scattering;\(^{12}\) Multiple linear regression with the \( B_{sp} \) as the dependent variable, and PM\(_{2.5} \) and PM\(_{10-2.5} \) concentrations as the independent variables;\(^{11}\) Multiple linear regression with the \( B_{sp} \) as the dependent variable, and PM\(_{2.5} \) and PM\(_{10-2.5} \) concentrations as the independent variables;\(^{11}\) 1-hr average data were used for comparisons, except for the FRM filter mass (24-hr average).
PM$_{10-2.5}$ concentrations are often correlated at Fresno, but the $\sigma_{spf}$ and $\sigma_{spc}$ are not necessarily constant. This results in some uncertainties, even negative values, for the multiple linear regression coefficients, especially for the TEOM measurements during summer.

On average, $B_{sp}$ from the NGN2 ambient temperature nephelometer (410 Mm$^{-1}$) was 1.6 times $B_{sp}$ from the Radiance nephelometer (265 Mm$^{-1}$) during the winter, which is expected, owing to the higher RH. This comparison indicates that water is being removed in the Radiance

**Figure 7.** Comparison of hourly average $B_{spf}$ from a Radiance Research M903 nephelometer with a PM$_{2.5}$ size-selective inlet and PM$_{2.5}$ mass determined by BAM at the FSF during (a) winter and (b) summer.
nephelometer by the smart heater. During summer when RH was much lower than winter, average NGN2 Bsp (19 Mm$^{-1}$) was comparable to Radiance Bsp (22 Mm$^{-1}$). After excluding Bsp values > 1000 Mm$^{-1}$ from the NGN2 dataset, correlations with the Radiance Bsp nephelometer ranged from 0.92 to 0.94.

The monthly average Bsp determined by the Radiance and OPTEC NGN2 nephelometers and PM$_{2.5}$ mass concentrations determined by the FRM, BAM, TEOM, DustTrak, and GreenTek are compared in Figure 8. During the winter, PM$_{2.5}$ TEOM was lower because of evaporation of NH$_4$NO$_3$ at its 50°C internal temperature. The filter dynamic measurement system quantifies TEOM evaporation, but this was not implemented at the FSF. Among all measurements, the two photometers consistently reported higher PM$_{2.5}$ mass. On average, the DustTrak reported 2.2 and 4.3 times higher PM$_{2.5}$ mass in winter and summer, respectively, than the GreenTek.

Figures 9a and 9b show similar diurnal variations between B$_{sp}$ and PM$_{2.5}$ mass at FSF. Although these are

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**Figure 8.** Monthly average B$_{sp}$ by Radiance Research M903 and OPTEC NGN2 nephelometers and PM$_{2.5}$ mass concentrations determined by PM$_{2.5}$ FRM filter sampler, BAM, TEOM, DustTrak photometer, and GreenTek photometer at the FSF from September 2000 to August 2001.

**Figure 9.** Diurnal variations of B$_{sp}$ determined by the Radiance Research M903 nephelometer with a PM$_{2.5}$ size-selective inlet and PM$_{2.5}$ mass concentration determined by BAM, averaged by the time of day at the FSF during (a) winter and (b) summer.
average values, examination of individual days shows that they track each other in most situations. This comparison supports the use of PM_{2.5} derived from Bsp to better understand PM_{2.5} variability within a 24-hr period at sites that do not have all of the Supersite instrumentation.

CONCLUSION
Site-type and season-specific PM_{2.5} Bsp can be applied to Bsp measurements from a nephelometer to estimate PM_{2.5} concentrations with reasonable accuracy and precision in California’s San Joaquin Valley. Periodic heating of the nephelometer inlet to obtain RH below a certain value (probably <60%) can be applied to remove liquid water while minimizing evaporation of volatile compounds such as NH_{4}NO_{3}. Best agreements between Bsp and PM_{2.5} are found during winter and for sites that are not located near sources. Summertime σ_{sp} were lower owing to drier conditions with less hygroscopic NH_{4}NO_{3} and a larger proportion of soil-related PM, all of which result in lower σ_{sp}.

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