Daily, Winter-Time Profiles of Fine Particle Mass, Nitrate and Black Carbon in California's San Joaquin Valley

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Abstract

The California Regional Particulate Air Quality Study provides a data set with sub-hourly concentrations for aerosols over a large geographical area encompassing California's central, San Joaquin Valley. Measured species include black carbon, nitrate, PM2.5 mass and particle light scattering. Presented here is an analysis of the spatial homogeneity and diurnal patterns during a two-month intensive study period commencing December 2000. Episodic and diurnal patterns are separated by deconvolution of the concentration profiles into two frequency domains corresponding to the 24-hr running average and a residual signal reflecting the diurnal variations. The 24-hr time domain shows homogeneity among the study sites within the Valley during this winter time study. Daily patterns exhibit differences among species and among sites. Comparison of patterns for black carbon, nitrate, particle number concentration, ozone, nitric oxide, and nitrogen dioxide support the hypothesis of the importance of night time formation of particulate nitrate aloft, which is then mixed to the ground in the morning hours.

Keywords: fine particulate nitrate, black carbon, diurnal variability, California Regional Particulate Air Quality Study, San Joaquin Valley

Introduction

California's San Joaquin Valley is an agricultural region encompassing approximately 64,000 km^2 and with a total population of 3 million. During the winter months, the Valley is subject to multiday periods of stagnation and is an area of non-attainment for ambient particulate levels. Wintertime, 24-hr average levels of $PM_{2.5}$ above 100 $\mu g/m^3$ have been reported, with major contributions from nitrate, organic and black carbon (Chow et al, 1993; Magliano et al, 1999; Watson and Chow, 2002).

To better characterize the periods of elevated particulate levels, the California Regional Particulate Air Quality Study (CRPAQS) was conducted under the auspices of the San Joaquin Air Valleywide Pollution Study Agency. Sub-hourly, chemically-speciated concentrations of aerosols were measured during a two month winter intensive study beginning in December 2000. The CRPAQS data set represents the most comprehensive, semi-continuous particle composition measurements collected simultaneously at multiple sites within the San Joaquin Valley to date. Time- and spatially resolved measurements include those for $PM_{2.5}$ mass, nitrate, black carbon, and RH-adjusted particle light scattering.

This highly time- and spatially- resolved data set is examined to determine the consistency in concentration profiles from day-to-day, and site-to-site. Of specific interest is how these profiles vary among constituents of differing origins. Temporal and spatial variations of $PM_{2.5}$ concentration profiles are examined by deconvolution of the signal into

two frequency domains in order to distinguish diurnal variations from multiday patterns, with comparison of these deconvoluted signals among sites and constituents. We address the question of the necessary time and spatial resolution required to characterize the peak level concentrations. In combination with gaseous data we examine how the differences in the diurnal patterns among constituents and sites relate to differences in sources and formation mechanisms.

Experimental Methods

Semi-continuous measurements were conducted over a two-month period beginning in December 2000 at six sites throughout the Valley and at its borders. Urban sites were located in the cities of Fresno (population 355,000), situated midway in the Valley, and in Bakersfield (population 175,000) at the southern end of the Valley. A nonurban, "background" site within the Valley was located at Angiola, an unincorporated cotton-farming region 20 km south of the town of Corcoran and 50 km west of the midway point between Fresno and Bakersfield. Three sites were located on the boundaries of the Valley. Two of these sites, located at Bethel Island and Walnut Grove, are in the river delta region approximately 200 km northwest of Fresno and are generally upwind of the Valley towns, along the air transport corridor from the populated San Francisco Bay area. A third boundary site was located in the Sierra Nevada mountain foothills, 50 km northeast of Fresno, and is often subject to upslope flow from the Valley. Details are given by Magliano and McDade (2001).

Nitrate concentrations were measured with 10-minute time resolution using the Rupprecht and Patashnick Model 8400N (Albany, NY). This system is based on the

method of Stolzenburg and Hering (2000) whereby aerosol sample is collected onto a metal strip by humidification and impaction, and then analyzed by flash vaporization with detection of the evolved nitrogen oxides by a chemiluminescence analyzer equipped with a molybdenum catalyst. Black carbon was measured with 5-minute time resolution using Aethalometer, that measures the light attenuation for particles deposited on a quartz filter, as described by Hansen et al (1984). PM2.5 mass was measured with hourly time resolution using beta attenuation (Met One Instruments). Fine particle light scattering was measured using a Radiance Research nephelometer equipped with a "smart" heater that prevented the relative humidity at the point of measurement from exceeding 65% RH. The measurement system for the Fresno site is described by Watson et al (2000).

Results

PM2.5 nitrate, black carbon and mass for the three Valley sites of Fresno, Bakersfield and Angiola are shown in Figure 1 for the period from December 1, 2000 through February 6, 2001. While detail cannot be discerned from these graphs, the predominant features are evident. Most pronounced are multiday periods of elevated concentrations, such as the period between December 26 and January 7. These high concentration events are observed concurrently at all three sites, with the largest values at the southernmost, Bakersfield site. As described by McDonald et al (2006), these multiday periods of high concentration are associated with atmospheric stagnation, characterized by low mixing layer heights and low wind speeds. Likewise, low concentration days are seen simultaneously throughout the Valley, and are usually coincident with storms impacting the

West Coast, with moderate to strong winds and a deep boundary layer providing higher ventilation and lower pollutant concentrations.

Figure 1 shows sharp, daily maxima in the black carbon concentrations, while the nitrate has a less dramatic diurnal variation. The PM2.5 mass, which is partially comprised of nitrate and black carbon, has a pattern intermediate between that of nitrate and black carbon.

Deconvolution of Diurnal and Episodic Patterns

To distinguish the diurnal variation from the synoptically driven multiday variation, the hourly averaged concentration data were deconvoluted into two components, as follows:

$$C = C_{24hr} + C_{res} \qquad (1)$$

where C is the measured hourly averaged concentration, C_{24hr} is the running 24-hr value centered on the time of measurement C, and C_{res} is the difference. In this analysis the multiday patterns are reflected in C_{24hr}, whereas the residual, C_{res}, shows the fluctuation about the 24-hr mean.

This deconvolution is illustrated in Figure 2, which shows the hourly concentrations of $PM_{2.5}$ nitrate at Bakersfield separated into a 24-hr running average and the residual. The residual value oscillates about zero, and captures the diurnal variation against a more smoothly changing background concentration represented by the 24-hr running average. A residual of zero does not mean that the concentration is constant, but rather that it is equal to the 24-hr average centered about that hour.

Figure 3 compares results for $PM_{2.5}$ nitrate and black carbon at Bakersfield. Over the entire study period, the 24-hr running average concentrations covarry (Figure 3a). Differences in the diurnal patterns are quite evident from the plot of the residuals, shown in detail for a period of high concentrations. Nitrate concentrations are largest midday, while black carbon concentrations are largest in the evening, with a secondary maximum in the early morning.

The "daily pattern" for each site and constituent is obtained by averaging C_{res} over each hour of the day:

$$C_{pattern,h} = \sum_{i=1}^{N} C_{res,h,i} \qquad (2)$$

where $C_{res,h,i}$ is the hourly residual on day i for hour h and N is the number of days. $C_{pattern}$ is very similar to the quantity obtained by computing the average concentration of each constituent for each hour of the day, with the difference that the overall mean concentration has been subtracted. (Another, less significant difference is that data for the initial and final dates are treated differently because $C_{res,h}$ is calculated with respect to the running 24-hr average.) As shown below, the evaluation of the average daily pattern from the residuals provides a tool for evaluating the consistency of the daily pattern, as well as providing the pattern itself.

The objective of this approach is to separate the daily fluctuations from the multi-day patterns associated with episodic changes induced by weather patterns. Questions addressed here are: (1) what is the reproduciblity of these diurnal patterns for each site, and among sites, (2) how accurately can one-hour daily maxima be inferred from measured 24-

hr average concentrations, and (3) can these patterns elucidate differences in source and transformation mechanisms.

Spatial Homogeneity

Figure 4 compares the 24-hr running average concentrations for PM2.5 mass, nitrate, black carbon and particle scattering at the six sites. As noted above, all of the sites show four periods of elevated concentrations, December 1-9, December 25-January 7, January 15-22, January 31-February 5. These periods are identified based on 24-hr averaged $PM_{2.5}$ mass values exceeding 40 $\mu g/m^3$ at the Fresno site. During each of these periods the particulate level concentrations tend to increase, reaching their highest levels toward the end of the episode. Those at Angiola tend to build more steadily than at either Fresno or Bakersfield. For example, during the 14-day period from Dec 25 to Jan 7, the high concentrations at Fresno and Bakersfield are attained on January 1, whereas those at Angiola are highest on the last two days. Similarly, during the episode period fom January 15 -22, the concentrations at Angiola are highest on the last day (January 22) while those for Fresno and Bakersfield reached a maximum two days earlier (January 20). The particle light scattering (Bsp) is more uniform among sites. This homogeneity within the San Joaquin Valley is similar to that reported by Magliano et al (1999) and Chow et al (1993).

Data for the sites bordering the Valley, shown in Figure 5, do not exhibit the same pattern as the locations within the Valley (Figure 4). The river delta sites of Bethel Island and Walnut Grove tend towards higher concentrations during the same periods as in the Valley (Dec 25-Jan7, Jan 15-21, Jan 30-Feb 6), but these are not as pronounced. Notable is the absence of a buildup in concentrations of PM2.5 mass, nitrate and black carbon that is

observed for Fresno, Bakersfield and Angiola during these periods of high concentration concentrations. Concentration patterns at the Sierra Nevada Foothills site, on the opposite side of the Valley, are the most inconsistent with the Valley sites.

Diurnal Variability

Figures 6, 7 and 8 show the hourly residuals, $C_{res,h}$ at Fresno, Bakersfield and Angiola for the episode period from December 25 through January 7. In these graphs the residuals are plotted on a uniform time axis, with different symbols representing each day. Weekdays are represented by solid symbols, weekends and holidays by open symbols. The spread in points indicates the day-to-day variability in the diurnal pattern. To better display the evening and night time events, the time axis starts at 6 am and continues through till the same time the next day.

The black carbon data show a consistent diurnal pattern at Bakersfield and Fresno, with a small early morning peak, and a large evening peak. This pattern repeats every day. The time of day of peak morning concentration varies from 7 AM to 8 AM, and that for the evening varies from 7 PM to midnight. The evening rise in black carbon has been attributed to resedential heating (Watson and Chow, 1992), and wood combustion (Rinehart et al, 2006). At Angiola, which has few local sources, the residual black carbon concentrations are nearly flat. This is not to say that it is constant, rather that concentrations change slowly, such that for any hour of the day the black carbon concentration is close to the value for the running 24-hr average centered on that hour.

The day-to-day variation in the diurnal signal for nitrate is larger, as is the difference among sites. At Fresno, the traces for individual days can exhibit either a midmorning or an evening peak, or both. For the 14 day period shown in Figure 6, 9 days

had both midmorning and evening peaks, while 3 had an evening peak only. The time of day of the morning is 10 to 11 am on most days, while that for the evening maxima varies from 7 pm to midnight. At Bakersfield, the nitrate concentrations are most often largest midmorning, between 10 AM and noon. Only 2 days of the 14 day period reach their highest levels in the evening hours. At the nonurban site of Angiola, the daily variation in nitrate concentrations is not as pronounced as at Fresno or Bakersfield. Yet most days show an increase between 10 am and noon, with values reaching a plateau with respect to the 24-hr running average. The Fresno and Bakersfield patterns for particulate nitrate are very similar to those reported by Magliano et al (1999) while that for Angiola is similar to what they report for the nonurban sites of Chowchilla and Kern Wildlife sites.

The diurnal pattern in $PM_{2.5}$ mass concentrations is a composite of those for black carbon and nitrate, and is quite distinct for these three sites. Although hourly data are not available for organic carbon, it has been found to be correlated with the black carbon for those days for which 4-hr filter data are available (Lurmann et al, 2006). At Fresno, the $PM_{2.5}$ mass is bimodal, with a smaller morning maxima and larger evening maxima, aligned with the respective maxima in nitrate and black carbon. At Bakersfield, the morning peak in the diurnal pattern for $PM_{2.5}$ mass is more pronounced, as would be expected from the larger morning nitrate maximum at this site. At Angiola, the $PM_{2.5}$ mass tends to increase in the morning hours, reaching a maximum midday. At none of the sites, and for none of the species, is there an apparent difference between weekdays and weekends and holidays, as seen by comparing the solid and open symbols.

Relationship between One-Hour Maximum and 24-hr Average Concentrations

Most monitoring for the chemical composition of particulate matter relies on 24-hr integrated, filter-based measurements. The relationship between the daily one-hour maximum concentration and the 24-hr average concentration is of interest to evaluate the relationship between 24 hr average concentrations that are more commonly measured to the one-hourly maximum concentration to which people may be exposed. It is quite apparent from Figure 2 that the larger absolute values of the hourly residuals occur during periods of high concentration. Correspondingly, the one-hour maximum concentration is related to the 24-hour mean concentration.

Through linear correlation we evaluated the relationship between the daily one-hour maximum concentration and the 24-hour average concentration beginning at midnight. Overall these values were highly correlated, with $R^2>0.8$ in most cases during this two-month winter study. Results given in Table 1 show that regression slopes are higher for the urban sites of Fresno and Bakersfield, and higher for black carbon, than for either nitrate or $PM_{2.5}$ mass. Black carbon exhibits the highest ratio between the one-hour maximum concentration and the 24-hr average, as is consistent with the discussion of the hourly residuals above.

The representativeness of these results for other seasons and years is examined at the Fresno site, where several years of data are available for nitrate and for black carbon. These data were divided into two-month periods, beginning at the onset of data collection in October 1999, through July 2002. The peak one-hour concentrations were fit to the 24-hour average utilizing a linear fit constrained to pass through the origin. The single parameter fit was used in order to remove the influence of the intercept on the regression

slope, thereby providing a direct basis for comparison among seasons. Figure 9 displays the seasonal dependence of the zero-intercept regression slope evaluated from this data set. For black carbon the peak one-hour concentration is highest relative to the 24-hr average during the fall and winter months. For nitrate the data are less definitive, but the seasonal dependence appears to be opposite of black carbon, with the peak one-hour winter time concentrations of only 30% to 50% above the 24-hr mean.

Mean Daily Patterns and Implications for Origins of Particulate Nitrate

The mean daily patterns are calculated by averaging over the residuals for each hour of the day, as given by equation (2). These are shown in Figure 10 for $PM_{2.5}$ nitrate, black carbon and mass for each of six sites in the Valley for the period of December 25 through January 7. As discussed above, for Fresno and Bakersfield the predominant features are small morning and large evening peaks in black carbon, and a morning peak in nitrate, and a second evening nitrate maxima at Fresno. The non-urban site of Angiola has a flat pattern for black carbon, with nitrate rising in the morning hours. The boundary sites of Bethel Island, Walnut Grove and Sierra Nevada Foothills show midday maxima in nitrate, with flat profiles for black carbon. $PM_{2.5}$ mass at these sites follows the pattern for nitrate. Similar patterns are seen for the period from January 15 through February 5, covering the final two episodes of elevated concentration, as shown in Figure 11.

Of interest is how the typical diurnal patterns reflect the origin of the aerosol constituents. Particulate nitrate is formed from the oxidation of NO_2, either by reaction with OH to directly form nitric acid, or by reaction with O_3 to form NO_3, with subsequent reactions with either NO_2 or H_2O to form HNO_3. Because the NO_3 intermediary rapidly photolizes, this second pathway occurs primarily at night. Additionally, the NO_3

intermediary reacts with NO sufficiently rapidly that the two species cannot coexist at mixing ratios larger than a few parts per trillion (Seinfeld and Pandis, 1998).

A number of investigators have suggested that the formation aloft via this night time mechanism is an important source for nitrate in the Valley during the winter (Smith et al, 1995, Atkinson et al, 1996; Pun and Seignuer,1999, 2001; Chow and Watson, 2002; and Lurmann et al 2006). During evening and night time hours, ozone concentrations at the surface are depleted through deposition, but the concentrations may remain elevated aloft, allowing for night time oxidation of NO_2. Measurements on the tower at the Angiola site for this study show the depletion of NO aloft, with significant O_3. The nitrate formed aloft is not seen at the surface until the inversion heights lift, and this air mass is mixed to the surface. The references cited above have suggested that the morning nitrate maxima may in fact be due to mixing from aloft of nitrate formed at night.

Figures 12 and 13 compare the diurnal patterns for nitrate and black carbon to those for NO, NO_2, O_3, and to the mixing heights (McDonald et al, 2006). All three sites exhibit a maxima in NO during the morning and evening, which at Fresno and Bakersfield is coincident with the peaks in black carbon concentrations. At Fresno these maxima track the total particle number concentration, which is indicative of fresh combustion emissions. The increase in nitrate and ozone concentrations occurs a few hours later, as the NO concentrations decline and the NO_2 begins to build. The slight lag in O_3 is consistent with reaction with NO, which depletes the O_3 from aloft until the NO is depleted. The increase in nitrate occurs at the very beginning of, or perhaps slightly ahead of the increase in the inversion heights. The rise in nitrate is faster than one would expect from photochemistry alone (Lurmann et al, 2006), pointing to the importance of mixing from aloft.

At Angiola, the morning increase in black carbon occurs later, increasing at the same time as the ozone and particulate nitrate, after the drop in NO and particle number concentration. Also, the incremental increase in particle number concentration is a factor of 10 lower than at Fresno, while that for black carbon is only a factor of 2 lower. Thus it seems likely that most of the Angiola black carbon is associated with aged, rather than fresh combustion emissions, consistent with what would be expected of a nonurban site. The coincidence of the morning increase in nitrate, black carbon and ozone at Angiola is consistent with mixing from aloft, although the reported mixing heights seem to lag slightly.

Figure 14 shows the daily patterns at the Walnut Grove Tower site for the period from December 25 through January 7. This site had measurements at two altitudes: near ground level (at 10 m AGL) and on the top of the tower at 244 m AGL. Inversion height data is from Sacramento, located approximately 46 km to the north. The ground-based nitrate shows a midday maxima, following the inversion height pattern, while black carbon is highest from 6 to 10 AM, and again in the evening around midnight. This is similar to the patterns observed for Bakersfield and Fresno. The nitrate at the top of the tower is highest at night reaching a maximum between midnight and 6 AM. The mean nitrate concentration as measured at the top of the tower is 11 $\mu g/m^3$, which is comparable to the level of 15 $\mu g/m^3$ reported for the ground site. From this data the portion of the nitrate which results from night time conversion aloft cannot be determined. What is evident is an overnight increase in nitrate aloft, and the sudden increase at ground level in the morning when the inversion heights lift, indicating that the night time formation aloft is significant.

Conclusions

Separation of the time-resolved data into episodic and daily patterns is shown to provide a useful tool for comparing time-resolved particulate data among days and sites. The 24-hr running average showed spatial homogeneity among sites within the San Joaquin Valley during this wintertime study. The one-hour daily maximum concentrations were highly correlated from the 24-hr average. The residual signal, obtained by difference from the hourly data and the 24-hr running average, showed clear differences in the diurnal patterns among constituents and between sites. These patterns are most consistent for black carbon, and at the urban sites of Fresno and Bakersfield, and less pronounced for the non-urban site of Angiola. The evaluation of these "daily patterns" by means of the residuals provides a ready means for evaluating the consistency of these patterns. The diurnal pattern for particulate nitrate, which shows a rapid rise in the morning hours, is consistent with that expected for the formation of nitrate aloft, brought to the surface by mixing when the inversion heights rise.

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List of Figures

Figure 1. Hourly concentrations of PM2.5 nitrate, black carbon and mass at the Angiola (ANG), Bakersfield (BAC) and Fresno (FSF) montitoring sites for the winter study period of December 1, 2000 through February 5, 2001.

Figure 2. Example of deconvolution of hourly nitrate concentration data (top) into 24-hour running average (middle) and the residuals calculated as the difference between the hourly concentration and the 24-hr running average (bottom). Data are from the Bakersfield site.

Figure 3. Comparison of the 24-hr running average and the hourly residuals for two species; nitrate (black) and black carbon (gray), at the Bakersfield site. The time axis for the hourly residuals has been expanded to 8 of the 62 study days.

Figure 4 Comparison among sites of the 24-hr running average for $PM_{2.5}$ mass, nitrate, black carbon and particle scattering. Sites are Fresno (FSF), Bakersfield (BAC), and Angiola (ANG), all of which are located within the San Joaquin Valley.

Figure 5. Comparison among sites of the 24-hr running average for $PM_{2.5}$ mass, nitrate, black carbon and particle scattering for sites located at the border of the San Joaquin Valley. These are Sierra Nevada Foothills (SNFH) to the east, Bethel Island (BTI) and Walnut Grove (WAG) located to the northwest, along the air corridor from the San Francisco Bay area.

Figure 6. Hourly residuals as a function of time of day for each of the days during the 14-day period from December 25 through January 7 at the Fresno site. Each symbol type shows results for an individual day. Weekdays are represented by solid symbols, weekends and holidays by open symbols.

Figure 7. Hourly residuals as a function of time of day for each of the days during the 14-day period from December 25 through January 7 at the Bakersfield site. Each symbol type shows results for an individual day. Weekdays are represented by solid symbols, weekends and holidays by open symbols.

Figure 8. Hourly residuals as a function of time of day for each of the days during the 14-day period from December 25 through January 7 at the non-urban site of Angiola, where each symbol type is for a different day. Weekdays are represented by solid symbols, weekends and holidays by open symbols.

Figure 9. Seasonal variation over a period of 3 years in the regression slope for the comparison of the daily one-hour maximum to the 24hr average concentration at the Fresno site.

Figure 10. Daily patterns, indicated by the average of the hourly residuals for nitrate, black carbon and PM2. 5 mass (labeled BAM) during the period of December 25 through January 7.

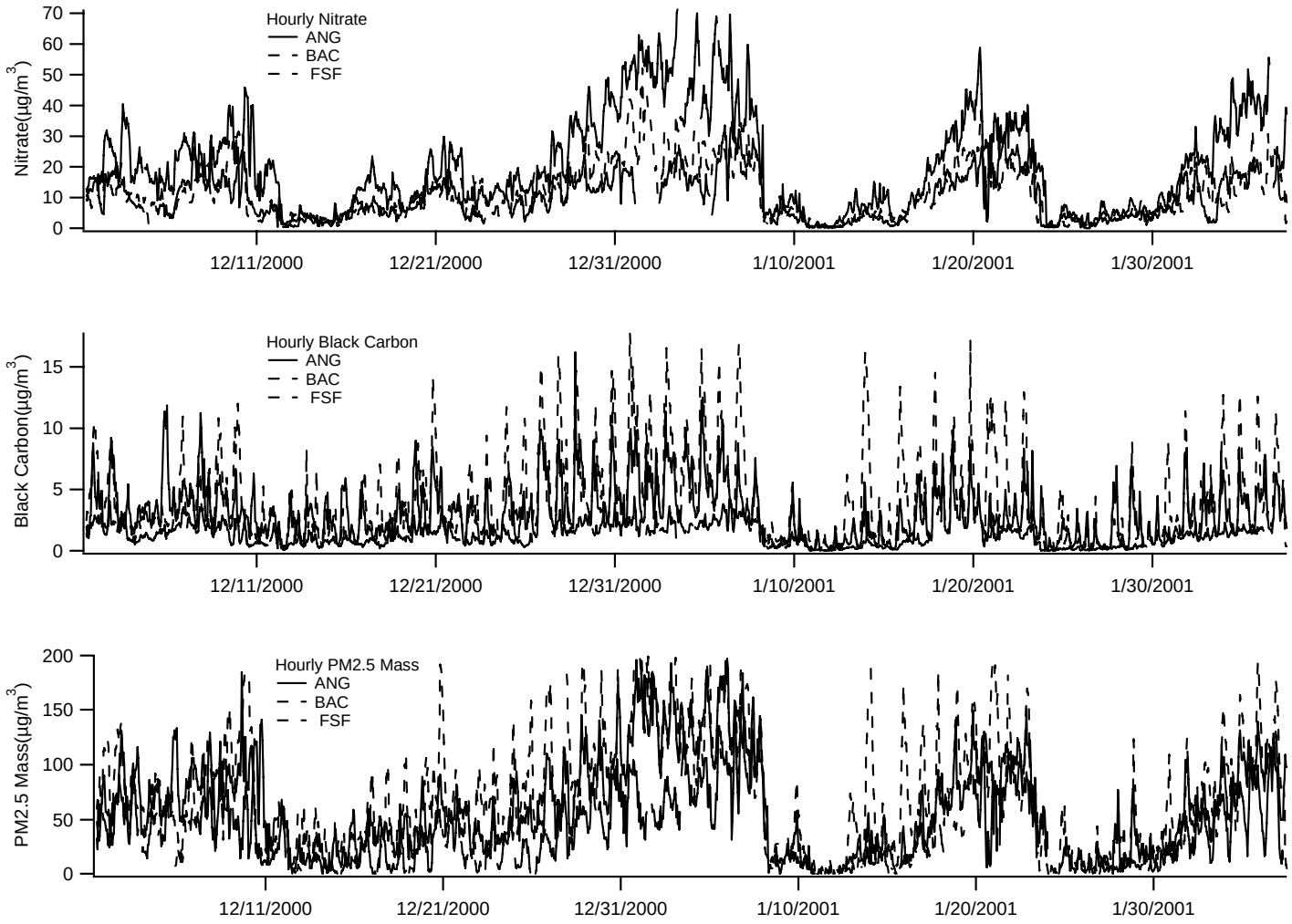
Figure 11. Daily patterns, indicated by the average of the hourly residuals for nitrate, black carbon and PM2. 5 mass (labeled BAM) during the period of January 15 through February 5, 2001.

Fig 12. Comparison of daily patterns for particle number, black carbon, nitrate (left hand axis) and mixing height, ozone and nitrogen oxides at the Bakersfield, Fresno and Angiola sites for the period from December 25 through January 7, 2001.

Table 1. Correspondence between Daily One-Hour Maximum and 24-Hr Averaged Concentrations.

Parameter	Site[1]	R^2	slope	intercept
Black Carbon (µg/m3)	FSF	0.79	1.86 ± 0.12	2.5 ± 0.5
	BAC	0.77	1.69 ± 0.11	1.8 ± 0.4
	ANGI	0.81	1.34 ± 0.08	0.4 ± 0.1
	SNFH	0.81	1.61 ± 0.10	0.6 ± 0.1
	BTI	0.69	2.02 ± 0.17	0.5 ± 0.3
	WAG	0.74	1.55 ± 0.11	0.6 ± 0.1
Nitrate (µg/m3)	FSF	0.91	1.35 ± 0.05	2.3 ± 0.7
	BAC	0.93	1.26 ± 0.04	4.0 ± 1.1
	ANGI	0.88	1.22 ± 0.06	2.7 ± 0.7
	SNFH	0.82	1.69 ± 0.10	2.3 ± 0.6
	BTI	0.81	1.52 ± 0.09	2.1 ± 0.7
	WAG	0.91	1.55 ± 0.06	1.6 ± 0.6
PM2.5 Mass (µg/m3)	FSF	0.73	1.11 ± 0.08	51.8 ± 6.8
	BAC	0.91	1.23 ± 0.05	26.1 ± 3.4
	ANGI	0.91	1.27 ± 0.05	15.8 ± 2.4
	SNFH	0.85	1.57 ± 0.08	8.7 ± 2.3
	BTI	0.87	1.60 ± 0.08	7.5 ± 2.3
Particle Scattering (mM-1)	FSF	0.88	1.47 ± 0.08	103.2 ± 32.6
	BAC	0.93	1.26 ± 0.04	112.2 ± 18.3
	ANGI	0.87	1.20 ± 0.06	98.8 ± 20.2
	BTI	0.85	1.54 ± 0.08	44.5 ± 13.2
	SNFH	0.84	1.44 ± 0.08	56.4 ± 10.6
	WAG	0.88	1.42 ± 0.07	41.3 ± 11.6

[1]Site Identifiers:
FSF: Fresno, First Street
BAC: Bakersfield, California Ave
ANG: Angiola, ground level
SNFH: Sierra Nevada Foothills
BTI: Bethel Island
WAG: Walnut Grove, base of tower


Hourly Nitrate
ANG
BAC
FSF
Nitrate(µg/m3)
70
60
50
40
30
20
10
0
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Hourly Black Carbon
ANG
BAC
FSF
Black Carbon(µg/m3)
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10
5
0
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12/21/2000
12/31/2000
1/10/2001
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1/10/2001
1/20/2001
1/30/2001

Figure 1.

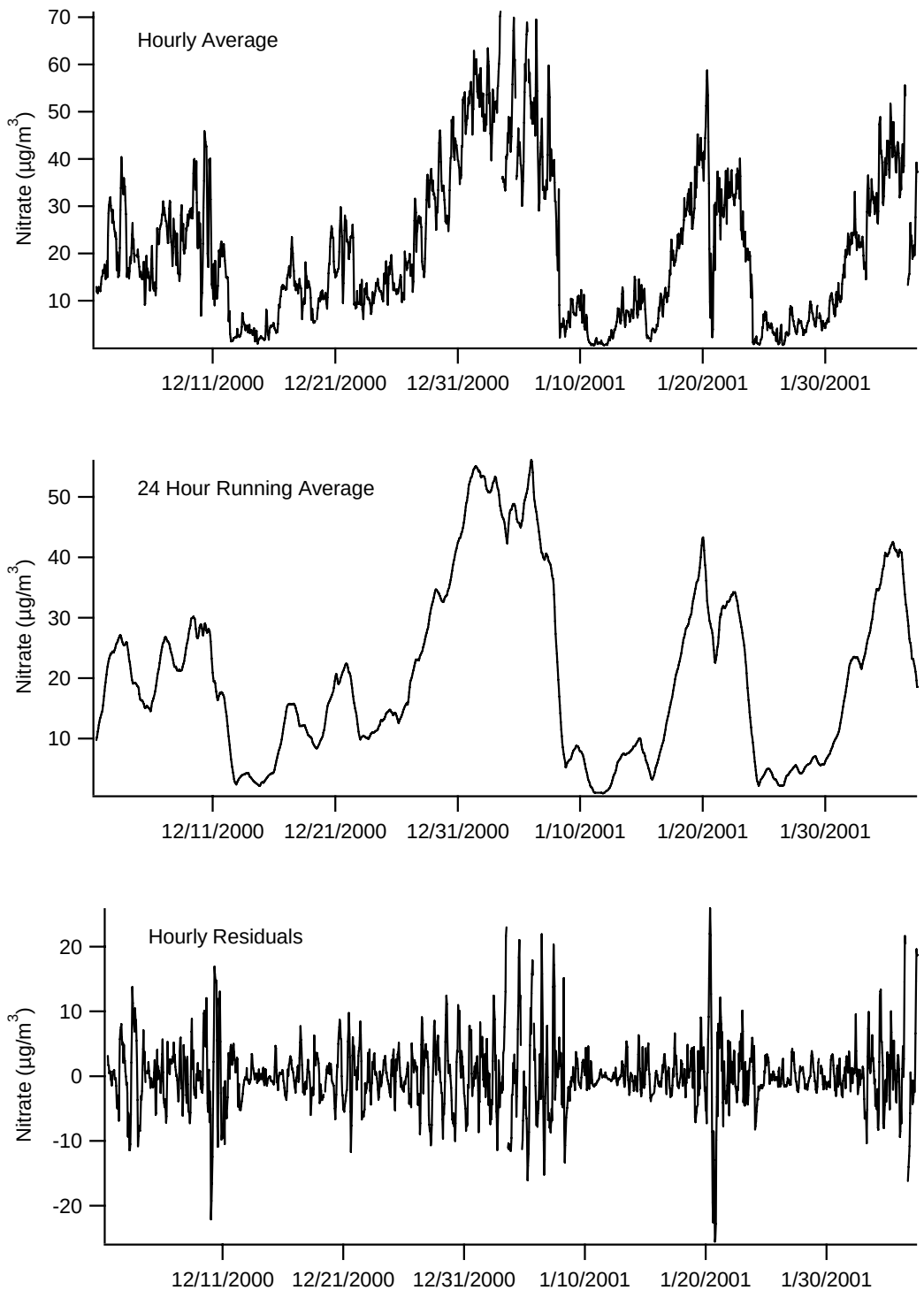
Hourly Average
Nitrate (µg/m3)
70
60
50
40
30
20
10
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
24 Hour Running Average
Nitrate (µg/m3)
50
40
30
20
10
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Hourly Residuals
Nitrate (µg/m3)
20
10
0
-10
-20
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001

Figure 2.

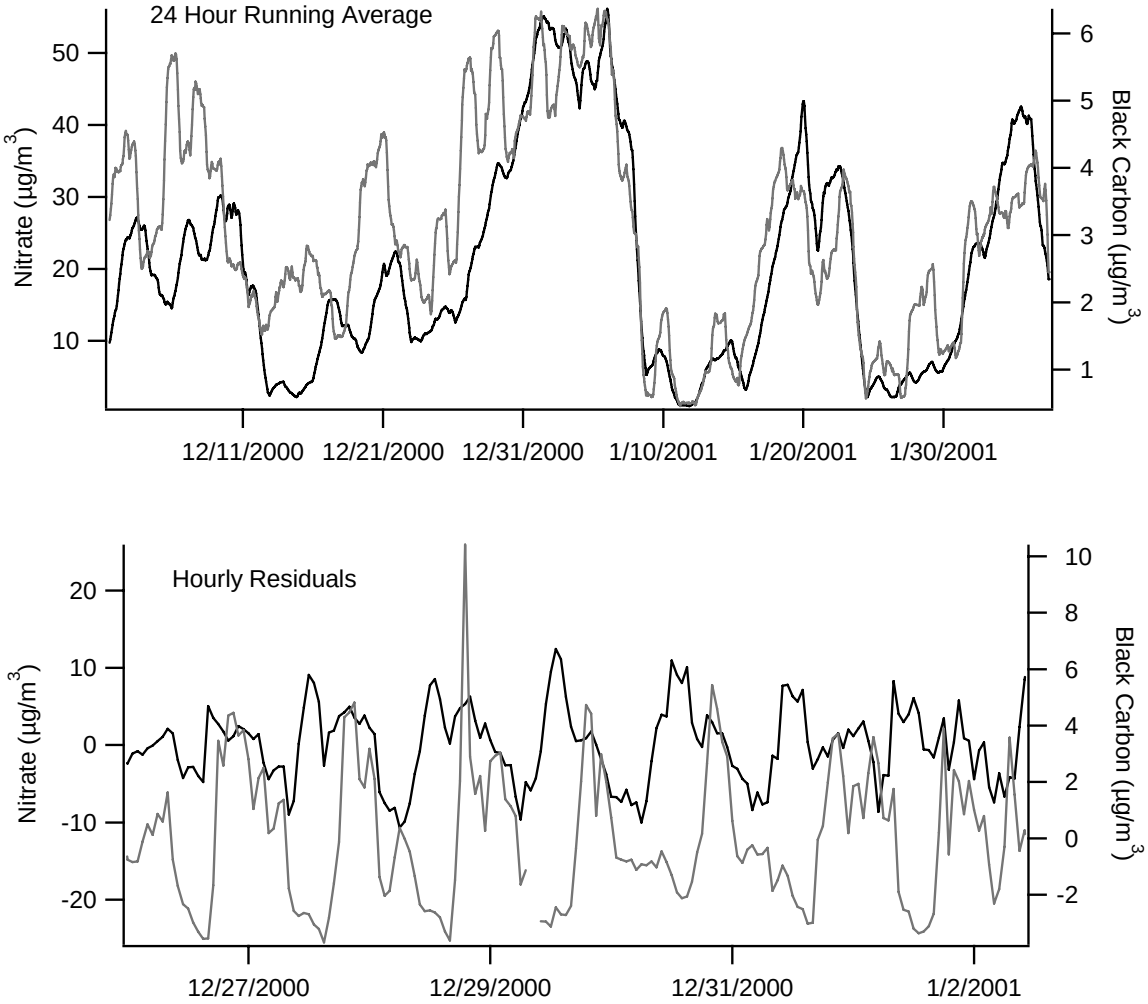
24 Hour Running Average
Nitrate (µg/m3)
Black Carbon (µg/m3)
50
40
30
20
10
6
5
4
3
2
1
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Hourly Residuals
Nitrate (µg/m3)
Black Carbon (µg/m3)
20
10
0
-10
-20
10
8
6
4
2
0
-2
12/27/2000
12/29/2000
12/31/2000
1/2/2001

Figure 3.

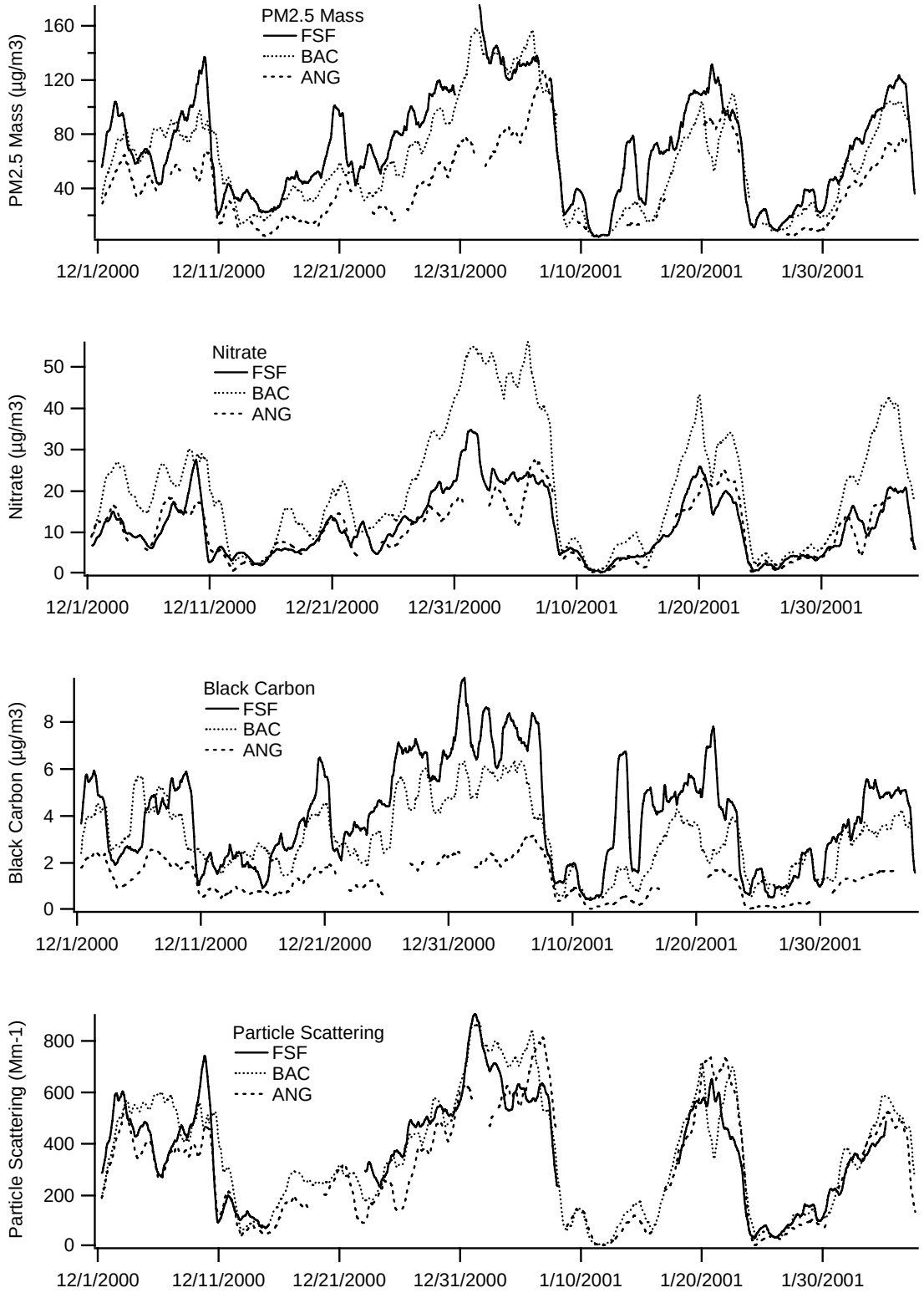
PM2.5 Mass
FSF
BAC
ANG
PM2.5 Mass (µg/m3)
160
120
80
40
12/1/2000
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Nitrate
FSF
BAC
ANG
Nitrate (µg/m3)
50
40
30
20
10
0
12/1/2000
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Black Carbon
FSF
BAC
ANG
Black Carbon (µg/m3)
8
6
4
2
0
12/1/2000
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Particle Scattering
FSF
BAC
ANG
Particle Scattering (Mm-1)
800
600
400
200
0
12/1/2000
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001

Figure 4

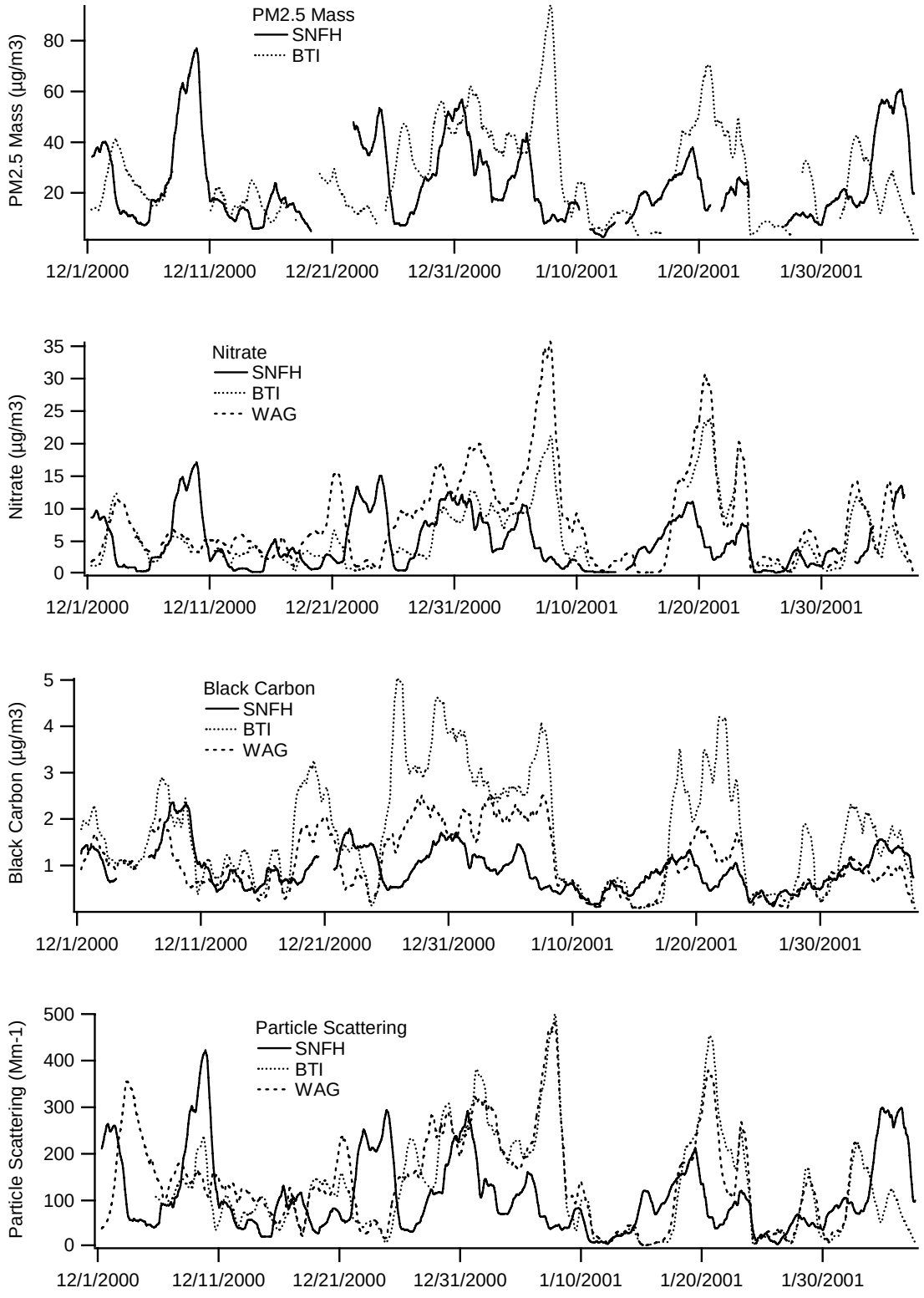
PM2.5 Mass
SNFH
BTI
PM2.5 Mass (µg/m3)
80
60
40
20
12/1/2000
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Nitrate
SNFH
BTI
WAG
Nitrate (µg/m3)
35
30
25
20
15
10
5
0
12/1/2000
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Black Carbon
SNFH
BTI
WAG
Black Carbon (µg/m3)
5
4
3
2
1
12/1/2000
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001
Particle Scattering
SNFH
BTI
WAG
Particle Scattering (Mm-1)
500
400
300
200
100
0
12/1/2000
12/11/2000
12/21/2000
12/31/2000
1/10/2001
1/20/2001
1/30/2001

Figure 5.

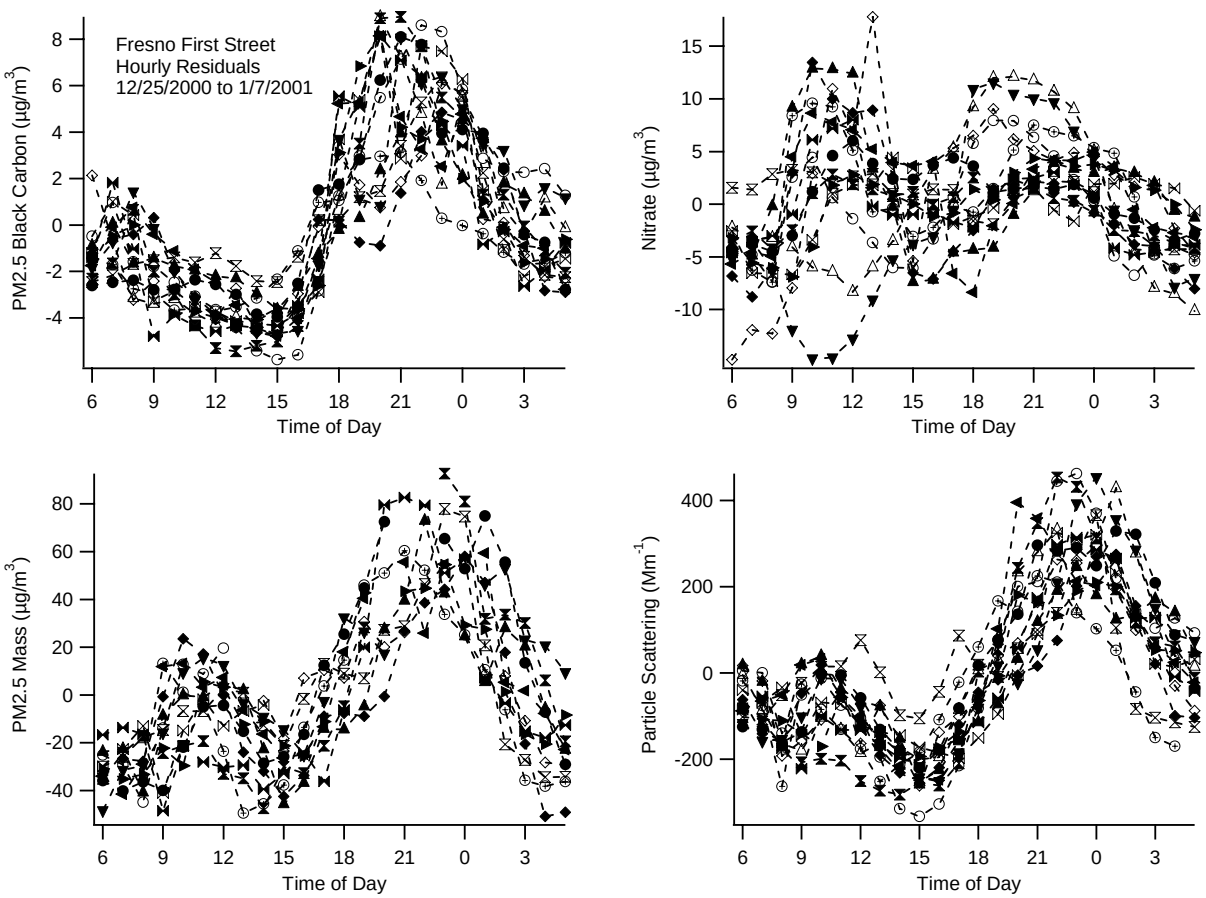
Fresno First Street
Hourly Residuals
12/25/2000 to 1/7/2001
PM2.5 Black Carbon (µg/m3)
Nitrate (µg/m3)
PM2.5 Mass (µg/m3)
Particle Scattering (Mm-1)
Time of Day

Figure 6.

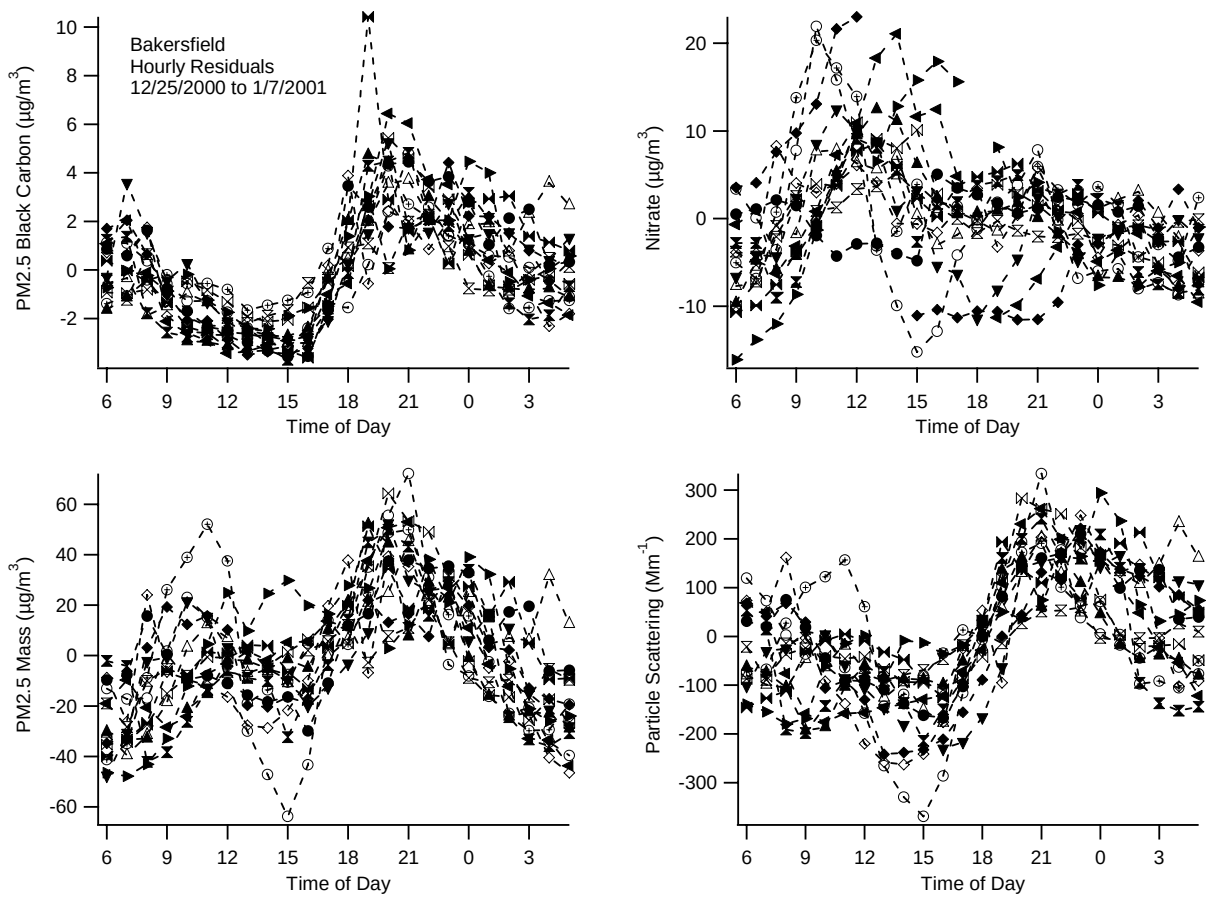
Bakersfield
Hourly Residuals
12/25/2000 to 1/7/2001
PM2.5 Black Carbon (µg/m3)
Nitrate (µg/m3)
PM2.5 Mass (µg/m3)
Particle Scattering (Mm-1)
Time of Day

Figure 7.

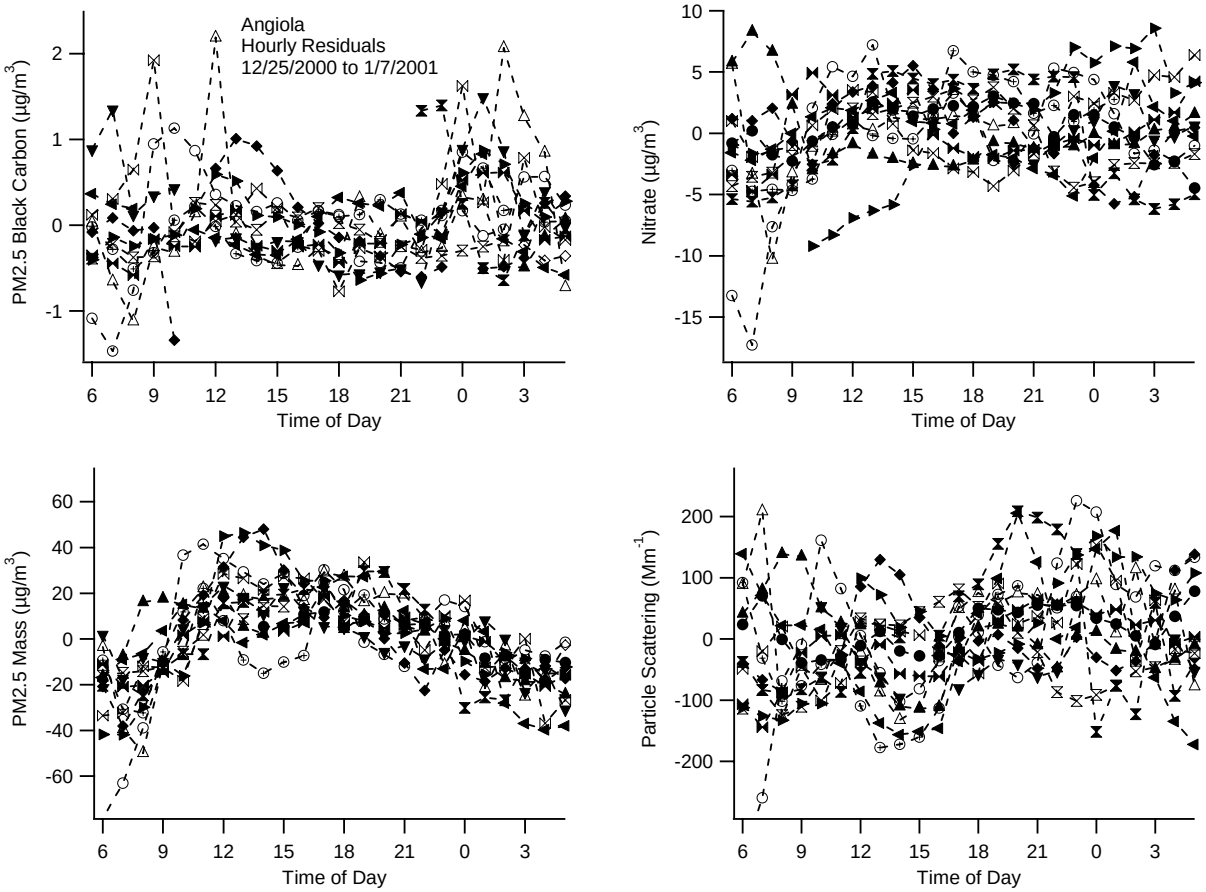
Angiola
Hourly Residuals
12/25/2000 to 1/7/2001
PM2.5 Black Carbon (µg/m3)
Nitrate (µg/m3)
PM2.5 Mass (µg/m3)
Particle Scattering (Mm-1)
Time of Day

Figure 8.

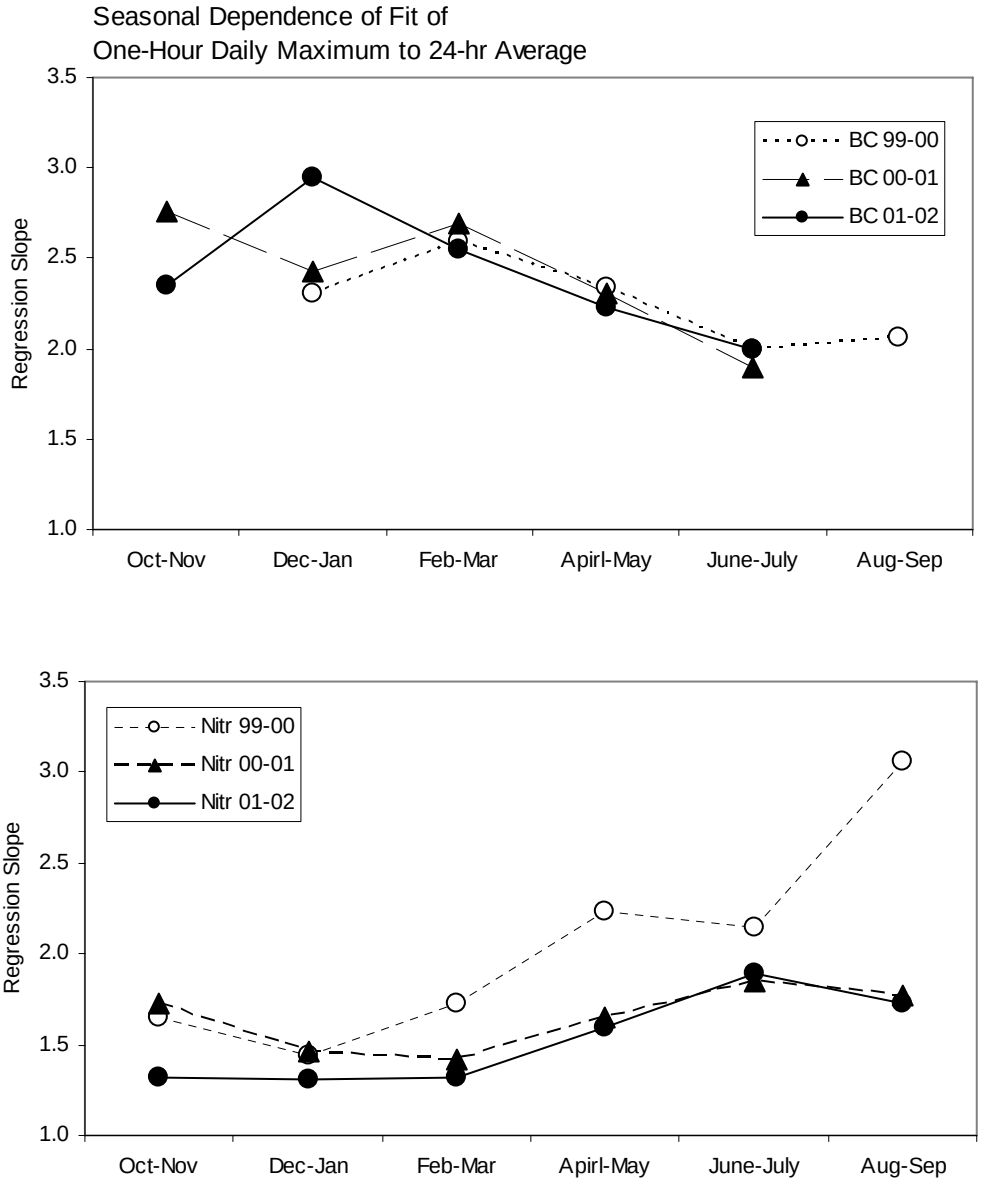
Seasonal Dependence of Fit of
One-Hour Daily Maximum to 24-hr Average
Regression Slope
3.5
3.0
2.5
2.0
1.5
1.0
BC 99-00
BC 00-01
BC 01-02
Oct-Nov
Dec-Jan
Feb-Mar
Apirl-May
June-July
Aug-Sep
Regression Slope
3.5
3.0
2.5
2.0
1.5
1.0
Nitr 99-00
Nitr 00-01
Nitr 01-02
Oct-Nov
Dec-Jan
Feb-Mar
Apirl-May
June-July
Aug-Sep

Figure 9.

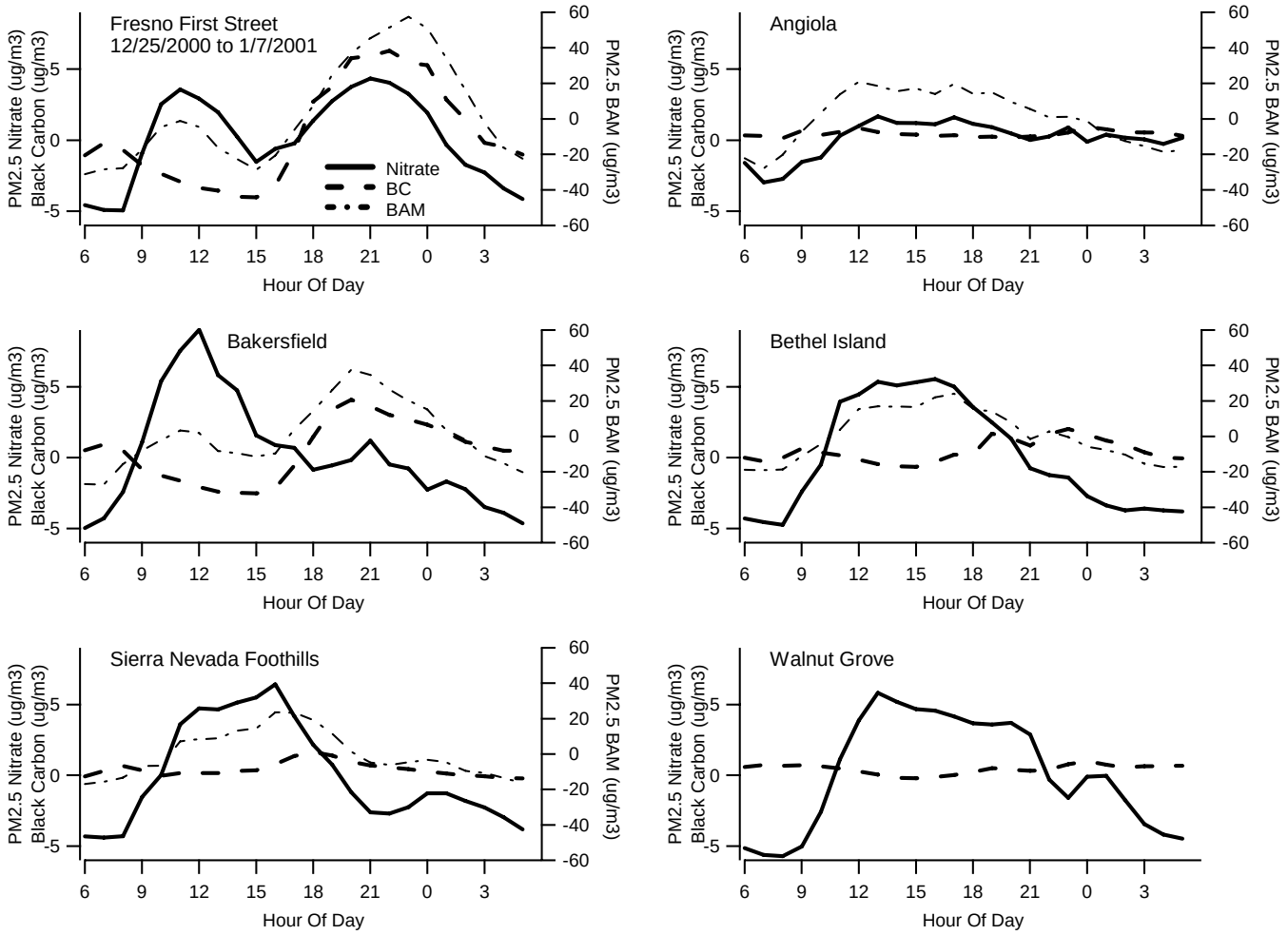
Fresno First Street
12/25/2000 to 1/7/2001
Nitrate
BC
BAM
Angiola
Bakersfield
Bethel Island
Sierra Nevada Foothills
Walnut Grove
PM2.5 Nitrate (ug/m3)
Black Carbon (ug/m3)
PM2.5 BAM (ug/m3)
Hour Of Day
6
9
12
15
18
21
0
3
60
40
20
0
-20
-40
-60
5
0
-5

Figure 10.

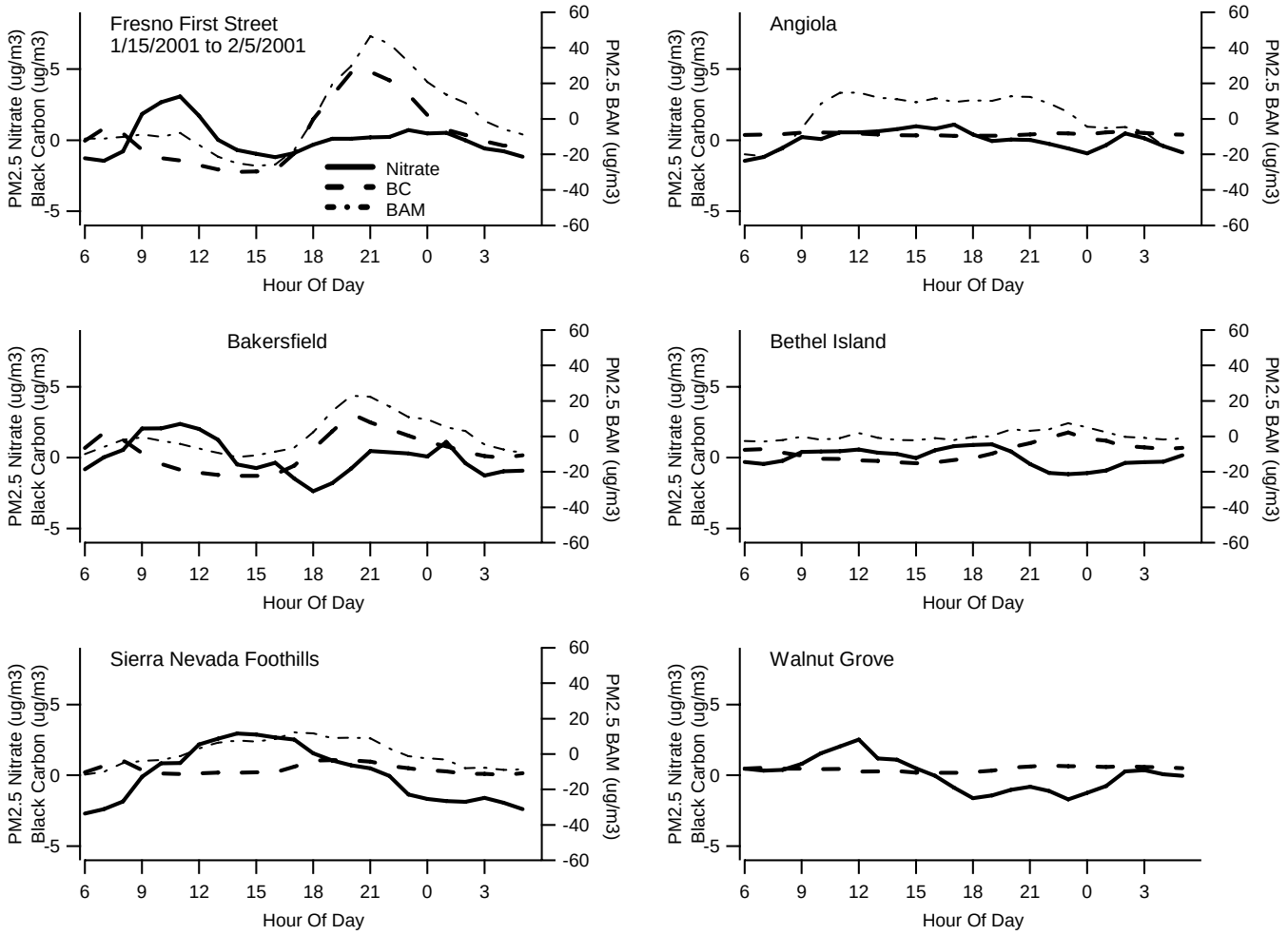
Fresno First Street
1/15/2001 to 2/5/2001
Nitrate
BC
BAM
Angiola
Bakersfield
Bethel Island
Sierra Nevada Foothills
Walnut Grove
PM2.5 Nitrate (ug/m3)
Black Carbon (ug/m3)
PM2.5 BAM (ug/m3)
Hour Of Day
6
9
12
15
18
21
0
3
5
0
-5
60
40
20
0
-20
-40
-60

Figure 11.

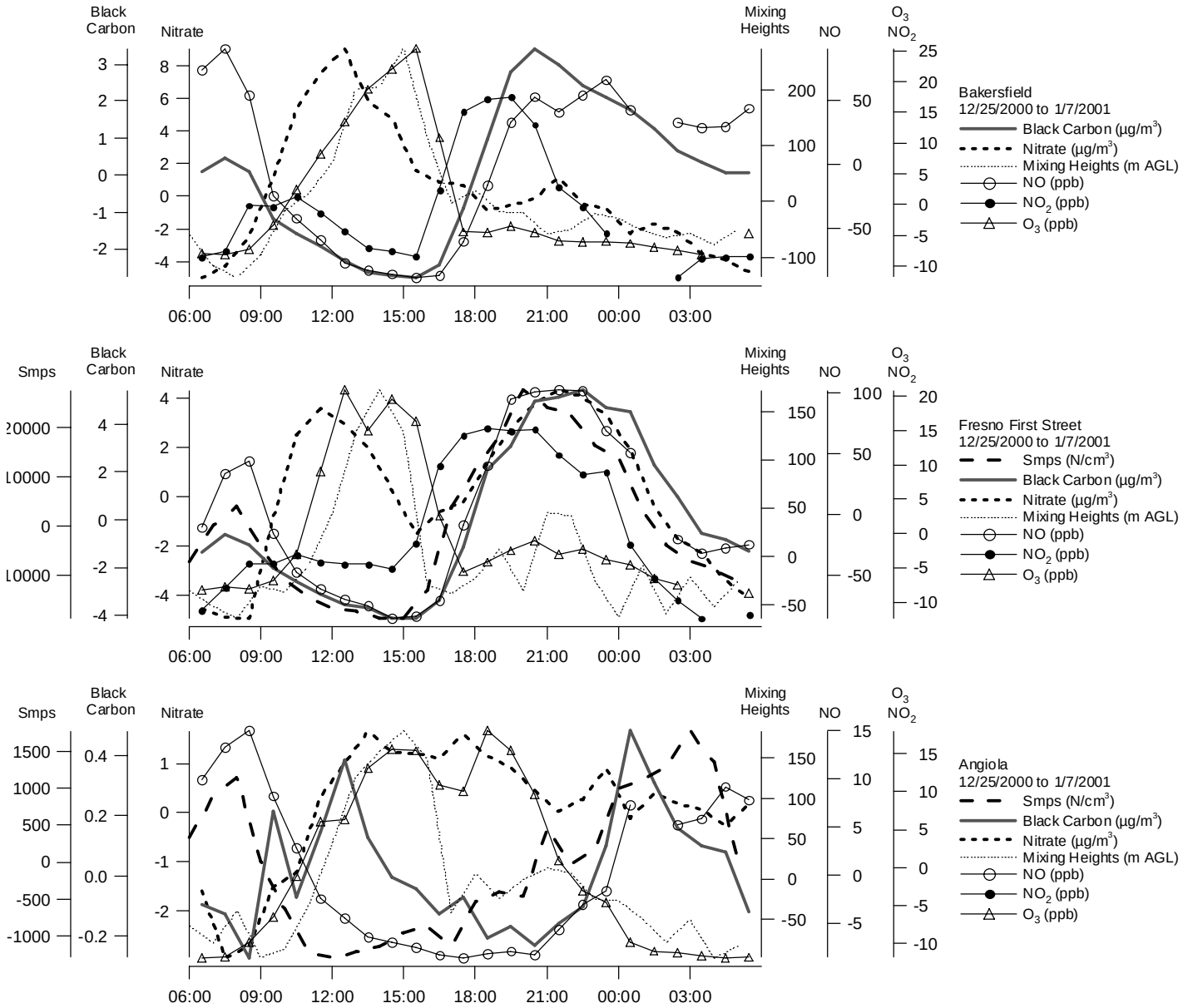
Black Carbon
Nitrate
Mixing Heights
NO
O_3
NO_2
Bakersfield
12/25/2000 to 1/7/2001
Black Carbon (µg/m^3)
Nitrate (µg/m^3)
Mixing Heights (m AGL)
NO (ppb)
NO_2 (ppb)
O_3 (ppb)
06:00
09:00
12:00
15:00
18:00
21:00
00:00
03:00
Smps
Fresno First Street
12/25/2000 to 1/7/2001
Smps (N/cm^3)
Angiola
12/25/2000 to 1/7/2001

Fig 12.

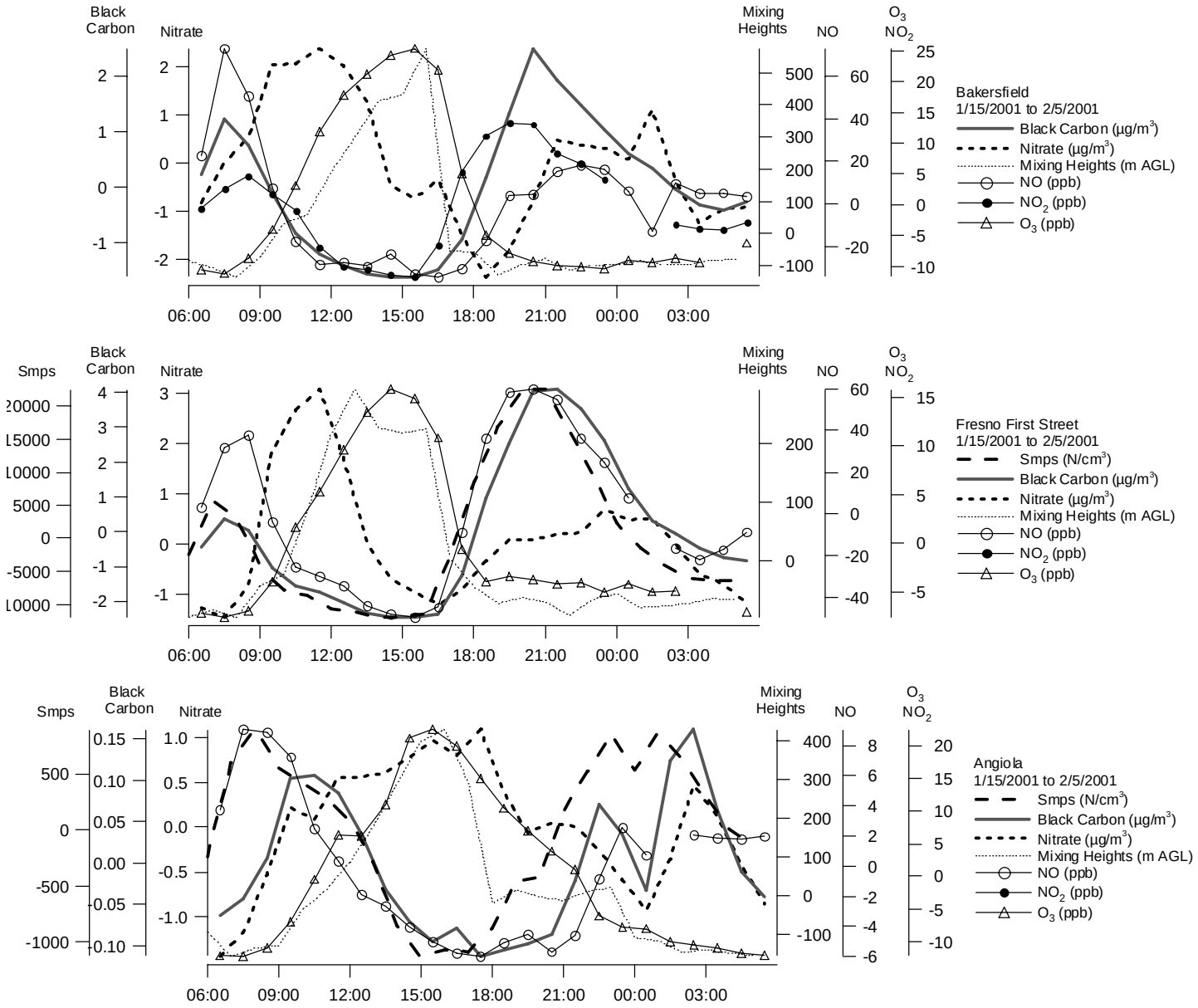
Black Carbon
Nitrate
Mixing Heights
NO
O3
NO2
Bakersfield
1/15/2001 to 2/5/2001
Black Carbon (µg/m3)
Nitrate (µg/m3)
Mixing Heights (m AGL)
NO (ppb)
NO2 (ppb)
O3 (ppb)
06:00
09:00
12:00
15:00
18:00
21:00
00:00
03:00
Smps
Fresno First Street
1/15/2001 to 2/5/2001
Smps (N/cm3)
Angiola
1/15/2001 to 2/5/2001

Fig 13.

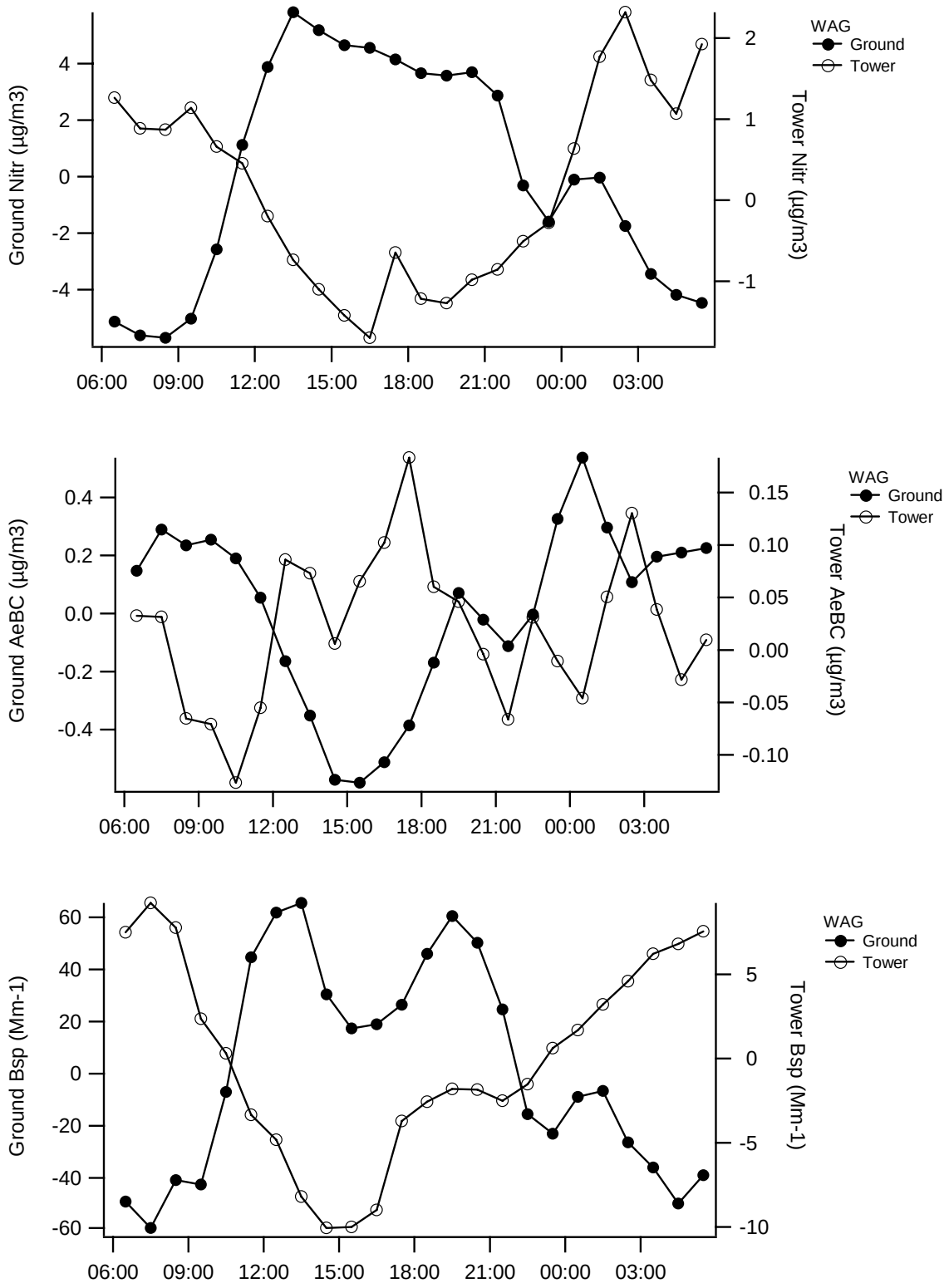
Ground Nitr (µg/m3)
Tower Nitr (µg/m3)
WAG
Ground
Tower
Ground AeBC (µg/m3)
Tower AeBC (µg/m3)
Ground Bsp (Mm-1)
Tower Bsp (Mm-1)
06:00
09:00
12:00
15:00
18:00
21:00
00:00
03:00

Figure 14.