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Comparison of Two Winter Air Quality Episodes during the California Regional Particulate Air Quality Study

Kasia Turkiewicz, Karen Magliano, and Theresa Najita
California Air Resources Board, Sacramento, CA

ABSTRACT

The duration, strength, spatial extent, and chemical makeup of particulate matter (PM) are compared for two winter air quality episodes captured during the California Regional Particulate Air Quality Study (CRPAQS). Each episode, from the beginning of the buildup through dissolution, lasted about 3 weeks. The first episode occurred from December 14, 1999, through January 1, 2000, with peak 24-hr average fine particulate matter ($PM_{2.5}$) concentrations reaching 129 $\mu g/m^3$. The second episode occurred a year later, from December 18, 2000, through January 8, 2001, with peak 24-hr average $PM_{2.5}$ concentrations reaching 179 $\mu g/m^3$. Although similar in duration, each episode exhibited unique characteristics. One significant difference was the episode buildup rate; rapid in 1999, but slow and steady in 2000. The rapid buildup of the first episode resulted in more days with $PM_{2.5}$ concentrations above the 24-hr federal standard, whereas the slow and steady increase of the second episode produced higher peaks. Spatial extent and progress also differed between the two episodes. The Northern Valley was impacted more during the December 1999 episode, and the Southern Valley during the December 2000 episode. The differences carried over into chemical composition. Ammonium nitrate dominated the $PM_{2.5}$ mass during the December 1999 episode. The second episode reflected a dichotomy typical to the San Joaquin Valley, with Fresno concentrations dominated by organic and elemental carbon and the rest of the Valley concentrations dominated by ammonium nitrate. Each episode showed a regional as well as a local component. Ammonium nitrate concentrations, which result from more regional-scale secondary formation and mixing of emissions, were fairly uniform among the urban and rural sites. Carbon concentrations were always higher at urban sites than at rural sites, corresponding to the higher emissions density of primary carbon sources in urban areas.

IMPLICATIONS

$PM_{2.5}$ concentrations in the San Joaquin Valley have a very strong seasonal pattern, with highest concentrations during winter. These high concentrations manifest themselves as multiday pollution episodes. Although the general weather pattern that leads to a PM episode is almost always the same (stagnant weather with low mixing heights and strong inversion), each episode shows unique characteristics, including buildup rates, strength, spatial extent, and chemical composition. Emission control strategies must address these differences to achieve compliance with the $PM_{2.5}$ National Ambient Air Quality Standard throughout the San Joaquin Valley.

INTRODUCTION

Particulate matter (PM) concentrations in the San Joaquin Valley vary with season.[1,2] High fine particulate matter ($PM_{2.5}$) concentrations occur almost exclusively during multiday pollution episodes under stagnant winter weather.[3] Although the episodes are infrequent, they can last for many days, resulting in multiple violations of the National Ambient Air Quality Standards (NAAQS). Based on the 1999–2001 average, the San Joaquin Valley experienced over 30 days/yr with $PM_{2.5}$ concentrations above the standard.[4] The start and end dates of an episode are determined on the basis of the meteorological conditions and the magnitude of PM concentrations. An episode is generally characterized by an upper-level ridge of high pressure over the San Joaquin Valley that results in shallow mixing heights and light winds, with buildup in PM concentrations above the level of one or both of the following NAAQS[5]: (1) 24-hr $PM_{2.5}$ standard of 65 $\mu g/m^3$; and (2) 24-hr particulate matter (PM_{10}) standard of 150 $\mu g/m^3$.

At the beginning of an episode, concentrations are low but increase daily because of both the accumulation of primary pollutants and the formation of secondary pollutants.[6] Concentrations continue to build until there is a change in the weather significant enough to wash out particles through rainfall or provide increased ventilation of the Valley.

The California Air Resources Board (CARB) and the local air districts have been monitoring PM concentrations in California since 1983. The California Regional Particulate Air Quality Study (CRPAQS) was designed to complement long-term monitoring to improve understanding of the PM program. During the CRPAQS field study, which ran from December 1999 through February 2001, the existing monitoring network was enhanced with additional sites and air quality and meteorological instruments. Although the existing routine network was designed to monitor $PM_{2.5}$ in populated areas,[7–9] many of the new sites were deployed in rural areas to better characterize the spatial extent of $PM_{2.5}$ and assess inter- and intrabasin transport.[10] CRPAQS captured seven air pollution episodes,[5] but two of them, occurring a year apart, stood out as the most severe in terms of both duration and concentration. The first one, referred to as the December 1999 episode, took place at the beginning of the study,

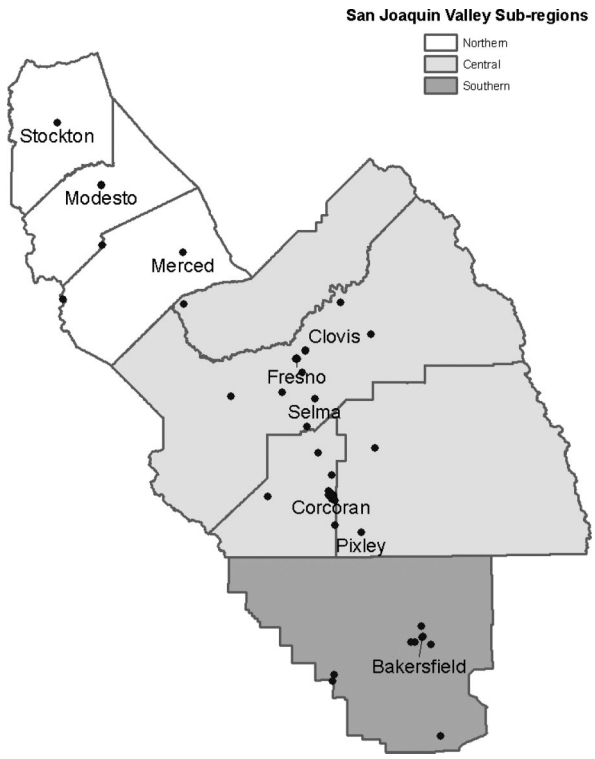


Figure 1. Locations of PM monitoring sites in the CRPAQS.

from December 14, 1999, through January 1, 2000. The second one, the December 2000 episode, occurred at the end of the study, from December 18, 2000, through January 8, 2001. This paper compares the duration, strength, spatial extent, and chemical makeup for these two episodes.

METHODS

Although the study domain included large portions of Northern and Central California, this analysis focused on the San Joaquin Valley, where most of the exceedances occurred. The San Joaquin Valley was divided into three parts: North, Central, and South (Figure 1). The northern part comprised San Joaquin, Stanislaus, and Merced Counties, which included the urban areas of Stockton, Modesto, and Merced. The central portion of the Valley included Madera, Fresno, Kings, and Tulare Counties. Fresno was the largest urban center in this part of the Valley and included multiple monitoring sites. The southern area included Kern County, with multiple sites in the Bakersfield urban area.

In addition to the above urban sites, a number of rural sites were located throughout the Valley.[10] Two rural sites mentioned specifically in this analysis are Selma and Pixley, both in the central portion of the Valley. Selma was an intrabasin transport site ~24 km south/southeast of Fresno. Pixley, also an intrabasin transport site, was located in a wildlife refuge ~110 km south of Fresno and 50 km north of Bakersfield.

$PM_{2.5}$ mass measurements were collected using the following samplers[9–12]: (1) Sequential Reference Ambient Aerosol Sampler (RAAS; Andersen Instruments, Smyrna, CA); (2) Spiral Aerosol Speciation Sampler (SASS; Met One, Grants Pass, OR); (3) Sequential Filter Sampler (SFS; Desert Research Institute [DRI], Reno, NV); and (4) Minivol Portable Air Sampler (Airmetrics, Eugene, OR).

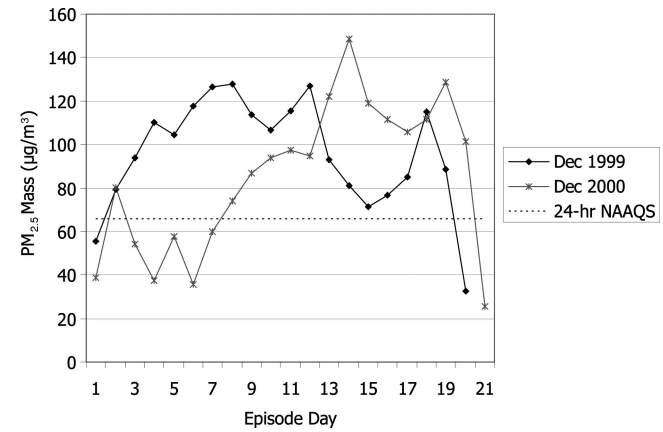


Figure 2. $PM_{2.5}$ concentrations at Fresno during two winter episodes.

In addition to measuring $PM_{2.5}$ mass, all SASS samples and selected SFS and Minivol samples were analyzed for elements, anions (nitrate and sulfate), cations (ammonium, sodium, and potassium), and total carbon (organic, elemental, and carbonate).[9,10] The chemical composition data were used to calculate the following components[13]:

- Ammonium nitrate: 1.29*nitrate
- Ammonium sulfate: 1.38*sulfate
- Organics: 1.4*organic carbon
- Elemental carbon: as measured
- Carbonaceous aerosols: organics + elemental carbon
- Geological materials: (1.89*aluminum) + (2.14*silicon) + (1.4*calcium) + (1.43*iron)
- Elemental species: sum of elements not included above.

RESULTS

Duration and Buildup Rate

Each episode, from the beginning of the buildup through the dissolution, lasted about 3 weeks. This, however, was their only common feature. The December 1999 concentrations built rapidly and remained high for many days (Figure 2). $PM_{2.5}$ concentrations at the Fresno monitoring site first exceeded the $PM_{2.5}$ 24-hr standard on the second day of the episode and remained above the standard for 18 consecutive days. The second episode, December 2000, was characterized by a slow and steady increase in $PM_{2.5}$ concentrations. Concentrations at the Fresno site briefly exceeded the standard on the second day, but declined only a day later. The consecutive exceedance days did not start until the 8th day of the episode and then continued for 12 days. Both episodes finally ended when a storm system moved into the area, breaking down the stagnation period and scavenging particles with rain.

Rural sites followed the same mass buildup but were delayed in time by up to a few days. The duration and intensity of the atmospheric stability (as defined by limited mixing heights and strong inversion) influenced the degree of delay. The stability parameter, defined as the difference between the temperature at the 850-mb level

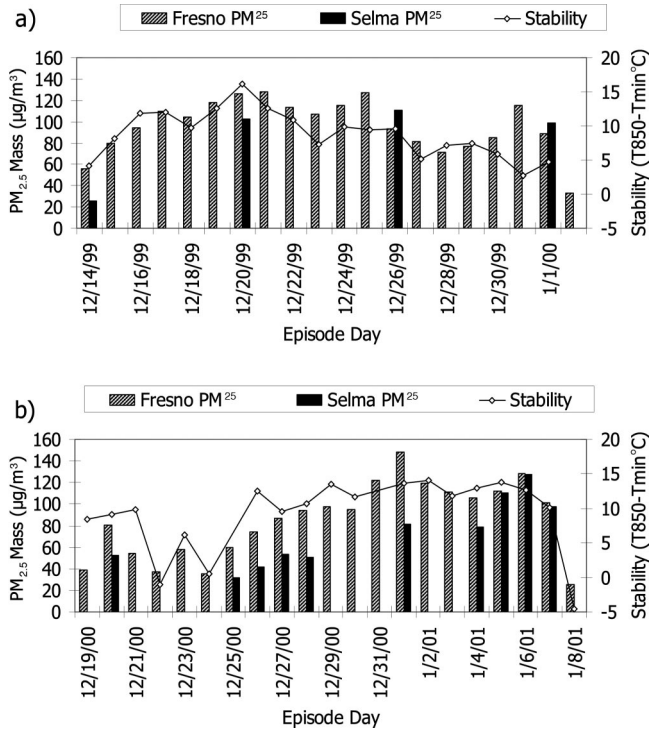


Figure 3. Atmospheric stability and buildup of $PM_{2.5}$ concentrations at an urban site (Fresno) and a rural site (Selma) in the Fresno area during: (a) the December 1999 episode; and (b) the December 2000 episode.

and the minimum surface temperature, was used in forecasting high PM concentrations. Weak pressure gradients during both episodes also contributed to the slow spread of PM and gaseous precursors throughout the Valley.[3] Figure 3a shows that the atmosphere was stable from the beginning of the December 1999 episode but then improved after the 7th day. During the December 1999 episode, rural concentrations built up almost as rapidly as urban. The $PM_{2.5}$ concentrations at Selma, a rural site ~24 km south/southeast of Fresno, were only 20% lower on the 7th day, and by the 13th day they exceeded urban concentrations (Figure 3a). The December 2000 episode had a longer lag time between urban and rural concentrations (Figure 3b). It took 18 days for rural concentrations to catch up with urban. Atmospheric stability decreased early in the episode, but then increased strongly after the first week, accounting for the delay in peak concentrations as well as the lag between urban and rural sites. Although, at the end of the episode, rural sites may have higher concentrations than urban sites, they still have fewer days above the standard and lower episode-average concentrations because of the lag in the buildup rate. During the December 1999 episode, based on 11 days with matching data, the rural site in Pixley had a peak concentration 6 $\mu g/m^3$ higher than an urban site in Bakersfield, but an episode-average concentration 20 $\mu g/m^3$ lower and two fewer measured days above the NAAQS.

Strength

The December 1999 episode had more cumulative days with unhealthy $PM_{2.5}$ levels, but peak concentrations were higher during the second episode in 2000. Table 1 summarizes the strength of each episode. $PM_{2.5}$ concentrations in the San Joaquin Valley exceeded the 24-hr standard on 18 days during the 1999 episode and 15 in 2000. Although the second episode had slightly fewer days above the standard, concentrations were higher. $PM_{2.5}$ concentrations exceeded the standard by more than 2-fold on 5 days. These very high concentrations, ranging from 131 to 179 $\mu g/m^3$, were found at multiple urban and rural locations throughout the Valley. The highest, on January 5, 2001, was measured at Edison in the Southern Valley near Bakersfield. The peak PM_{10} concentration was also in the Southern Valley, that was 208 $\mu g/m^3$ measured in Bakersfield on January 4, 2001.

Table 1. Episode strength comparison.

Statistics	Dec 1999 Episode	Dec 2000 Episode
Days exceeding $PM_{2.5}$ standard	18	15
Days exceeding $PM_{2.5}$ standard by more than 2-fold	0	5
Max PM_{10}	174 $\mu g/m^3$	208 $\mu g/m^3$
Max $PM_{2.5}$	129 $\mu g/m^3$	179 $\mu g/m^3$

Peak concentrations were significantly lower during the December 1999 episode. The highest $PM_{2.5}$ value was 129 $\mu g/m^3$ measured at Clovis, in the central portion of the Valley near Fresno, on December 20, 1999. Similarly, PM_{10} concentrations were also lower, with the peak of 174 $\mu g/m^3$ captured at Corcoran on December 17, 1999.

Spatial Differences

The large-scale meteorological conditions were dominated by a strong upper-level ridge of high pressure located over Central California during both episodes. The high-pressure system caused stagnant conditions with strong inversion, low mixing heights, and light and variable winds. However, the position of the ridge that defines the area of greatest stability was further to the north in December 1999 than in December 2000, which resulted in different spatial patterns in the location of peak concentrations and chemical composition. Figures 4a and 4b illustrate peak $PM_{2.5}$ concentrations for each day for the December 1999 and December 2000 episodes, respectively. The December 1999 episode initially centered over the Northern and Central Valley, with concentrations from Stockton in the north to Fresno in the south approaching or even exceeding 100 $\mu g/m^3$. The winds were generally light and disorganized, except for several days when enhanced wind flow from the north, with a speed of 2–4 m/sec for several hours during the day, helped to spread concentrations to the south. As a result, monitoring sites such as Corcoran and Pixley reached $PM_{2.5}$ concentrations of 100 $\mu g/m^3$. Although high, concentrations in Bakersfield in the Southern Valley were on average 30% lower than the more central Fresno sites.

The December 2000 episode started out with high concentrations in the Southern and Central Valley (Figure 4b). The two regions followed the same temporal pattern. $PM_{2.5}$ concentrations briefly peaked on December 20, declined slightly the next day, and by December 24 began a

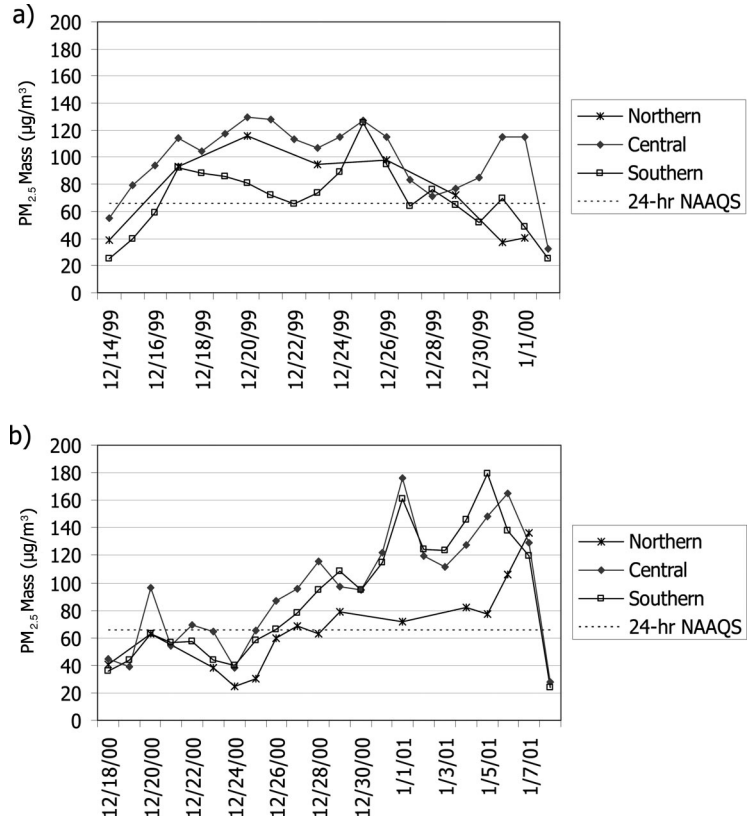


Figure 4. Peak $PM_{2.5}$ concentrations in the Northern, Central, and Southern San Joaquin Valley during: (a) the December 1999 episode; and (b) the December 2000 episode.

slow and steady increase. By January 1, 2001, multiple sites in the Southern and Central Valley had $PM_{2.5}$ concentrations greater than 100 $\mu g/m^3$. The highest concentration on January 1 (176 $\mu g/m^3$) was captured at a Fresno site. Once again the winds were light and disorganized, except for the last few days of the episode when the southerly winds increased ahead of an approaching frontal system, spreading concentrations to the north. During this period of enhanced wind flow, the Sacramento Valley and the San Francisco Bay Area experienced $PM_{2.5}$ concentrations above the federal $PM_{2.5}$ standard.

Chemical Composition

During winter episodes, over 80% of the $PM_{2.5}$ mass in the Central Valley of California comes from ammonium nitrate and carbonaceous aerosols [organics and elemental carbon (EC)].[1,2,14] The relative proportions between ammonium nitrate and carbonaceous material depend on site characteristics and location. Rural sites throughout the San Joaquin Valley had $PM_{2.5}$ mass dominated by ammonium nitrate (~60%) with a small carbonaceous fraction (~20%; Figure 5). Urban chemical composition was more location-dependent, with most of the sites, including Bakersfield, exhibiting more ammonium nitrate (~55%) than carbonaceous material (~30%). However, the opposite was true for the Fresno area, with ~35% ammonium nitrate and ~50% carbonaceous aerosols. Rural sites, despite the relatively small contribution from carbonaceous material, had a potential to achieve $PM_{2.5}$ concentrations similar to or even higher than urban sites, because of higher concentrations of ammonium nitrate that compensated for the deficit in carbonaceous material.

The variations in terrain, emissions, and meteorology throughout the San Joaquin Valley produced subregions with different $PM_{2.5}$ concentrations and chemical characteristics. Although concentrations of carbonaceous material varied significantly even within a subregion, ammonium nitrate concentrations were relatively uniform, especially toward the end of the episode. The most uniform concentrations were measured on December 26, 1999, during the first episode and on January 6, 2001,

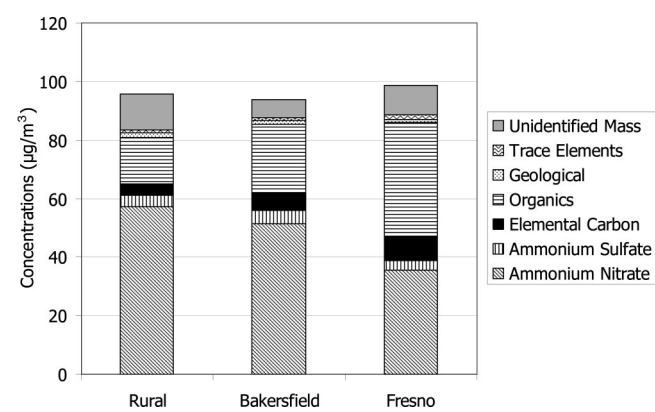
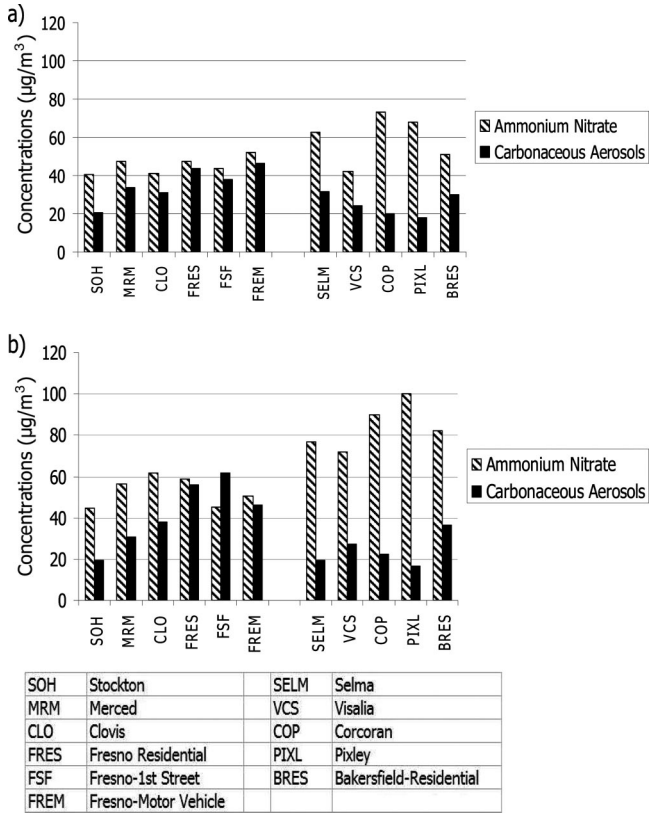


Figure 5. Comparison of $PM_{2.5}$ chemical composition on a high $PM_{2.5}$ day at urban and rural locations (average based on days with concentrations greater than 65 $\mu g/m^3$).



SOH	Stockton		SELM	Selma
MRM	Merced		VCS	Visalia
CLO	Clovis		COP	Corcoran
FRES	Fresno Residential		PIXL	Pixley
FSF	Fresno-1st Street		BRES	Bakersfield-Residential
FREM	Fresno-Motor Vehicle			

Figure 6. Spatial variation of $PM_{2.5}$ ammonium nitrate and carbonaceous aerosols on: (a) December 26, 1999, during the December 1999 episode; and (b) January 6, 2001, during the December 2000 episode.

during the second episode (Figures 6a and 6b). One subregion, with lower but still fairly uniform ammonium nitrate concentrations, extended from Stockton in the north to Fresno in the south. During the December 1999 episode, ammonium nitrate concentrations in this area ranged from 40 to 52 $\mu g/m^3$, and the spatial coefficient of variation was 10%. During the second episode, concentrations were slightly higher, from 45 to 62 $\mu g/m^3$, but still fairly uniform with 14% coefficient of variation. Carbonaceous aerosols in this area exhibited a wider range of concentrations than ammonium nitrate, from 20 to 46 $\mu g/m^3$ in December 1999 and from 20 to 62 $\mu g/m^3$ in December 2000, and almost three times higher coefficient of variation. The second subregion encompassed an area south of Fresno, including Bakersfield. The ammonium nitrate concentrations in this area were not only higher, but also more uniform, especially during the December 2000 episode when, despite very high concentrations ranging from 72 to 100 $\mu g/m^3$, the coefficient of variation was only 13%. Concentrations of carbonaceous aerosols were much more variable, especially during the December 2000 episode, when they ranged from 16 to 37 $\mu g/m^3$ and had a 32% coefficient of variation.

This difference in spatial distribution between ammonium nitrate and carbonaceous aerosols was related to their origin and formation. Ammonium nitrate is considered a secondary pollutant (formed from directly emitted gases by transformation in the atmosphere).[15] Much of ammonium nitrate is believed to be formed aloft and controlled by nitrogen oxides (NO_x) emission rates.[16] Spatial homogeneity of ammonium nitrate is influenced by higher wind speeds aloft (which allow more efficient transport) and diurnal variations in mixing heights (which allow entrainment of ammonium nitrate down to the surface). Stagnant meteorological conditions at the surface allow significant accumulation of not only ammonium nitrate but also primary pollutants (directly emitted into the atmosphere as a particle). Most of the carbonaceous aerosols, including all of EC and over 80% of organics, are considered a primary pollutant.[16,17] Because they are emitted into the atmosphere as particles, their transport is more limited compared with gaseous ammonium nitrate precursors. Stagnant meteorological conditions hinder it even further, resulting in significant accumulation close to the source. Concentrations of carbonaceous material were two to three times higher at urban sites than at rural because of the greater number of primary emission sources in the urban areas.

Although $PM_{2.5}$ concentrations are always comprised of different chemical components, ammonium nitrate drives the valleywide exceedances of the $PM_{2.5}$ standard (Figures 7a and 7b). During the December 1999 episode, ammonium nitrate concentrations first peaked in the Northern and Central San Joaquin Valley (December 20, 1999) and alone were high enough to violate the 24-hr $PM_{2.5}$ standard. Six days later, on December 26, 1999, the peak ammonium nitrate concentrations dropped by 20 $\mu g/m^3$ in the Northern Valley but increased by 3 $\mu g/m^3$ in the Southern Valley. During the December 2000 episode, high ammonium nitrate concentrations were first measured in the Southern and Central Valley. Toward the end of the episode (January 5–7, 2001), southerly winds picked up ahead of the approaching frontal system.[18] The peak ammonium nitrate concentrations increased over 30 $\mu g/m^3$ in the Northern San Joaquin Valley but decreased in the Central and Southern Valley by 20 and 40 $\mu g/m^3$, respectively.

The December 2000 episode was more severe than the December 1999 episode at most of the San Joaquin Valley sites, including Bakersfield and Fresno (Figure 8). At Bakersfield the two main components of the $PM_{2.5}$ mass, ammonium nitrate and carbonaceous aerosols, were higher during the second episode by 70 and 50%, respectively. However, both episodes were dominated by ammonium nitrate, which is typical for a winter episode at Bakersfield. At Fresno, the two episodes had different chemical composition. The second episode, December 2000, with $PM_{2.5}$ mass dominated by carbonaceous material represented a typical winter episode at Fresno. The first episode, with more ammonium nitrate than carbonaceous material, was rather unusual for this area. The position of the ridge over Central California, which was further to the north during the December 1999 episode, may have resulted in higher stability and the enhanced potential for greater accumulation of ammonium nitrate over the Fresno area during the first episode. Colder overnight minimum temperatures in the Valley, which led to enhanced wood burning, combined with stronger surface-based inversions resulted in higher concentrations of carbonaceous material during the December 2000 episode

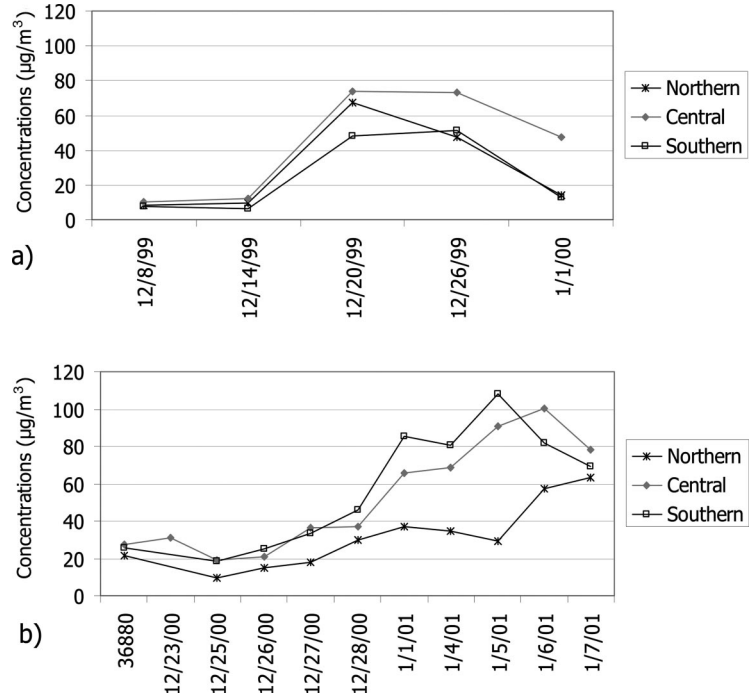


Figure 7. Peak $PM_{2.5}$ ammonium nitrate concentrations during: (a) the December 1999 episode; and (b) the December 2000 episode.

compared with December 1999 at Bakersfield as well as Fresno (Figure 8).

CONCLUSIONS

The two PM episodes that occurred almost a year apart, December of 1999 and December of 2000, produced very high $PM_{2.5}$ concentrations throughout the San Joaquin Valley for almost 3 weeks each. Although similar meteorology brought on both episodes (low mixing heights and strong inversions), each had its own unique characteristics. The more stable air during the early part of the December 1999 episode resulted in a quick buildup of concentrations, as opposed to the slow and steady buildup brought on by the slower increase in stability during the second episode. The more rapid 1999 buildup produced more exceedance days, whereas the slow and steady buildup of 2000 resulted in higher peaks. The December 1999 episode affected the Northern and Central Valley more than Southern Valley, whereas the December 2000 episode was more prominent in the Southern and Central Valley.

On days when $PM_{2.5}$ concentrations exceeded the 24-hr standard, ammonium nitrate and carbon comprised over 80% of the $PM_{2.5}$ mass. Ammonium nitrate concentrations were higher than carbon at all rural and most urban sites. Only urban sites in the Fresno area stood out

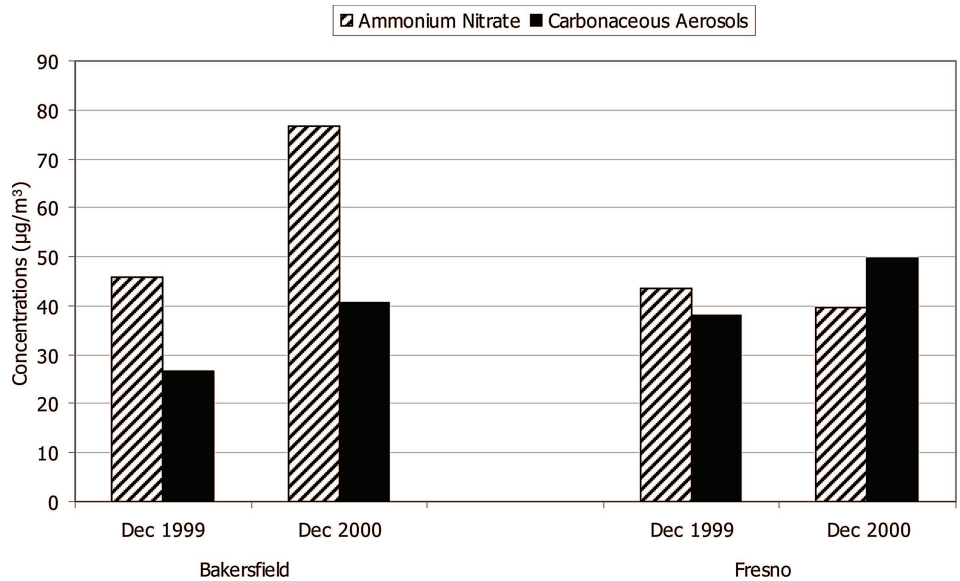


Figure 8. Comparison of $PM_{2.5}$ ammonium nitrate and carbonaceous aerosols concentrations during the December 1999 episode (December 26, 1999) and the December 2000 episode (January 4, 2001) at Bakersfield and Fresno.

as having more carbon than ammonium nitrate, but this too was episode-dependent. During the first episode, ammonium nitrate concentrations exceeded carbon even in the Fresno area. Because of differences in formation (secondary for ammonium nitrate and primary for carbon), the two components exhibited different spatial patterns. Ammonium nitrate concentrations were more uniform spatially, and their buildup pattern was consistent with the $PM_{2.5}$ mass buildup. Total carbon concentrations were more localized and were always higher in the urban than rural environment. Tracking daily changes in ammonium nitrate concentrations showed that these concentrations spread in the opposite direction, to the south in December 1999 and to the north in December 2000.

REFERENCES

1. Motallebi, N.; Taylor, C.A.; Croes, B.E. Spatial, Temporal, and Compositional Patterns of $PM_{2.5}$, PM_{10-25}, and PM_{10}; *J. Air & Waste Manage. Assoc.* **2003**, *53,* 1517-1530.
2. Chow, J.C.; Egami, R.T. San Joaquin Valley Integrated Monitoring Study: Documentation, Evaluation, and Descriptive Analysis of PM_{10}, $PM_{2.5}$, and Precursor Gas Measurement; Technical Support Studies No. 4 and No. 8, Final Report; prepared for California Regional Particulate Air Quality Study, Sacramento, CA, by Desert Research Institute: Reno, NV, 1997.
3. Ferreria, S.R.; Shipp, E.M. Historical Meteorological Analysis in Support of the 2003 San Joaquin Valley PM_{10} State Implementation Plan; San Joaquin Valley Air Pollution Control District: Fresno, CA, 2005.
4. The 2003 California Almanac of Emissions and Air Quality; California Air Resources Board: Sacramento, CA, 2003.
5. Particulate Matter Air Quality Episodes during California Regional $PM_{2.5}/PM_{10}$ Air Quality Study; California Air Resources Board: Sacramento, CA, 2005.
6. Watson, J.G.; Chow, J.C.A. Wintertime $PM_{2.5}$ Episode at the Fresno, CA, Supersite; *Atmos. Environ.* **2002**, *36,* 465-475.
7. Turkiewicz, K.; O'Brien, G.; Rothacker, R.; Montez, N.; Motallebi, N. California Particulate Matter Monitoring Network Description; California Air Resources Board: Sacramento, CA, 1998.
8. Watson, J.G.; Chow, J.C.; DuBois, D.W.; Green, M.C.; Frank N.H.; Pitchford, M.L. Guidance for Network Design and Optimal Site Exposure for $PM_{2.5}$ and PM_{10}; EPA-454/R-99-022; U.S. Environment Protection Agency: Research Triangle Park, NC, 1997.
9. Chow, J.C.; Watson, J.G. Guideline on Speciated Particulate Matter Monitoring; prepared for California U.S. Environmental Protection Agency, Research Triangle Park, NC, by Desert Research Institute: Reno, NV, 1998; available at http://www.epa.gov/ttn/amtic/specgen.html (accessed Sept 2005).
10. Watson, J.G.; DuBois, D.W.; DeMandel, R.; Kaduwela, A.P.; Magliano, K.L.; McDade, C.; Mueller, P.K.; Ranzieri, A.J.; Roth, P.M.; Tanrikulu, S. Field program plan for the California Regional $PM_{2.5}/PM_{10}$ Air Quality Study (CRPAQS); prepared for California Air Resources Board: Sacramento, CA, by Desert Research Institute: Reno, NV, 1998; available at http://www.arb.ca.gov/airways/crpaqs/publications.htm#field (accessed Sept 2005).
11. Chow, J.C. Measurement Methods to Determine Compliance with Ambient Air Quality Standards for Suspended Particles; *J. Air & Waste Manage. Assoc.* **1995**, *45,* 320-382.
12. Chow, J.C.; Watson, J.G.; Lowenthal, D.H.; Chen, L.A.; Tropp, R.; Park, K.; Magliano, K. $PM_{2.5}$ and PM_{10} Mass Measurements in California's San Joaquin Valley; *Aerosol Sci. Technol.*, submitted for publication.
13. Solomon, P.A.; Fall, T.; Salomon, L.; Cass, G.R.; Gray, H.A.; Davidson, A. Chemical Characteristics of PM_{10} Aerosols Collected in the Los Angeles Area; *JAPCA*, **1989**, *39,* 154-163.
14. Chow, J.C.; Watson, J.G.; Lowenthal, D.H.; Solomon, P.A.; Magliano, K.L;. Ziman; S.D.; Richards, L.W. PM_{10} and $PM_{2.5}$ Compositions in California's San Joaquin Valley; *Aerosol. Sci. Technol.* **1993**, *18,* 105-128.
15. Watson, J.G.; Chow, J.C.; Lurmann, F.; Musarra, S. Ammonium Nitrate, Nitric Acid, and Ammonia Equilibrium in Wintertime Phoenix, Arizona; *J. Air & Waste Manage. Assoc.* **1994**, *44,* 405-412.
16. Lurmann, F.W.; Brown, S.G.; McCarthy, M.C.; Roberts, P.T. Processes Influencing Secondary Aerosol Formation in the San Joaquin Valley during Winter; *J. Air & Waste Manage. Assoc.*, submitted for publication.
17. Pun, B. CRPAQS Data Analysis Task 2.7; prepared for California Air Resources Board: Sacramento, CA, by Atmospheric and Environmental Research, Inc.: San Ramon, CA, 2004; available at: http://www.arb.ca.gov/airways/crpaqs/da/final/AER27.pdf (accessed Dec 2005).
18. Lilly, M.R.; MacDonald, C.P.; Roberts, P.T.; Dye, T.S.; Wheeler, N.J.M. Transport and Dispersion during Wintertime Particulate Matter Episodes in the San Joaquin Valley, California; *J. Air & Waste Manage. Assoc.*, submitted for publication.

About the Authors

Kasia Turkiewicz and Theresa Najita are air pollution specialists, and Karen Magliano is chief of the Air Quality Data Branch at the California Air Resources Board in Sacramento, CA. Address correspondence to: Kasia Turkiewicz, California Air Resources Board, P.O. Box 2815, Sacramento, CA 95812; phone: +1-916-445-6497; fax: +1-916-327-8524; e-mail: kturkiew@arb.ca.gov.