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Dispersion Meteorology for the Fall 2000 and Winter 2001 California Regional $PM_{10}/PM_{2.5}$ Air Quality Study Episode

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Dispersion Meteorology for the Fall 2000 and Winter 2001 California Regional $PM_{10}/PM_{2.5}$ Air Quality Study Episode

During the Fall 2000 and Winter 2001 episode, strong high pressure at the surface and aloft resulted in limited morning and afternoon mixing and light offshore wind flow. Cool damp mornings and strong stability contributed to the formation of nitrates and sulfates during the episode. The California Regional Particulate Air Quality Study (CRPAQS) fall and winter measurements can be divided into seven distinct events. These events, characterized by limited atmospheric dispersion, were separated by vigorous trough passages. Analysis of synoptic patterns shows that once a particulate period begins, a deep trough must traverse the region at both the upper levels of the atmosphere and at the surface as a cold frontal boundary in order to significantly decrease particulate matter (PM) concentrations. These types of troughs are normally associated with strong vertical mixing, moderate to high boundary layer mixing heights, precipitation, and wind speed and directional sheer within the boundary layer.

The meteorological analysis for CRPAQS utilized synoptic analyses, precipitation patterns, and atmospheric stability parameters to determine episode strength and periodicity. Analysis of $PM_{2.5}/PM_{10}$ ratios and nitrate levels reveal that when the overnight minimum temperature decreased to below 40 degrees Fahrenheit, coupled with significant warming aloft, fine particulate levels climbed. When prolonged periods of these conditions occurred, $PM_{2.5}$ levels climbed above the National Ambient Air Quality Standards (NAAQS). In even stronger more persistent stability regimes, PM_{10} exceeded the NAAQS. **Figure 1** shows precipitation, $PM_{2.5}$, PM_{10}, and stability parameters for the CRPAQS period at the Fresno-1st site. General patterns in these parameters were also evident at other sites. Precipitation influenced PM concentrations during CRPAQS. For the CRPAQS episode, when a frontal system was strong enough to produce precipitation of 0.10 inch or more of liquid water, 24 hour averaged $PM_{2.5}$ concentrations dropped to below 15 $\mu g/m^3$. Seven distinct events were identified when particulate levels lowered to near background levels.

Each event was marked by limited mixing heights with strong inversions of approximately 500 feet for 18 or more hours of the day. Maximum mixing depths of highest $PM_{2.5}$ concentration days ranged between 1,500 to 2,500 feet. Moisture availability from recent rainfall and minimal solar insulation, led to prime nitrate and sulfate forming conditions. Typically, light fog, with humidity measurements between 85 – 100% were needed in order to maximize particulate forming potential. The higher the humidity, the heavier and wetter the fog, resulted in the removal of particulates by wet deposition.

Within these seven distinct measurement periods, a violation of the Federal 24 hour $PM_{2.5}$ standard of 65 micrograms/cubic meter were recorded during the 4th, 5th, 6th, and 7th events at various locations across the San Joaquin Valley. The following analysis will investigate the meteorological and dispersion conditions surrounding each event.

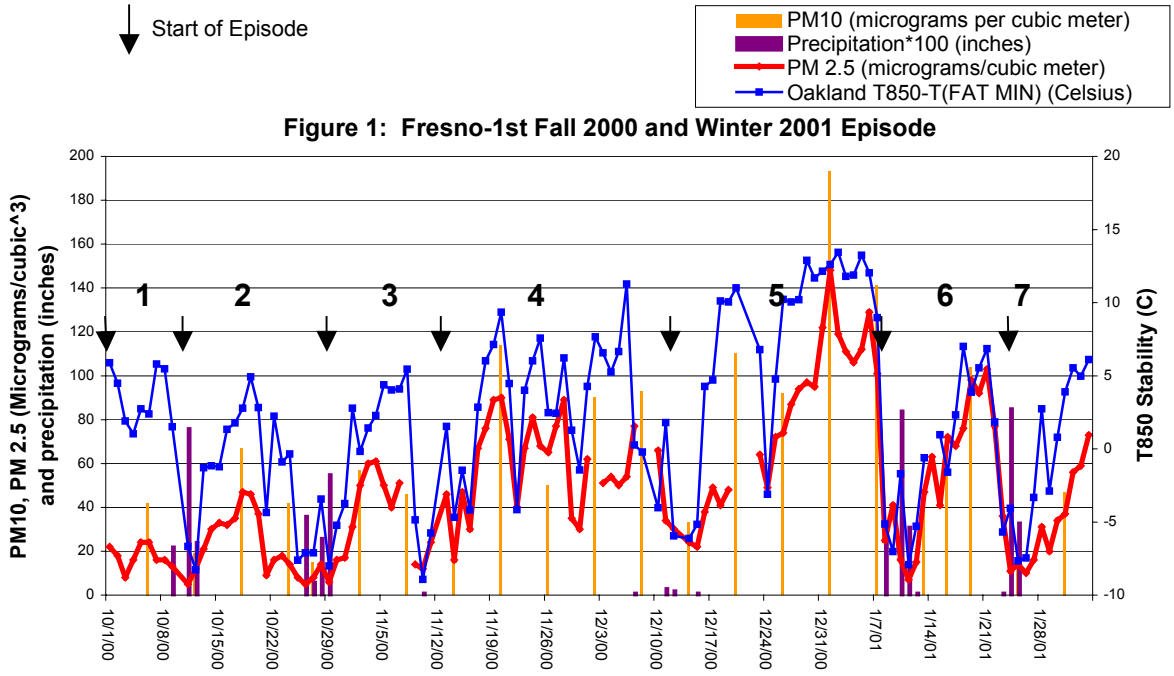


Figure 1: Fresno-1st Fall 2000 and Winter 2001 Episode

Event #4: November 16 through December 14, 2000

Meteorologically, dispersion worsened and particulate formation conditions became more favorable from November 16th to December 10th. As is evident in **Figure 1**, event #4 lasted about 28 days and was marked by two main $PM_{2.5}$ peaks, which exceeded the Federal Standard. After the passage of a weak cold front on November 14, 2000, which brought a trace to a few hundredths of an inch of precipitation across the region, moisture became available for atmospheric chemistry reactions. Humidity measurements of 90 – 100 % in the morning across the Valley Floor showed a moist atmosphere, with light fog and haze being reported on measured high $PM_{2.5}$ days. These cool damp mornings and strong stability favored the formation of nitrates and sulfates. It does not appear that the water content of the atmosphere was high enough to create deposition of particles that exceeded formation.

Synoptically during the first part of event #4, the eastern Pacific high built over the Pacific Northwest on November 17th then expanded southward on the 18th, bringing increasing stability and poor dispersion conditions through November 30th. From November 17th through the 30th, the high strengthened and intensified on November 19th through the 20th and once again on November 24th through the 28th, further tightening the lid and trapping the pollutants within the San Joaquin Valley boundary layer.

With a strong lid in place aloft and maximum high temperatures in the upper 50's to low 60's on the 19th and 20th, and upper 40's to low 50's on the 24th through the 27th, the afternoon hours were marked by limiting mixing, resulting in increasing particulate potential. Mixing heights at Fresno remained below 500 feet under a strong inversion

during a majority of the day (18 or more hours) on days when the fine particulates climbed above the standard. During the afternoon hours, there were high mixing depths (maximum mixing depth of 1,500 to 2,500 feet), but the bulk of the day had limited mixing. Maximum and minimum temperatures from November 19th through the 27th, were below normal, indicating a potential for increasing residential wood burning emission activity, and nitrate forming reactions.

Light fog and haze were reported at the Valley surface during the early morning hours of November 19th through the 27th, resulting in slightly lower solar radiation intensities. Along with lower solar radiation intensities due to the early morning fog and haze, low sun angle, and reduced daylight hours, the atmospheric chemistry reactions may have favored the secondary particulate forming regime. Light fog would be indicative of moderate atmospheric water content that contribute to the formation of ammonium nitrate. Heavier fogs result in the removal of particulates by wet deposition.

Meteorological data during the first part of event #4 showed limited mixing depths and light and disorganized wind flow resulted in minimal transport and dispersion of pollutants. Both primary and secondary pollutants from local emissions across the San Joaquin Valley accumulated resulting in the exceedance of the 24-hour $PM_{2.5}$ standard at Fresno-1st on November 19th, Modesto 14th, Clovis-Villa, Fresno-1st, Visalia-Church, Corcoran-Patterson, Oildale, Bakersfield-Golden and California on November 20th, Bakersfield-California on November 21st, Fresno-1st on November 24th, Bakersfield-California on November 25th, Bakersfield-Golden and California on November 26th, Bakersfield-California on November 27th, and Clovis-Villa, on November 28th.

A dissipating cold front moved over the San Joaquin Valley on the 29th, bringing an end to the first part of event #4 that lasted from November 16th through the 30th. The disturbance brought moderate dispersion conditions across the Valley, allowing for pollutants to lower into the 25 to 30 micrograms per cubic meter range, but was not significant enough to drop $PM_{2.5}$ levels to background.

High pressure rebuilt over the region on December 1st, leading to the second part of event #4. Meteorologically, dispersion rapidly deteriorated and particulate formation conditions became more favorable on December 2nd. Humidity measurements of 90 – 100 % in the morning across the Valley Floor showed a continued moist atmosphere, with light fog and haze being reported on measured high $PM_{2.5}$ days. These cool damp mornings and strong stability favored the formation of nitrates and sulfates.

Synoptically during the second part of event #4, the eastern Pacific high built along the West Coast on the 1st then expanded eastward on the 2nd, bringing increasing stability and poor dispersion conditions through the end of event # 4 on December 12. During this period, the high strengthened and intensified on December 2nd and once again on December 8th through the 10th, further tightening the lid trapping the pollutants within the San Joaquin Valley boundary layer.

With a strong lid in place aloft and maximum high temperatures in the upper 40's to low 50's, the afternoon hours of December 2nd through the 8th were marked by limiting mixing, resulting in increasing particulate potential. Mixing heights at Fresno remained below 500 feet under a strong inversion during a majority of the day (18 or more hours) on days when the fine particulates climbed above the standard. During the afternoon hours, there were high mixing depths (maximum mixing depth of 1,000 to 2,500 feet), but the bulk of the day had limited mixing.

Maximum and minimum temperatures from December 2nd through the 5th were slightly below normal and from December 7th to the 12th were above normal. Light fog and haze were reported at the Valley surface during the early morning hours of December 2nd through the 10th, resulting in slightly lower solar radiation intensities. Along with lower solar radiation intensities due to the early morning fog and haze, low sun angle, and reduced daylight hours, the atmospheric chemistry reactions may have favored the secondary particulate forming regime. Light fog would be indicated of moderate water content's that contribute to the formation of ammonium nitrate. Heavier fogs result in the removal of particulates by wet deposition.

Meteorological data during the second part of event #4 showed limited mixing depths and light and disorganized wind flow resulted in minimal transport and dispersion of pollutants. Daily filter measurements at Bakersfield-California and Fresno-1st indicated that between December 3rd and 4th, $PM_{2.5}$ levels dropped below the $PM_{2.5}$ standard in response to heavy fog, which lead to the removal of particulates by wet deposition. However, on the 7th and 8th the fog lifted to low clouds across the San Joaquin Valley causing both primary and secondary pollutants from local emissions across the region to accumulate resulting in the exceedance of the 24-hour $PM_{2.5}$ standard at various monitoring sites from December 5th through the 10th. An exceedance of the 24-hour $PM_{2.5}$ standard were measured at Bakersfield California on December 5th through the 10th, Modesto-14th, Clovis-Villa, Fresno 1st, Visalia, Corcoran, Oildale, Bakersfield-Golden, and Edison, on December 8th, and Fresno 1st on December 9th. A moderate cold front traversed over the San Joaquin Valley on December 11th bringing upwards to 0.05 to 0.10 of an inch of precipitation across different parts of the District. This frontal passage brought moderate dispersion conditions across the Valley, allowing for pollutants to lower to near background levels bringing an end to event #4.

Event #5: December 15, 2000 through January 11, 2001

Meteorologically, dispersion worsened and particulate formation conditions strengthened from December 10th to January 7th. As is shown in **Figure 1**, event #5 lasted about 27 days and was marked by a gradual buildup of $PM_{2.5}$ that lead to multiple days the Federal $PM_{2.5}$ Standard was exceeded. During event #5, strong high pressure at the surface and aloft resulted in limited afternoon mixing and light offshore wind flow. Cool damp mornings and strong stability contributed to the formation of nitrates and sulfates during the episode.

After the passage of a cold front on December 11, 2000, which brought a few hundredths of an inch of precipitation to the region, moisture became available for atmospheric chemistry reactions. Humidity measurements of 90 – 100 % in the morning across the Valley Floor showed a moist atmosphere, with light fog and haze being reported on the exceedance days. These cool damp mornings and strong stability favored the formation of nitrates and sulfates.

Synoptically during event #5, the eastern Pacific high built over the San Joaquin Valley on December 12, 2000 and dominated the region's weather through January 7, 2001. The event was divided into two periods from December 15 through December 24, 2000 and December 24, 2000 to January 11, 2001. A trough moved into northern California on December 24, allowing for slightly better dispersion conditions and a decrease in fine particulate levels across the San Joaquin Valley.

High pressure gradually intensified over the San Joaquin Valley between December 12th through the 20th, leading to $PM_{2.5}$ levels exceeding the National Ambient Air Quality Standards on December 20th at Fresno-1st. However, by December 22 a weak trough moved into northern California providing improving dispersion conditions across the San Joaquin Valley and lowering fine particulate measurements to below the National and California Ambient Air Quality Standards.

By December 25th, the combination of increased local emissions due to the Christmas and New Year Holiday's and intensifying stability aloft initiated an eleven day stretch were numerous sites across the San Joaquin Valley exceeded the $PM_{2.5}$ Standard. These violations began in the urban areas of Fresno, Modesto, and Bakersfield and spread regionally into the rural sections by the end of the episode on January 7. The meteorology surrounding this event were classified as an intense high dominating central California's air quality, leading to strong stability and light wind flow.

With a strong lid in place aloft and maximum high temperatures in the upper 50's to low 60's, the afternoon hours were marked by limited mixing, resulting in increasing particulate potential. Mixing heights at Fresno remained below 500 feet under a strong inversion for 19 hours on January 1st, breaking out after 4:00 P.M and reforming shortly after 7:00 P.M. During the afternoon hours, there were higher mixing depths (maximum mixing depth of 1,000 feet), but the bulk of the day had limited mixing.

Maximum and minimum temperatures for the exceedance day were slightly above normal, further illustrating the intensity of the high pressure system that was controlling the region's weather. Light fog was reported at the Valley surface during the early morning hours of January 1st, resulting in slightly lower solar radiation intensities. Along with lower solar radiation intensities due to the early morning fog, low sun angle, and reduced daylight hours, the atmospheric chemistry reactions may have favored the secondary particulate forming regime. Light fog would be indicative of moderate water content's that favor the formation of ammonium nitrate. Heavier fogs result in the removal or particulates by wet deposition. Chemical composition and meteorological

data showed limited mixing depths and light and disorganized wind flow resulted in minimal transport and dispersion of pollutants.

Meteorological conditions remained extremely stable between January 1st through the 4th, leading to elevated fine particulate conditions continuing across the San Joaquin Valley. Without a significant weather disturbance moving through the area to scour out the particulates, $PM_{2.5}$ concentrations continued to climb and exceeded the NAAQS at multiple urban and rural monitoring sites on January 4th.

With a strong lid in place aloft and maximum high temperatures in the low 60's, the afternoon hours on January 4th, were marked by limited mixing, resulting in increasing particulate conditions. Mixing heights at Fresno remained below 500 feet under a strong inversion for 20 hours on January 4th. During the afternoon hours, there were higher mixing depths (maximum mixing depth of 2,000 feet), but the bulk of the day had limited mixing.

Maximum temperatures for this exceedance day were above normal, further illustrating the intensity of the high pressure system that was controlling the region's weather. Light fog reported at the Valley surface during the early morning hours, resulted in slightly lower solar radiation intensities. Along with lower solar radiation intensities due to the low sun angle and reduced daylight hours, the atmospheric chemistry reactions may have favored the secondary particulate forming regime. Meteorological data showed limited mixing depths and light and disorganized wind flow resulted in minimal transport and dispersion of pollutants. The following day, January 5th, $PM_{2.5}$ measurements recorded the highest levels during event #5.

Between January 5th and January 7th, meteorological conditions began to slowly improve leading to slightly lower but continued elevated particulate conditions across the San Joaquin Valley. Without a significant weather disturbance moving through the area to scour out the fine particulates, $PM_{2.5}$ and PM_{10} concentrations continued to remain high and exceeded the Federal Standard, (**Table 1 and Figure 2, 3, 4, and 5**). Humidity measurements of 85 – 100 % on the morning of January 7th, across the Valley Floor showed a relatively moist atmosphere, with light fog and haze being reported. The cool damp mornings and strong stability favored the formation of nitrates and sulfates. Synoptically, the eastern Pacific high began to slowly weaken and move into the Intermountain Region on January 7, 2001, slightly weakening the lid over the San Joaquin Valley.

On January 7th a moderately strong lid was in place aloft and maximum high temperatures were in the mid 60's. The afternoon hours were marked by limited mixing, resulting in elevated particulate conditions. Mixing heights at Fresno remained below 500 feet under a strong inversion for 16 hours on January 7th. During the afternoon hours, there were higher mixing depths (maximum mixing depth of 2,000 feet), but the bulk of the day had limited mixing. Maximum temperatures for this exceedance day were above normal, further illustrating the intensity of the high pressure system that was controlling the region's weather.

Light fog reported at the Valley surface during the early morning hours, resulted in slightly lower solar radiation intensities. Along with lower solar radiation intensities due to the low sun angle and reduced daylight hours, the atmospheric chemistry reactions may have favored the secondary particulate forming regime. Chemical composition and meteorological data showed limited mixing depths and light and disorganized wind flow resulting in minimal transport and dispersion of pollutants. Event # 5 came to an end when a significant trough from the eastern Pacific moved through the region on January 8th, bringing superior dispersion conditions and measurable amounts of precipitation.

Table 1
PM_{10} Chemical Composition Data[1] for January 1, 4 and 7, 2001
at selected exceedance sites.
Data Collected as part of the Routine and CRPAQS Networks.

SITE NAME	Date	Concentrations (µg/m^3)					Percent of PM10 Mass			
		PM10	PM2.5	Nitrate/ Sulfate	TC	Geo-logical	PM2.5	Nitrate/ Sulfate	TC	Geo-logical
Bakersfield-California	1/1/01	186	*133*	100	33		71	54	18	
Bakersfield-California	1/4/01	190	*127*	98	30		67	51	16	
Bakersfield-California	1/7/01	159	119	81	24		75	51	15	
Bakersfield-Golden	1/1/01	205								
Bakersfield-Golden	*1/4/01*	*208*		*106*	*38*	*47*		51	18	23
Bakersfield-Golden	*1/7/01*	174								
Clovis-N Villa	1/1/01	155	*130*	77			84	50		
Corcoran-Patterson	1/7/01	165	121	93			73	56		
Fresno-1st Street	1/1/01	193	*148*	76	51	7	77	40	26	4
Fresno Drummond	*1/1/01*	186								
Fresno Drummond	*1/4/01*	*159*		*58*	*52*	*29*		37	33	18
Hanford-S Irwin	1/7/01	185		105				57		
Modesto-14th St.	1/7/01	158	*136*	88	26		86	56	16	
Oildale-Manor	1/1/01	158	*141*	96			89	61		
Oildale-Manor	*1/4/01*	*195*		*119*	*28*	*43*		61	14	22

[1] The following fonts were used in the table to distinguish data sources:

- Regular font for routine data (FRM mass and chemical composition)
- Underlined font for mass collected using dichotomous sampler

Italics font for CRPAQS data

Figure 2: Fresno-1st (Coarse) and (PM2.5) January 2001 Episode

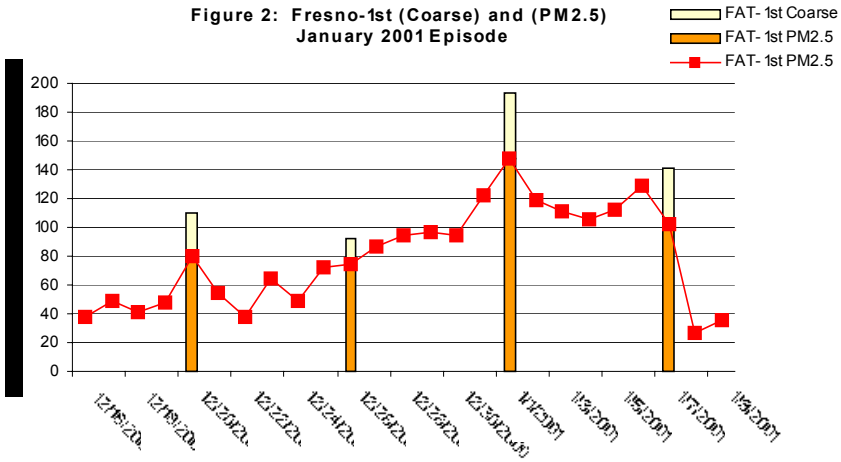


Figure 3: Bakersfield California (Coarse) and (PM2.5) January 2001 Episode

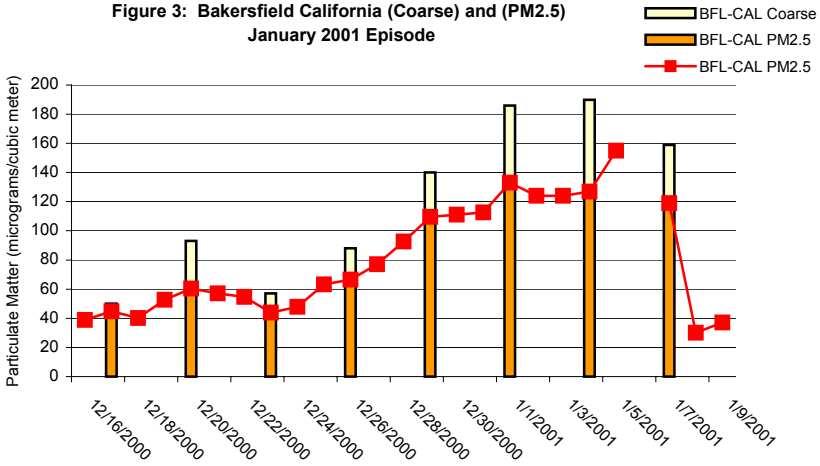
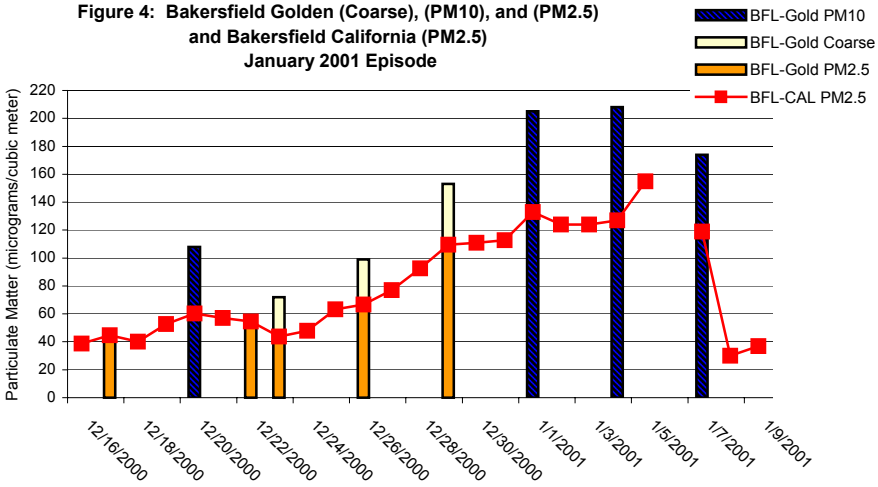
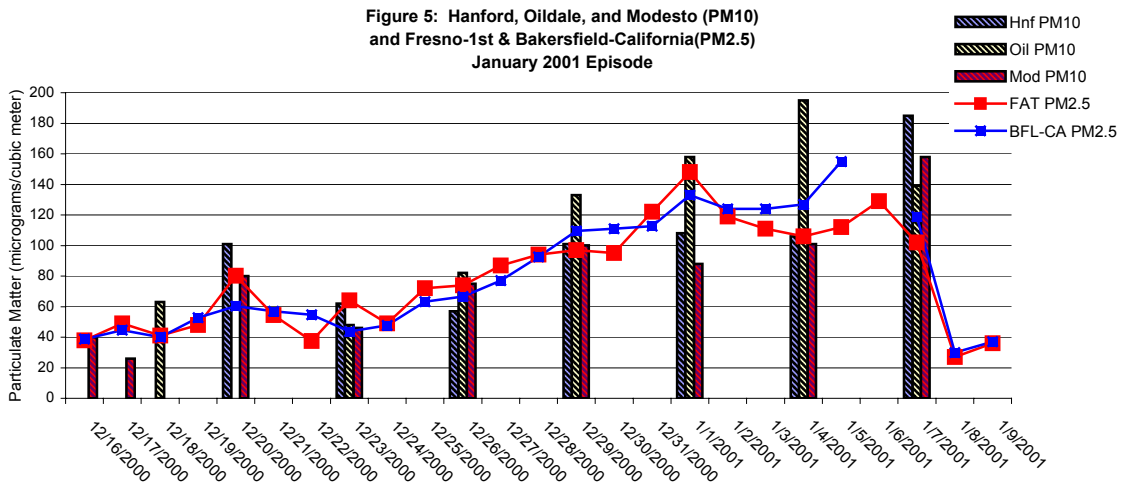


Figure 4: Bakersfield Golden (Coarse), (PM10), and (PM2.5) and Bakersfield California (PM2.5) January 2001 Episode





Event #6: January 12, 2001 through January 24, 2001

Meteorologically, dispersion worsened and particulate formation conditions became more favorable from January 14th to January 23rd. As is shown in **Figure 1**, event #6 lasted about 12 days and was marked by a gradual buildup of $PM_{2.5}$ that lead to multiple days the Federal $PM_{2.5}$ Standard was exceeded. After the passage of a trough on January 13th, which brought measurable precipitation across the region, moisture became available for atmospheric chemistry reactions. Humidity measurements of 90 – 100 % in the morning across the Valley Floor showed a moist atmosphere, with light fog and haze being reported on measured high $PM_{2.5}$ days. These cool damp mornings and strong stability favored the formation of nitrates and sulfates.

Synoptically during event #6, the eastern Pacific high built over the Pacific Northwest on January 15th then expanded southward on the 18th, bringing increasing stability and poor dispersion conditions through January 22nd. During this period, the high strengthened and intensified on January 18th, further tightening the lid and trapping the pollutants within the San Joaquin Valley boundary layer.

With a strong lid in place aloft and maximum high temperatures in the low 50's on the 18th and 19th, and low 60's on the 20th through the 22nd, the afternoon hours were marked by limiting mixing, resulting in increasing particulate potential. Mixing heights at Fresno remained below 500 feet under a strong inversion during a majority of the day (20 or more hours) on days when the fine particulates climbed above the Standard. During the afternoon hours, there were high mixing depths (maximum mixing depth of 1,500 to 2,500 feet), but the bulk of the day had limited mixing. Maximum and minimum temperatures from January 18th through the 21st, were below normal, indicating a potential for increase residential wood burning emission activity, and nitrate forming reactions.

Light fog and haze were reported at the Valley surface during the early morning hours of January 18th through the 22nd, resulting in slightly lower solar radiation intensities. Along with lower solar radiation intensities due to the early morning fog and haze, low sun angle, and reduced daylight hours, the atmospheric chemistry reactions may have favored the secondary particulate forming regime. Light fog would be indicated of moderate water content's that contribute to the formation of ammonium nitrate.

Meteorological data showed during event #6 limited mixing depths and light and disorganized wind flow resulted in minimal transport and dispersion of pollutants. Both primary and secondary pollutants from local emissions across the San Joaquin Valley accumulated resulting in the exceedance of the 24-hour $PM_{2.5}$ standard at Fresno-1st on January 16th through January 22nd, Visalia-Church, Corcoran-Patterson, Oildale-Manor, Bakersfield-Golden, Bakersfield-California, Angiola, and Edison, on January 19th, Modesto-14th, Angiola, and Bakersfield-Californian on January 20th, Angiola and Bakersfield-California on January 21st, Angiola, Bakersfield-California, Corcoran-Patterson, Visalia-Church, and Bakersfield-Golden on January 22nd. A vigorous cold front moved over the San Joaquin Valley on January 23rd, bringing and end to event # 6 that lasted from January 12th through January 24th. This disturbance brought superior dispersion conditions across the Valley, allowing pollutants to lower into the 5 to 11 micrograms per cubic meter range (background levels).

Event #7: January 25th through February 7th, 2003

A series of Pacific storms moved through the region from January 25th through January 30th, resulting in superior dispersion conditions over the San Joaquin Valley, with $PM_{2.5}$ concentrations nearing background levels. As is evident in **Figure 1**, event #7 lasted about 13 days and was marked by a gradual buildup of $PM_{2.5}$ that lead to multiple days the Federal $PM_{2.5}$ Standard was exceeded. High pressure rebuilt over the region on January 31st, leading to building particulate concentrations over the central and southern portions of the District. Meteorologically, dispersion rapidly deteriorated and particulate formation conditions became more favorable on February 1st. Humidity measurements of 90 – 100 % in the morning across the Valley Floor showed a continued moist atmosphere, with light fog and haze being reported on measured high $PM_{2.5}$ days. These cool damp mornings and strong stability favored the formation of nitrates and sulfates.

Synoptically during event #7, the eastern Pacific high built along the West Coast on February 1st then expanded eastward on the 2nd, bringing strengthening stability and poor dispersion conditions through the end of event # 7 on February 6th. During this period, the high strengthened and intensified on February 1st, further tightening the lid trapping the pollutants within the San Joaquin Valley boundary layer.

With a strong lid in place aloft and maximum high temperatures in the mid to upper 60's, the afternoon hours were marked by limited mixing, resulting in increasing particulate potential. Mixing heights at Fresno remained below 500 feet under a strong inversion

during a majority of the day (18 or more hours) on days when the fine particulates climbed above the NAAQS. During the afternoon hours, there were high mixing depths (maximum mixing depth of 1,000 to 2,500 feet), but the bulk of the day had limited mixing. Maximum and minimum temperatures from February 3rd through the 5th were above normal. Light fog and haze were reported at the Valley surface during the early morning hours of February 3rd through the 5th, resulting in slightly lower solar radiation intensities.

Along with lower solar radiation intensities due to the early morning fog and haze, the atmospheric chemistry reactions may have favored the secondary particulate forming regime. Light fog would be indicated of moderate water content's that contribute to the formation of ammonium nitrate. Meteorological data showed limited mixing depths and light and disorganized wind flow resulted in minimal transport and dispersion of pollutants. An exceedance of the 24-hour $PM_{2.5}$ standard were measured at Bakersfield California on February 3rd through the 5th, Bakersfield Golden on February 3rd and 6th, Corcoran on February 3rd, Fresno 1st on February 3rd and 4th, and Clovis on February 3rd. A cold front traversed over the San Joaquin Valley late in the afternoon on February 6th, producing trace amounts of precipitation across different parts of the District. This frontal passage brought weak to moderate dispersion conditions across the Valley, lowering PM2.5 levels to below the NAAQS. A vigorous upper level system moved through the region on the 7th, allowing for pollutants to lower to near background levels, bringing an end to event #7.