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Windblown Dust Contributes to High PM_{25} Concentrations

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Windblown Dust Contributes to High $PM_{2.5}$ Concentrations

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ABSTRACT

The revised National Ambient Air Quality Standards for PM include fine particulate standards based upon mass measurements of $PM_{2.5}$. It is possible in arid and semi-arid regions to observe significant coarse mode intrusion in the $PM_{2.5}$ measurement. In this work, continuous PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were measured during several windblown dust events in Spokane, WA. $PM_{2.5}$ constituted ~30% of the PM_{10} during the dust event days, compared with ~48% on the non-dusty days preceding the dust events. Both PM_{10} and $PM_{2.5}$ were enhanced during the dust events. However, $PM_{1.0}$ was not enhanced during dust storms that originated within the state of Washington. During a dust storm that originated in Asia and impacted Spokane, $PM_{1.0}$ was also enhanced, although the Asian dust reached Washington during a period of stagnation and poor dispersion, so that local sources were also contributing to high particulate levels. The "intermodal" region of PM, defined as particles ranging in aerodynamic size from 1.0 to 2.5 μm, was found to represent a significant fraction of $PM_{2.5}$ (~51%) during windblown dust events, compared with 28% during the non-dusty days before the dust events.

INTRODUCTION

Atmospheric PM is commonly thought of as containing fine-mode and coarse-mode particles. These two modes have distinctly different sources, transformations, removal pathways, chemical compositions, optical properties, and deposition mechanisms in the human respiratory tract.[1] Fine-mode PM is primarily anthropogenic in origin. Typically, it results either from condensation of hot combustion vapors (nuclei mode, 0.005–0.1 μm, not accounting for much mass), or from the coagulation of nuclei particles and condensation of vapors onto existing particles (accumulation mode, from 0.1 to ~3 μm, accounting for most of the fine particulate mass). Coarse-mode PM, typically > ~1 μm, tends to result from mechanical processes and contains a significant portion of geological material. There is some overlap between fine-mode and coarse-mode PM in the particle size range of approximately 1–3 μm aerodynamic diameter. In this paper, we distinguish between fine-mode PM and $PM_{2.5}$ in that the $PM_{2.5}$ cut point allows for capture of most of the fine-mode PM but also includes coarse-mode PM in the fine size fraction.

The recent attempt by the U.S. Environmental Protection Agency to revise the National Ambient Air Quality Standards for PM to include a fine PM standard targets fine-mode particles.[2] The measure of fine particles, for regulatory purposes, is based upon gravimetric measurement of PM collected in a device with a 50% cut point at an aerodynamic diameter of 2.5 μm ($PM_{2.5}$). Given the overlap between fine- and coarse-mode PM between 1 and 3 μm, such a device, intended to collect fine-mode particles, can potentially collect some coarse-mode particles as well, thus introducing a positive error in the fine-mode particle mass measurement. This may be particularly true in arid and semi-arid areas that are subjected to relatively high fugitive dust emissions.

In Spokane, WA, a semi-arid, western city with nonattainment status for PM_{10}, high particulate concentrations occur as a result of a number of sources,

IMPLICATIONS

If the objective of implementing a new PM standard is to regulate fine-mode rather than coarse-mode particles, then the use of a $PM_{2.5}$ inlet may positively bias the measurement during dust storms, due to the inclusion of coarse-mode PM. The use of a 1.0-μm cut point diameter should reduce this error for arid and semi-arid regions that are prone to windblown dust.

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including combustion processes such as residential wood combustion, vehicular exhaust, and industrial point sources, and also fugitive dusts from paved and unpaved roads and parking lots. Moreover, the expansive area upwind of Spokane, in the central and eastern portions of Washington, is primarily dryland farmland. Due to the specific farming practices in this area, it is not uncommon for the central and eastern portions of Washington to experience particulate air pollution from windblown dust from these areas.[3] It has been observed that these dust storms lead to high concentrations not only of PM_{10}, but also of $PM_{2.5}$.[4]

The objective of this study is to examine real-time concentrations of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$, in order to evaluate $PM_{2.5}$ compared with $PM_{1.0}$ as an appropriate indicator of fine-mode PM during dust storms occurring in a semiarid city.

METHODS

Real-time mass concentrations were made in Spokane for PM_{10} and $PM_{2.5}$, using tapered element oscillating microbalances (TEOMs) (Rupprecht and Patashnik) equipped with PM_{10} and $PM_{2.5}$ inlets. TEOMs with $PM_{2.5}$ inlets were deployed at two locations in Spokane in 1994 and have been operating since. The two sites include a residential site (RW) and an industrial site (CZ). In January 1995, a TEOM equipped with a $PM_{1.0}$ inlet (designed by A. McFarland) was deployed at the residential site, which is the most extensively instrumented of these two sites. In addition to real-time PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ sampling at this site, daily, 24-hr samples of both fine- ($PM_{2.5}$) and coarse-mode PM (between 2.5 and 8 μm) have been collected since January 1995 and have been analyzed for chemical species, including elements, via energy-dispersive x-ray fluorescence (EDXRF). Additional information regarding the entire sampling and analysis program is provided by Finn et al.[5]

PM data were extracted from the TEOMs as hourly averages. Data screening was conducted by verifying that, for collocated instruments, $PM_{1.0} < PM_{2.5} < PM_{10}$. Data were further screened to remove any negative values. The precision of the TEOM PM_{10} measurements was determined by periodically collocating a second TEOM instrument at each site. The TEOM PM_{10} measurement was also compared with that obtained from a size-selective inlet instrument located at each site. The TEOM $PM_{2.5}$ measurement was compared with that obtained from a versatile air pollutant sampling system (URG, Inc.) also located at the RW site. Further information on the performance of these instruments is provided in Haller et al.[4] and Finn et al.[5]

For the purpose of this work, coarse-mode PM was calculated from the difference between the PM_{10} and $PM_{2.5}$ concentrations. To obtain the event average value of the coarse mode concentration, the coarse-mode PM was calculated for each hour, and the resulting hours were averaged. Similarly, "intermodal" PM (IM) was calculated from the difference between the $PM_{2.5}$ and $PM_{1.0}$ concentrations on an hourly basis, and the event average was obtained by averaging the hourly values.

RESULTS

Since 1990, several windblown dust events have impacted Spokane air quality (Table 1). In the early 1990s, several dust storms occurred per year. There were no major windblown dust events in 1995 and a brief dust storm in 1994. In 1998, moderately high PM_{10} levels were related to long-range transport of dust from a major windblown dust storm that originated in Asia. The transport of the Asian dust storm in late April of 1998 was detected by GOES9 satellite imagery[6] and followed by a community of scientists in both Asia and North America.[7] The dust plume was observed to impact southwestern British Columbia and western Washington State in late April 1998,[8] leading to enhanced PM_{10} levels over the usual local sources. A significant regional dust storm occurring on September 25, 1999, led not only to very high concentrations of PM_{10} in Spokane (Figure 1), but also to a major traffic accident involving numerous vehicles in north central Oregon.

Real-time $PM_{2.5}$ and PM_{10} were measured beginning January 1994. After this time, it was observed that during dust events, both $PM_{2.5}$ and PM_{10} were enhanced (Figure

Table 1. History of dust storms and PM_{10} since 1990 in Spokane. All PM data were obtained from TEOM measurements.

Date	24-hr Average Wind Speed (m/sec) at CZ	24-hr Average PM_{10} (μg/m^3) at CZ	24-hr Average PM_{10} (μg/m^3) at RW
9/8/90	1.6	217	160
10/4/90	6.2	342	268
11/9/90	8.3	268	166
11/23/90	8.6	N/A	251
10/21/91	5.6	351	267
9/4/92	5.9	321	N/A
9/12/92	5.3	803	N/A
9/13/92	3.6	126	132
9/26/92	4.9	252	N/A
10/8/92	3.3	185	N/A
9/11/93	5.1	300	255
11/3/93	3.1 (at airport)	207	100
7/24/94	2.7	167	102
8/30/96	4.5	214	128
4/29/98	<1.0	98	80
9/23/99	3.8	141	125
9/25/99	5.4	401	256

1). This was first seen during a brief dust event that occurred in July 1994 (Table 2). During the event, peak hourly PM_{10} reached nearly 1200 µg/m³, and peak hourly $PM_{2.5}$ approached 150 µg/m³.

Since the deployment of a TEOM equipped with a $PM_{1.0}$ inlet at the RW site, four additional windblown dust events have been observed in Spokane (August 30, 1996; April 29, 1998; September 23, 1999; and September 25, 1999). During the two September 1999 events, both PM_{10} and $PM_{2.5}$ were enhanced; however, $PM_{1.0}$ remained low at the RW site (maximum $PM_{1.0}$ concentration was approximately 10 µg/m³). Similarly, on August 30, 1996, both PM_{10} and $PM_{2.5}$ increased, but $PM_{1.0}$ did not (Figure 2). As mentioned earlier, the April 1998 event was a multiple-day dust episode that was attributed to long-range transport of dust from Asia. The peak of the event occurred in Spokane on April 29, 1998. In that case, the ratio of $PM_{2.5}$ to PM_{10} was somewhat higher (0.37) than

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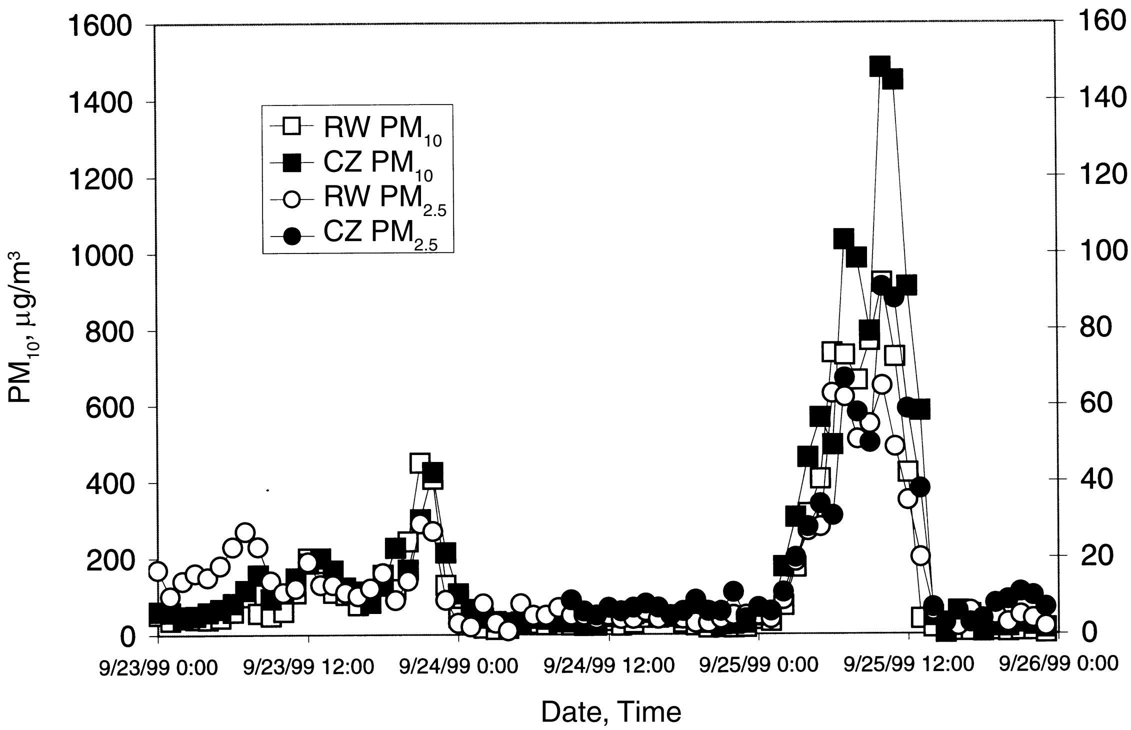

Figure 1. Hourly PM in Spokane for a windblown dust event, September 23–25, 1999. CZ denotes the industrial site and RW the residential/light commercial site.

Table 2. PM_{10} and $PM_{2.5}$ concentrations measured in Spokane using TEOMs during recent windblown dust events.

Date	24-hr PM_{10} (µg/m³)	Maximum 1-hr PM_{10} (µg/m³)	24-hr $PM_{2.5}$ (µg/m³)	Maximum 1-hr $PM_{2.5}$ (µg/m³)	24-hr $PM_{1.0}$ (µg/m³)	Maximum 1-hr $PM_{1.0}$ (µg/m³)
7/24/94						
RW/CZ	102/167	1105/1879	21/22	123/127	NA[a]/NA[b]	NA/NA
8/30/96						
RW/CZ	128/214	415/717	25/29	52/72	13/NA	49/NA
4/29/98						
RW/CZ	80/98	113/	29/	44/	14/NA	22/NA
9/23/99						
RW/CZ	125/141	450/425	16/NA	29/NA	8/NA	8/NA
9/25/99						
RW/CZ	256/401	922/1483	22/27	65/91	6/NA	10/NA

Notes: [a]$PM_{1.0}$ was not available at the RW site until January 1995; [b]There was no $PM_{1.0}$ device at the CZ site.

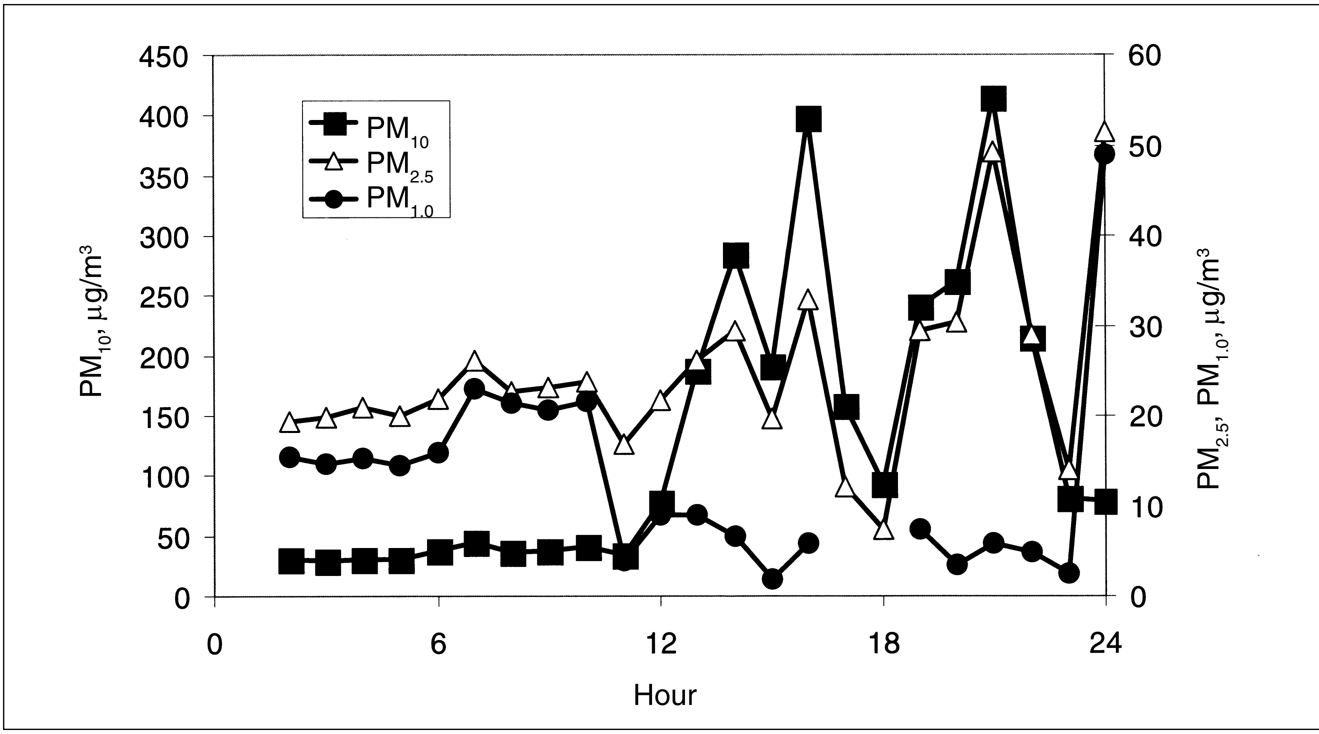

Figure 2. Hourly PM for an August 30, 1996, dust storm, at the residential site (RW) in Spokane.

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that for the other events (ranging from 0.20 to 0.37) (Table 3), which is consistent with the longer lifetime of $PM_{2.5}$ compared with PM_{10}. This period was also a time of poor dispersion, so it is likely that the higher $PM_{2.5}$ was affected by local sources as well. In general, the ratio of $PM_{2.5}$ to PM_{10} was quite variable, ranging for the non-dust days from 0.33 (September 22, 1999) to 0.75 (August 29, 1999). Haller et al.[4] reported that, from July 1994 through November 1995, the average ratio of $PM_{2.5}$ to PM_{10} in Spokane, obtained from TEOM measurements, was approximately 50%. The ratio of $PM_{2.5}$ to PM_{10} on the dust episode day was significantly smaller than the ratio on the non-dust day before.

The IM was enhanced during the dust storms of September 23 and 26, 1999 (Figure 3), and August 30, 1996 (Figure 4), while the fine-mode PM, as determined from $PM_{1.0}$, was not. For the dust event of April 29, 1998, the fine mode ($PM_{1.0}$) was also high, and possibly enhanced, as well (Table 3). The Asia dust event reached Washington during a stagnant period of poor dispersion conditions,[8] and it is speculated that the higher values of $PM_{1.0}$ during the April 1998 event in Spokane were due at least in part to local sources. The IM comprised, on average, 28% of the $PM_{2.5}$ for the non-dusty day before each windblown dust event, but for the dust event days (including the Asian dust event), it comprised 51% of the $PM_{2.5}$ on average.

DISCUSSION

The IM often represents a small fraction of $PM_{2.5}$; however, during arid conditions in regions susceptible to fugitive dusts and windblown dust storms, this fraction

Table 3. Comparison of coarse-mode PM ($PM_{10} - PM_{2.5}$), IM ($PM_{2.5} - PM_{1.0}$), and fine PM ($PM_{1.0}$), for five windblown dust events and the non-dusty day before the event. All PM data were taken from TEOM measurements. All values for the individual events and the non-dusty day before the event were calculated from hourly values and averaged for the day.

Date	Coarse Mode	IM	$PM_{1.0}$	$IM/PM_{2.5}$	$PM_{2.5}/PM_{10}$
7/23/94 (non-dust)	22	NA[a]	NA	NA	0.41
7/24/94 (dust)	94	NA	NA	NA	0.28
8/29/96 (non-dust)	11	6	21	0.25	0.75
8/30/96 (dust)	104	13	13	0.48	0.37
9/22/99 (non-dust)	31	5	11	0.29	0.33
9/23/99 (dust)	109	8	8	0.48	0.20
9/25/99 (dust)	234	19	6	0.55	0.29
4/27/98 (non-dust)	25	4	10	0.29	0.39
4/29/98 (dust)	51	15	14	0.51	0.37
Average non-dust	22	5	14	0.28	0.47
Average dust	118	14	10	0.51	0.30

Note: [a]The $PM_{1.0}$ instrument was not available for the 1994 event as it was deployed in January 1995.

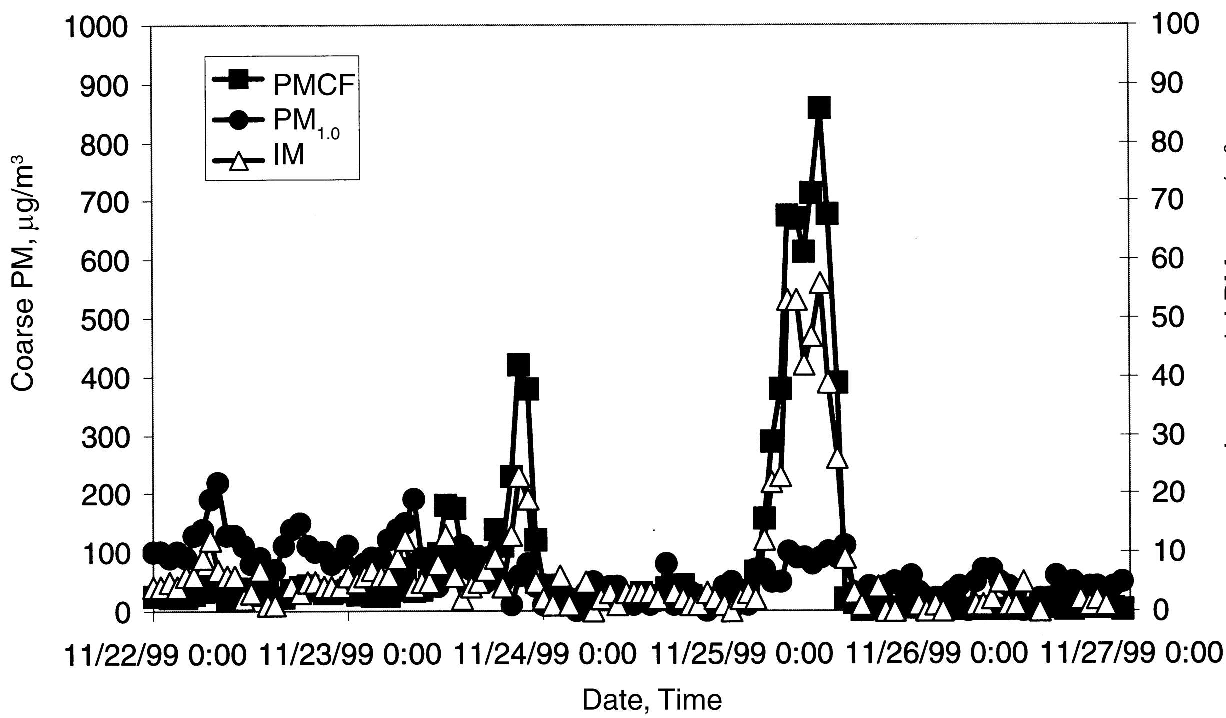

Figure 3. Hourly PM at the residential site (RW) in Spokane for September 22–26, 1999. PMCF is the coarse fraction PM ($PM_{10} - PM_{2.5}$). IM is the intermodal fraction ($PM_{2.5} - PM_{1.0}$).

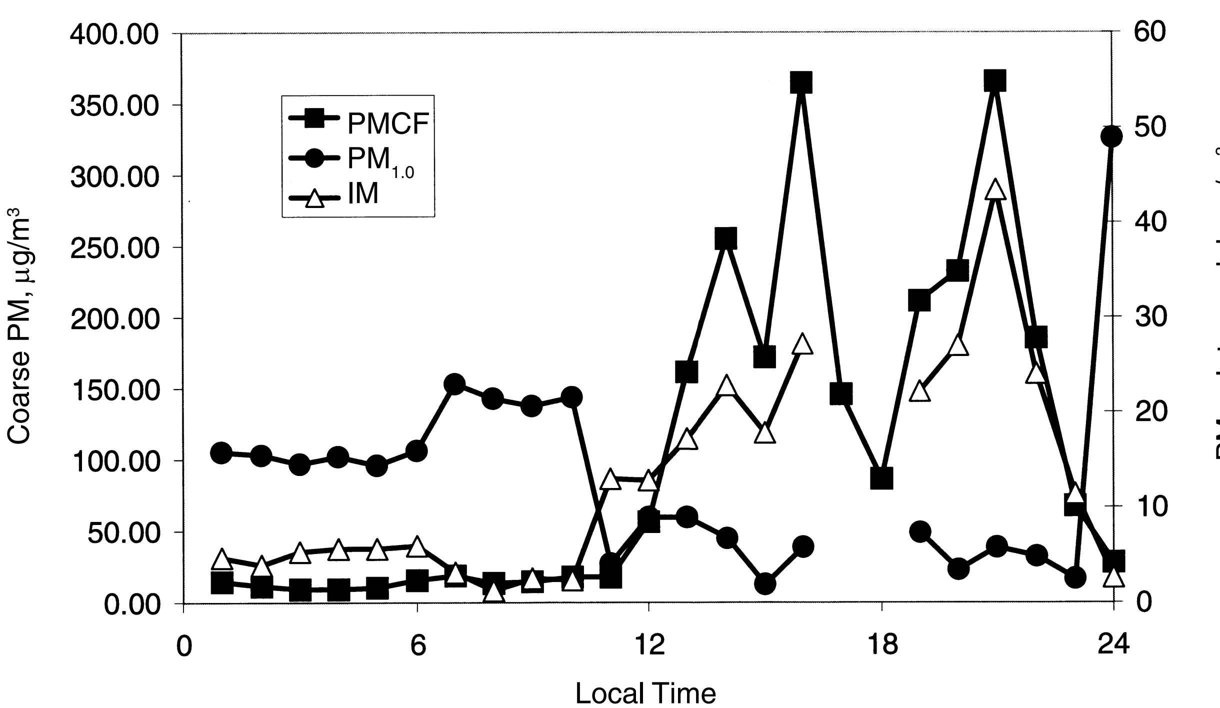

Figure 4. Hourly $PM_{1.0}$, intermodal (IM), and coarse fraction PM (PMCF) in Spokane for August 30, 1996.

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can comprise a significant contribution of coarse-mode PM. Observations consistent with this have been made previously in Spokane and in Phoenix, AZ, another arid city. An analysis of chemical speciation data from Phoenix (March–December 1995) showed that the intermodal fraction was correlated to the $PM_{2.5}$ soil fraction as calculated from a mass attribution model based upon EDXRF analysis.[4] Haller et al.[4] noted that, in Spokane, the IM was statistically correlated to the coarse-mode fraction (at the 95% confidence level) during the summer (June–August) which, in Spokane, is hot and dry (the correlation coefficient was 0.62 for summer). However, the IM was not correlated to either the fine or coarse fraction for other seasons (during which the correlation coefficient ranged from 0.02 to 0.21).

CONCLUSION

These results show that windblown dust events enhance both PM_{10} and $PM_{2.5}$ in a semi-arid airshed. This work has also shown that $PM_{1.0}$ is not necessarily enhanced during dust storms. The results are consistent with a previous study in Spokane that showed that the intermodal PM (between 1.0 and 2.5 μm in aerodynamic diameter) is significantly correlated to the coarse mode during the hot, dry season. Results from Phoenix[4] are also consistent with these findings in that the fine particulate soil fraction in that arid city is correlated to the intermodal fraction.

True fine-mode PM would not be expected to be affected by windblown dust. If the objective of the recently proposed PM standards is to regulate fine-mode rather than coarse-mode PM, then the use of $PM_{2.5}$ inlets may introduce a positive bias during windblown dust storms due to the inclusion of coarse-mode PM. The use of a 1.0-μm cut point inlet should reduce this error in arid or semi-arid regions.

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This work has not been reviewed by either EPA or WADOE and does not necessarily reflect the views of either agency. The mention of trade names does not constitute an endorsement of the instruments mentioned.

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