United States
Department of
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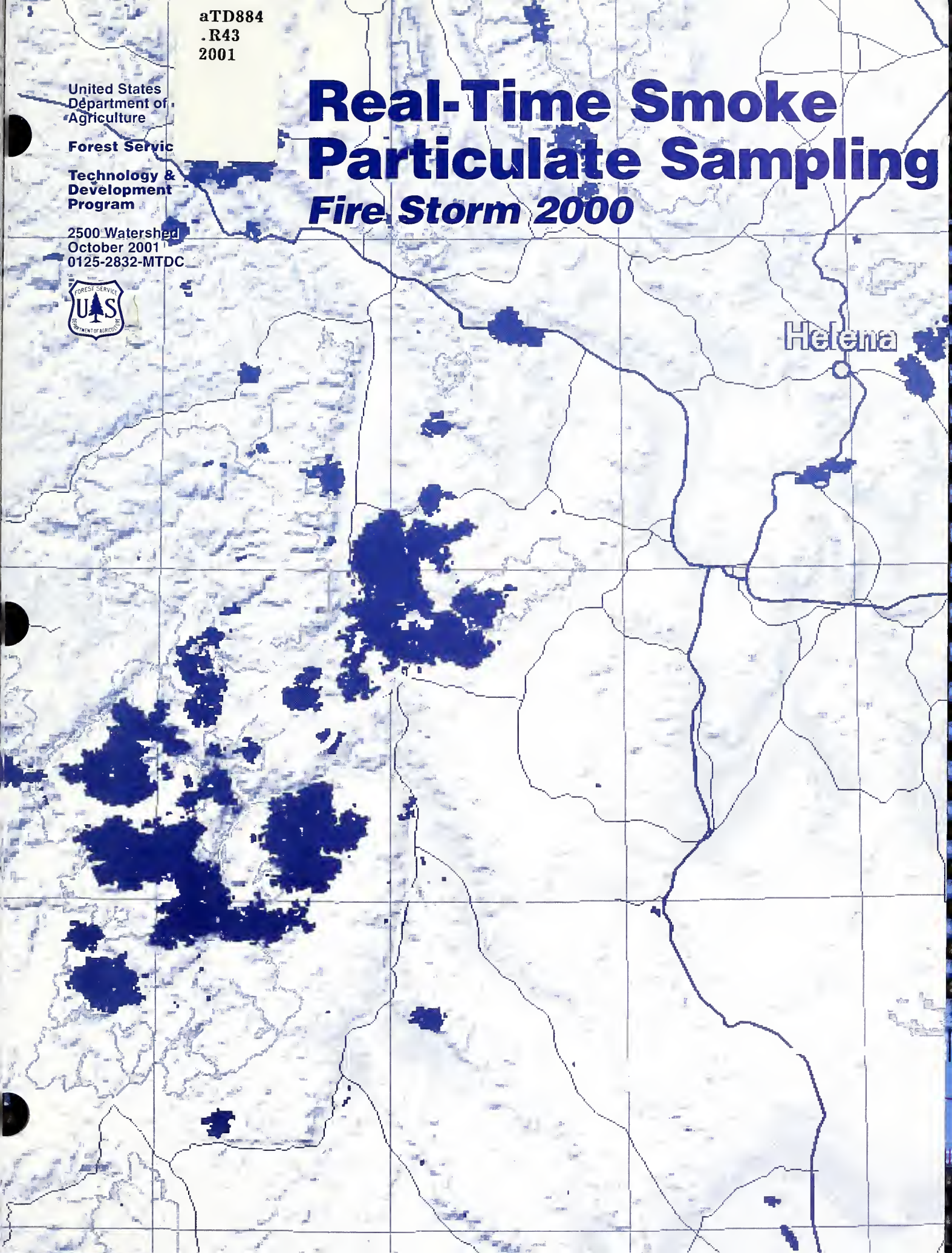
Forest Servic

Technology &
Development
Program

2500 Watershed
October 2001
0125-2832-MTDC

Real-Time Smoke Particulate Sampling

Fire Storm 2000



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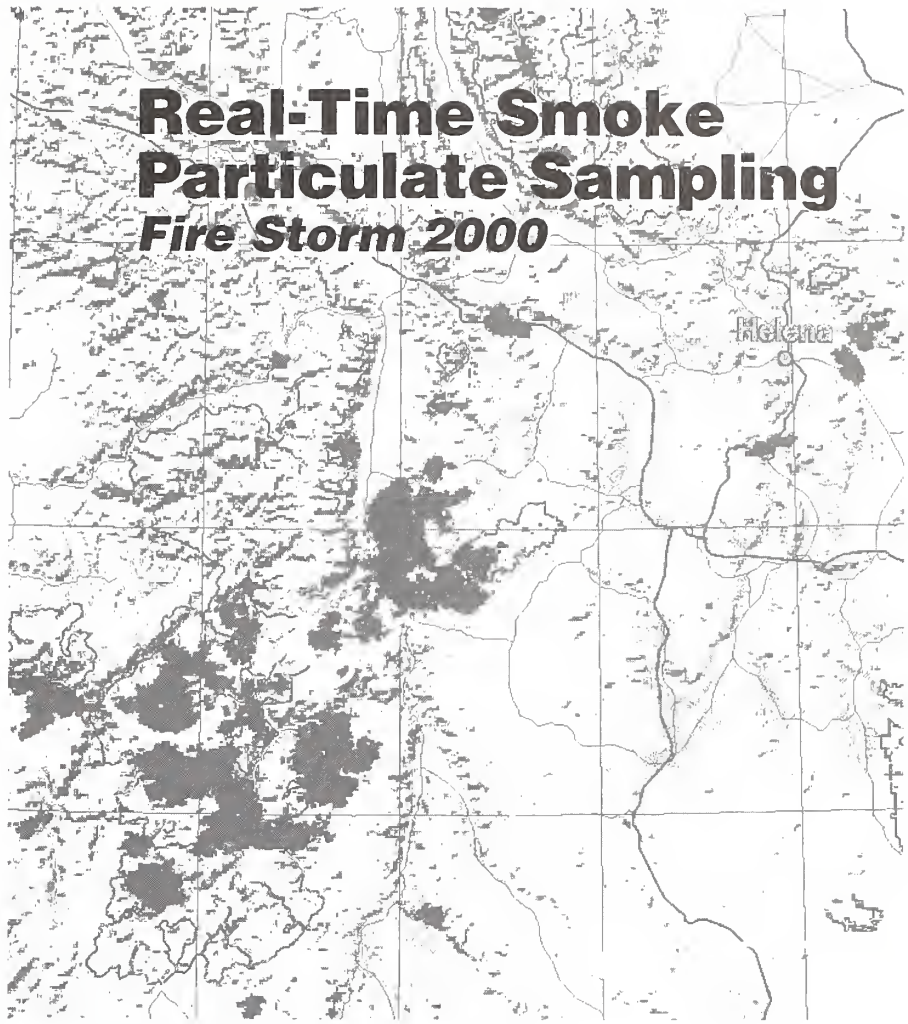

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9E92F52—$PM_{2.5}$ Air Sampler

October 2001

Table of Contents

Introduction

During the summer of 2000, extremely dry, hot conditions resulted in large natural wildfires throughout western Montana and Idaho. Area residents called the fire season Fire Storm 2000. Massive amounts of smoke settled in the valleys around western Montana and Idaho. The U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center (MTDC) deployed and evaluated real-time, particulate monitoring instruments to measure the smoke particulate concentrations. The center maintained two sets of real-time instruments, one in Missoula, MT, and one in Hamilton, MT. A U.S. Environmental Protection Agency (EPA) Federal Reference Method (FRM) $PM_{2.5}$ sampler was collocated with the instruments at each location. The main goal of the instrument collocation study during Fire Storm 2000 was to determine the accuracy of the real-time instruments when measuring smoke particulate concentrations from natural wildfires.

Airborne particulates, especially particles smaller than 2.5 microns (μm) in diameter ($PM_{2.5}$), pose potential health, visibility, safety, and nuisance problems at certain concentrations. Smoke particles, whether from prescribed burning or natural wildfire, are generally smaller than 2.5 μm and pose a potential health threat to individuals, especially persons with respiratory problems. Small particles are also the main reason smoke reduces visibility. The EPA has proposed annual and 24-h average $PM_{2.5}$ standards to protect human health. Regional haze regulations to improve visibility also target fine particles.

The center has been evaluating commercially available optical instruments that estimate particulate concentration in real time. These instruments can provide land managers and air quality specialists with valuable real-time airborne particulate concentration information during managed forest and rangeland burning. Managing smoke to protect human health and public welfare is an essential part of each prescribed burn plan. The proper use of ambient air quality monitoring can help ensure that prescribed burning complies with State and Federal air-quality laws and regulations while satisfying land management objectives.

The real-time particulate monitoring instruments can also provide local and State health department personnel, wildfire safety personnel, and communities with important particulate concentration information during times of severe wildland fires. Many rural communities do not have instruments to assess particulate concentrations. Communities can rely on visual techniques to estimate particulate concentrations, but these techniques are subjective and less accurate. Real-time instruments could provide community officials with more timely information to issue air quality stage alerts designed to protect local area residents.

The center has published two reports (figure 1), *Laboratory Evaluation of Two Optical Instruments for Real-Time*

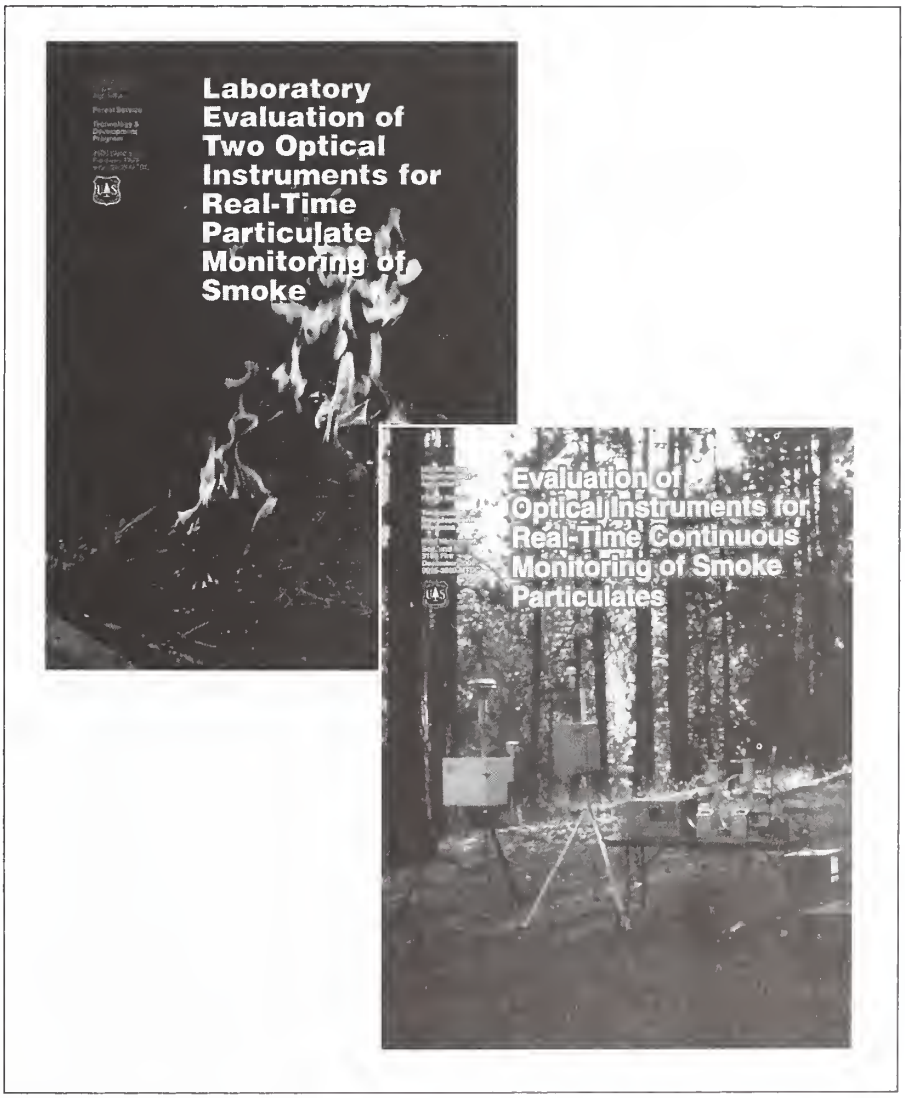

Figure 1—Two reports (9925-2806-MTDC and 0025-2860-MTDC) detail the evaluation of several real-time particulate monitors in a laboratory and field setting.

Particulate Monitoring of Smoke (9925-2806-MTDC) and *Evaluation of Optical Instruments for Real-Time Continuous Monitoring of Smoke Particulates* (0025-2860-MTDC). These reports provide details on real-time instrument evaluations in laboratory and field situations. Filter-based, direct mass measurements, specified by the EPA as reference or equivalent methods, are the standard techniques for determining particulate mass concentrations. Results from gravimetric samplers were used as the assumed actual representative particulate concentration in all the tests. While most of the results in the two reports were from laboratory work, the instruments were also collocated downwind of several prescribed burns to test them in field situations. We found it difficult to obtain results from prescribed burning activities. Most of the prescribed burns were small and did not produce large amounts of smoke. More importantly, these burns were conducted during conditions that allowed the smoke to disperse. Regulatory requirements dictate that airsheds must be in suitable conditions before burning to prevent smoke from impacting populated areas. Most of the smoke from the prescribed burns lofted high into the air, far above our instruments. The numerous, intense fires during Fire Storm 2000 provided us with an excellent chance to evaluate the real-time instruments during natural wildfire conditions.

Fire Storm 2000

The fire season of 2000 shaped up as one of the biggest in the last four decades. Fire scorched significant portions of northern Idaho and western Montana from mid-July to mid-September. By August 14, the fires in the Bitterroot Valley had burned more than 120,000 acres. Numerous smoke alerts and advisories were issued for the communities in the Bitterroot Valley and for Missoula. By the end of August, fires had burned 307,000 acres of the 1.6-million-acre Bitterroot National Forest and an additional 49,000 acres of State and private forests (figure 2). Heavy rains and snow at higher elevations during early September allowed firefighters to effectively manage the wildfires. A total of 900,000 acres had been burned in Montana. Another 1,250,000 acres had been burned in Idaho.

Smoke from the fires followed local weather patterns, affecting most communities in western and central Montana. Wind patterns and terrain caused the smoke to travel north and east (figure 3). Communities around Hamilton were subjected to much higher concentrations of smoke particulate than communities around Missoula.

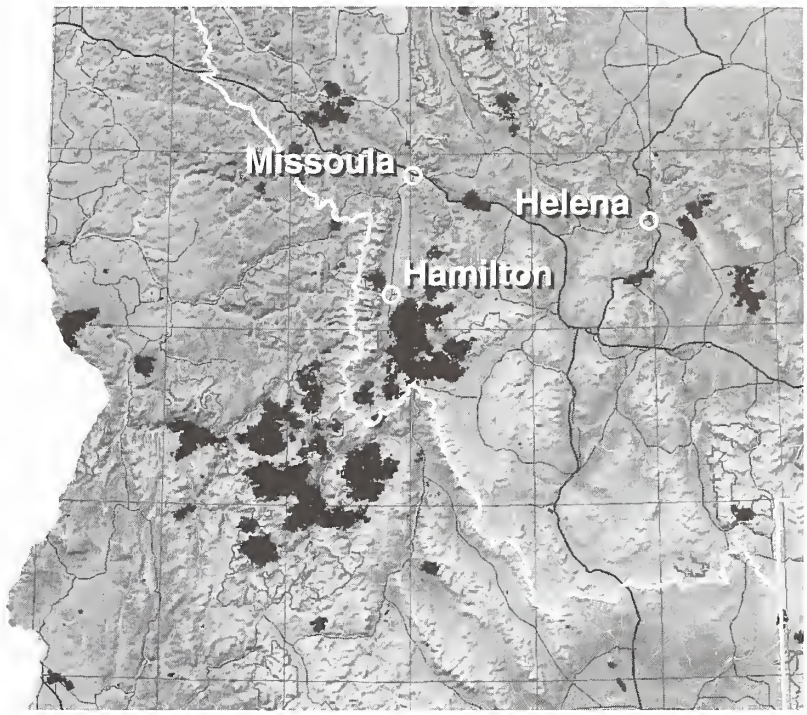

Figure 2—The cumulative burned areas in central Idaho and western Montana beginning July 4 to September 17, 2000 (available on the Internet at: *http://www.fs.fed.us/r4/rsgis_fire/images_sep2000/idmtwy_cm_burn00-09-18.jpg*).

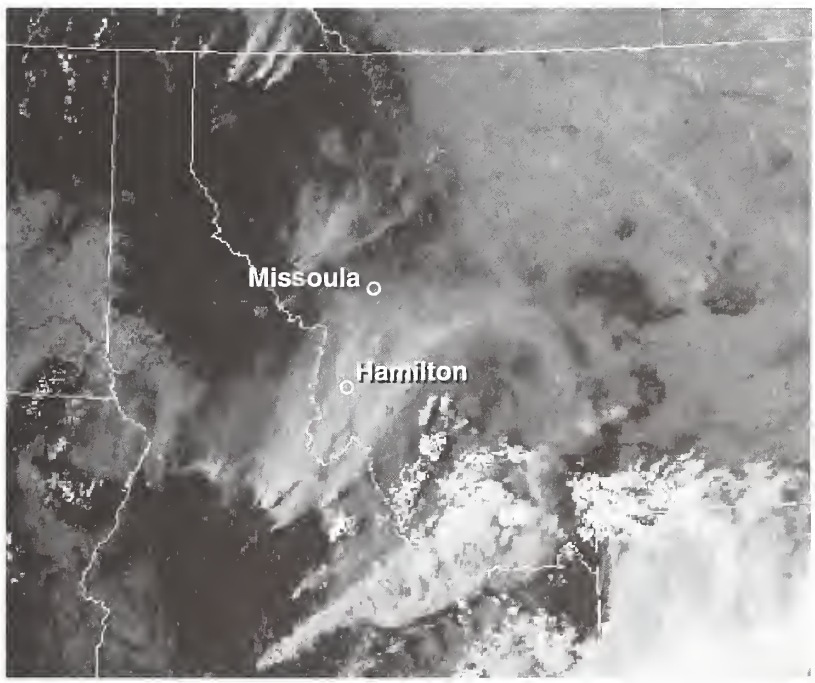

Figure 3—Smoke from fires in Idaho and Montana moving to the northeast on August 17, 2000 (available on the Internet at: *http://www.fs.fed.us/r4/rsgis_fire/images_aug2000/smk0008180020.jpg*).

Regional Air Quality

The smoke from the fires had a severe impact on air quality in the communities across western Montana. Most of the larger communities, including Missoula and Hamilton, have EPA-approved federal reference method (FRM) $PM_{2.5}$ gravimetric samplers. Several communities also have tapered element oscillating microbalance (TEOM) instruments to provide real-time particulate level information to air-quality specialists. For those communities with a TEOM instrument, air-quality stage alerts were determined using information from that instrument. Other communities used visual techniques to estimate particulate concentrations.

Air Quality Standards

The Clean Air Act, which was last amended in 1990, requires the EPA to set national ambient air quality standards (NAAQS) for pollutants considered harmful to public health and the environment. The Clean Air Act establishes two types of national air quality standards. *Primary standards* set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. *Secondary standards* set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. Both PM_{10} (particulate less than 10 microns in diameter) and $PM_{2.5}$ are established *primary* and *secondary* pollutants.

The limits set by EPA for PM_{10} are 50 $\mu g/m^3$ for the annual average and 150 $\mu g/m^3$ for the 24-h average. Limits set by EPA for criteria pollutant $PM_{2.5}$ are 15 $\mu g/m^3$ for the annual average and 65 $\mu g/m^3$ for the 24-h average.

The EPA developed an air quality index (AQI) to provide a consistent and easy way to understand air pollutant concentrations and their health implications. The EPA AQI values are based on $PM_{2.5}$ for the 24-h average. To help communities further understand the air quality issues associated with forest fire smoke, the Montana State Department of Environmental Quality (MT DEQ) established AQIs for 8-h and 1-h average concentrations. Table 1 shows the values and associated health risks for all three AQIs.

Table 1—Air quality index (AQI) as established by the U.S. Environmental Protection Agency and the Montana Department of Environmental Quality. Values are for 1-, 8-, and 24-h averages.

Categories	Health effects	Cautionary statements	EPA 24h AQI ($\mu g/m^3$)	MT DEQ 8h AQI ($\mu g/m^3$)	MTDEQ 1h AQI ($\mu g/m^3$)
Good	None	None	0–15	0–22	0–38
Moderate	Possibility of aggravation of heart or lung disease among persons with cardiopulmonary disease and in the elderly.	None	15–40	22–58	38–101
Unhealthy for sensitive groups	Increased likelihood of respiratory symptoms in sensitive individuals. Aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and in the elderly.	People with respiratory or heart disease, the elderly, and children should limit prolonged exertion.	40–65	58–93	101–164
Unhealthy	Increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and in the elderly; increased respiratory effects in the general population.	People with respiratory or heart disease, the elderly, and children should avoid prolonged exertion; everyone else should limit prolonged exertion.	65–150	93–215	164–376

Table 1 continued. . .

Very unhealthy	Significant aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; significant risk of respiratory effects in the general population.	People with respiratory or heart disease, the elderly, and children should avoid any outdoor activity; everyone else should avoid prolonged exertion.	150–250	215–358	376–626
Hazardous	Serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and in the elderly; serious risk of respiratory effects in the general population.	Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly, and children should remain indoors.	250 +	358 +	626 +

The MT DEQ also established visibility ranges (table 2) to help communities without real-time monitoring equipment estimate particulate concentrations. The MT DEQ established these visibility ranges using empirical data collected from the Automated Surface Observing System visibility sensor located at the Helena airport and particulate concentrations collected nearby.

Table 2—Visibility ranges defined by the Montana Department of Environmental Quality corresponding to the department's air quality index.

Montana Department of Environmental Quality (DEQ) visibility categories	
Category	**Visibility (miles)**
Good	> = 11.6
Moderate	4.45–11.5
Unhealthy for sensitive groups	2.75–4.44
Unhealthy	1.2–2.74
Very unhealthy	0.7–1.1
Hazardous	< 0.7

Missoula and Hamilton Air Quality

The real-time instruments deployed by MTDC for this evaluation were operated almost continuously from about August 10 through the end of the month. Data from the real-time instruments were corrected using empirical formulas developed as a result of the evaluation. The following summary of the air quality in Missoula and Hamilton is based on the results from the real-time instruments' corrected data.

In Hamilton, the 1-h running average peak for $PM_{2.5}$ reached as high as 500 $\mu g/m^3$ and the running 24-h average reached as high as 284 $\mu g/m^3$ (figures 4 and 5). The 24-h $PM_{2.5}$ average reached

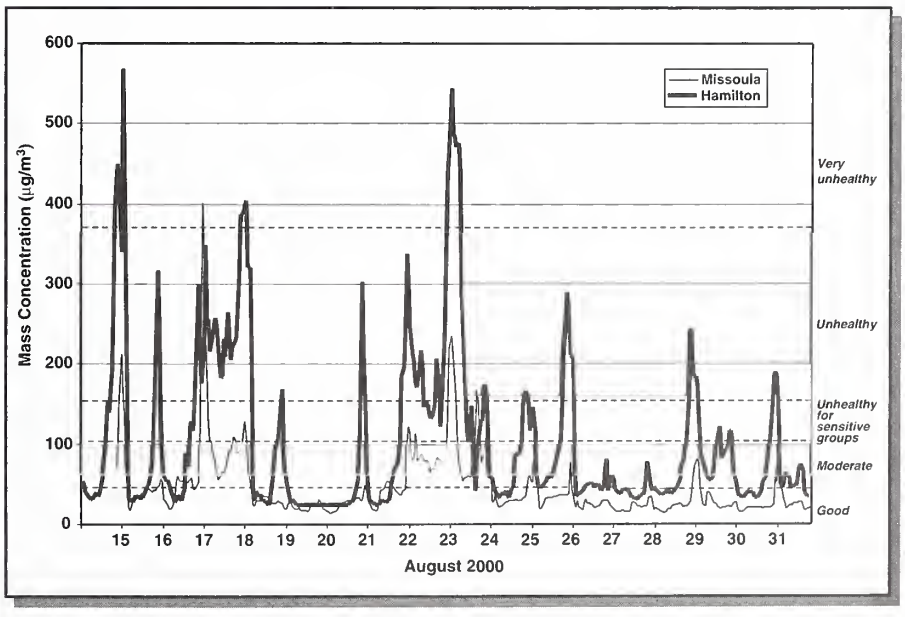

Figure 4—The estimated 1-h running mass concentration averages for $PM_{2.5}$ in Missoula and Hamilton, MT, during August 2000. Results are from the corrected values of the MIE DataRam real-time particulate monitor. Hazard category levels for forest fire smoke were determined by the Montana Department of Environmental Quality.

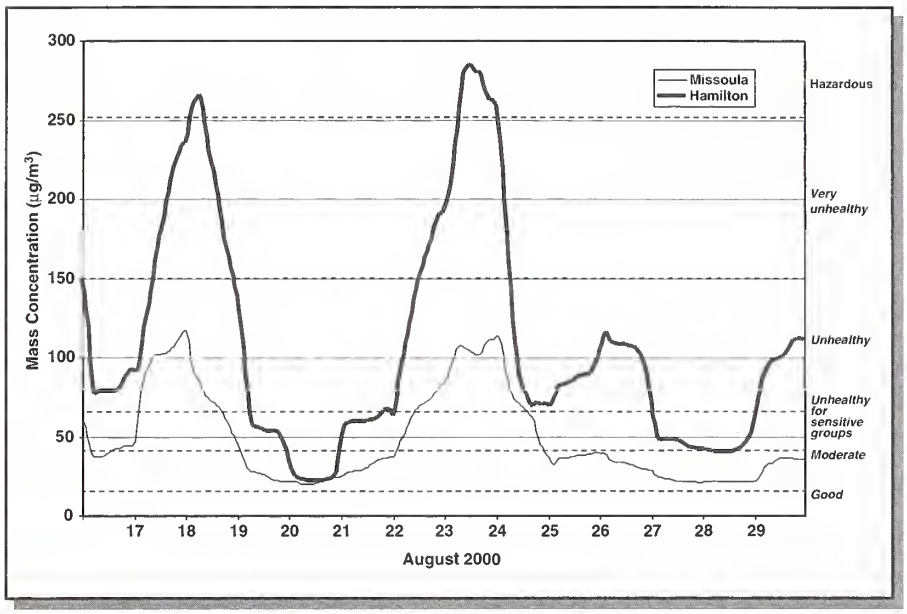

Figure 5—The estimated 24-h running mass concentrations for $PM_{2.5}$ in Missoula and Hamilton, MT during August 2000. Results are from the corrected values of the MIE DataRam real-time particulate monitor. Hazard category levels were determined by the Montana Department of Environmental Quality for forest fire smoke.

Daily 24-h $PM_{2.5}$ averages were calculated for Missoula and Hamilton (figure 8). The proposed 24-h EPA $PM_{2.5}$ standard of 65 $\mu g/m^3$ is shown in the graph. Hamilton exceeded this level 10 times from August 14 to 30, while Missoula exceeded the level 6 times from August 11 to September 1.

the hazardous level as described by the EPA and MT DEQ AQI. Missoula reached running 1-h average peaks of 400 $\mu g/m^3$ and 24-h average peaks of 204 $\mu g/m^3$ for $PM_{2.5}$.

Figures 6 and 7 show the percentage of time the air quality was in the various hazard categories based on the $PM_{2.5}$ AQI for Hamilton and Missoula. From August 14 to 30, the air quality index for the general public in Hamilton was categorized as unhealthy or worse about 67 percent of the time. If you include sensitive people (those with respiratory or heart disease, the elderly, and children), the air quality index was unhealthy or worse 93 percent of the time. Missoula's air quality was much better with no hazardous or very unhealthy peaks. The air quality index could be categorized as unhealthy 28 percent of the time from August 11 to 30, or unhealthy for 39 percent of the time if sensitive groups are included.

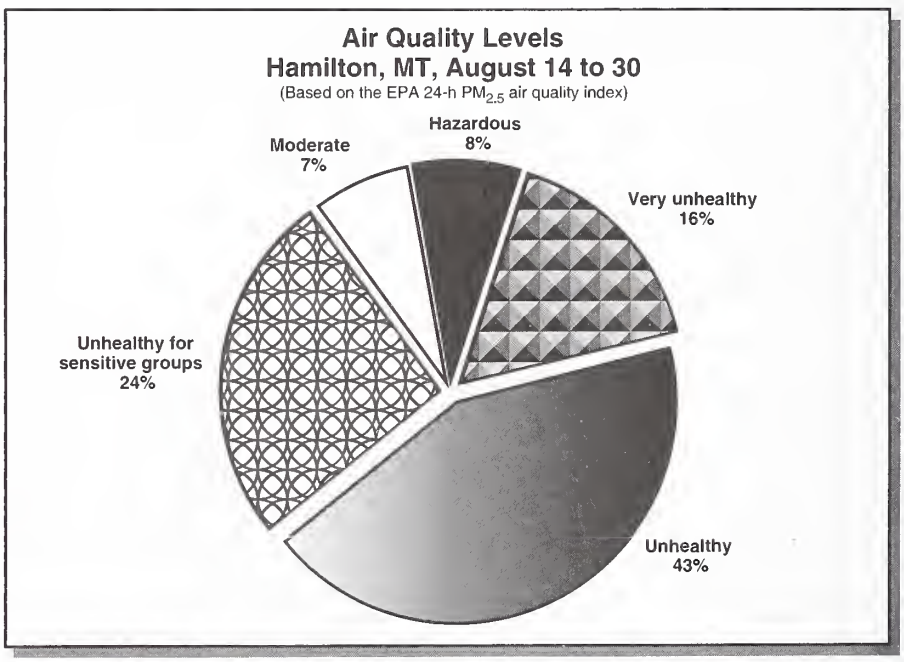

Figure 6—Air quality levels in Hamilton, MT, from August 14 to 30, 2000. The hazard categories are based on the U.S. Environmental Protection Agency air quality index for particulates smaller than 2.5 $\mu g/m^3$.

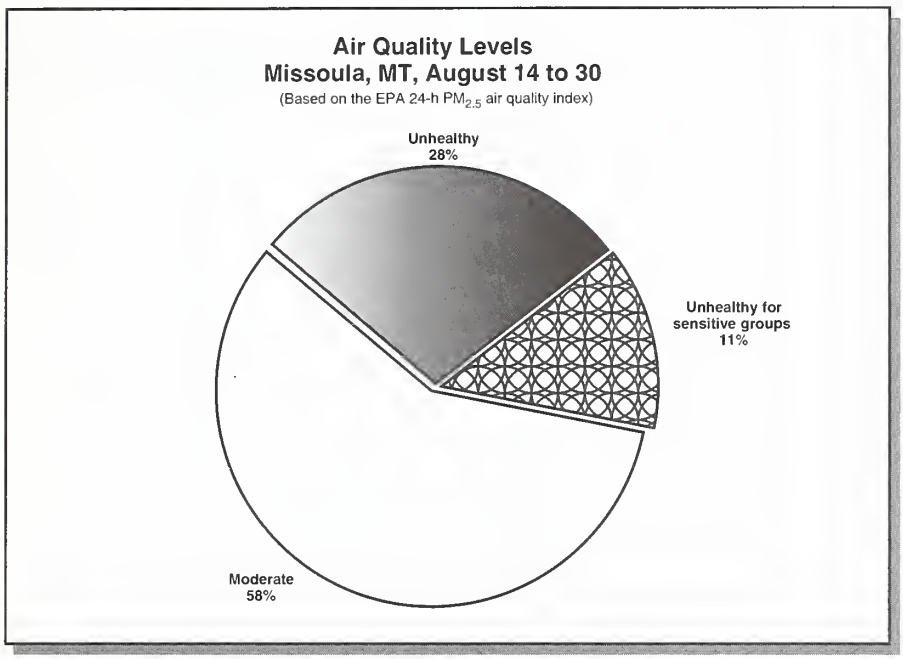

Figure 7—Air quality levels in Missoula, MT, from August 14 to 30, 2000. The hazard categories are based on the U.S. Environmental Protection Agency air quality index for particulate matter smaller than 2.5 $\mu g/m^3$.

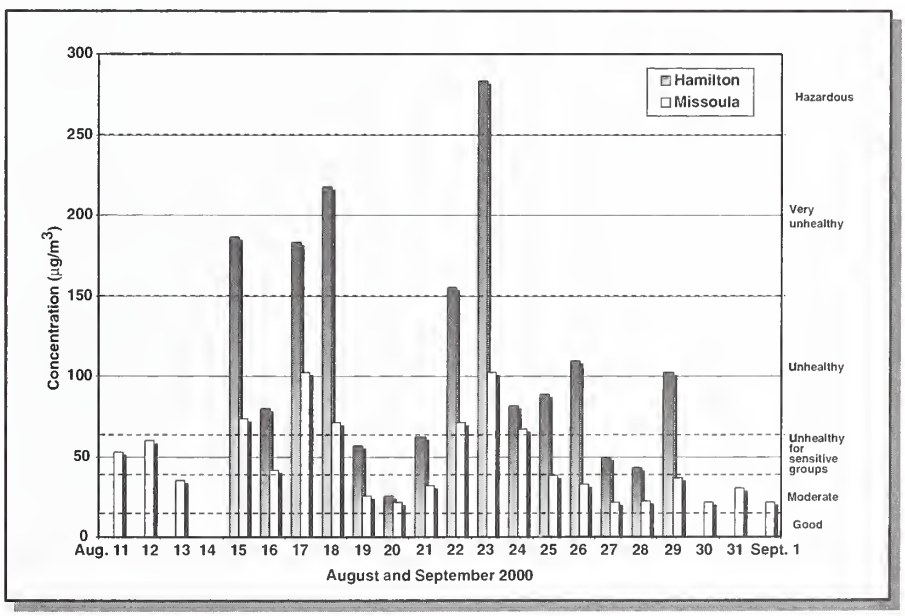

Figure 8—The estimated 24-h (midnight to midnight) $PM_{2.5}$ concentrations for Missoula and Hamilton, MT, from August 11 to September 1, 2000. Results are from the corrected MIE DataRam real-time particulate monitor.

Instrument Descriptions

Three categories of instruments are discussed in this report: optical real-time, continuous particulate monitors, mass quantifying real-time continuous particulate monitors, and gravimetric (filter-based) samplers.

Optical Real-Time, Continuous Particulate Monitors

Two types of optical real-time, continuous particulate monitors were used in this evaluation: predominantly light-scattering instruments and predominantly light-absorbing instruments. Light-scattering instruments, called nephelometers, measure the amount of light scattered over a known path length and use a mathematical relationship to estimate the aerosol mass concentration. The light-scattering coefficient (b_{sp}) is determined by illuminating particles, individually or as a group, and measuring the scattered intensity at different orientations from an incident light source. The orientation of the light source to the particles and receiver will determine whether the instrument is primarily back scattering (sun is at the viewer's back and light is scattered back to viewer), forward scattering (sun is at the viewer's front where light is scattered to the viewer), or total integrating (considers both back and forward scattering).

Light-absorbing instruments, called aethalometers, quantify the light-absorbing aerosol (black carbon, for example) by depositing the aerosol on a quartz-fiber filter and measuring the light transmission or reflectivity. Aethalometers also compute measured light attenuation due to black carbon.

Light-Scattering Instruments

Met One GT-640

The Met One GT-640 particulate monitor (figure 9) is a complete ambient air sampler using a forward light-scattering detector and built-in data logger. A laser optical sensor detects and measures particulate concentrations up to 10,000 $\mu g/m^3$. Built-in calibration functions are included. The unit has an internal relative humidity sensor that turns on an inlet heater at 55-percent relative humidity.

The monitor can be configured with either a PM_{10} (particulate matter finer than 10 μm) or $PM_{2.5}$ (particulate matter finer than 2.5 μm) cutoff inlet. Total suspended particulate concentrations can be estimated by removing the cutoff device. Data are digitally recorded and stored with time and date information. Stored data are retrieved through an RS-232 port connected to a laptop computer or through an external modem.

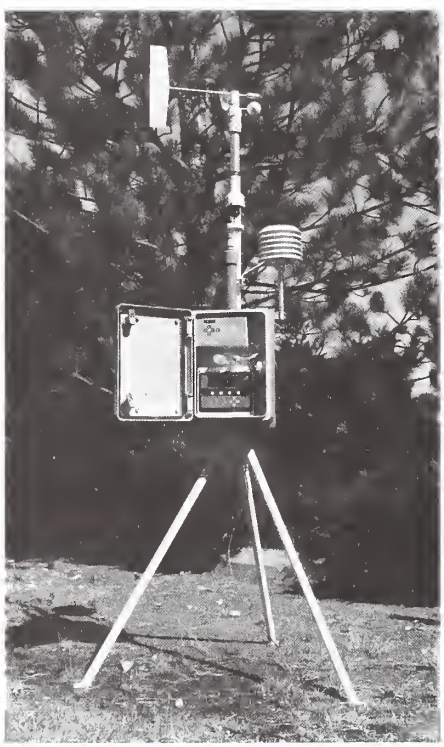

Figure 9—The Met One GT-640 particulate monitor with meteorological instrumentation.

The logger will record concentrations automatically, along with date and time, whenever power is applied. Optional connections on the bottom of the GT-640 allow various meteorological sensors to be attached. All internal components are housed in a weatherproof enclosure. The unit can be powered by an ac or dc power source.

MIE DataRam

The DataRam (figure 10) is a compact, self-contained instrument that internally estimates mass concentration from the measured scattering of light. The instrument can measure particulate concentrations from 0.1 to 400,000 $\mu g/m^3$, according to the vendor. The instrument continuously displays the current and time-weighted average mass concentration while logging up to 10,000 data points. Data can be downloaded from the instrument through an RS-232 port. The DataRam can be configured with either a $PM_{2.5}$ or PM_{10} impactor head to prevent particles larger than 2.5 or 10 μm from entering the optical chamber. For custom calibrations, or to analyze the chemical composition of particulates, the particulates can be collected on a 37-mm filter located in the instrument's base. An inline heater may also be installed for monitoring in humid conditions (the manufacturer suggests using the heater when the relative humidity is higher than 70 percent). The instrument's tubular heater is designed to heat the sampled air stream to evaporate liquid water from airborne particles or to eliminate fog droplets. The DataRam is powered by an internal rechargeable battery or by an external dc or ac power source. The DataRam has a built-in, internal calibration device.

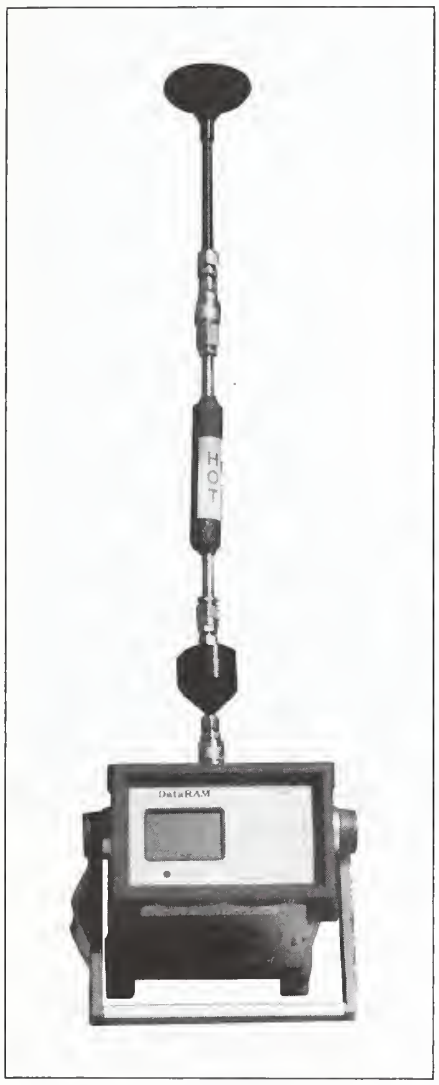

Figure 10—The MIE DataRam.

Optec NGN-3 Nephelometer

The Optec NGN-3 $PM_{2.5}$ size-cut nephelometer (figure 11) is a self-contained instrument developed to estimate $PM_{2.5}$ aerosol scattering and mass concentrations. The NGN-3 is based on the Optec NGN-2 ambient nephelometer that has been used by the IMPROVE interagency program for visibility studies and in other applications. The NGN-3 integrates the optical design of the NGN-2 ambient nephelometer with both a $PM_{2.5}$ size-cut separator and an inline sample heater to measure the dry-scattering fraction of extinction by fine-mass aerosols. Once

Figure 11—The Optec NGN-3 $PM_{2.5}$ size-cut nephelometer

measured, the back scattering is converted to mass concentration using a region-specific, user-selected empirical conversion factor. The NGN-3 continuously outputs both back scattering and a fine-mass concentration estimate with a minimum integration time of 2 min. The NGN-3 has no internal data storage capabilities, outputting data in serial or analog form. Portable remote monitoring data loggers, such as the Campbell Scientific CR-23X, or a laptop computer, are needed for data storage.

The NGN-3 draws ambient air through a sample inlet line. A spiral inlet manufactured by SKC mounted at the sample air inlet removes coarse particulates from the sample stream. The sample air is heated (to lower the relative humidity) as it enters the nephelometer. The temperature of the heated air is output continuously. To ensure monitoring accuracy, the instrument performs automatic zero calibrations at user-defined intervals. Manual zero and span calibration checks may be performed at any time. An external span gas, such as Freon, is required for calibration. The NGN-3 can be powered by either an ac or dc power source.

Radiance Research Nephelometer

The Radiance Research nephelometer, M903 (figure 12) is a lightweight, low-power instrument designed for portable operation as well as general environmental monitoring. The M903 measures and displays the back-scattering coefficient. It does not display a computed estimate of mass concentration, as do the other nephelometers in the evaluation. Mass concentrations can be estimated from the back-scattering readings. The instrument has a particulate measurement range of about 1 to 1,000 $\mu g/m^3$ when mass concentration is estimated from back scattering. The

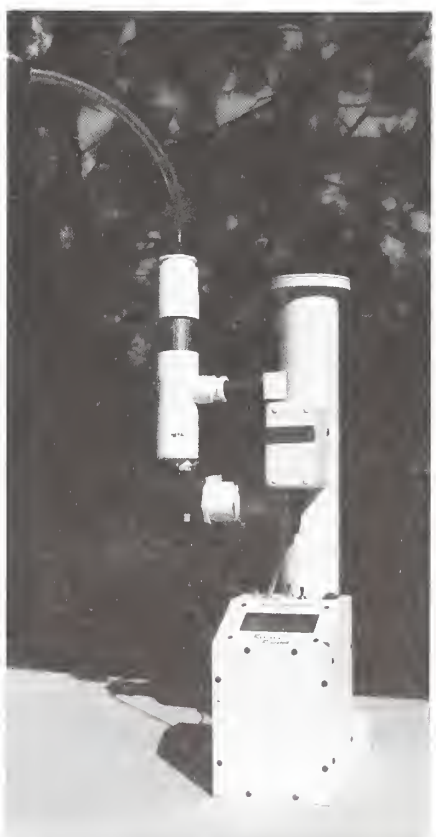

Figure 12—The Radiance Research M903 nephelometer (with attached inlet heater).

instrument has an internal data logger that will store scattering coefficient averages and the operating parameters that are used to estimate the back scattering. The stored data can be retrieved using a personal computer through an RS-232 port. Different averaging times and log intervals may be set. The instrument can store about 2 weeks of 5-minute averages. An external span gas, such as Freon, is required for calibration. The unit can be powered by an ac or dc power source.

Light-Absorbing Instruments

Andersen RTAA 900 Aethalometer

The Andersen RTAA 900 aethalometer (figure 13) measures suspended carbonaceous particulates. Aerosol black carbon (BC) is a ubiquitous component of combustion emissions. The aethalometer uses a continuous filtration and optical transmission technique to measure the concentration of BC in near real time. The model RTAA 900 is a dual wavelength system that measures both the BC at 800 nm (nanometers) and the UV (ultraviolet) at 325 nm.

The aethalometer is fully automatic and completely self-contained. It is constructed in a standard 19-in enclosed chassis and includes a filtration and analysis chamber with an automatically advancing quartz fiber tape, a sample aspiration pump and air mass flow meter or controller (typical flow rates are 2 to 6 L/min), and temperature-stabilized optics and electronics. The instrument is operated by an embedded computer with display screen and keypad that controls all instrument functions and records the data to a built-in 3.5-in floppy diskette. The instrument has a communications (COM) port for digital data stream output and an analog voltage terminal that can be programmed to represent the measured concentrations or to function as an on/off threshold alarm.

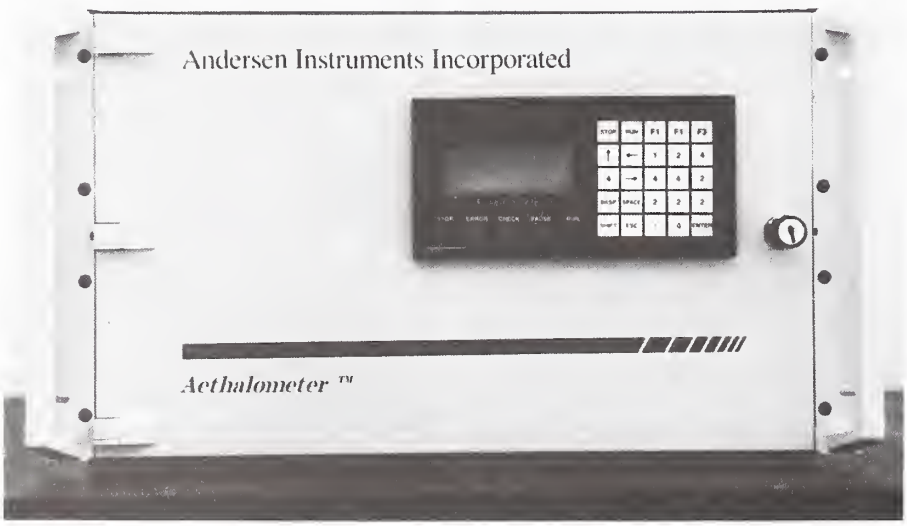

Figure 13—The Andersen RTAA 900 aethalometer.

Mass Quantifying Real-Time Continuous Monitors

One method of determining particulate mass concentrations in real time uses a TEOM instrument. Particulate is continuously collected on a filter mounted on the tip of a glass element that oscillates in an electric field. The glass element is hollow, with the wider end fixed. Air is drawn through the filter and through the element. The oscillation of the glass element is maintained based on the feedback signal from an optical sensor. The resonant frequency of the element decreases as mass accumulates on the filter, directly measuring inertial mass. Temperatures should be maintained at a constant value to minimize thermal expansion of the tapered element.

Tapered Element Oscillating Microbalance Ambient Particulate Monitor

Rupprecht & Patashnick Co., Inc., (figure 14) manufactures a TEOM ambient particulate monitor, Model 1400a. This monitor is designated by the EPA as an equivalent method PM_{10} monitor. It incorporates an inertial balance that directly measures the mass collected on an exchangeable filter cartridge by monitoring the corresponding frequency changes of the tapered element. Typical averaging times are 1 h. These monitors are deployed worldwide, including one in Missoula, MT, operated by the MT DEQ. The instrument can be configured for PM_{10}, $PM_{2.5}$, PM_1 or total suspended particulate (TSP). The instrument has internal data logging storage for 40 weeks of data with one variable stored every hour. Data can be downloaded using an RS-232 port. The instrument also has three real-time analog outputs. The Rupprecht & Patashnick TEOM is very large and heavy (52 in high by 47

Figure 14—The Rupprecht & Patashnick tapered element oscillating microbalance instrument.

in wide by 24 in deep, weighing 180 lb, in its environmental enclosure) compared to the optical, real-time continuous samplers and is usually a more permanent installation.

Gravimetric-Based Instruments

Gravimetric-based instruments were used in the evaluation to produce standard results for comparison with the real-time samplers. Gravimetric- or filter-based instruments work by drawing air at a controlled rate through a filter that collects the fine particulate matter. The filter is carefully weighed at a special facility before and after sampling. This method provides very accurate results of the quantity of particulate that was collected during the test period. The particulate mass value is divided by the total volume of air drawn through the filter, yielding the average mass concentration for the test period, typically in micrograms per cubic meter.

BGI, Inc., Federal Reference Method $PM_{2.5}$ PQ 200 Air Sampler

The BGI, Inc., PQ 200 (figure 15) sampler was used in the real-time collocation study. One sampler was located at Missoula and another in Hamilton, MT. They both have similar design, performance characteristics, and operational requirements. The BGI PQ 200 is a microprocessor-controlled, volumetric flow rate air-sampling instrument that obtains a valid $PM_{2.5}$ air sample. Two inertial separators designed by the EPA separate particulate matter finer than 2.5 μm. These particulates are collected on a 47-mm Teflon membrane at a volumetric sample rate of 16.67 L/min.

Measurements are made at ambient temperature and pressure. A microprocessor and volumetric flow control system are integrated to maintain constant flow. Volume flow rate, 5-min average ambient temperature and pressure, and filter temperature and pressure are continuously logged into the processor memory. The operator recovers measured values and flags (indicating anomalies) by downloading the summary to a laptop computer. The instruments may be powered by an internal battery, external batteries, or solar power.

Filters collected by the BGI PQ 200s were weighed at the Montana Department of Public Health and Human Services environmental laboratory in Helena, MT.

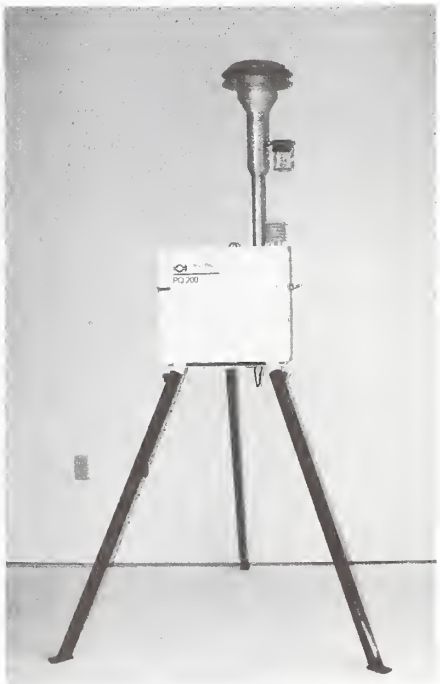

Figure 15—The BGI PQ 200 federal reference method $PM_{2.5}$ air sampler.

Methods and Test Descriptions

The instruments operated by MTDC and the MT DEQ were located in Missoula and Hamilton (table 3). The center's fabrication shop is in Missoula at 1800 Strand Avenue near the center of town. The MT DEQ has a Rupprecht & Patashnick TEOM instrument operating at Missoula's Boyd Park at the corner of Russell and Ernest Streets in Missoula. MTDC located a set of real-time instruments and an FRM sampler at the Bitterroot National Forest supervisor's office in Hamilton, MT.

All the MTDC real-time instruments were deployed at the center's fabrication shop on August 10, 2000. On August 14, one set of instruments including a Met One GT-640, MIE DataRam, Optec NGN-3 nephelometer, Radiance Research nephelometer, and an FRM sampler were taken to Hamilton (figure 16). The Optec NGN-3 was brought back to Missoula on August 23. All the instruments operated until early September 2000. Table 3 shows the date and location where each instrument was deployed.

Table 3—Dates and locations where each instrument was deployed during the August 2001 wildfires.

Instrument	City Location		
	Hamilton Bitterroot NF supervisor's office	***Missoula MTDC fabrication shop***	***Missoula Boyd Park***
MIE DataRam SN 2484		Aug. 10 to Sept. 2 (continuous)	
MIE DataRam SN 2327	Aug. 14 to Sept. 1 (continuous)	Aug. 10 to 13 (continuous)	
Radiance Research nephelometer SN 0102		Aug. 10 to Sept. 2 (continuous)	
Radiance Research nephelometer SN 0101	Aug. 14 to Sept. 1 (continuous)	Aug. 10 to 13 (continuous)	
Met One GT-640 SN 5278		Aug. 10 to Sept. 2 (continuous)	
Met One GT-640 SN 1466	Aug. 14 to Sept. 1 (continuous)	Aug. 10 to 13 (continuous)	
Optec NGN-3 nephelometer	Aug. 14 to 23 (continuous)	Aug. 10 to 13, Aug. 23 to Sept. 2 (continuous)	
Andersen aethalometer		Aug. 18 to Sept. 1 (continuous)	
MTDC BGI PQ 200		Aug. 10 to Sept. 1 (variable)	
MTDC BGI PQ 200	Aug. 14 to Sept. 1 (variable)		
MT DEQ R&P TEOM			Continuous- (1-, 8-, and 24h averages)

A total of 32 FRM filter samples were collected at the MTDC fabrication shop area from August 10 through September 1, 2000. The average FRM sampling period was 10.9 h with the shortest sampling period being 1.5 h and the longest being 24 h. We collected 29 FRM filter samples in Hamilton from August 14 through September 1, 2000. The average FRM sampling period in Hamilton was 10.4 h, with the shortest period being 3 h and the longest period being 24 h. The MIE DataRam, Radiance Research nephelometer, and Met One GT-640 instruments ran almost continuously, taking 5-min averages. The Optec NGN-3 and Andersen aethalometer were taking 2-min and 1-min averages, respectively. Power was lost to the instruments in Hamilton on several occasions. Data were lost during those periods. Data from the real-time instruments were downloaded to a laptop computer at both sites.

The real-time instruments were equipped with $PM_{2.5}$ inlets except for the Radiance Research nephelometer, which estimated total suspended particulate (TSP) concentrations. The instruments were also operated with their respective inlet heaters.

The TEOM instrument ran continuously, providing running 1-, 8-, and 24-h averages.

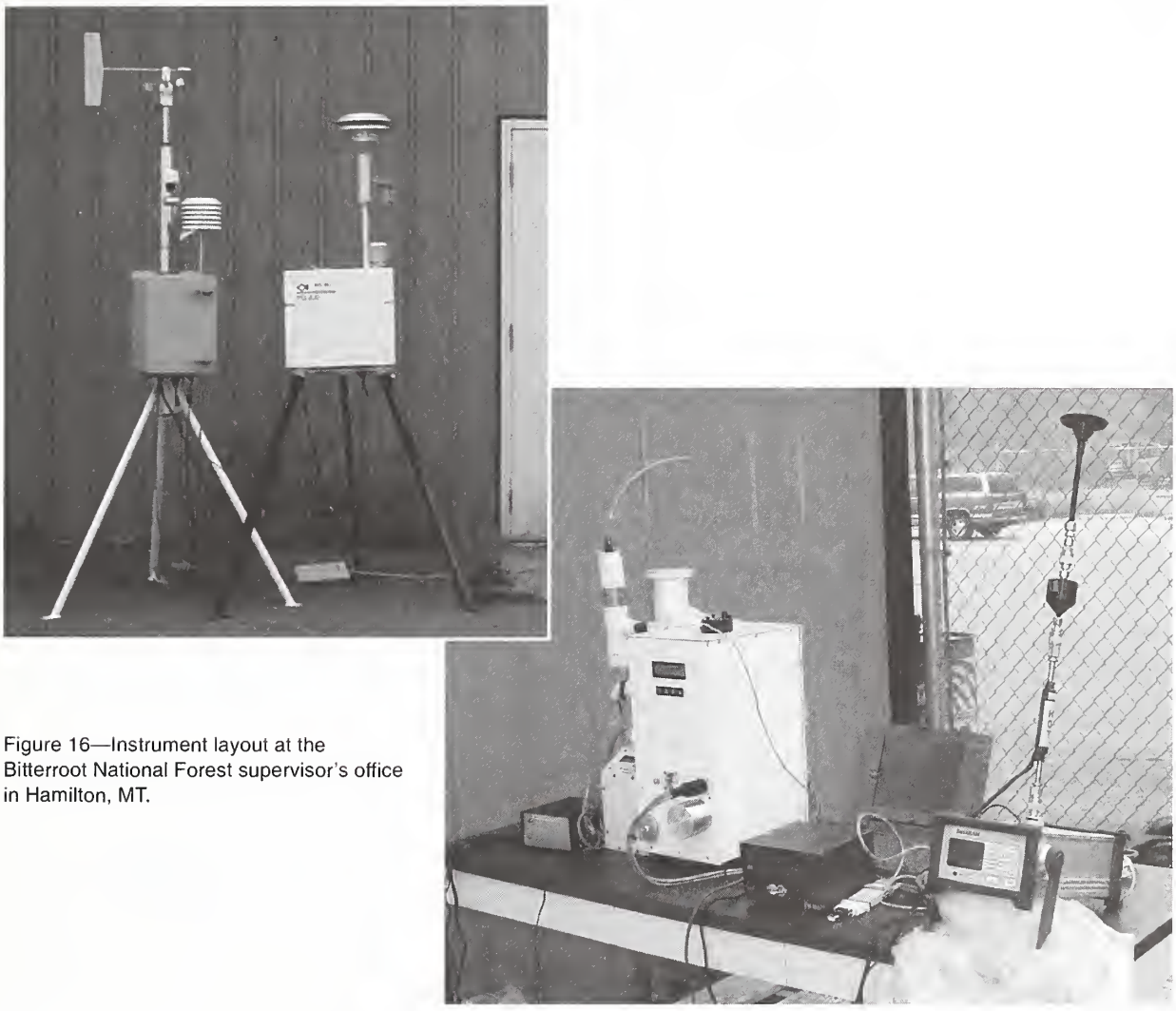

Figure 16—Instrument layout at the Bitterroot National Forest supervisor's office in Hamilton, MT.

Results

Real-Time Instrument Accuracy

The accuracy of each of the real-time instruments was determined by its computed average mass concentration compared to the FRM $PM_{2.5}$ concentration. The data from the various instrument types and locations are compared in figures 17 to 32 using the least squares linear regression coefficients. Each figure shows the appropriate data points, slope equation with intercept, and the correlation coefficient. Dashed lines indicate a one-to-one relationship. Solid lines show the best-fit regressions.

Figures 17 (Missoula) and 18 (Hamilton) show the nephelometer-based instrument data. All regression statistics for each instrument are summarized in table 4.

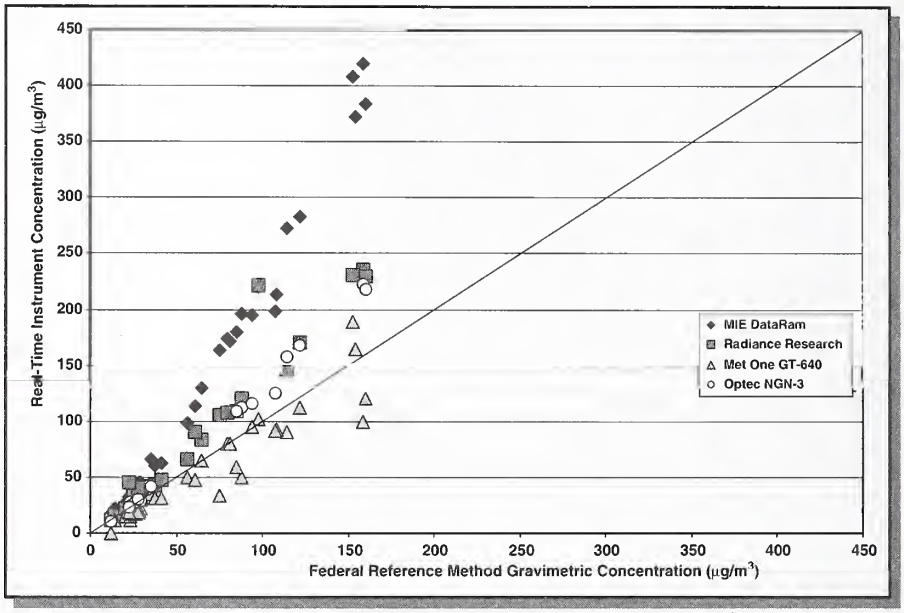

Figure 17—Test results of all the light-scattering instruments at Missoula, MT.

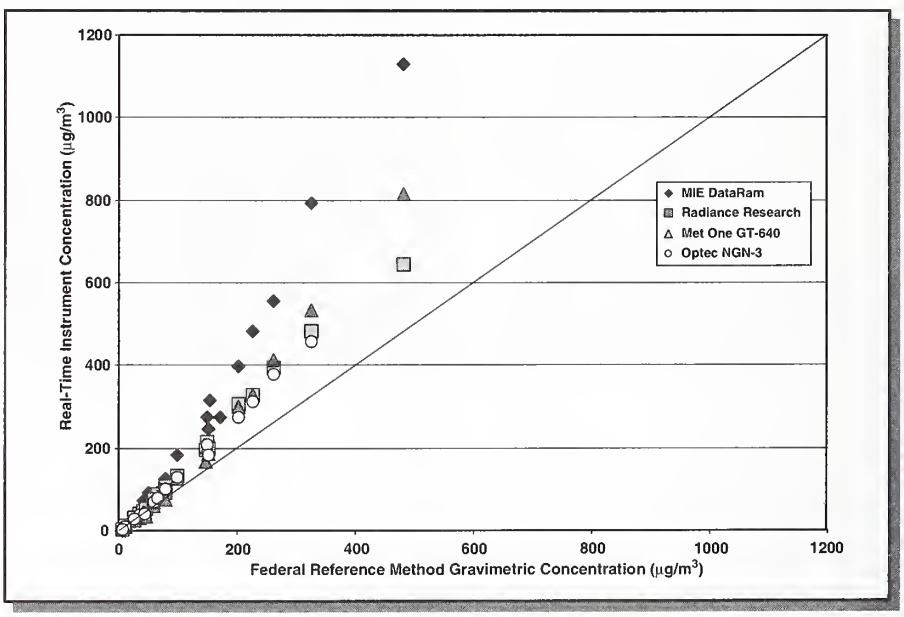

Figure 18—Test results of real-time instruments at Hamilton, MT.

Table 4—Regression results for real-time instruments compared to the BGI PQ 200 federal reference method air sampler.

Instruments	*(Intercept included)*			*(No intercept)*		
	Regression slope	Intercept (μg/m³)	Correlation coefficient	Regression slope	Intercept	Correlation coefficient
Nephelometers						
DataRam SN 2484/FRM[1]	2.61	-32.43	0.98	2.28	0	0.96
DataRam SN 2327/FRM	2.34	-45.92	0.98	2.10	0	0.96
Radiance Research SN 102/FRM	1.52	-6.88	0.94	1.45	0	0.94
Radiance Research SN 101/FRM	1.43	-6.59	0.99	1.39	0	0.99
Met One GT-640 SN 5278/FRM	0.94	-6.15	0.87	0.88	0	0.87
Met One GT-640 SN 1466/FRM	1.67	-30.26	0.99	1.52	0	0.97
Optec NGN-3 Neph/FRM	1.43	-11.04	1.00	1.36	0	0.99
Aethalometers						
Andersen 370 nm channel/FRM	0.051	0.349	0.970	0.055	0	0.959
Andersen 880 nm channel/FRM	0.027	0.111	0.980	0.029	0	0.974

[1] FRM stands for federal reference method gravimetric sampler, the standard against which all instruments were compared.

Andersen RTAA 900 Aethalometer

A total of 15 filter samples were taken by the FRM while the Andersen aethalometer was operating. Figure 19 compares the aethalometer results to the FRM. The 880-nm channel of the aethalometer had a slope of $y = 0.027x + 0.111$ with a correlation coefficient of 0.98. The 370-nm channel had a slope of $y = 0.051x + 0.349$ with a correlation coefficient of 0.97.

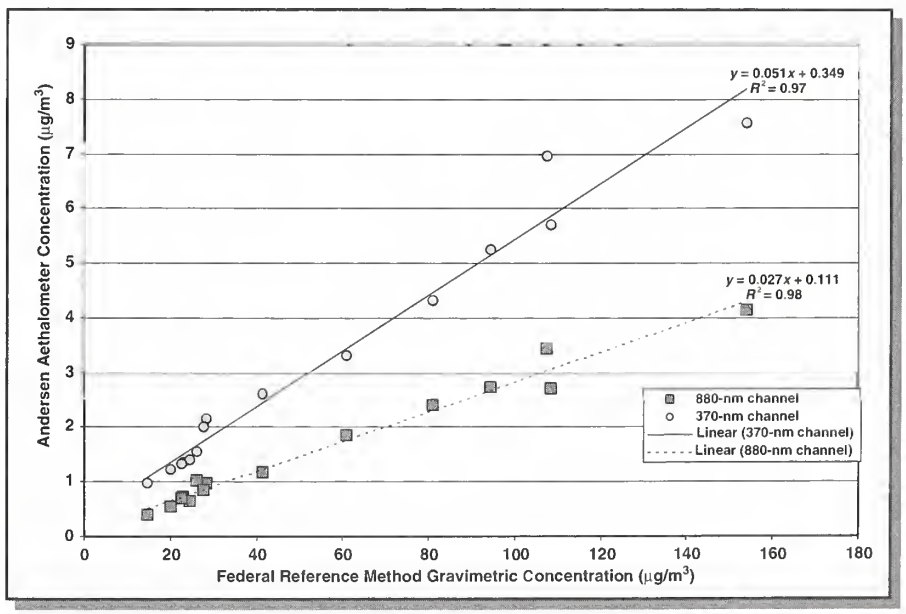

Figure 19—Regression results of the Andersen RTAA 900 aethalometer and the BGI federal reference method sampler at Missoula, MT.

According to the manufacturer, the 880-nm channel represents the black or elemental carbon percentage of the total mass of the wood smoke. So, for these wildfires, black carbon accounted for about 2.7 percent of the total mass of smoke. The manufacturer noted that in urban areas where automobile traffic affects air quality, the BC is typically 10 percent of the total mass. The UV or "aromatic" channel showed concentrations 1.93 times higher than the BC channel, implying that organics are about 5 percent of the total smoke mass. The consistent relationship (correlation coefficient of 0.98) between the UV channel response and the BC channel response (figure 20) suggests that the relationship between black carbon and aromatic organic carbon was consistent in this wood smoke.

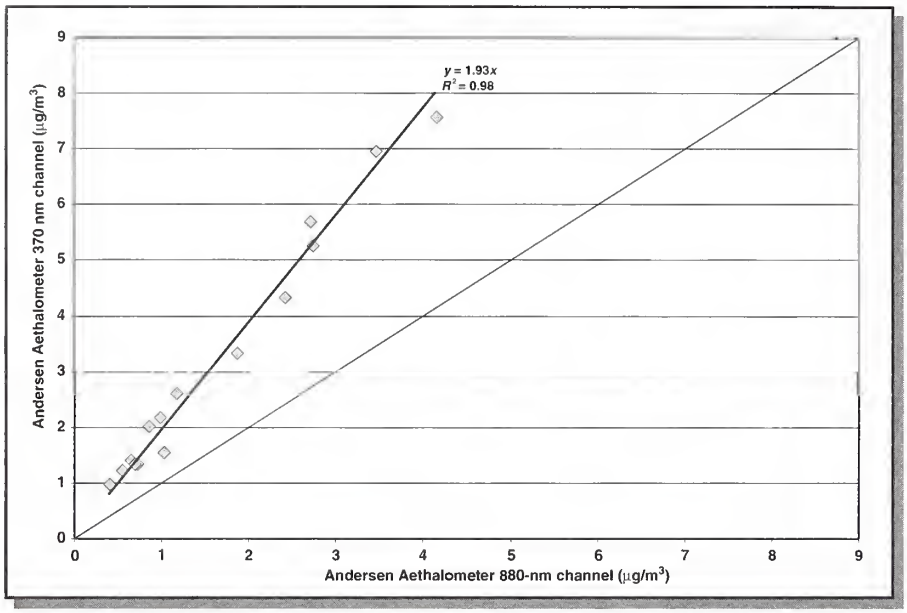

Figure 20—Comparison of the BC (black carbon) and UV (ultraviolet) channel results from the Andersen aethalometer.

Met One GT-640s

Two Met One GT-640s were deployed, one in Missoula and the other in Hamilton. The Missoula instrument had 32 filter comparison test results. The Hamilton instrument had 22 results. Figure 21 shows the results from each instrument. The Met One GT-640 in Missoula (serial No. 5278) had a slope of 0.94*x* and a *y*-intercept of -6.15 µg/m³. The correlation coefficient was 0.87. The instrument located in Hamilton (serial No. 1466) underestimated the mass concentration when compared to the gravimetric results. The Met One GT-640 in Hamilton had a slope of 1.67*x* and a *y*-intercept of -30.26 µg/m³. The correlation coefficient was 0.99.

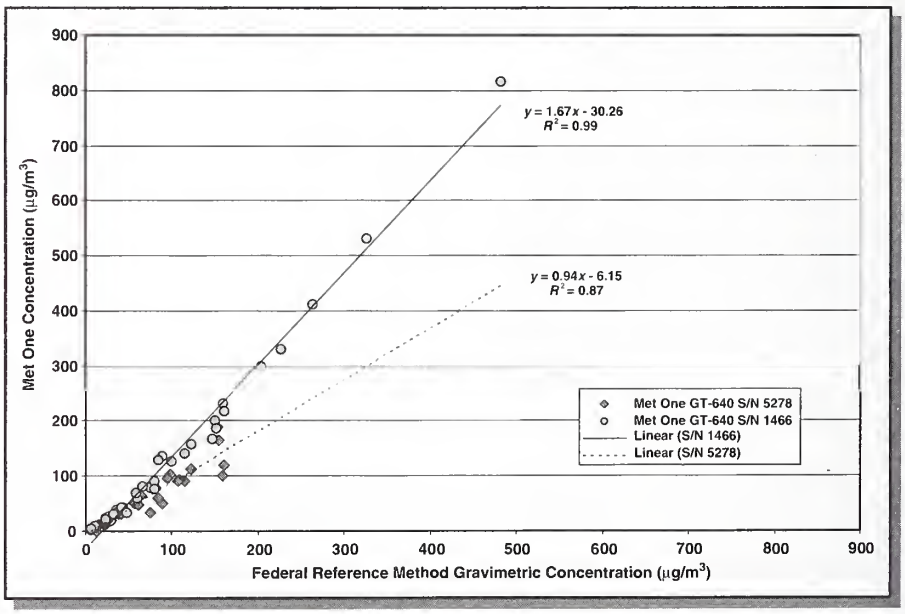

Figure 21—Results from the two Met One GT-640 and BGI PQ 200 federal reference method air samplers deployed at Missoula (Met One serial No. 5278) and Hamilton, MT (Met One serial No. 1466).

MIE DataRams

Two DataRams were operated, one in Missoula and the other in Hamilton. A total of 32 results were obtained in Missoula and 27 were obtained in Hamilton (figure 22). DataRam No. 2327, located in Hamilton, overestimated the mass concentration by 2.34 times with a *y*-intercept of -45.92 $\mu g/m^3$. The correlation coefficient was 0.98. The other DataRam (serial No. 2484) in Missoula overestimated the mass concentration by 2.61 times with a *y*-intercept of -32.43 $\mu g/m^3$. The correlation coefficient was 0.98.

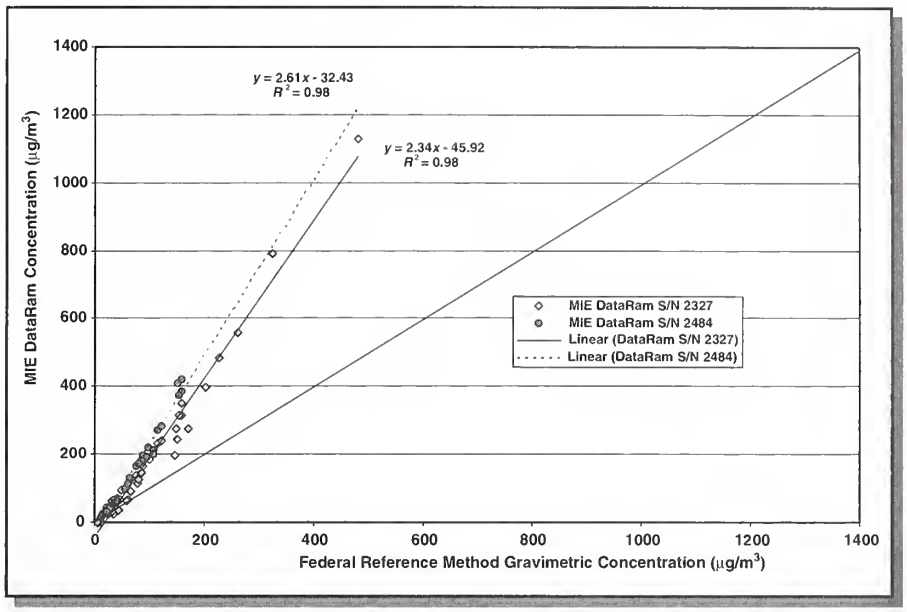

Figure 22—Results of the two MIE DataRams and BGI PQ 200 federal reference method samplers. The DataRam with serial No. 2327 was in Hamilton and the DataRam with serial No. 2484 was in Missoula, MT.

Optec NGN-3 Nephelometer

The Optec NGN-3 nephelometer was operated in both Missoula and Hamilton. Figure 23 shows the results of both sets of tests. The instruments performed almost identically at both Missoula and Hamilton. The instruments overestimated the smoke mass concentration by about 42 to 44 percent with a *y*-intercept of 9 to 11 $\mu g/m^3$. Both had correlation coefficients greater than 0.99. Figure 24 shows the results from combining both sets of tests. The combined instruments overestimated the mass concentration by 43 percent with a *y*-intercept of -11.01 $\mu g/m^3$. The correlation coefficient was 1.00.

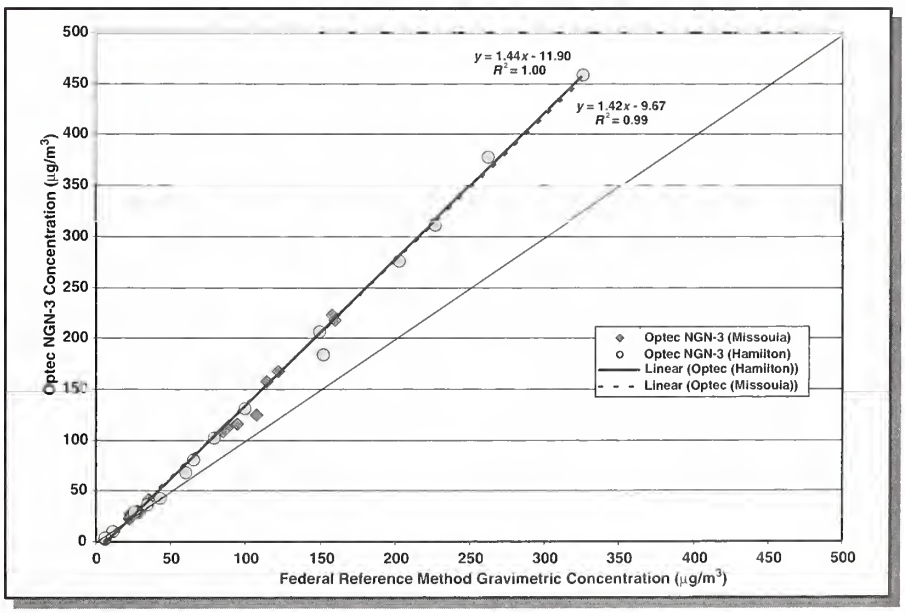

Figure 23—Results from the Optec NGN-3 nephelometer and the BGI PQ 200 federal reference method sampler in Missoula and Hamilton, MT. The Missoula and Hamilton, MT, tests are separate.

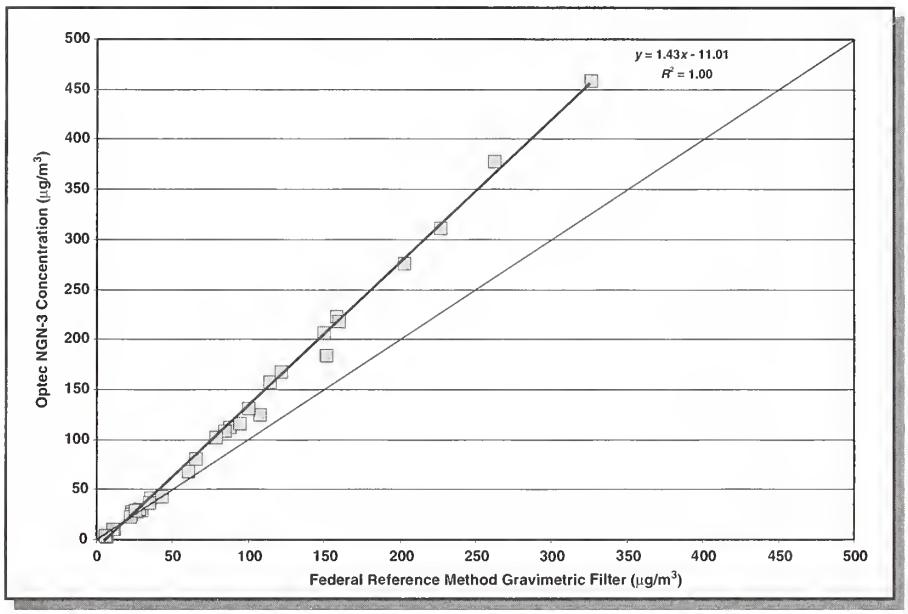

Figure 24—Combined results of the Optec NGN-3 nephelometers in Missoula and Hamilton and the BGI PQ 200 federal reference method sampler.

Radiance Research Nephelometers

Two Radiance Research nephelometers were operated, one in Missoula and one in Hamilton. Figure 25 shows the results from both instruments. The nephelometer (serial No. 0101) in Hamilton overestimated the mass concentration by 43 percent with a *y*-intercept of -6.59 $\mu g/m^3$. The correlation coefficient was 0.99. The nephelometer in Missoula (serial No. 0102) overestimated the mass concentration by 52 percent with a *y*-intercept of -6.88 $\mu g/m^3$. The correlation coefficient was 0.94.

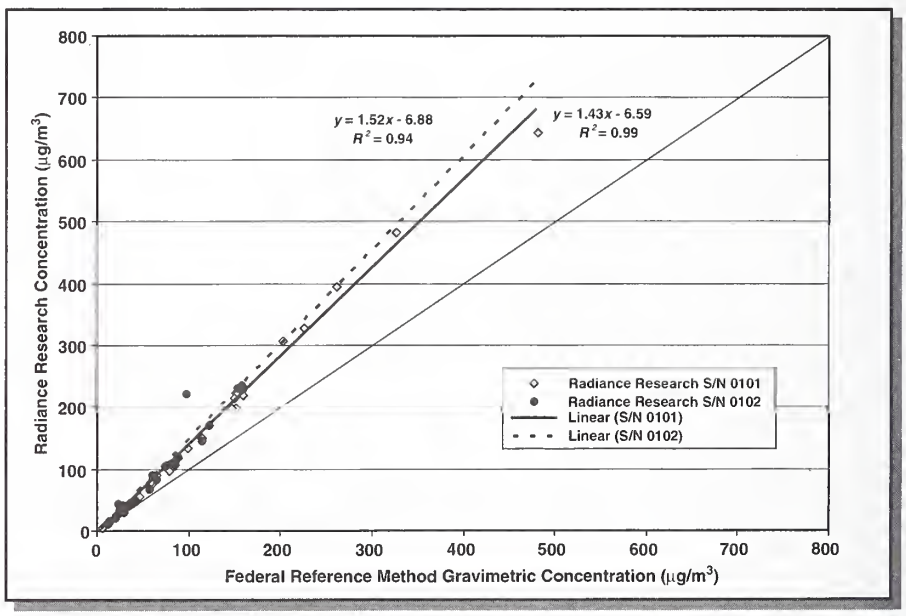

Figure 25—Results of the two Radiance Research nephelometers and the PQ 200 federal reference method samplers. The nephelometer with serial No. 0101 was in Hamilton and the nephelometer with serial No. 0102 was in Missoula, MT.

Comparison of Instruments Used in Both Missoula and Hamilton

Several of the instruments were moved from Missoula to Hamilton during the test and operated in both locations. These instruments include the Met One GT-640, MIE DataRam, Radiance Research nephelometer, and the Optec NGN-3 nephelometer. We have the opportunity to determine whether the instruments responded differently to the smoke at different locations. Doing so may give us information about the optical scattering characteristics of the smoke at the two sites. Because the fires were closer to Hamilton than to Missoula, we may be able to say that the Hamilton smoke was "newer" than the Missoula smoke. Smoke in Missoula was probably from several different fires, including some near Hamilton. We could say the Missoula smoke was "aged." The results are based on the assumption that the instruments performed similarly in both locations.

Except for the Optec NGN-3 nephelometer, the instruments operated at both locations were in Hamilton longer than they were in Missoula. There are considerably more results from Hamilton than from Missoula. Also, the mass concentrations were much higher in Hamilton than in Missoula. Concentrations in Missoula ranged up to 160 $\mu g/m^3$ as determined by the gravimetric sampler, while concentrations in Hamilton reached as high as 480 $\mu g/m^3$. The age of the smoke and the difference in average particulate concentrations between Missoula and Hamilton may explain some of the differences in instrument performance.

Met One GT-640

Figure 26 shows results from the Met One GT-640. When the instrument was in Missoula, it overestimated the mass concentration by 1.48 times based on 11 filter samples. The instrument overestimated the mass concentration in Hamilton by 1.69 times based on 24 samples.

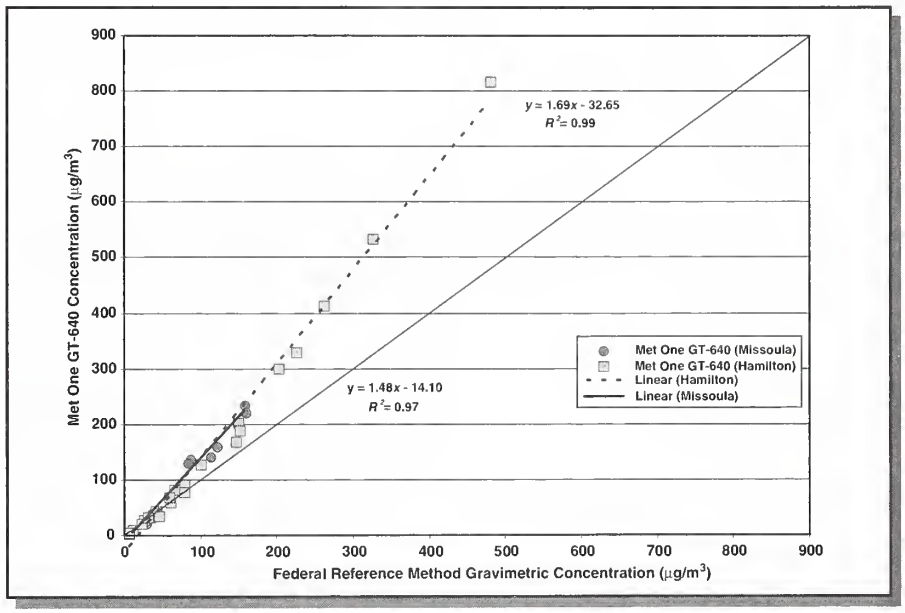

Figure 26—Results from the Met One GT 640 (serial No. 1466) deployed first in Missoula and then in Hamilton, MT.

MIE DataRam

Figure 27 shows results from the MIE DataRam. When the instrument was in Missoula, it overestimated the mass concentration by 2.18 times with a *y*-intercept of -21.21 $\mu g/m^3$ based on 11 filter samples. The instrument overestimated the mass concentration in Hamilton by 2.36 times with a *y*-intercept of -52 $\mu g/m^3$ based on 29 filter samples.

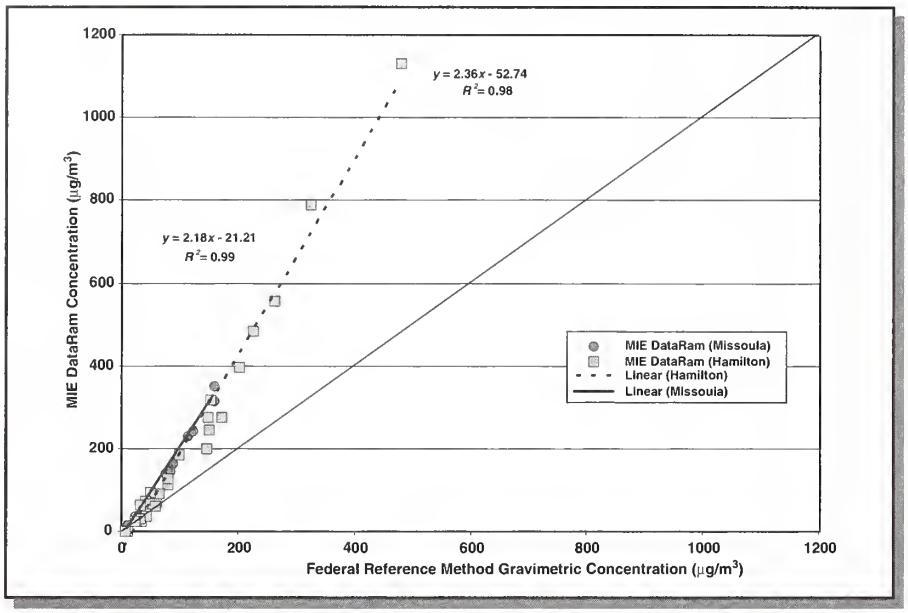

Figure 27—Results from the MIE DataRam (serial No. 2327) deployed first in Missoula and then in Hamilton, MT.

Optical and Tapered Element Oscillating Microbalance

The proximity (about ½ mile) of the optical, real-time instruments and the MT DEQ TEOM instrument in Missoula allows the center to compare the results of the instruments. The corrected 1-h average value of the DataRam and the TEOM are plotted in time series in figure 29. The same values are shown in an *X-Y* scatter plot in figure 30. Regression statistics show the best-fit linear line has a slope of 1.06 and a *y*-intercept of +8.35. The correlation coefficient was 0.78. Figures 31 and 32 show the results of the 8- and 24-h averages for the same instruments.

Optec NGN-3 Nephelometer

Figure 23 shows results from the Optec NGN-3 nephelometer. When the instrument was in Missoula, it overestimated the mass concentration by 1.44 times with a *y*-intercept of -11.90 $\mu g/m^3$ based on 16 filter samples. The instrument overestimated the mass concentration in Hamilton by 1.42 times with a *y*-intercept of -9.67 $\mu g/m^3$ based on 16 filter samples.

Radiance Research Nephelometer

Figure 28 shows results from the Radiance Research nephelometer. When the instrument was in Missoula, it overestimated the mass concentration by 1.44 times with a *y*-intercept of -9.22 $\mu g/m^3$ based on 11 filter samples. The instrument overestimated the mass concentration in Hamilton by 1.42 times with a *y*-intercept of -5.6 $\mu g/m^3$ based on 24 filter samples.

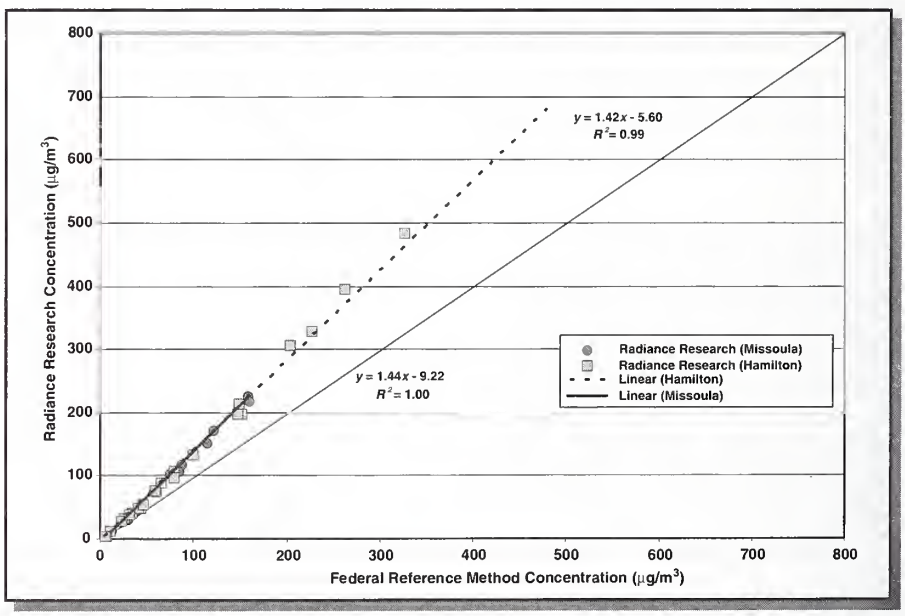

Figure 28—Results from the Radiance Research nephelometer (serial No. 0101) deployed first in Missoula and then in Hamilton, MT.

The DataRam tended to give slightly lower readings than the TEOM instrument. This may be because the TEOM instrument measured PM_{10} while the real-time instruments measured $PM_{2.5}$.

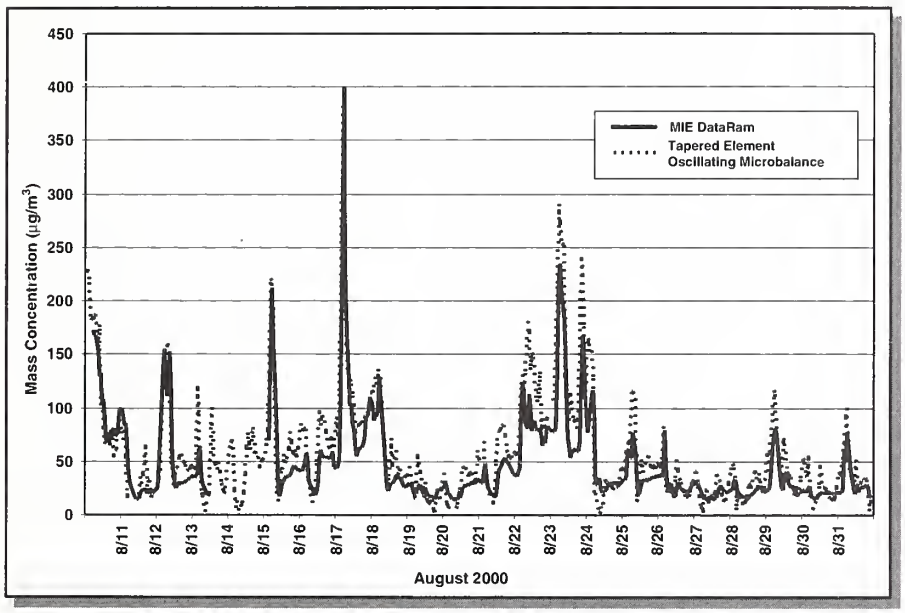

Figure 29—Results of the corrected values from the MIE DataRam (serial No. 2484) in Missoula and the Montana Department of Environmental Quality's tapered element oscillating microbalance instrument at Boyd Park (Missoula). Shown are the 1-h average readings from both instruments.

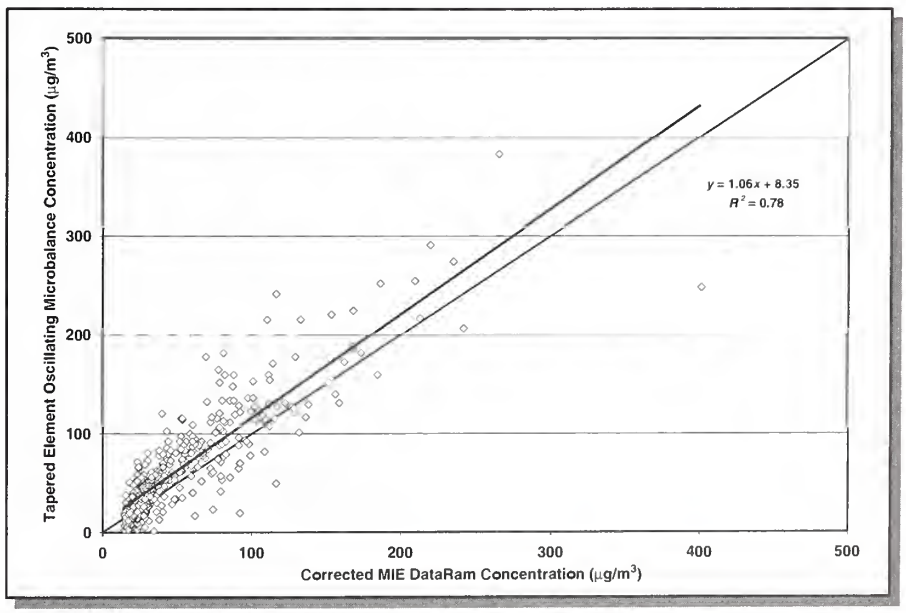

Figure 30—Regression results of the 1-h average readings from the Montana Department of Environmental Quality's tapered element oscillating microbalance instrument and the corrected values from the MIE DataRam (serial No. 2484).

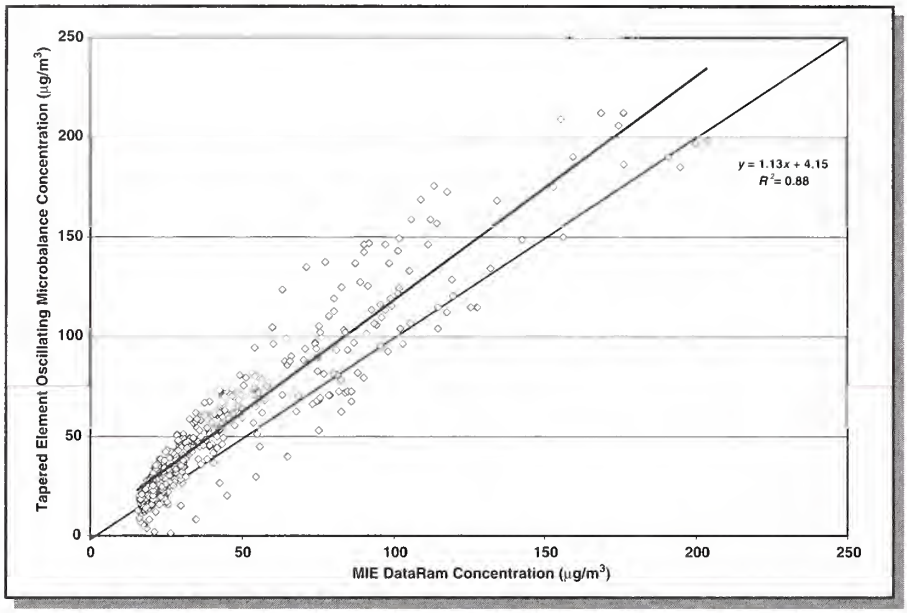

Figure 31—Regression results of the 8-hr average readings from the Montana Department of Environmental Quality's tapered element oscillating microbalance instrument and the corrected values from MIE DataRam (serial No. 2484).

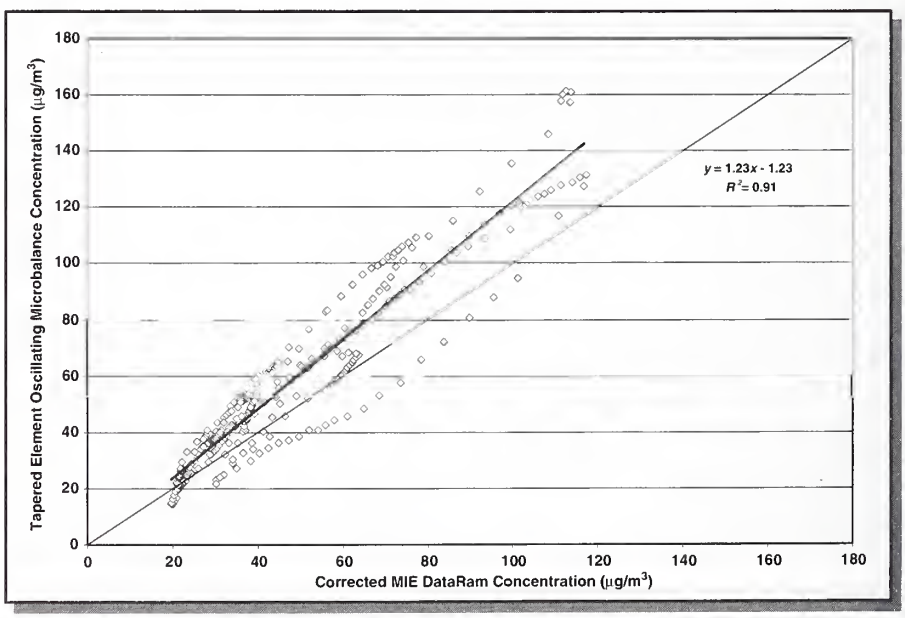

Figure 32—Regression results of the 24-h average readings from the Montana Department of Environmental Quality's tapered element oscillating microbalance instrument and the corrected values from the MIE DataRam (serial No. 2484).

Conclusions

The center evaluated several real-time optical particulate monitors during the August 2000 wildfires in Montana. The real-time instruments were collocated with an EPA federal reference method gravimetric sampler in both Missoula and Hamilton, MT, to determine the accuracy of the instruments. The instruments were also compared to an EPA equivalent method PM_{10} instrument (a Rupprecht & Patashnick TEOM). This work was part of an ongoing evaluation the center has been conducting since 1998 to survey commercial off-the-shelf instruments to monitor smoke particulate. Two other publications, *Laboratory Evaluation of Two Optical Instruments for Real-Time Particulate Monitoring of Smoke* (9925-2806-MTDC) and *Evaluation of Optical Instruments for Real-Time Continuous Monitoring of Smoke Particulates* (0025-2860-MTDC) provide details on real-time instrument evaluations in both laboratory and field situations.

The particulate concentrations measured in Missoula and Hamilton ranged from low levels (less than 10 $\mu g/m^3$) to very high levels (higher than 500 $\mu g/m^3$). All the real-time instruments were capable of estimating particulate levels in this range. Two types of real-time instruments (light scattering and light absorbing) were used.

The performance of the light-scattering instruments when compared to an EPA FRM sampler were:

- Met One GT-640 (serial No. 5278)–Underestimated concentrations by 0.94 times (*y*-intercept = -6.15 $\mu g/m^3$)
- Met One GT-640 (serial No. 1466)–Overestimated concentrations by 1.67 times (*y*-intercept = -30.26 $\mu g/m^3$)
- MIE DataRam (serial No. 2327)–Overestimated concentrations by 2.34 times (*y*-intercept = -32.43 $\mu g/m^3$)
- MIE DataRam (serial No. 2484)–Overestimated concentrations by 2.61 times (*y*-intercept = -45.92 $\mu g/m^3$)
- Optec NGN-3 nephelometer–Overestimated concentrations by 1.43 times (*y*-intercept = -11.04 $\mu g/m^3$)
- Radiance Research nephelometer (serial No. 0102)–Overestimated concentrations by 1.52 times (*y*-intercept = -6.88 $\mu g/m^3$)
- Radiance Research nephelometer (serial No. 0101)–Overestimated concentrations by 1.43 times (*y*-intercept = -6.59 $\mu g/m^3$)

The performance of the light-absorbing aethalometer was:

- Andersen aethalometer (370-nm channel)–Underestimated concentrations by 0.051 times (*y*-intercept = 0.349 $\mu g/m^3$)
- Andersen aethalometer (880-nm channel)–Underestimated concentrations by 0.027 times (*y*-intercept = 0.111 $\mu g/m^3$)

The correlation coefficients for all the regression results were excellent for all the instruments.

Several of the instruments were used both in Missoula and Hamilton. This allowed us to determine whether the instruments performed differently based on possibly different optical properties of the smoke particulates at the different locations. Several of the instruments had considerably more samples taken when deployed in Hamilton. However, the Optec NGN-3 nephelometer took the same number of samples in Missoula and Hamilton. Results from the Optec NGN-3 nephelometer when compared to the FRM results were:

- Optec (Missoula)–Overestimated concentrations by 1.44 times (*y*-intercept = -11.90 $\mu g/m^3$)
- Optec (Hamilton)–Overestimated concentrations by 1.42 times (*y*-intercept = -9.67 $\mu g/m^3$)

The Missoula real-time instruments (corrected based on the above results) were compared to the MT DEQ TEOM for 1-, 8-, and 24-h running averages. The TEOM (configured to estimate PM_{10}) typically overestimated the corrected results from the real-time instruments (configured for $PM_{2.5}$). Results of the TEOM compared to the corrected values of the MIE DataRam were:

- 1-h average–Overestimated concentrations by 1.06 times (*y*-intercept = 8.35)
- 8-h average–Overestimated concentrations by 1.13 times (*y*-intercept = 4.15)
- 24-h average–Overestimated concentrations by 1.23 times (*y*-intercept = -1.23)

Recommendations

The results from this evaluation are the most complete the center has developed for determining the accuracy of real-time instruments in a field situation. Results from the various real-time instruments should be corrected based on these results to better estimate the particulate concentrations from burning biomass.

These results are from one particular region and vegetation type. Results may differ if the vegetation type or moisture content is significantly different than the conditions during these fires. Other factors such as relative humidity, background particulate concentrations, and fuel moisture may influence the instruments' mass concentration estimations.

Whenever possible, collocate an EPA federal reference method gravimetric sampler with your instrument to establish correction values to meet your conditions.

None of the instruments was designed as a complete particulate sampler nor should any of these instruments be expected to replicate a gravimetric device.

Notes:

Notes:

★U.S. GOVERNMENT PRINTING OFFICE: 2001-789-244/15089

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Andy Trent is a Project Engineer at MTDC. He received his bachelor's degree in mechanical engineering from Montana State University in 1989. He came to MTDC in 1996, and works on projects for the Nursery and Reforestation, Forest Health Protection, and Watershed, Soil, and Air programs.

Mary Ann Davies is a Project Leader working for the Facilities, Recreation, Fire, and Watershed, Soil, and Air Programs. She received a bachelor's degree in mechanical engineering with a minor in industrial and management engineering from Montana State University in 1988. Her Forest Service career began in the Pacific Northwest Region where she worked with facilities, tramways, fire, and recreation. Mary Ann worked for the Rocky Mountain Research Station's Fire Sciences Laboratory in Missoula before coming to MTDC in 1998.

Dick Karsky has been program leader of forest health protection since the fall of 1999. Dick has been a project leader at MTDC in the resource areas of GPS, range, cooperative forestry, engineering, fire, reforestation and nurseries, residues, recreation, and forest health protection. He obtained a bachelor's degree in agricultural engineering from North Dakota State University and a master's degree in agricultural engineering from the University of Minnesota. He worked for private industry before coming to the Missoula Technology and Development Center in 1977.

Rich Fisher has bachelor's degrees in life science (U.S. Air Force Academy) and in meteorology (North Carolina State University). He has master's degrees in earth science (Colorado State University) and in international and strategic studies (Naval War College). He is a consulting meteorologist and is Resource Assistant to the Director of Weather for the U.S. Air Force in the Pentagon.

Library Card

Trent, Andy. Real-time smoke particulate sampling: fire storm 2000. Tech. Rep. 0125-2832-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 26 p.
Reports the findings of a study comparing the results of instruments measuring smoke particulate in real time to gravimetric samplers at Missoula and Hamilton, MT, during the summer of 2000. Real-time, particulate monitoring instruments were evaluated to determine their accuracy when measuring smoke particulate concentrations from natural wildfires. Light-scattering instruments (Met One GT-640, MIE DataRAM, Optec NGN-3 nephelometer, and Radiance Research nephelometer) and light-absorbing instruments (Andersen RTAA 900 aethalometer) measured optical properties of the air to determine particulate concentrations. The Rupprecht & Patashnick Co., Inc. TEOM (tapered element oscillating microbalance) instrument was also included in the test. This ambient particulate monitor determines particulate mass concentrations by continuously collecting particulate on a filter and averaging the weight for 1-h increments.

The real-time instruments were collocated with a U.S. Environmental Protection Agency federal reference method gravimetric sampler. Gravimetric instruments use filters to collect particulate. The filters are carefully weighed to determine the amount of particulate they have captured.

This study indicates that results from real-time instruments can be corrected to estimate the particulate concentrations from burning biomass.

Keywords: air quality, nephelometers, real time, smoke management

We're moving!!

MTDC will be moving by spring 2002, so our new address will change as shown here.

USDA Forest Service, MTDC
5785 Highway 10 West
Missoula, MT 59808

Phone numbers, fax numbers, and electronic addresses will remain the same.

Additional single copies of this document may be ordered from:
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