AIR QUALITY IMPACT FROM AGRICULTURAL FIELD BURNING IN EASTERN WASHINGTON

By

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A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCES

WASHINGTON STATE UNIVERSITY
Program in Environmental Sciences and Regional Planning

August 2002

ACKNOWLEDGMENTS

First and foremost, I must thank Candis Claiborn for all her continuous support, encouragement and guidance. She has provided me with the chance to experience a great environment of work and friendship here at the Laboratory for Atmospheric Research. I am sure many would agree with me that her enthusiasm, expertise and patience are a great motivation for a student.

Second, I would like to thank Dr. Brian Lamb and Dr. Emmett Fiske for being a part of my thesis committee. I would especially like to thank Emmett for his friendship and helping me to be here. I would also like to thank the faculty members, graduate students, and staff members for providing me an unforgettable learning experience.

I would like to acknowledge Karen Wood from the Washington Department of Ecology for making this research possible. Laurie Ames from the Idaho Department of Environmental Quality for providing regional air quality data.

I would like to thank my family in Chile for all their support and encouragement throughout my studies. I would like to especially thank my father; he is a constant inspiration to me.

Finally, I would like to acknowledge the National Scholarship Program of Chile for the scholarship award, which provided me with the necessary funds to support my graduate studies.

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Abstract

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Biomass burning is one of the major global sources of atmospheric pollution. It releases large amounts of chemical compounds and particulate matter, which are linked to health and visibility problems. In Washington State field burning is regulated and allowed when ventilation conditions disperse the smoke away from urban areas. However, there have been an increasing number of smoke complaints and some reported health problems, including death. Despite the complaints, it has been difficult to identify the real impact of stubble burning in the populated areas of Eastern Washington. The objectives of this study were to characterize the air quality impacts from agricultural field burning and to evaluate the Washington Department of Ecology Smoke Management Program. The burn seasons 2000 and 2001 were selected and data collected included: meteorological conditions, burn reports, burn calls and citizen complaints, along with observed air quality data from regional monitoring stations. Backward trajectories were developed for selected smoke episodes. Eight smoke events observed in Pullman, WA were analyzed. Results show that in four cases, field burning was found to contribute to

the air pollution observed. Occurrences of smoke intrusion were also identified in Pullman on days when agricultural burning was not allowed due to poor ventilation. The year 2001 had a smaller number of acres burned during the Fall (26,652 acres) compared to the Spring (99,633 acres). But it also had fewer burn days (22 days) in Fall. During the Fall 2000 burn season, wildfires in the region had a significant impact on the air quality in Eastern Washington.

The correlation between citizens' complaints and stubble burning was also examined in this study. In both years, most complaints were triggered in the Fall. Whitman County reported most of the complaints linked to agricultural field burning. The analysis also showed that periods of poor air quality conditions observed in Pullman triggered complaints in the area, especially during the September 19, 2001 smoke episode.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

For many years, cereal and grass farmers have been utilizing prescribed burning as part of the farming practices in Eastern Washington and Northern Idaho. They have been growing commercial species such as wheat, barley and grass seed. In the year 2000, Washington State alone had 2,475,000 acres seeded with wheat and 500,000 acres with barley (USDA, 2001). The choice of burning to clear fields of vegetation and debris has long been an inexpensive and efficient way to prepare the ground for farming activities. The main purposes of burning are to: (a) eliminate surface organic matter; (b) control undesirable weeds; (c) control plant pests and diseases; and (d) return nutrients and minerals to the soil (Meland and Boubel, 1966). However, neighboring communities in rural areas have noticed an impact in the air quality from these burning practices. In addition, people have reported health related problems, which include asthma, headaches and other respiratory and heart conditions (Roberts and Corkill, 1998). Clearly as populations in rural, traditional farming communities continue to grow, there is a need for improved smoke management programs in order to minimize air quality impacts while allowing farmers to continue to use fire as a tool for field preparation.

1.1 Agricultural region

The climate in Eastern, Central Washington and Northern Idaho is semi-arid with a relatively hot, dry period during the summer. Most of the precipitation occurs during the fall and winter months. The land is used as dry-land farming with commercial species such as grass seed, wheat, barley and lentils as principal crops. This agricultural region (Figure 1.1) involves eleven counties; eight from the state of Washington and three from the state of Idaho as is shown in Table 1.1. Columbia, Walla Walla, Whitman and Benewah Counties have the largest number of acres involved in burning activities. The last county, Benewah, in Idaho, includes the Coeur d'Alene Indian Reservation (CDA tribe). There are several populated areas within this region (Figure 1.2). Citizens in the cities and small towns including Spokane, Coeur d'Alene and the Pullman-Moscow area have voiced concern about the air quality impacts related to agricultural practices.

1.2 The situation in Washington State

In the past decade, grass burning has been the subject of intense analysis and public debate in the state of Washington. In 1998, the Washington Department of Ecology (WDOE) prohibited the utilization of fire as a tool to clear grass seed fields in the entire state of Washington. Grass seed production also takes place in Idaho and Oregon, where grass seed field burning regulations differ from those in Washington State (WDOE, 1998).

After WDOE banned grass seed field burning in Washington, citizen complaints have been directed at other burning activities such as orchard debris and wheat stubble burning. In 1999, the Washington Association of Wheat Growers and the WDOE signed an agreement to reduce smoke emissions from agricultural burning by fifty percent (WDOE, 1999). Yet field burning remains a farmer's tool under the WDOE regulations.

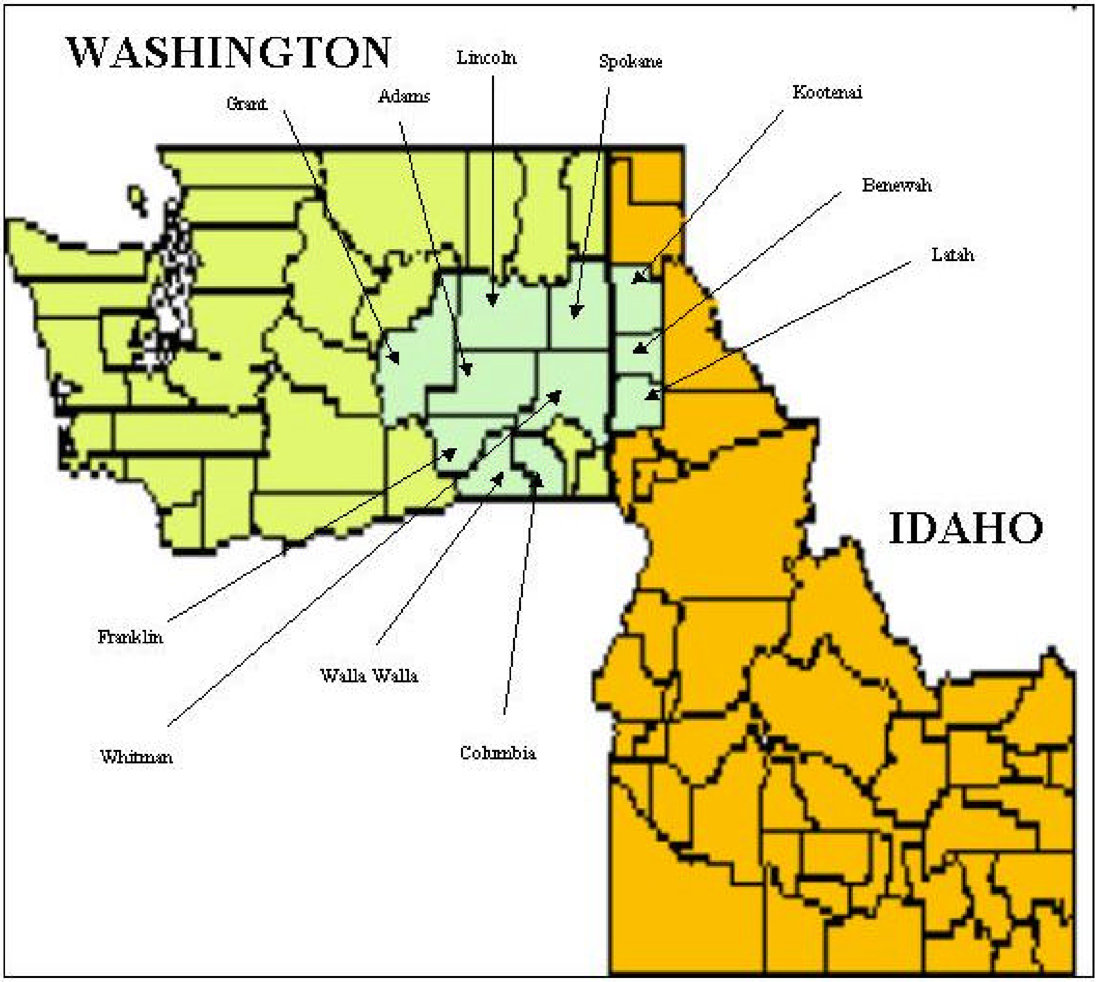
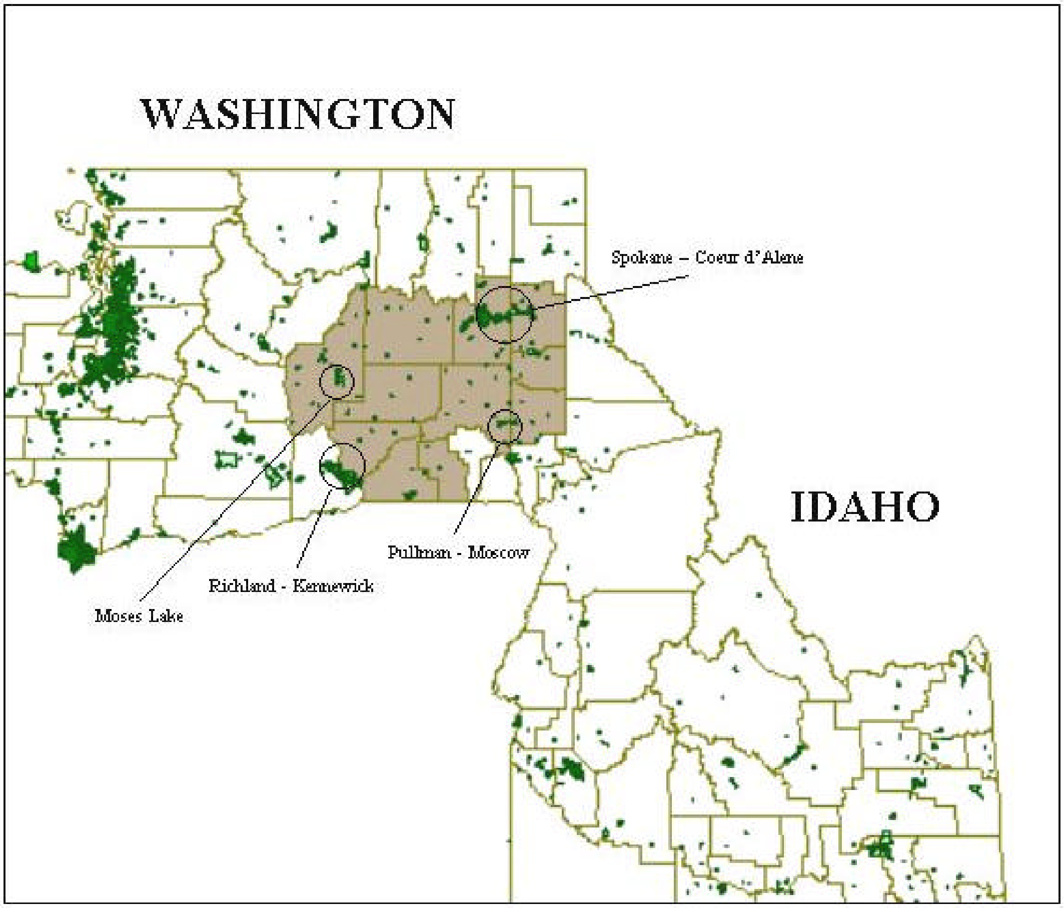


Figure 1.1. Agricultural region in Eastern, Central Washington and Northern Idaho constituted by Washington counties (Adams, Columbia, Franklin, Grant, Lincoln, Spokane, Walla Walla, Whitman) and Idaho counties (Benewah, Latah, Kootenai).

Table 2.1. Counties within the agricultural region in Eastern, Central Washington and Northern Idaho.

Washington State counties	Idaho State counties
Adams	Benewah[b]
Columbia	Kootenai[b]
Franklin	Latah
Grant	
Lincoln	
Spokane[a]	
Walla Walla	
Whitman	

[a] Non-extensive agricultural burning practices.
[b] Includes Indian tribe reservation.



Source: Tiger map http://tiger.census.gov/cgi-bin/mapsurfer

Figure 2.2. Populated areas in Eastern, Central Washington and Northern Idaho.

During the year 1999, the WDOE approved more than 2,600 burn applications for the year 2000 in the state of Washington, involving more than 190,000 acres (WDOE, 2000).

Despite the smoke complaints, it has been difficult to identify and quantify the real impact of agricultural smoke in urban areas. Health effects from exposure to smoke might be expected. Several components present in the smoke are known carcinogens, such as benzene and polycyclic aromatic hydrocarbons (Roberts and Corkill, 1998). But because of the relatively short-term exposure, usually less than 24 hours, smoke does not often lead to air quality standards violations. Smoke from field burning may be more of an acute exposure problem, or it may be a nuisance. Certainly smoke is visually observed. Individuals who have asthma or respiratory problems are more likely to increase doses of medication due to the occurrence of smoke (Long et al., 1998) and the Idaho coroner's office declared grass field smoke as contributing to the death of a woman in Rathdrum, Idaho (Flowers, 2000).

Variables that affect smoke emissions from field burns including fuel density, moisture content and timing are hard to quantify in the field for each particular burn. Spatial and temporal variability of smoke concentrations in the air may differ between field burnings. Unexpected changes in the meteorological conditions, such as wind speed and wind direction, may trigger smoke episodes in urban areas. In addition, it has been difficult to quantify the real impact of agricultural burning in the rural areas of Eastern Washington because of the lack of continuous air quality data from rural communities, far from urban centers.

The purpose of this study was to characterize the air quality impacts from cereal residue burning in Eastern Washington and to evaluate the Washington Department of Ecology Smoke Management Program. This study will result in an improved understanding of the air quality impacts in this region from agricultural field burning, as well as, provide further information to improve actual agricultural burning management programs. The objectives of this study were to:

1. Identify periods of smoke intrusion in the air quality observations.
2. Identify burn periods from available permit records and burn calls.
3. Examine the spatial distribution of the field burnings in Eastern Washington from available permit records.
4. Identify periods of potential smoke intrusion from citizens' smoke complaints and meteorological data.
5. Correlate smoke complaints to air quality data and agricultural field burning.

The burn seasons of the years 2000 and 2001 in the state of Washington were selected for this study. Data collected included burn applications, post-burn reports and citizen complaints, along with air quality data from regional air quality monitoring stations. Additionally, meteorological conditions, satellite images and media were included in the analysis to verify and identify possible smoke sources. Air parcel trajectories were obtained from numerical models for selected days in order to qualitatively characterize source areas by direction and possible location.

The major air quality analysis was conducted for air quality data observed in the city of Pullman, located in Whitman County, Washington. Pullman is located in a farming community and has several air quality and meteorological monitoring instruments and other nearby monitoring sites.

This study is organized into three chapters. The first chapter includes an introduction to the study, a brief background of the agricultural field burning issue in Eastern Washington and Northern Idaho, and the objective statement for this study. Chapter two reviews the literature on emissions from biomass burning, smoke plume behavior and dispersion, and methods to predict pollutant transport and dispersion. The third chapter describes the research conducted and is organized for submittal for publication. This chapter includes the methodology utilized, results obtained and the conclusions and discussions of the results.

1.3 References

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Biomass burning has been identified as one of the major global sources of atmospheric pollution. It releases large amounts of dense smoke, which contains chemical compounds and particulate matter that affect air quality, and it is linked to health and visibility problems. Biomass burning is used to clear fields, control pests and diseases, and return nutrients and minerals to the soil (Meland and Boubel, 1966). Seiler and Crutzen (1980) estimated that the amount of agricultural waste burned ranges from 1700 to 2100 Tg of dry matter per year, based on a extrapolation from waste production in the United States and assuming that 80% of the overall agricultural residue is burned in developing countries and 50% in developed nations. The purpose of this chapter is to review the factors that influence smoke emissions from biomass burning and to determine conditions that enhance smoke dispersion.

2.2 Characteristics of smoke from biomass burning

Prescribed biomass burning is considered a significant source of air pollution throughout the world (Jenkins et al., 1993). Biomass burning releases large amounts of smoke into the air and contains several chemical compounds of concern including, carbon monoxide (CO), volatile organic compounds (VOC’s), polycyclic aromatic hydrocarbons (PAH’s), nitrogen oxides (NO_x), and particulate matter (PM) (Jenkins et al., 1996). These pollutants are produced by incomplete combustion, which result from low combustion temperature, insufficient mixing, and inadequate residence time in the combustion zone (Werther et al., 2000).

Some of the compounds present in smoke from biomass are highly irritating. These compounds include acrolein, formaldehyde (HCHO) and aldehydes. Others are potentially hazardous and include carbon monoxide (CO), fine particles (PM), polycyclic aromatic hydrocarbons (PAH's) and benzene (Roberts and Corkill, 1998). The last two compounds are known carcinogens, but are emitted in relatively low concentrations (Reinhardt et al., 2001). Smoke from biomass burning also includes nitrogen compounds (NO_X) (Chan et al., 1999). Fine particles present in smoke (less than 2.5 μm in diameter $PM_{2.5}$) can be associated with human health problems. Smaller particles can travel deeper into the long alveolar cells and can be related to health problems (Roberts and Corkill, 1998). In some cases, exposure to smoke has been linked to early death cases (Long et al., 1998); (Flowers, 2000). Reinhardt (2001) analyzed the air quality conditions in a rural town in Brazil (Rondônia) during the prescribed agricultural fire season. He documented that people living in the area are exposed to high levels of smoke for multiple days. The ambient levels of pollutants for particulate matter (PM) for a 24-hour averaged 191 $\mu g/m^3$, 12.8 ppb for formaldehyde (HCHO), 4.2 ppm for carbon monoxide (CO), and 3.2 ppb for benzene. In addition, the author mentioned that a smoke management strategy was, in fact, implemented at the time.

Fine particles can be suspended in the atmosphere for several days and may travel thousands of kilometers (Fraser and Lakshmanan, 2000) (Swap et al. 1996). Fine particles have light scattering and light absorption capacities (Chan et al., 1999), which affect light transmission in the atmosphere, and lead to degraded visibility. Smoke from biomass burning has contributed to the problems of visibility degradation in cities and scenic views of natural monuments (Gebhart et al., 2001). Visibility degradation is not only an aesthetic problem, but also a visual indicator of air quality conditions in an area. Jayaratne and Verma (2001) studied the visibility impact (aerosol concentration) from biomass burning in Gaborone, Botswana in South Africa. The visibility in this city dropped to less than a kilometer at times during the winter, due to particles from biomass burning. This problem was enhanced when inversion impeded pollutant dispersion.

During biomass burning, two different fires regimes can be present, flaming and smoldering combustion. The flaming phase is represented by a hot, fast fire with a good supply of oxygen, whereas the smoldering phase has a lower rate of pyrolysis (oxidation) and no flame (Ortiz de Zárate et al., 2000). Figure 2.1 shows the temporal evolution (flaming and smoldering phases) of carbon dioxide (CO_2), nitrogen oxides (NO_x) and total particulate matter (TPM) observed in a cereal straw field burning experiment conducted in Spain (Ortiz de Zárate et al. 2000). The figure shows that the emissions of CO_2 and NO_x decrease during the smoldering phase; however the TPM emissions strongly increase during this phase.

Most of the particles present in biomass smoke are formed through agglomeration of condensed hydrocarbons, ashes and tar materials. The greater the emission levels and particle concentrations present in the smoke, the faster the particles can grow by agglomeration (Carroll et al., 1977). According to Reinhardt et al. (2001) the average particle size emitted from biomass combustion is less than 1 μm in diameter. This size is important for health reasons since particles in this range are deposited in the lower respiratory tract. This size range is also optically active.

The major factor influencing particle emissions is the combustion efficiency achieved during the burning. High combustion efficiencies release smaller amounts of particles, but also produce smaller particles in size (Jenkins et al., 1993). The field experiment in Spain identifies changes in combustion efficiency (η) throughout the flaming phase (η ~ 88%) and smoldering phase (η ~74%) during biomass incineration (Ortiz de Zarate 2000).

The combustion efficiency is strongly dependent on the fuel moisture content. Figure 2.2 shows the relation between particulate matter emissions and fuel moisture content. High moisture content can lead to poor ignition, and decrease the combustion temperature, thus lowering the combustion efficiency (Werther et al., 2000). Low moisture content in the fuel produces low particle emissions throughout the burning.

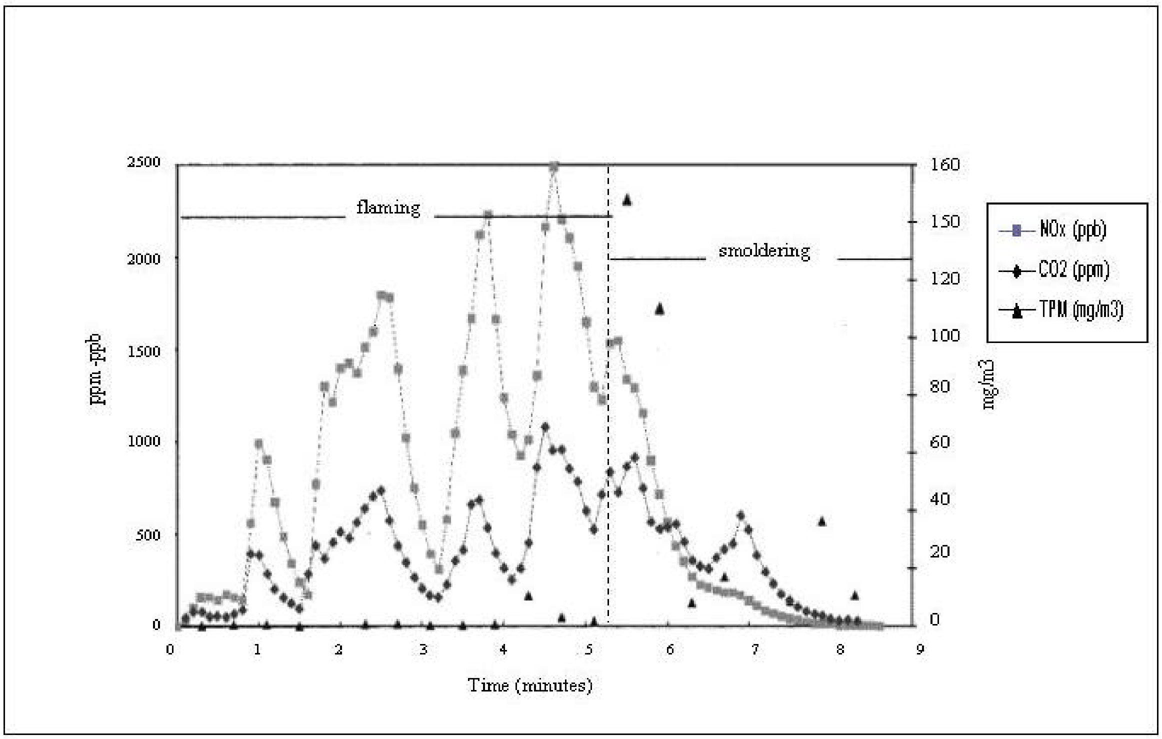
Finally, the ignition technique has an influence on the amount of particles emitted (Figure 2.3). Headfire and backfire techniques differ in the way that the flame advances in the field relative to the wind direction. Backfire techniques (against the wind) can emit about one half of the Total Suspended Particles (TSP) mass as a headfire technique (down wind) at the same moisture content (Carroll et al., 1977). The particle emissions from both techniques appear to be similar during the flaming phase, but backfires show no significant smoldering phase. Thus, this technique releases a smaller amount of particles compared to headfires. However, backfires have less flame propagation and require more time to burn the field than headfires. Backfires require higher fuel density to maintain the flame front compared to headfires, and the moisture content in the fuel can drastically decrease the performance of this technique (Carroll et al., 1997).

2.3 Smoke dispersion

Meteorological conditions and ignition techniques can determine the behavior of the smoke plume rising from a burning field (Meland and Boubel, 1966). Atmospheric stability, mixing height and wind speed are important to achieve good pollutant dispersion. Unstable atmospheric conditions enhance pollutant dispersion, and the mixing height and wind speed should also be considered to determine the rise of the smoke plume. With light winds close to the ground (less than 2 m/s) a well-defined rising plume will be generated (Carroll et al., 1977). The maximum altitude at which the plume rises would be determined by the mixing height present at the time. As wind speed near the ground increases, the well-shaped plume tends to disappear as pollutants disperse. With wind speeds greater than 7 m/s, the smoke would be close to the ground for long distances (8 – 16 km) (Carroll et al., 1977). The ignition technique has an influence on the behavior of the smoke plume when winds near the ground are greater than 2 m/s (Meland and Boubel, 1966). Backfires have less buoyant plumes than headfires, so that smoke from backfires may stay near the ground especially when wind speed increases.

In addition to types of fires, other factors considered for minimizing the negative air quality impact from field burning include: meteorological conditions (including local weather forecasts), fuel moisture content, residue load, and timing. If the wind speed is lower than 2 m/s, the wind direction is not clearly defined and smoke from the field burning can potentially be directed to urban areas. However, with wind speeds greater than 7 m/s, smoke fumigation occurs. Lastly, the time during the day selected for setting the fire should be considered, because the residual material may not be dry enough to burn in the mornings or during relatively high humidity periods.

The stochastic nature of the atmosphere complicates the precision in predicting its behavior. Since meteorological conditions are the major factor in concentration, dilution and transport of air pollution, it is important to monitor atmospheric conditions. Meteorological data are generally available, but often there are only a limited number of surface locations, which in some cases is an insufficient amount of information to determine the surface wind field (Blanchard, 1999). Until recent years, measurements of vertical structures of the atmosphere were made primarily by launching balloon soundings equipped with instruments. However, these were limited to just a few locations and times. Instruments placed on the ground, such as radar profilers (Angevine et al. 1998) and acoustic sounders (Beydich, 1997) can provide continuous vertical profiles of



Source: Ortiz de Zarate et al. (2000)

Figure 2.1. Temporal evolution of Carbon dioxide (CO_2), nitrogen oxide (NO_x) and total particulate matter (TPM) observed in a field burning experiment conducted in Spain.

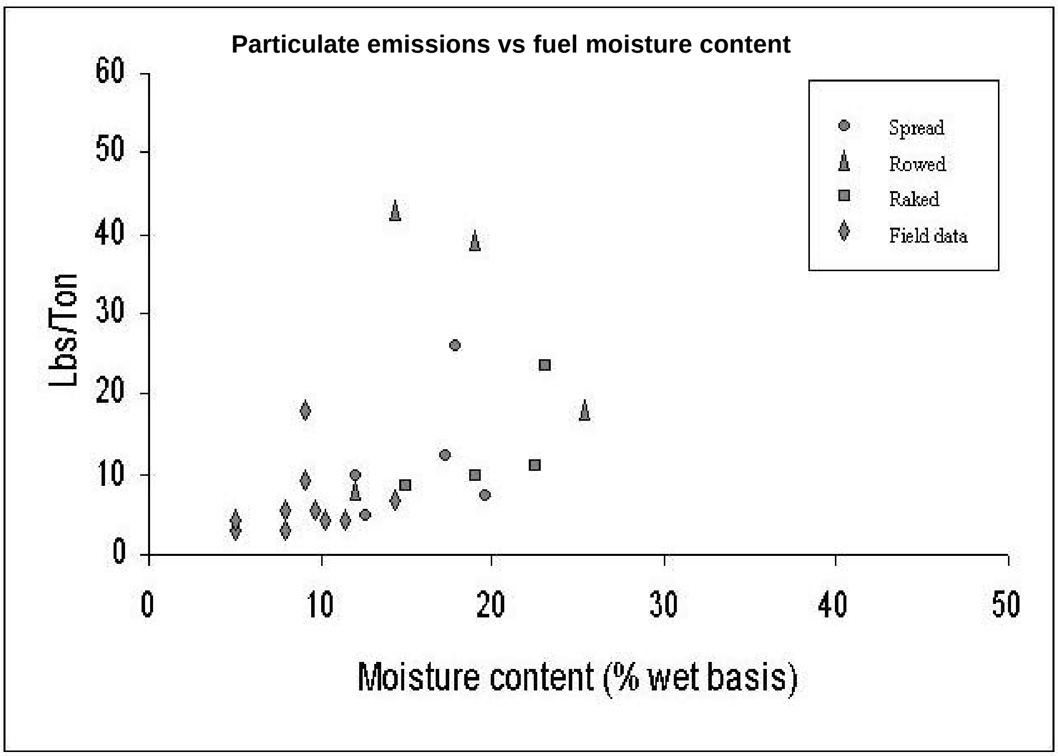


Figure 2.2. Particulate emissions versus fuel moisture content observed during an open field rice burn experiment conducted by *Carroll et al. (1977).*

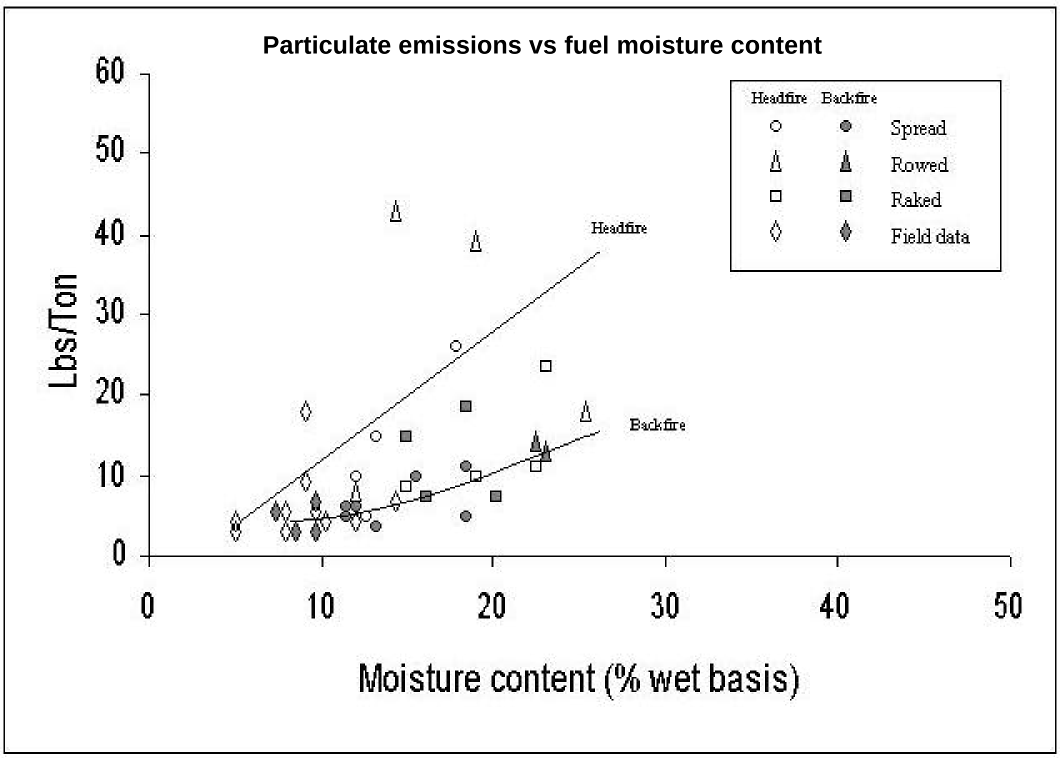


Figure 2.3. Particulate emissions versus fuel moisture content for backfire and headfire ignition techniques observed during an open field rice burn experiment conducted by *Carroll et al. (1977).*

temperature, wind speed and wind directions at different locations, but may not be available in rural locations where agricultural burning takes place.

In summary, in order to predict air quality impacts from smoke, as well as transport, it is important to recognize the factors influencing smoke emissions from agricultural field burning and to determine conditions that enhance smoke dispersion. The major factors influencing the amount of particles emitted from biomass combustion are related to the combustion conditions (temperature, time and turbulence). Higher combustion efficiencies decrease smoke emissions, but also emit smaller particles in size. Nevertheless, small particles are harmful, since they can travel deep into the respiratory system. A knowledge of residue load, fuel moisture content and meteorological conditions present during field burning are critical for predicting smoke dispersion. Backfires have less impact on the air quality than headfires due to the lower particle emissions generated during the combustion (less smoldering). However, this type of technique has lower flame propagation, requiring more fuel density and time to clear the field. Finally, atmospheric conditions, including wind speed, wind directions and mixing height, must be considered in order to manage smoke to minimize adverse air quality impacts in nearby communities.

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CHAPTER THREE

AIR QUALITY IMPACT FROM AGRICULTURAL FIELD BURNING IN EASTERN WASHINGTON

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3.1 Abstract

Every year, cereal crop farmers in Washington State prepare their fields for seeding and some of their practices include the use of fire. Field burning is regulated and allowed when ventilation conditions disperse the smoke away from urban areas. However, under certain conditions, smoke may impact nearby and downwind communities. There have been an increasing number of citizen complaints in recent years and some reported health problems related to smoke episodes, including death. Despite the complaints, it has been difficult to identify the real impact of field smoke in the populated areas of Eastern Washington. The objectives of this study were to characterize the air quality impacts from cereal crop residue burning in Eastern Washington and to evaluate the Washington Department of Ecology Smoke Management Program. The burn seasons 2000 and 2001 were selected for this study and data collected included: meteorological conditions, burn reports, burn calls and citizen complaints, along with observed air quality data from regional air quality monitoring stations. Backward trajectories were developed for selected smoke episodes. Eight smoke events observed in

Pullman, WA were analyzed. Results show that in four cases, agricultural field burning was found to contribute to the air pollution observed. Occurrences of smoke intrusion were also identified in Pullman on days when agricultural burning was not allowed due to poor ventilation. During the Fall 2000 burn season, wildfires in the region had a significant impact on the air quality in Eastern Washington. The year 2001 had a smaller number of acres burned during the Fall (26,652 acres) compared to the Spring of the same year (99,633 acres). But also, the Fall had fewer burn days (22 days) compared to the Spring 2001 season (70 days).

The correlation between citizens' complaints and stubble burning was examined in this study. In both years, most complaints were triggered in the fall. Whitman County reported most of the complaints linked to agricultural field burning. The analysis also showed that periods of poor air quality conditions observed in Pullman triggered complaints in the area, especially during the September 19, 2001 smoke episodes.

3.2 Introduction

In the past decade, agricultural burning has been the subject of intense analysis, discussion and public debate in Eastern Washington. The main purposes of burning are to: (a) eliminate surface organic matter; (b) control undesirable weeds; (c) control plant pests and diseases; and (d) return nutrients and minerals to the soil (Meland and Boubel, 1966). Citizens are concerned about possible health problems related to smoke exposure, as well as potential negative impacts on tourism and economic activities (Roberts and Corkill, 1998). In order to express their anxiety, citizens are increasingly complaining about smoke in the air and any type of burning activities that they might consider harmful to themselves or their communities.

Smoke from biomass burning contains numerous chemical compounds including carbon monoxide (CO), hydrocarbons (HC), volatile organic compounds (VOC's), nitrogen oxides (NO_x), polycyclic aromatic hydrocarbons (PAH's) and fine particulate matter (PM) (Jenkins et al., 1996). Particles present in smoke may be associated with human health problems. Smaller particles can travel deep into the lung alveolar cells. In some cases, smoke has been linked to early death (Long et al., 1998) (Flowers, 2000).

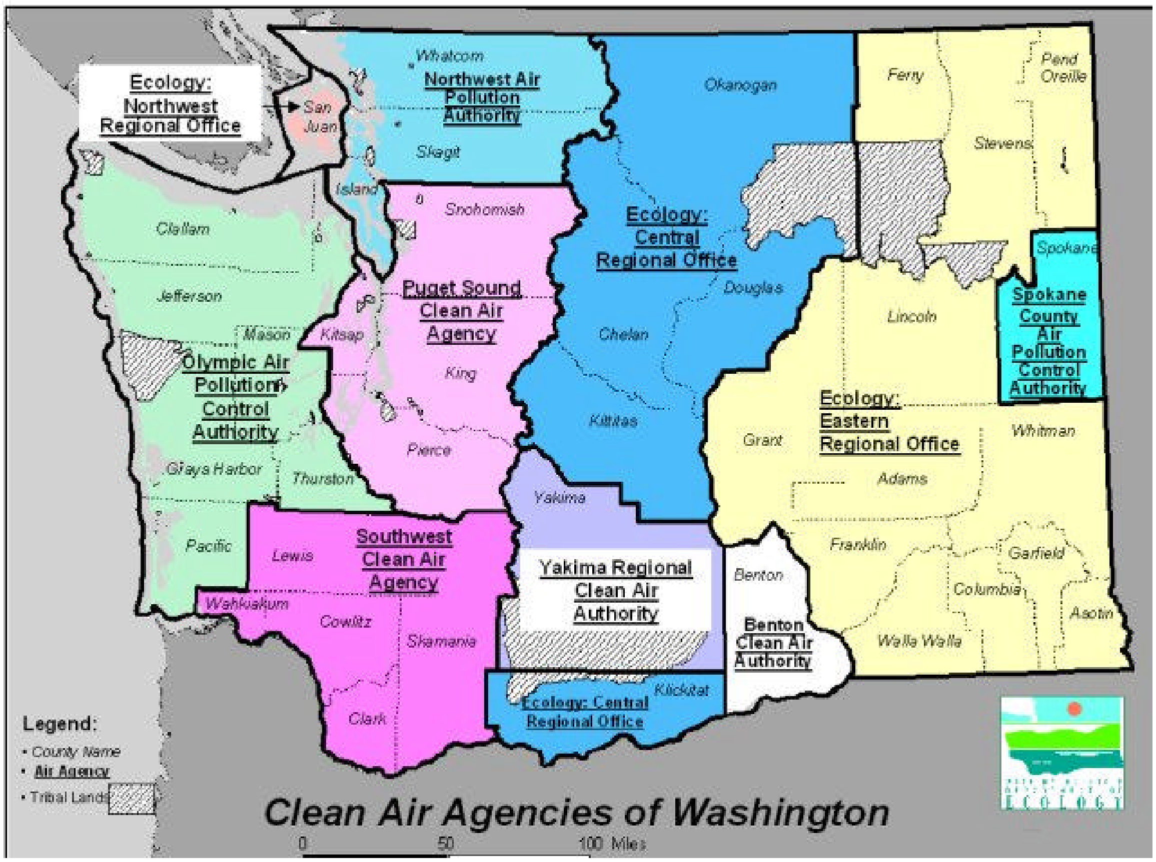
The state of Washington requires a burn permit for any type of agricultural burning activity including orchards, crop residues and other organic debris. Farmers must apply for burn permits with the Washington Department of Ecology (WDOE). Approval to burn is issued when no other reasonable or practical alternative exists. In 1999, WDOE implemented a burning program called Best Management Practices Program for cereal crop burning. This program was created in order to reduce emissions from agricultural burning, and includes sections related to farming plans, residual removal and renovation. The Department of Ecology delegated the authority to issue burn permits to local agencies (Figure 3.1). This action facilitates the application and enhances the enforcement of the program.

WDOE coordinates the burning activities in Central and Eastern Washington as a result of the implementation of the Burn Call Program (BCP). This analysis is conducted for all the locations (counties) within the BCP, listed in Table 3.1. Burning activities are allowed on days forecasted to have adequate ventilation, as determined by meteorological forecasts obtained from The Pacific Northwest MM5 Mesoscale Numerical Forecasts, from the University of Washington (http://www.atmos.washington.edu/mm5rt/). Forecast data includes: local ventilation conditions, wind direction and wind speed.

Prior to 2001, farmers voluntarily reported their burns, resulting in a low response rate. In the year 2001, the state of Washington required that farmers submit a post-burn report after they burned their fields. The report is submitted to the local regulatory agency within seven days following the burn. The post-burn report includes information identifying the farm, including the owner, location, and the permit number. It also includes information about the burn event, such as the date, number of acres burned, and meteorological conditions, including wind speed and direction.

Variables that affect smoke emissions from field burns including fuel density, moisture content and timing are hard to quantify in the field for each particular burn. Unexpected changes in the meteorological conditions, such as wind speed and wind direction, may trigger smoke episodes in urban areas. In addition, it has been difficult to quantify the real impact of agricultural burning in the rural areas of Eastern Washington because of the lack continuous air quality data from rural communities, removed from urban centers.

The purpose of this study was to characterize the air quality impacts from cereal residue burning in Eastern Washington and to evaluate the Washington Department of Ecology Smoke Management Program. The specific objectives of this study were to: (a) Identify periods of smoke intrusion in the air quality observations, (b) Identify burn periods from available permit records and burn calls, (c) Identify the spatial distribution of the field burns in Eastern Washington from available permit records, (d) Identify periods of potential smoke intrusion from citizens smoke complaints, and (e) Correlate smoke complaints to air quality data and agricultural field burning.



Source: Washington State Department of Ecology. Air Quality Program
http://www.ecy.wa.gov/programs/air/local.html

Figure 3.1. Air Pollution Control Agencies in Washington. Note that Native Americans have authority over air quality within the boundaries of their reservations.

Table 3.1. Central and Eastern Washington counties in the Burn Calls Program (BCP) regulated by the Washington State Department of Ecology (WDOE).

WASHINGTON COUNTIES WITHIN THE BURN CALLS PROGRAM	
Adams	Kittitas
Asotin	Klickitat
Benton	Lincoln
Chelan	Okanogan
Columbia	Stevens
Douglas	Pend Oreille
Franklin	Walla Walla
Garfield	Whitman
Grant	

3.3 Methods

The burn seasons from the years 2000 and 2001 were selected for this study. Data collected included burn applications, post-burn reports and citizen complaints, along with air quality data from regional air quality monitoring stations. Additionally, meteorological conditions, satellite images and media were included in the analysis to identify smoke sources.

The approach in this work included the following tasks:

- Examination of air quality data for identification of possible smoke intrusion periods,
- Identification of burn periods from available permits, burn reports and burn calls,
- Spatial mapping of the field burns in Eastern Washington from available permit records and/or burn reports,
- Identification of periods of potential smoke intrusions from citizens' smoke complaints,
- Examination of the correlations between smoke complaints and air quality data,
- Identification of fire locations from available satellite pictures and media records, and
- Analysis of the transport of smoke using a combination of trajectory analyses and dispersion modeling.

3.3.1 Air Quality Data

Eastern Washington, a semi-arid region, can have significant levels of particles in the air from a variety of sources. These sources include combustion processes (such as wood stoves), industrial areas and dusts released from paved and unpaved roads. Furthermore, in the region, occasional wind blown dust storms can occur (Claiborn et al. 1998). These events are observed at the air quality monitoring stations, especially on the PM_{10} instruments because of the larger particle size of dust.

Geological dust, like windblown dust and dust from roads, tends to be in the coarse mode size range (above ~ 1 μm in aerodynamic diameter) while particles from combustion processes tend to occur in the fine mode size range (less than ~ 1 μm). Characteristics of smoke from agricultural burning would therefore include a high ratio of $PM_{2.5}$ to PM_{10}. Also, due to the rapid nature of the burns, short periods of very high particulate concentrations are more likely to occur as a result of agricultural burning, as opposed to extended periods of relatively constant and elevated PM levels. Finally, due to the distribution of field burns, elevated levels are not expected to be spatially uniform.

Thus, where possible, the ratio of $PM_{2.5}$ to PM_{10} was examined to identify and exclude windblown dust events from further analysis. It was not deemed adequate to examine $PM_{2.5}$ observations alone, since intrusion of coarse material can be observed in the $PM_{2.5}$ measurements during dust storms (Claiborn et al., 2000). Continuous data was also useful for identifying short-term, very high PM concentrations.

Air quality data collected included continuous PM_{10} and $PM_{2.5}$ data from either Tapered Element Oscillating Microbalance (TEOM) or light scattering (nephelometer) instruments operated by several different agencies in Eastern Washington and Northern Idaho (Table 3.2). Three measurement stations located at Rockwood, Crown Zellerbach (in Spokane) and upwind Spokane, near Cheney (Turnbull) are operated by WDOE and/or SCAPCA (Spokane County Air Pollution Control Authority). Three other stations are located at the Colfax Public Safety Building (Whitman County), Pullman Pioneer Building (Whitman County) and at the Ritzville County Shop (Adams County), and are also operated by WDOE. Both Ritzville and Turnbull stations have been in operation since October 2000, and the monitoring equipment located in Colfax was relocated to Colville (Stevens County) in the year 2001. Finally, another station located in Moscow, Idaho, operated by the Idaho DEQ, began to record air quality data in July of 2001. In addition to these monitoring sites, continuous PM_{10} and $PM_{2.5}$ (TEOM) measurements were collected from instruments located at WSU on the Dana Hall roof, operated by the Laboratory for Atmospheric Research (LAR), Department of Civil and Environmental Engineering. Figure 3.2 shows the locations of the monitoring sites in Eastern Washington.

Periods of possible smoke intrusion were based on the air quality data observed in the city of Pullman, located in Whitman County, Washington. This city has local particulate matter sources including a coal power plant located at WSU, and area sources such as roads during traffic hours. In addition, occasional wind blown dust storms can occur in the region. Possible periods of smoke intrusion from field burning were analyzed for potential interference with local PM sources, as well as, evaluated for temporal and spatial variations using data collected by other air quality monitoring stations in Eastern Washington and Northern Idaho. Moreover, measurements recorded at the same location by different instruments (TEOM and nephelometer) were also compared for consistency.

3.3.2 Burn permits, Burn calendar and Post-Burn reports

In order to manage smoke from agricultural burning, WDOE issues burn calls on a daily basis. Growers wishing to use fire to condition their lands must apply for a permit, which also requires a fee payment that is refundable if the grower does not burn the field. After the burn, the grower is to file a post-burn report that was voluntary in 2000 and mandatory starting January, 2001. Thus, the burn calls, burn permit applications (and refunds), and post-burn reports were all consulted to determine the extent of agricultural burning in Eastern Washington.

The burn calendar compiled all burn decisions (burn calls) made for each day and for each county in Washington State (Table 3.1). Burn calls and post-burn reports were also obtained from WDOE for the years 2000 and 2001. This information was used to determine the distribution of agricultural burning by county and by season. Additionally, farmers’ participation within the program and possible non-authorized burns were determined from this data. However, the year 2000 only included voluntary post-burn reports for the Fall burning season, since it did not become mandatory for farmers to report their burns until the year 2001. For 2000, the acreage burned was estimated from the burn permits.

Burn permits submitted for the year 2000 in Washington were obtained from WDOE. Those records contained information such as the grower, location, number of acres and target date for burn. The burn application requires a fee payment that is proportional to the number of acres involved. This fee is refundable if no burn is performed. From this data, the temporal and spatial distributions of the agricultural burns were determined for the year 2000. During this period of time, growers were not required to submit a burn report. Thus, the burn applications alone did not provide sufficient information on the number of acres burned. Not all of the farmers burned the amount of acres for which they applied. In fact, some of them utilized alternative methods for stubble removal. So, to estimate the number of acres burned, the refunded fees were used.

3.3.3 Complaint log

WDOE maintains a special phone number (hotline) so that citizens can report any incident or complaint related to smoke and burning activities. These complaint logs from 2000 and 2001 were used along with other data in order to determine: (a) correlations between smoke complaints and agricultural field burnings reported, (b) citizens' response during periods of smoke intrusion, (c) sources of the complaint and their locations, and (d) spatial and temporal distribution of complaints.

Table 3.2. Air quality monitoring stations located in Eastern Washington considered for analysis.

Measurement	Method	Location	Agency
PM_{10}	Continuous (TEOM)[a]	Rockwood, Spokane	SCAPCA
PM_{10}	Continuous (TEOM)[a]	Crown Zellerbach, Spokane	SCAPCA
PM_{10}	Continuous (TEOM)[a]	WSU, Pullman	WSU
$PM_{2.5}$	Continuous (TEOM)[a]	WSU, Pullman	WSU
$PM_{2.5}$	Nephelometer[c]	Pullman, WA	WDOE
$PM_{2.5}$	Continuous (TEOM)[a]	Rockwood, Spokane	SCAPCA
$PM_{2.5}$	Continuous (TEOM)[a]	Crown Zellerbach, Spokane	SCAPCA
$PM_{2.5}$	Nephelometer[c]	[e]Colfax, WA	WDOE
$PM_{2.5}$	Nephelometer[c]	[a]Cheney, WA	WDOE
$PM_{2.5}$	Nephelometer[c]	[a]Ritzville, WA	WDOE
$PM_{2.5}$	Nephelometer[c]	[a]Walla Walla, WA	WDOE
$PM_{2.5}$	Continuous (TEOM)[a]	[d]Moscow, ID	IDEO

[a] Air quality data available since October 2000
[b] Tapered Element Oscillating Microbalance instrument
[c] Light scattering instrument
[d] Air quality data available since July 2001
[e] Air quality monitoring station moved to Colville in 2001

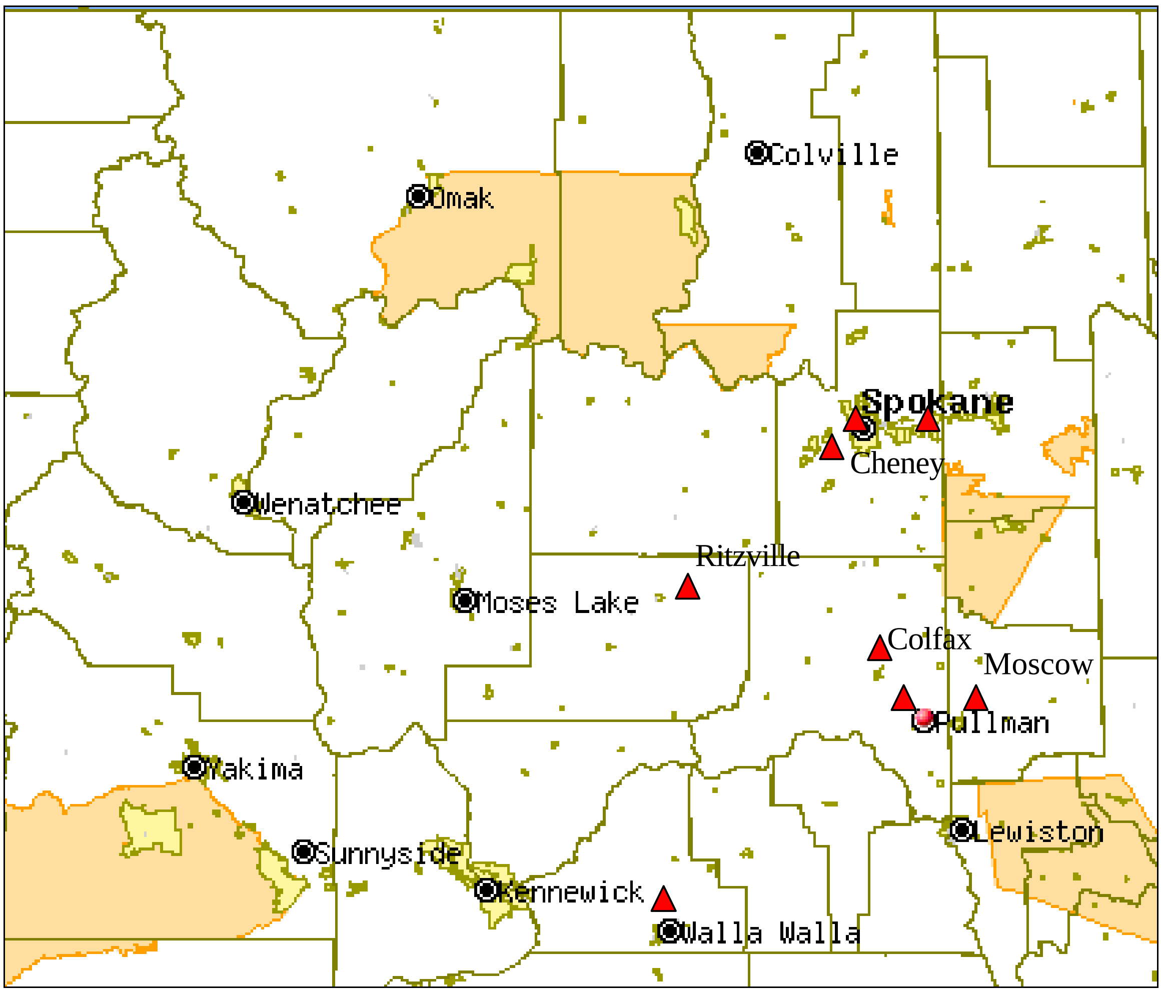


Figure 3.2. Location of the air quality monitoring stations in Eastern Washington and Moscow, ID.

The complaints were separated into three categories based on comments and testimony registered for each call. The first category included complaints that specified visual observation of burning activities. The second category included reports of smoke in the air. This is the category that was the most closely related to some degree of smoke impact in the air quality. The last category included all other complaints and could include unknown sources, and/or non-relevant complaints. It should be noted that a single complaint could also be included in more than one category.

3.3.4 Trajectory analysis

To determine the origin of air parcels arriving at particular locations during smoke episodes, backward trajectories were calculated using the National Oceanic and Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectories (HYSPLIT) (Draxler and Hess, 1998), which is the newest version of a complete system for computing air parcel trajectories as well as dispersion and deposition simulations. This model is available on the NOAA website (http://www.arl.noaa.gov/ss/models/hysplit.html).

The input data used in this model were archived meteorological data generated by the National Weather Service's National Center for Environmental Prediction (NCEP). They generate forecasts using both the Global Data Assimilation System (GDAS), and the EDAS (ETA Data Assimilation System), which covers the United States (Stunder, 1997). Both systems generate basic fields, such as the u- and v-wind components, temperature, and humidity. However, the archives differ from each other because of the horizontal, vertical and temporal resolution (Stunder, 1997). The EDAS archive grid covers the continental United States and has a horizontal resolution of 80 km. The FNL (GDAS) archives cover both hemispheres with 191 km of resolution (Draxler and Hess, 1998). Since the input data used by HYSPLIT are forecasted meteorological data, trajectories generated by this model may not always represent the real transport process that occurred in the atmosphere. For some particular days, hand trajectories were also generated using surface observed data and were compared to those produced by HYSPLIT.

Trajectory analyses were developed for selected days using HYSPLIT. The trajectories generated were used to qualitatively characterize source contribution by possible location and timing. This was valuable for source identification during selected smoke episodes that had several potential sources, such as both agricultural field burnings and forest wildfires.

3.4 Results

3.4.1 Air Quality

One of the characteristics of air quality impacts from field burning is the short duration, high peak $PM_{2.5}$ concentrations. Thus, air quality data were examined as a function of time to identify periods of smoke intrusion in the air quality observations. One way to do this was by estimating the ratio of the peak to the mean value for a 24-

hour period. This procedure was expected to identify short-terms of high levels of $PM_{2.5}$ hidden in the mean value, by an increased ratio. However, this procedure did not behave as was expected during days with high $PM_{2.5}$ peak levels and an increased mean value, because of the very low concentrations of $PM_{2.5}$, which tended to increase the ratio during days with overall low $PM_{2.5}$ observations, but some minor peak levels. Finally, it was decided to evaluate the magnitude of the $PM_{2.5}$ peak. Peak values greater than 40 $\mu g/m^3$ were considered for further analysis.

Throughout the year 2000, the air quality monitoring stations located in Pullman and Colfax observed similar patterns in the $PM_{2.5}$ concentrations, as determined from nephelometer instruments. Figures 3.3a-g illustrate the correlation between both sites. This was expected due to the relatively close proximity (14 miles) of the stations, as well as similar characteristics of the locations. Both monitoring sites were located in rural areas without a significant source of industrial and/or vehicular air pollution. Because of the similarity in values, the Colfax monitor was removed in February 2001.

In general, the Pullman monitoring site observed relatively low $PM_{2.5}$ levels in the years 2000 and 2001 (refer to Appendix A for air quality observations). The station primarily recorded concentrations of $PM_{2.5}$ below 20 $\mu g/m^3$ (nephelometer instruments) for 24-hour averages (*Current National Ambient Air Quality Standards for $PM_{2.5}$ is 65 mg/m^3 24-hour average and 25 mg/m^3 annual average*). However, high concentrations of

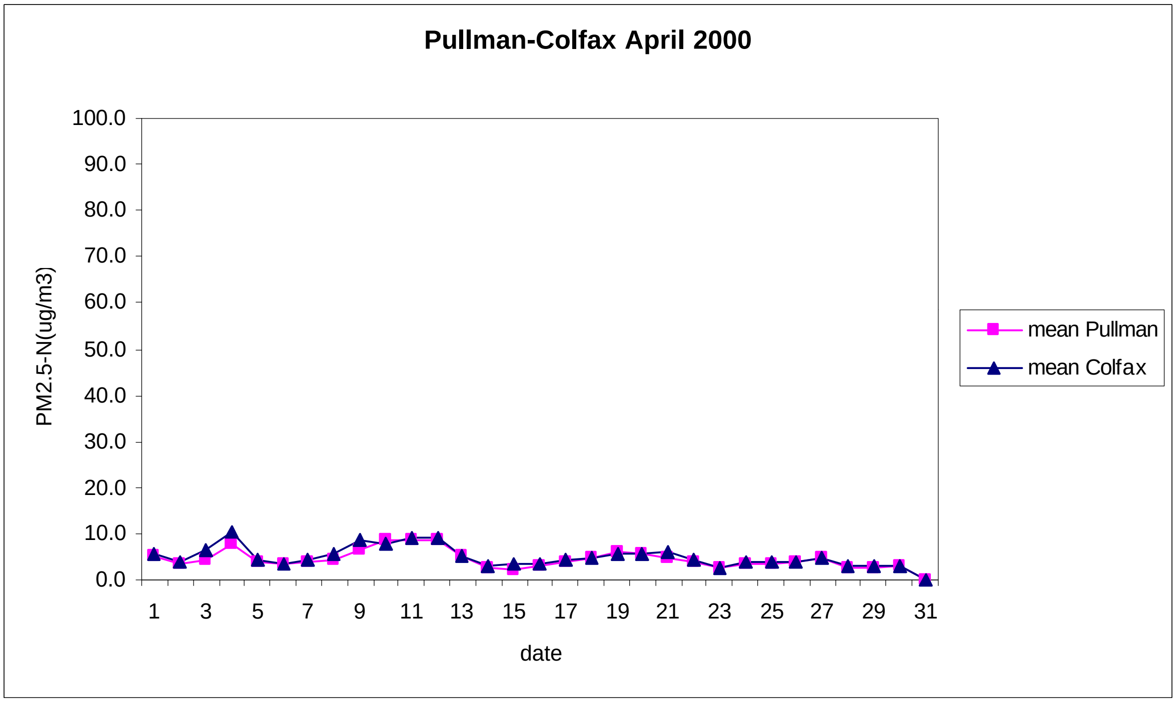


Figure 3.2a. Mean $PM_{2.5}$ (nephelometer) correlation between Pullman and Colfax air quality monitoring sites for April 2000.

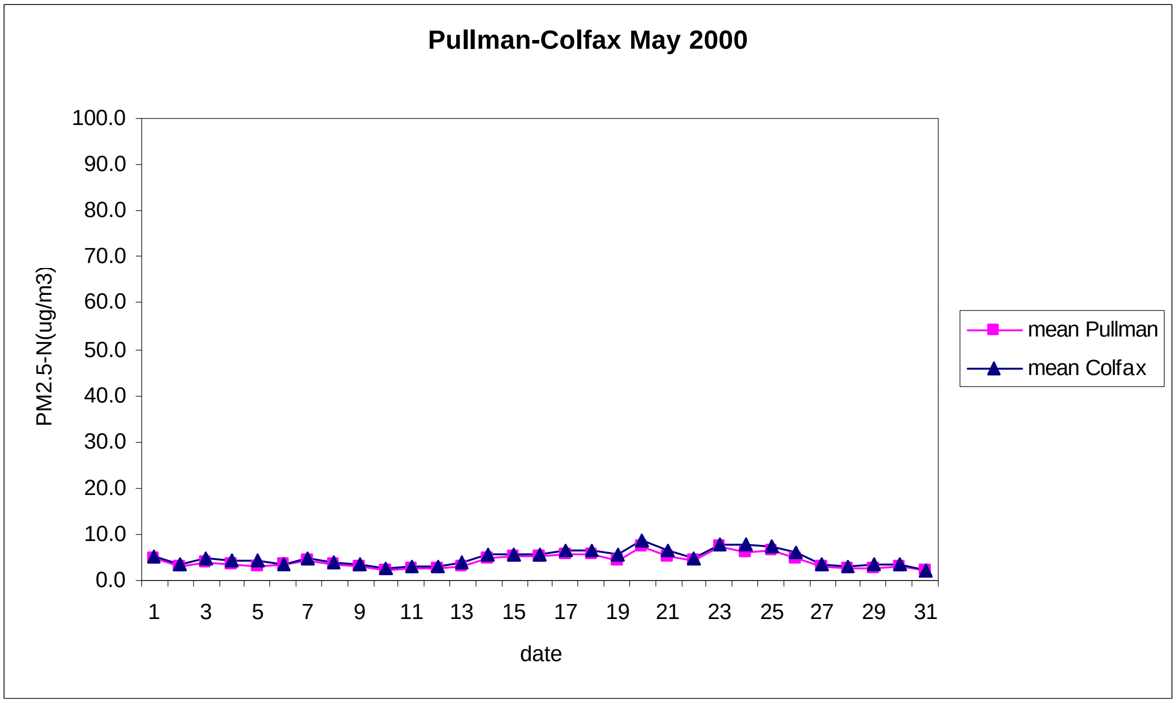


Figure 3.3b. Mean $PM_{2.5}$ (nephelometer) correlation between Pullman and Colfax air quality monitoring sites for May 2000.

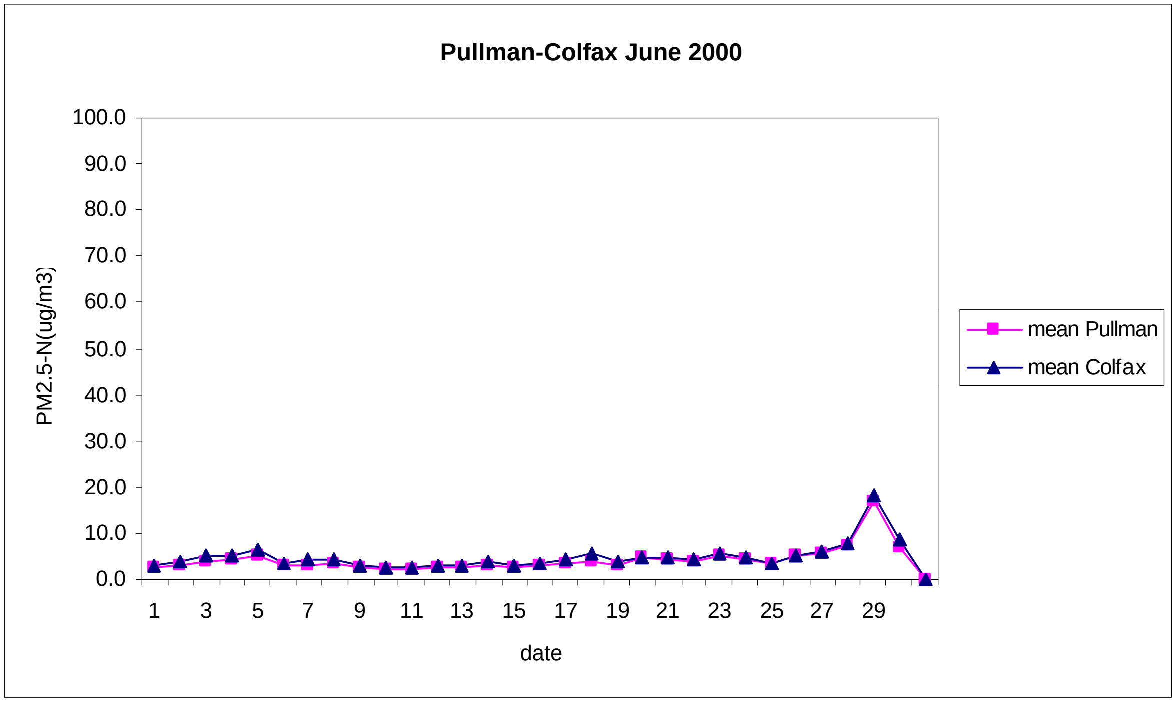


Figure 3.3c. Mean $PM_{2.5}$ (nephelometer) correlation between Pullman and Colfax air quality monitoring sites for June 2000.

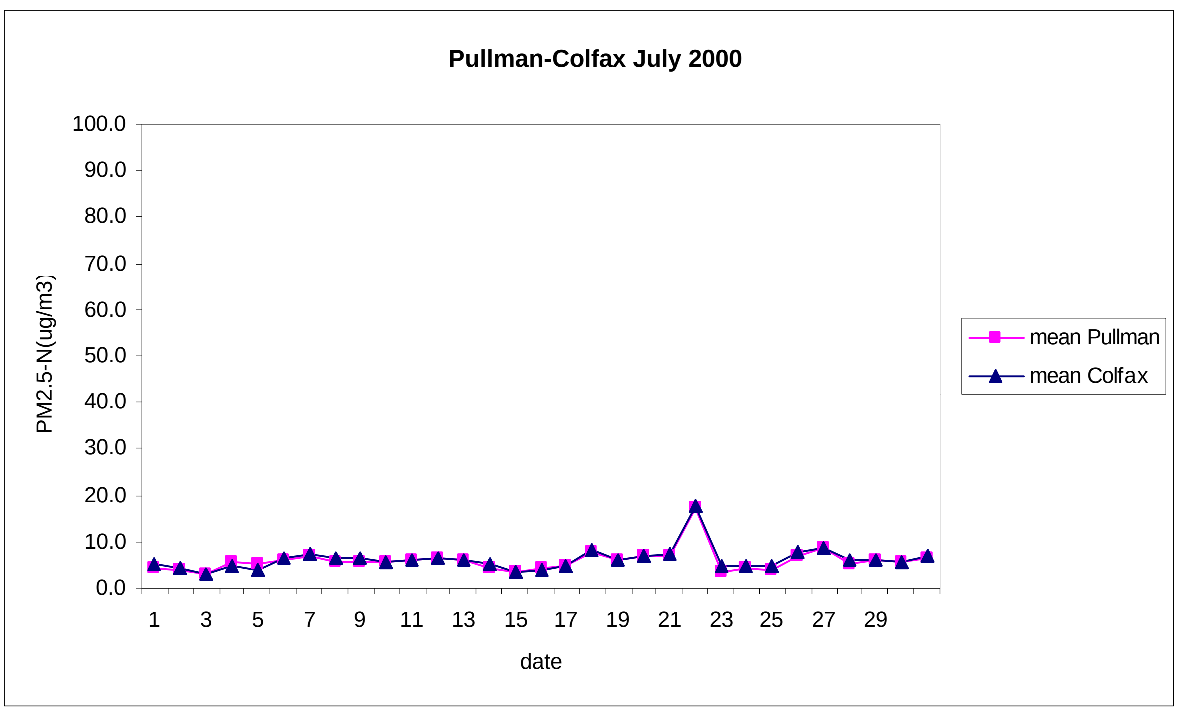


Figure 3.3d. Mean $PM_{2.5}$ (nephelometer) correlation between Pullman and Colfax air quality monitoring sites for July 2000.

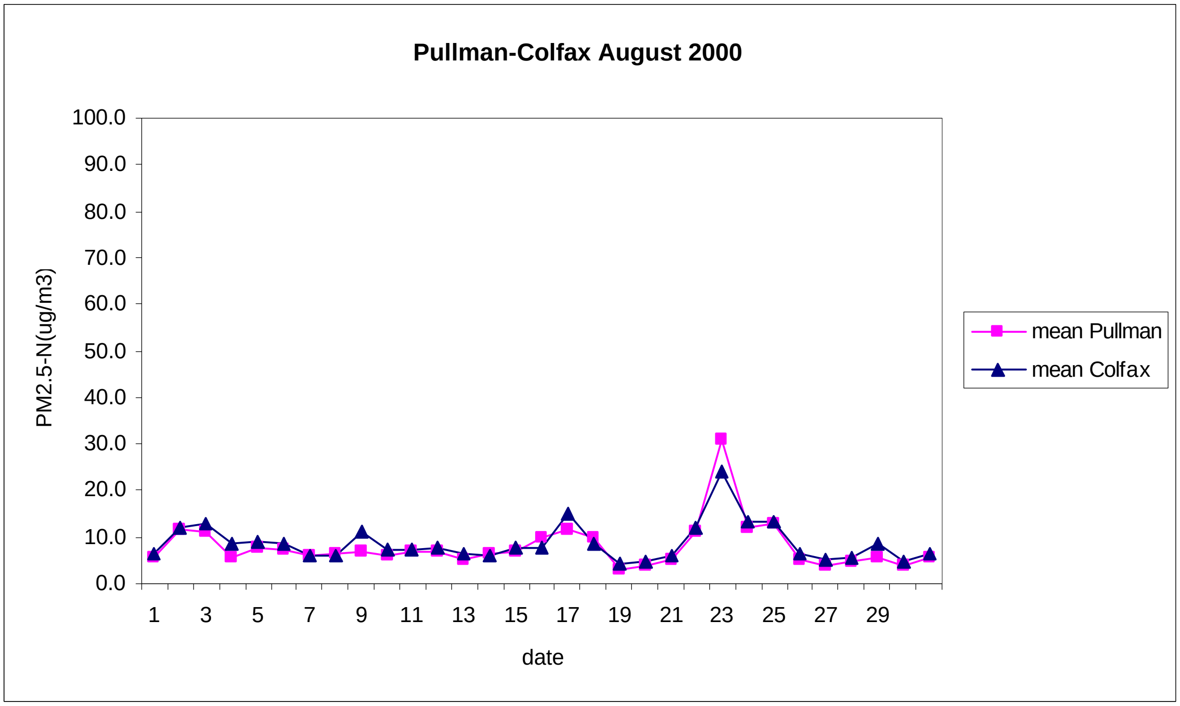


Figure 3.3e. Mean $PM_{2.5}$ (nephelometer) correlation between Pullman and Colfax air quality monitoring sites for August 2000.

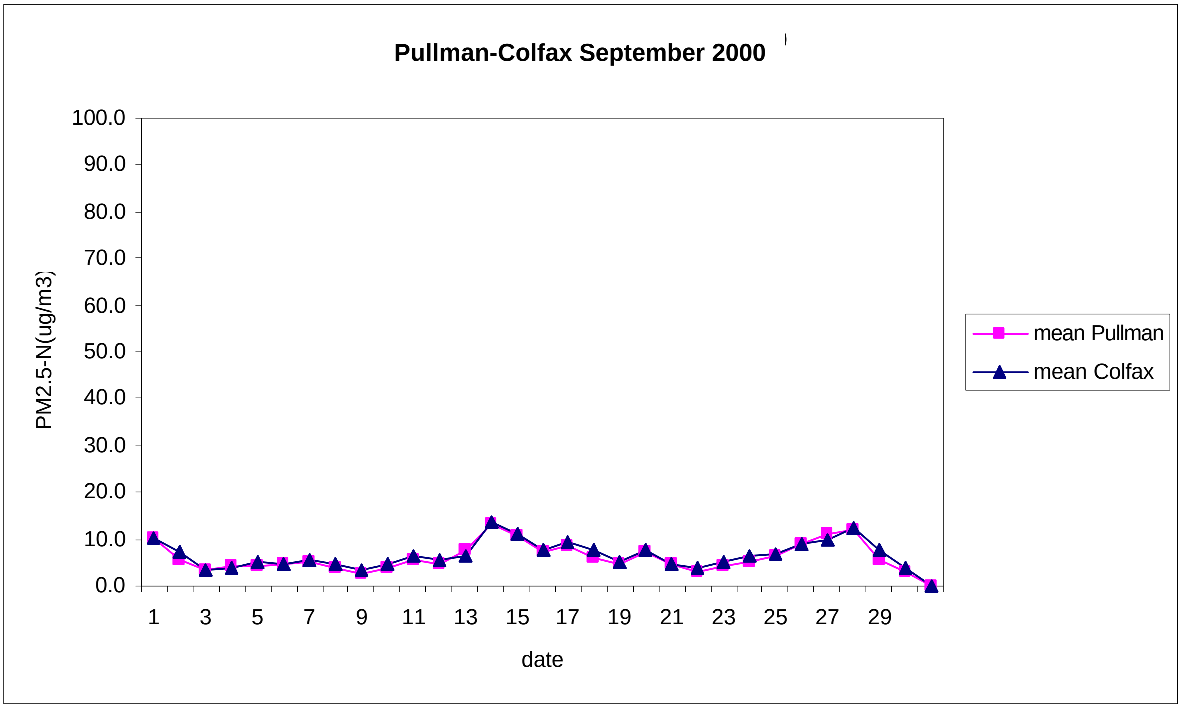


Figure 3.3f. Mean $PM_{2.5}$ (nephelometer) correlation between Pullman and Colfax air quality monitoring sites for September 2000.

fine PM (above 40mg/m^3) were registered for short periods of time on eight days in summer and fall in both years: Table 3.3 summarizes these eight episodes of smoke intrusion in the air quality observation in Pullman, WA. These days are discussed in more detail in the study, to illustrate how the source of the smoke was determined as indicated in the last column of Table 3.3.

The summer and fall of 2000 was one of the worst wildfire seasons for the Western U.S., with more than 500 new fires reported on some days. On the peak day, August 29th, 28,462 firefighters, 1,249 fire engines, 226 helicopters, and 42 air tankers were fighting the blazes covering 1.6 million acres. By the end of the season, wildfires had burned a total of 8.4 million acres in United States (Fire Wars, 2002). Smoke from those wildfires contributed to the regional haze observed in Eastern Washington. Figure 3.4 shows the wildfire impacts on the $PM_{2.5}$ measurements in Pullman during the Fall 2000 (refer to Appendix B for more analysis of $PM_{2.5}$ observations in Eastern Washington for the years 2000 and 2001).

During both years, smoke from the 4th of July fireworks in Pullman was noticed in the air quality data recorded by the monitoring instruments located in the city. The short terms of high $PM_{2.5}$ values were consistent with the timing of the firework display (at dusk). Those smoke events were excluded from further analysis.

Table 3.3. Summary of smoke intrusion episodes in Pullman, WA in the years 2000 and 2001.

Smoke Episode	Complaints	Field Burns Reported	Burn Call	Wildfires in the Region	Wind Direction	Possible Source
June 29, 2000	0	0	9-6pm	South Central Washington 100,000 acres	W-SW	Wildfire
July 22, 2000	0	0	10-6pm	Central Idaho 46,000 acres South Central Washington 6,000 acres	W-SW	Wildfire
August 23,2000	2	0	No	Central Idaho 400,000 acres	E-SE	Wildfire
September 14, 2000	2	4,440 acres	No	Central Idaho 350,000 acres	E	Likely Ag burning
October 9, 2000	0	4,000 acres	11-4pm	Central Idaho 216,000 acres	SW	Ag burning
October 26, 2000	0	0	No	Not reported	E	Stagnant weather
September 12, 2001	8	CDA tribe	No	North Central Washington 50,000 acres	NE	Ag burning
September 19, 2001	11	1,300 acres on Sept 18	Limited <100 acres	North Central Washington 45,700 acres South east Washington 5,000 acres	W	Wildfire from Ag burning

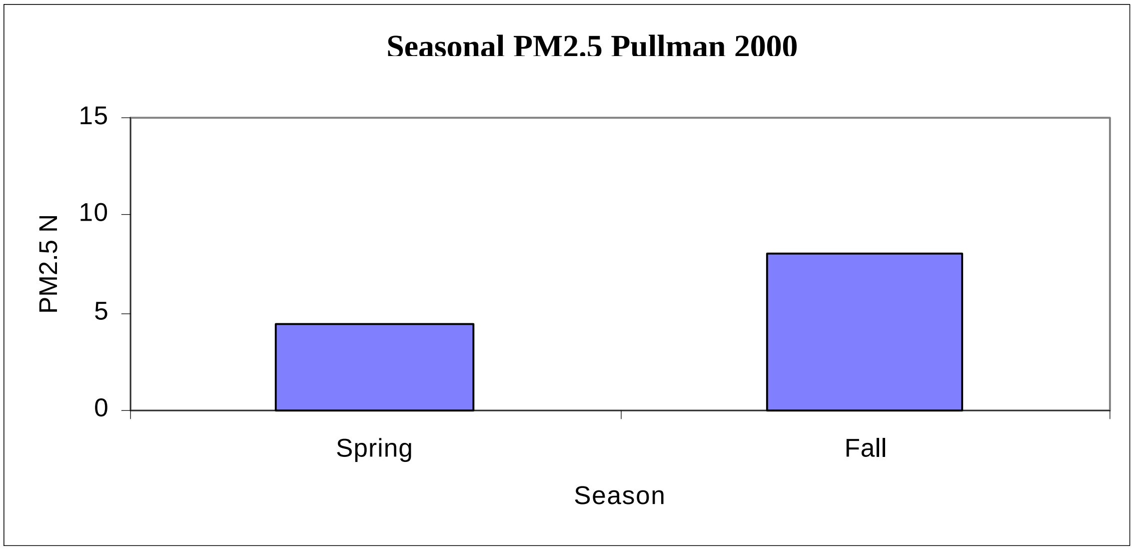
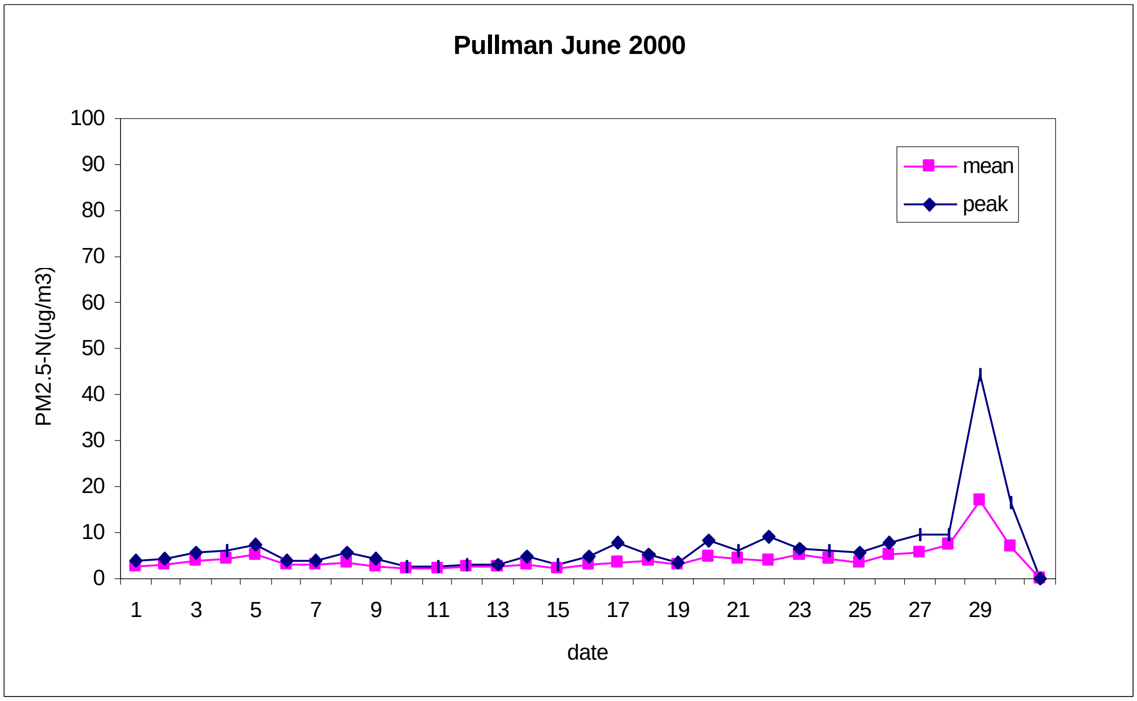


Figure 3.4. Average particulate matter ($PM_{2.5}$) observed in Pullman during the Spring and Fall 2000.

June 29, 2000. During late June, high levels of $PM_{2.5}$ were observed at the Pullman and Colfax monitoring sites (Figure 3.5). On the morning (10:00 am PST) of June 29, 2000, hourly peaks for $PM_{2.5}$ (nephelometer) greater than 50 μg/m3 were observed at both sites. The timing of the peak was also similar at both locations. For that day no smoke complaints were registered and no agricultural burns were voluntarily reported in the region. However, field burns were authorized in Whitman County between 9 am and 6 pm.

Wildfire activities were reported about 100 miles west-southwest of Pullman. The Two Fork fire burning at the U.S. Department of Energy Hanford was estimated to be more than 100,000 acres in size. This wildfire was captured in high-resolution satellite pictures (Figure 3.6) taken at 15:30 UTC on June 29, 2000 by the Operational Significant Event Imagery team (OSEI) at the National Oceanic and Atmospheric Administration (NOAA) Science Center in Suitland, Maryland.

The backward trajectories for air parcels arriving in Pullman on June 29 at 10:00 am PST (18 UTC June 29, 2000) are shown in Figure 3.7a and 3.7b. Figure 3.7a was generated using the archived FNL meteorological forecast data (191 km resolution) and Figure 3.7b was generated using archived EDAS forecast data (80 km resolution). The back-trajectories estimated that the air parcels arriving in Pullman on June 29 at 10:00 am were coming from the west, where the wildfire activity (Hanford site) was reported. This analysis suggested that the smoke observed in Pullman throughout that morning was related to the wildfire event.



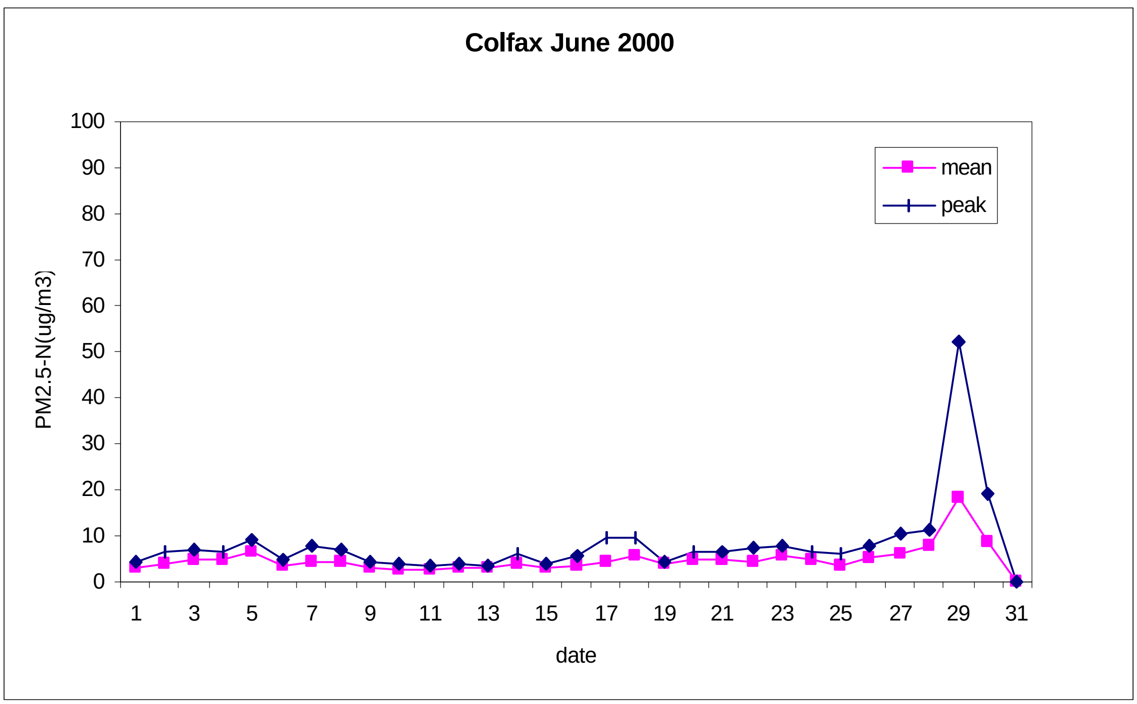
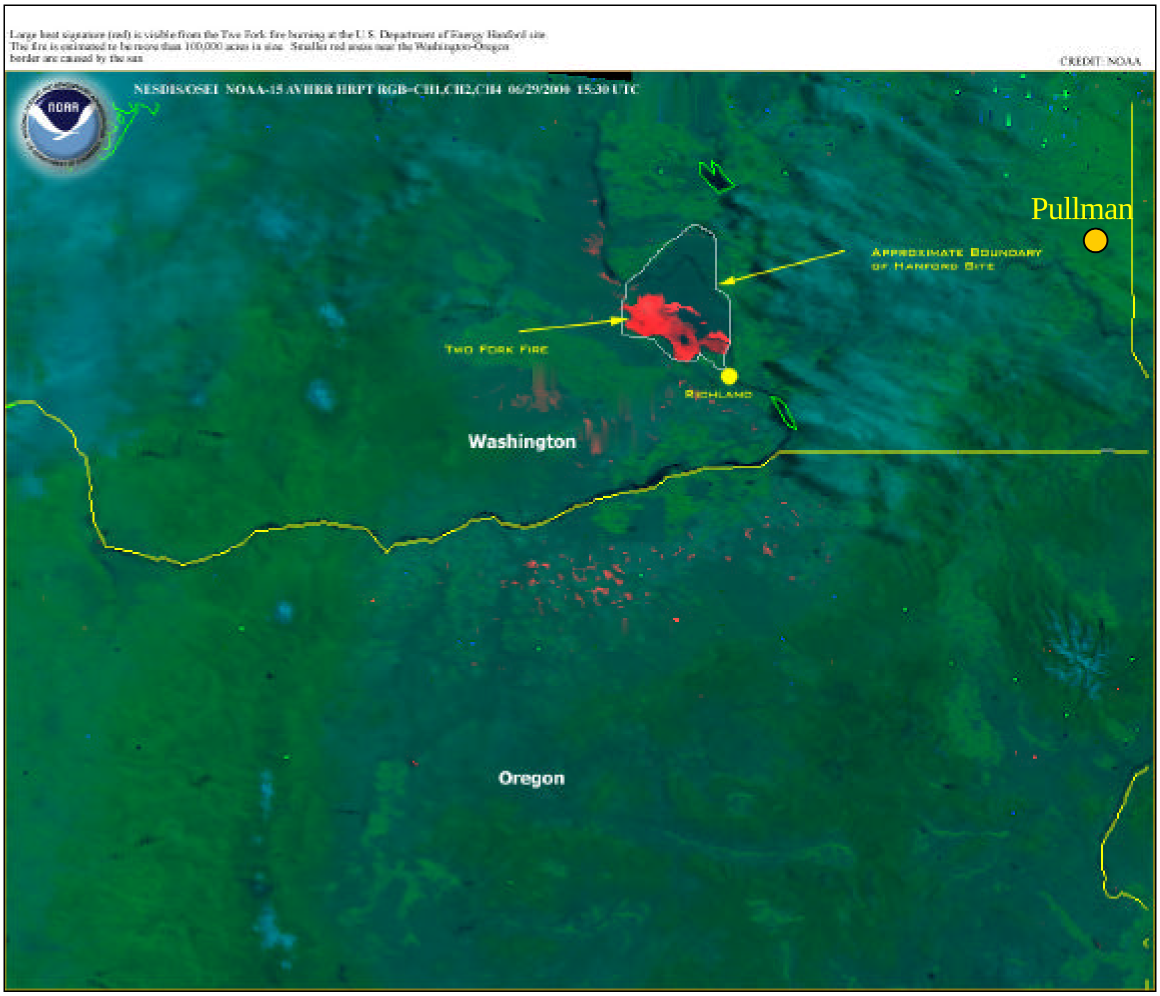
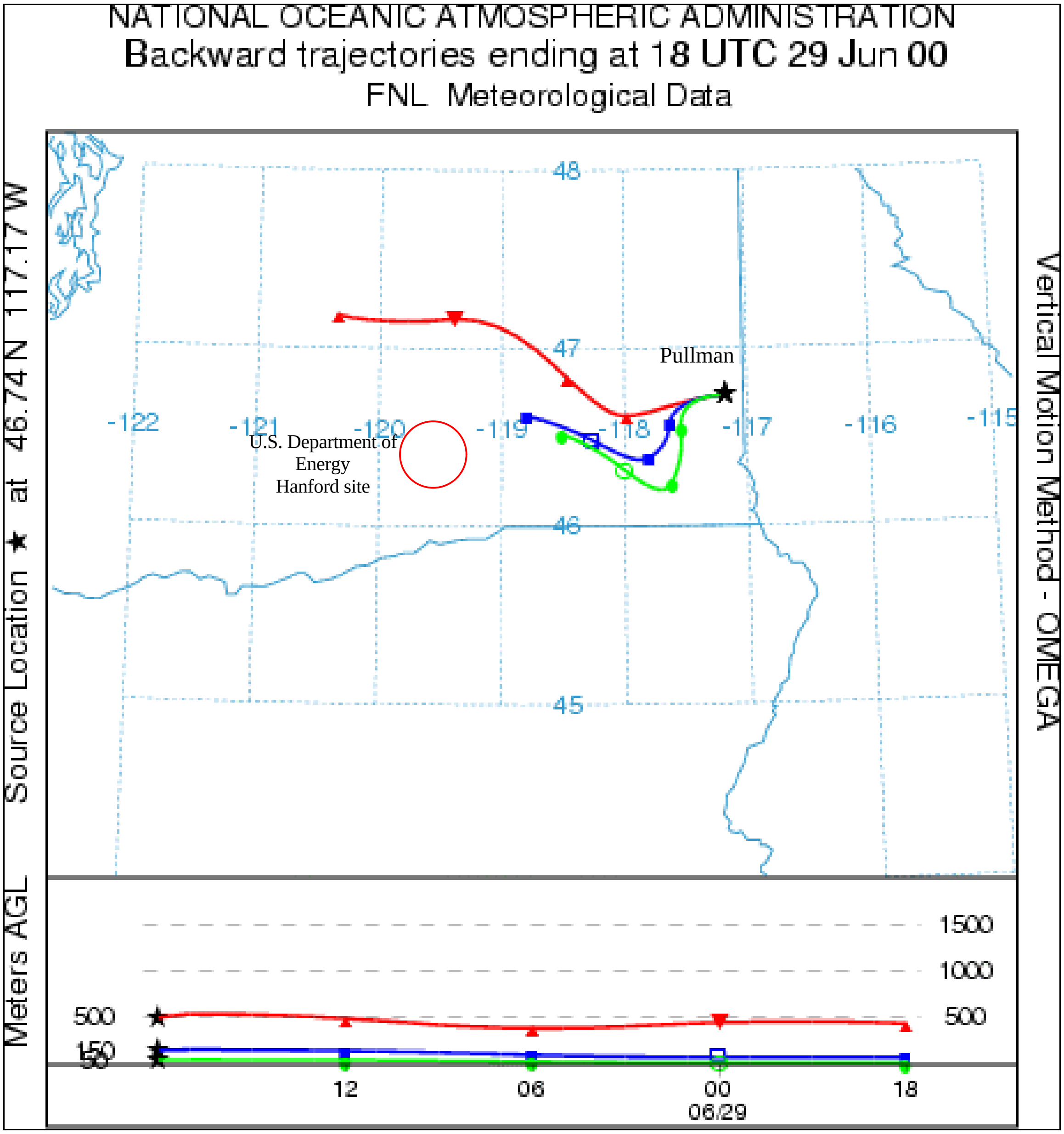


Figure 3.5. Relatively high PM levels observed on June 29, 2000 in the continuous $PM_{2.5}$ (nephelometer) measurements registered at Pullman and Colfax sites.



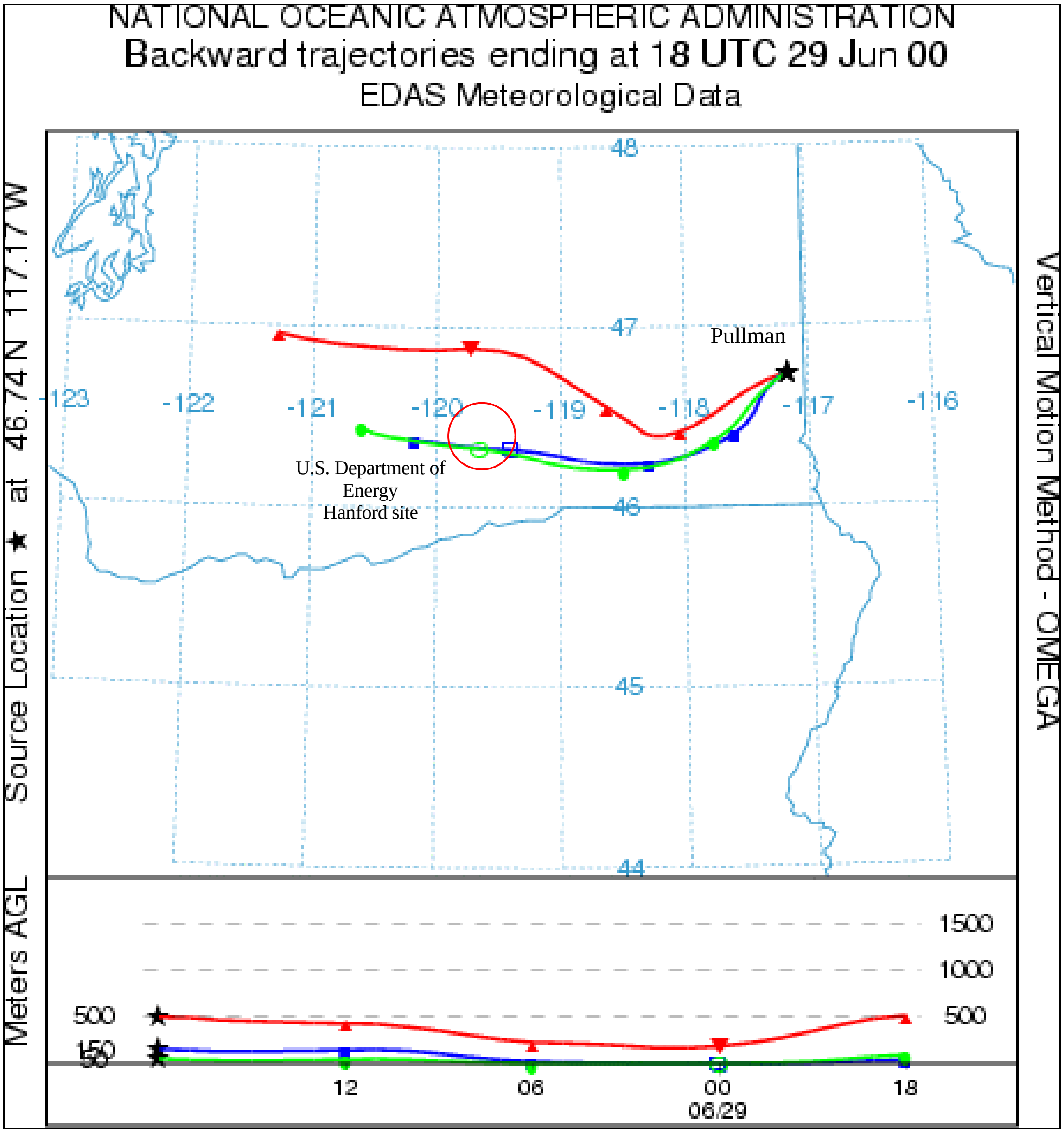
Source: http://www.osei.noaa.gov/Events/Fires/US_Northwest

Figure 3.6. Wildfire activities in South Central Washington captured on a satellite picture taken at 15:30 UTC on June 29, 2000 (8:30 pm PDT, June 29, 2000). The Two Fork fire burning at the U.S. Department of Energy Hanford site estimated to be more than 100,000 acres in size.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model. Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.7a. Backward trajectory generated from Pullman at 18 UTC on June 29, 2000 using archived FNL meteorological forecast data. The red circle points to the estimated location of the wildfire at the Hanford site.

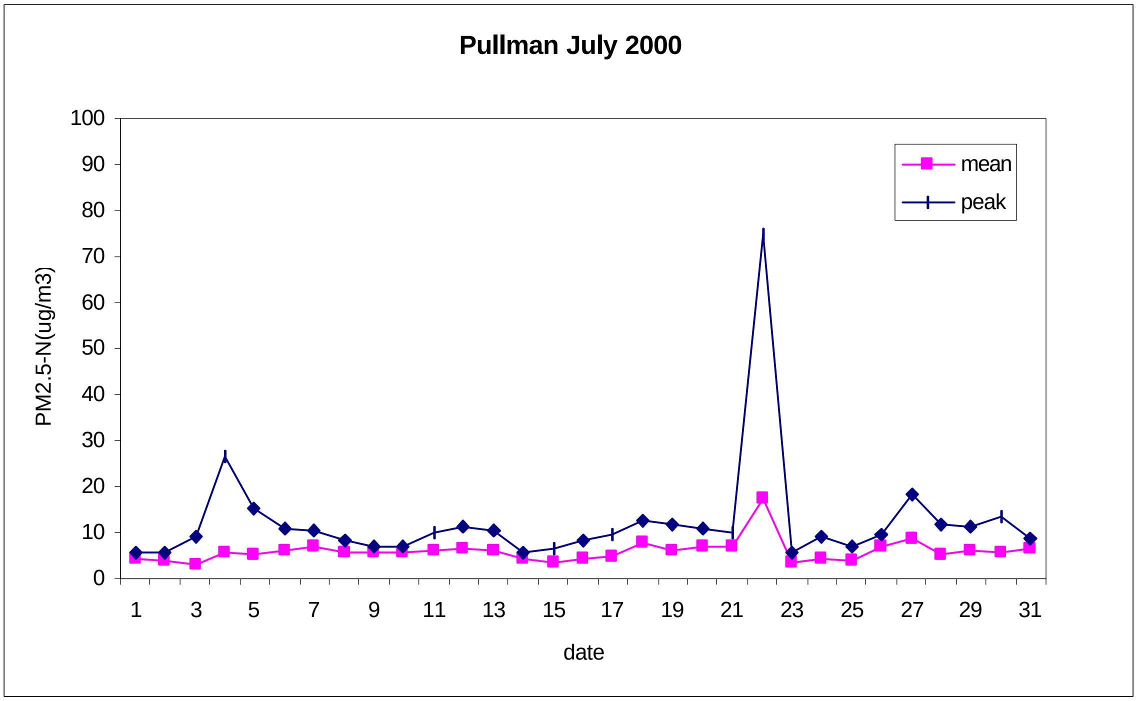


Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.7b. Backward trajectory generated from Pullman at 18 UTC on June 29, 2000 using archived EDAS meteorological forecast data. The red circle points to the estimated location of the wildfire at the Hanford site.

July 22, 2000. On the afternoon (6:00 pm PST) of July 22, 2000 high $PM_{2.5}$ levels (> 75 $\mu g/m^3$ nephelometer) were observed at both Pullman and Colfax monitoring sites (Figure 3.8). This episode lasted for 4 hours. For that day no smoke complaints were registered and no agricultural burns were reported in the area of Eastern Washington. Nevertheless, field burning was authorized in Whitman County between 10 am and 6 pm for that day. Meanwhile, wildfires were reported in Central Idaho and South Central Washington. The Burgdorf Junction and Clear Creek fires were burning in Idaho with approximately 6,000 and 40,000 acres in size. The wildfires in Idaho were captured on high-resolution satellite images (Figure 3.9) taken at 22:42 UTC on July 23, 2000 by *OSEI* at the National Oceanic and *NOAA*. In Washington, the Alderdale wildfire was reported in Klickitat County with approximately 6,000 acres in size and as 70% contained for this day.

The trajectories generated by HYSPLIT are shown in Figure 3.10a and 3.10b. The backward trajectories estimated that the air parcels arriving in Pullman on July 22 at 6:00 pm PST (02 UTC July 23, 2000) were coming from the west-southwest. From that area, the Alderdale wildfire was reported in Klickitat County, South Central Washington. The smoke observed in Pullman on the evening of July 22, 2000 may be linked to the wildfire that occurred in Washington on that day.



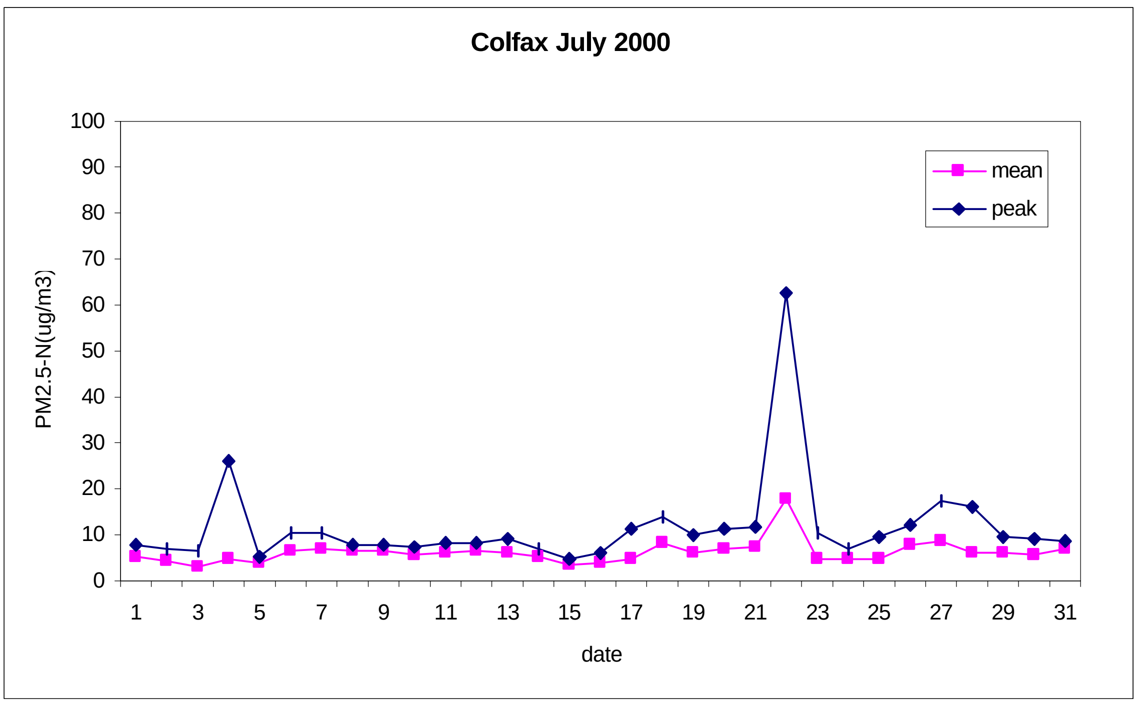
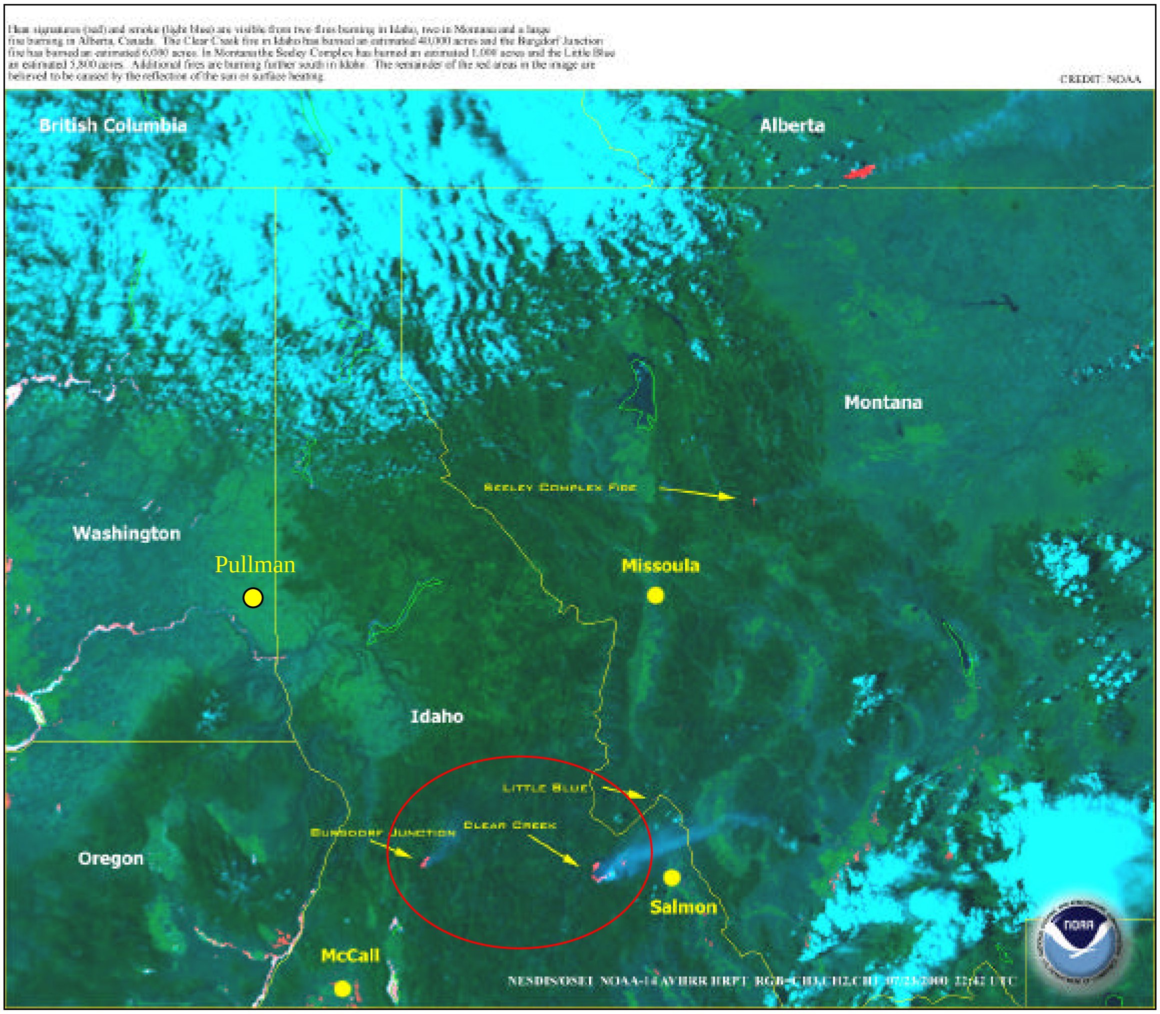
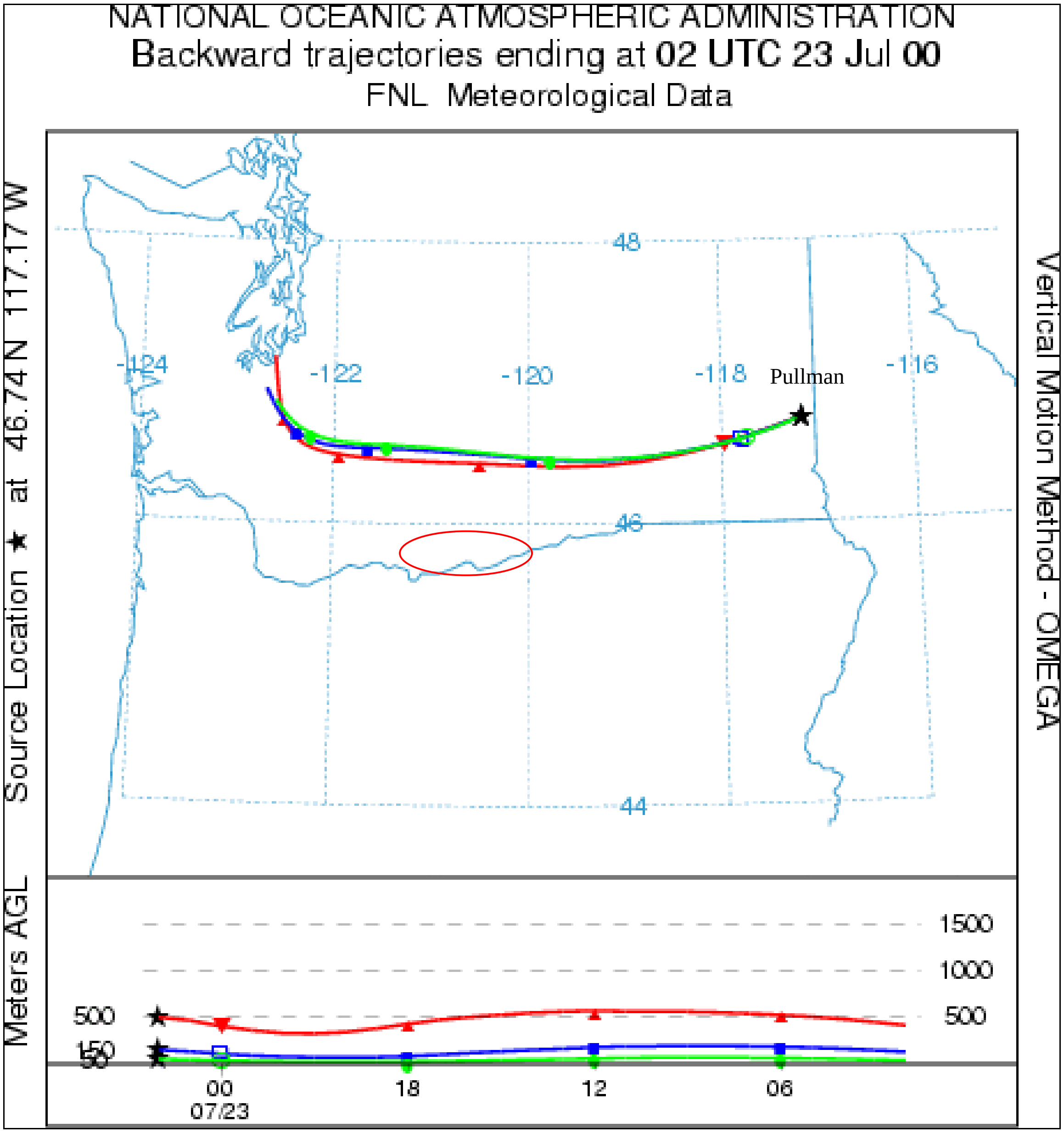


Figure 3.8. Relatively high PM levels observed on July 22, 2000 in the continuous $PM_{2.5}$ (nephelometer) measurements registered at Pullman and Colfax sites. Note a peak on July 4, may be linked to smoke 4th of July firework show.



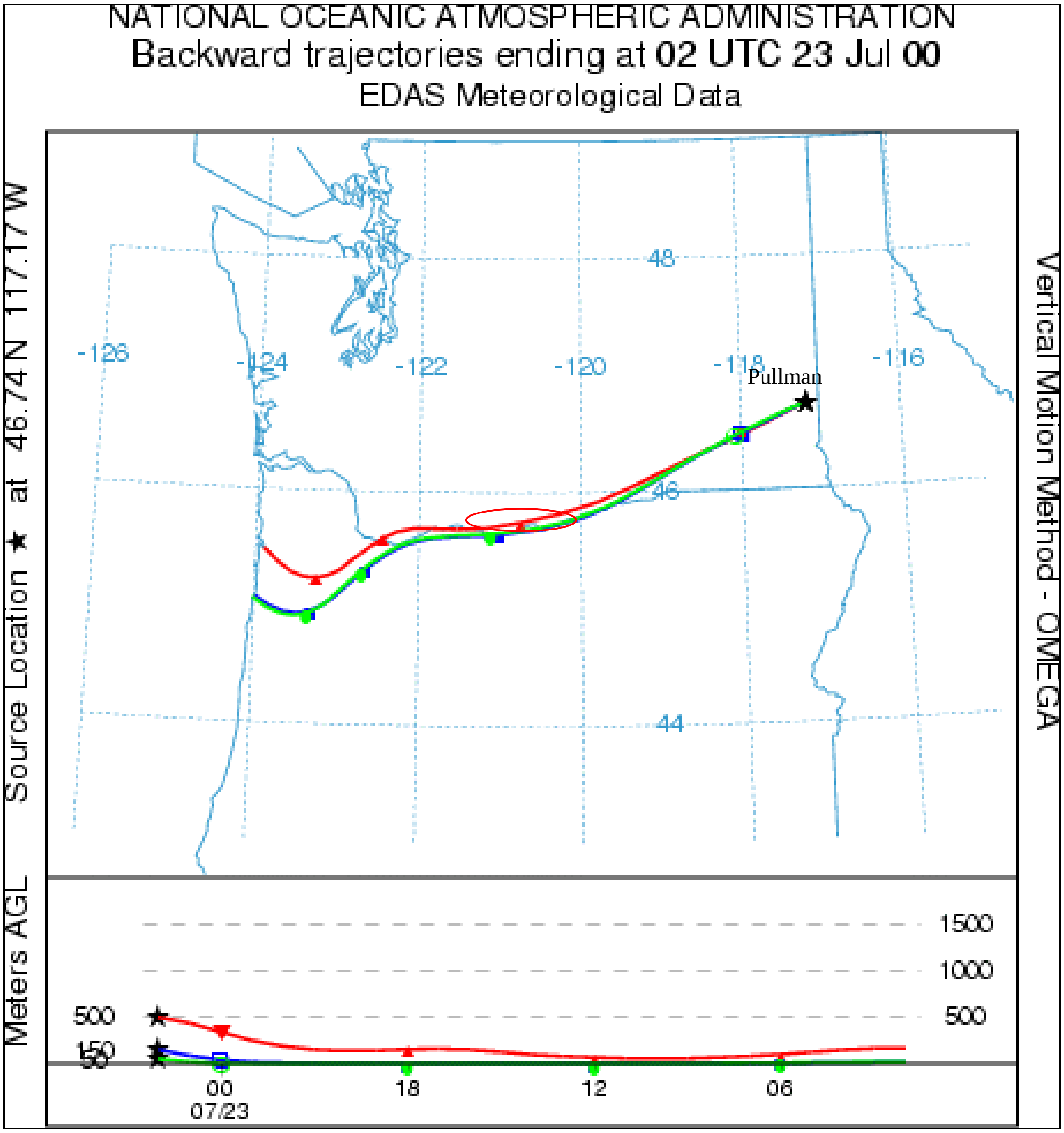
Source: http://www.osei.noaa.gov/Events/Fires/US_Northwest

Figure 3.9. Wildfire activities in Central Idaho captured on a satellite picture taken at 22:42 UTC on July 23, 2000 (3:42 pm PDT, July 23, 2000). The Burgdorf Junction and Clear Creek fires burning in Central Idaho with approximately 6,000 and 40,000 acres in size.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.10a. Backward trajectory generated from Pullman at 02 UTC on June 23, 2000 using archived FNL meteorological forecast data. The red circle points to the estimated location of the Alderdale wildfire in Klickitat County in Washington.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

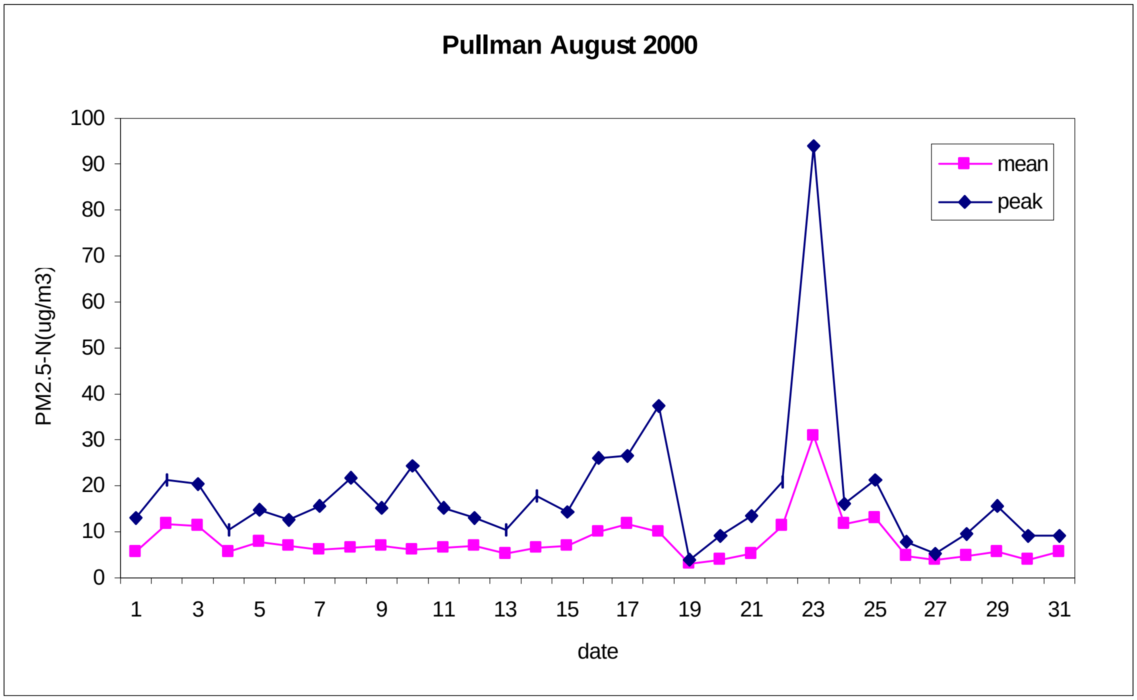
Figure 3.10b. Backward trajectory generated from Pullman at 02 UTC on June 23, 2000 using archived EDAS meteorological forecast data. The red circle points to the estimated location of the Alderdale wildfire in Klickitat County in Washington.

August 23, 2000. On the morning of August 23, 2000 (10:00 am PDT), high levels of $PM_{2.5}$ (nephelometer 95 $\mu g/m^3$) were observed in Pullman and Colfax (Figure 3.11). This three hour smoke episode was also noticed at the Dana Hall instruments (TEOM $PM_{2.5}$ 97.3 $\mu g/m^3$ peak) during the same morning (Figure 3.12). For that day, no agricultural burns were reported. Furthermore, burning activities were prohibited in the state for that day. Two smoke complaints were reported in the area of Pullman during this smoke episode.

In Central Idaho and Western Montana, several wildfires were reported. Wildfire updates for August 23 from Salmon-Challis Fire Information Center and the Center for International Disaster Information are summarized in Table 3.4. In addition, a satellite picture showed the wildfire activities. Several heat sources and smoke coming from Central Idaho and Western Montana can be observed in the picture (Figure 3.13). This digital image was taken at 00:00 UTC on August 23, 2001 by *OSEI* from *NOAA*, monitoring the fire events in the Pacific Northwest. Smoke from those fires was visually observed in the image. The smoke plume moving toward Montana, captured in the image, was used to evaluate consistency of the HYSPLIT Model with the visual observation of the smoke plume in the satellite image. Appendix C includes trajectories developed for the wildfire in Central Idaho.

The trajectories generated by HYSPLIT for air parcels arriving in Pullman on August 23 at 10:00 am (18 UTC August 23, 2000) are shown in Figure 3.14a and 3.14b. The figures also show descending air parcels arriving in Pullman. This descending air mass may be originated from a high pressure system moving into the area. The back-trajectories estimated that air parcels were coming from the southeast (Idaho), where wildfires were reported during that period of time. The analysis suggested that the smoke observed in Pullman was related to wildfire events that occurred in Central Idaho.

September 14, 2000. On the afternoon (5:00 pm PST) of September 14, 2000, $PM_{2.5}$ levels greater than 50 $\mu g/m^3$ were recorded in Pullman (Figure 3.15). In addition, the instruments (TEOM) located at the Dana Hall Roof observed the same high $PM_{2.5}$ levels (78 μg/m3 TEOM) and levels increased throughout the evening and night of September 14 (Figure 3.16). However, during this smoke event, the air quality monitoring station located at Colfax did not observe similar high PM concentrations (Figure 3.15). Two complaints were reported during this day, but none of them were directly related to either smoke or burning activities. The WDOE did not authorize field burnings on September 14 in all counties in Washington. However, nine agricultural burns took place in Adams and Columbia Counties, with at least 2,030 acres involved. It is suspected that the field burns in Columbia were authorized by the local agency in Columbia County, but were not recorded as such in the burn calendar compiled by WDOE for 2000. Another 2,411 acres burned were reported on that day from the Coeur d’ Alene Indian Reservation, located in Northern Idaho. Table 3.5 summarizes the location and number of acres burned in agricultural activities during that day.



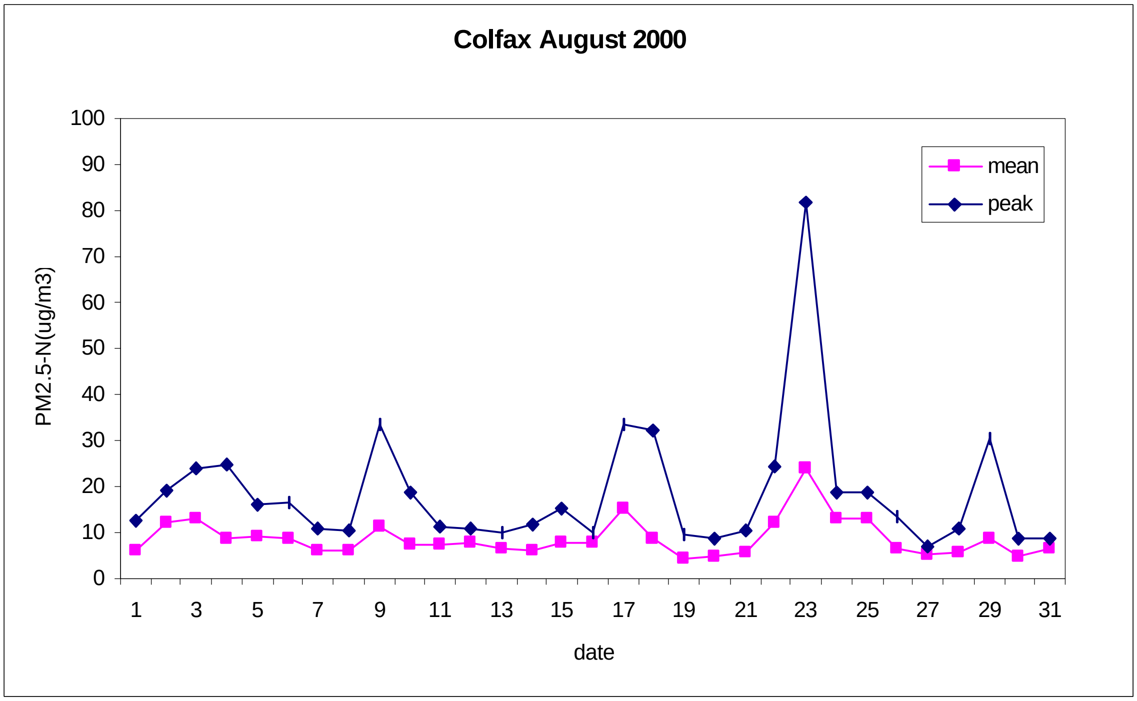


Figure 3.11. High PM levels observed on August 23, 2000 in the continuous $PM_{2.5}$ (nephelometer) measurements registered at Pullman and Colfax sites. Note several minor peaks possibly related to smoke from wildfires in Central Idaho and Western Montana.

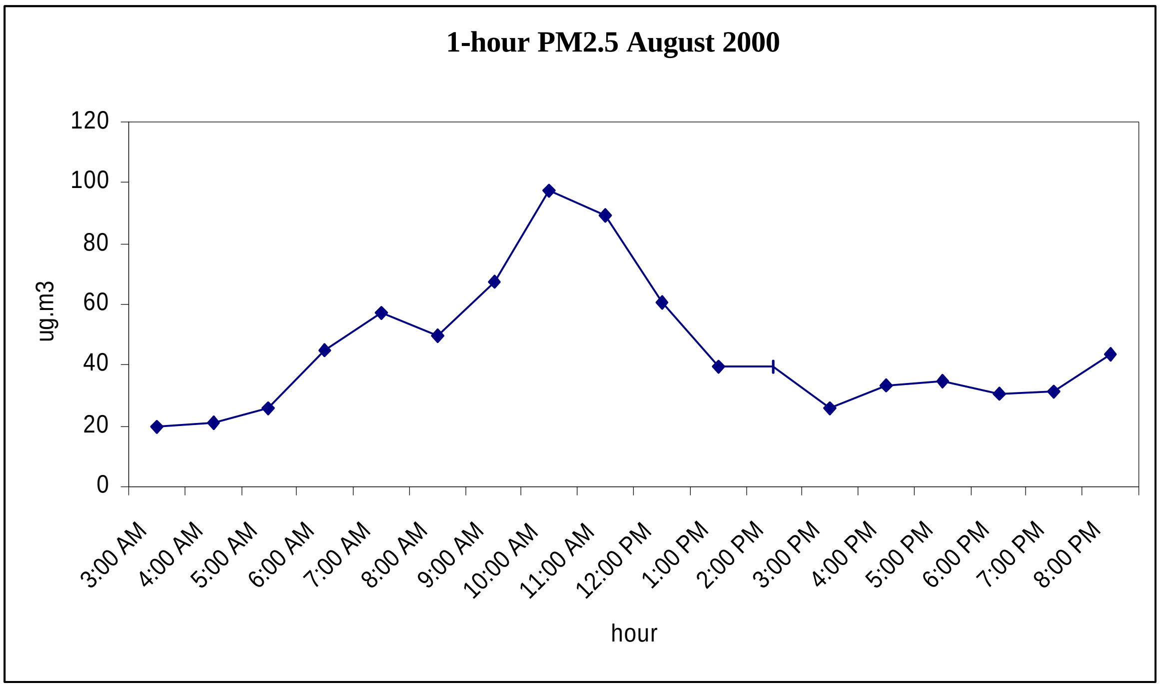
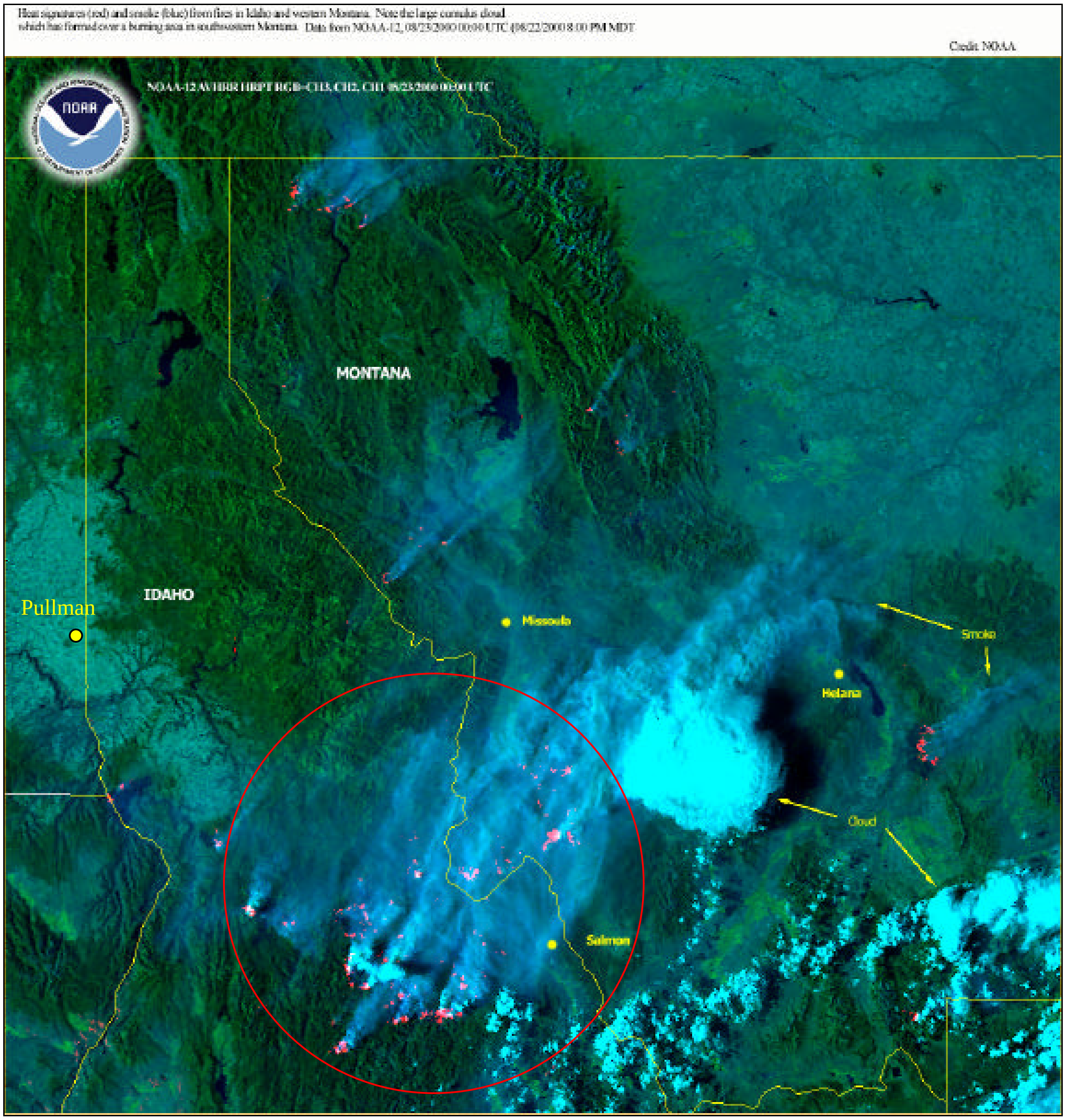


Figure 3.12. High PM levels observed in the morning of August 23, 2000 on the continuous $PM_{2.5}$ (TEOM) measurements registered at Dana Hall roof, WSU in Pullman.

Table 3.4. Wildfire updates reported from Salmon-Challis Fire Information Center and the Center for International Disaster Information, for August 23, 2000.

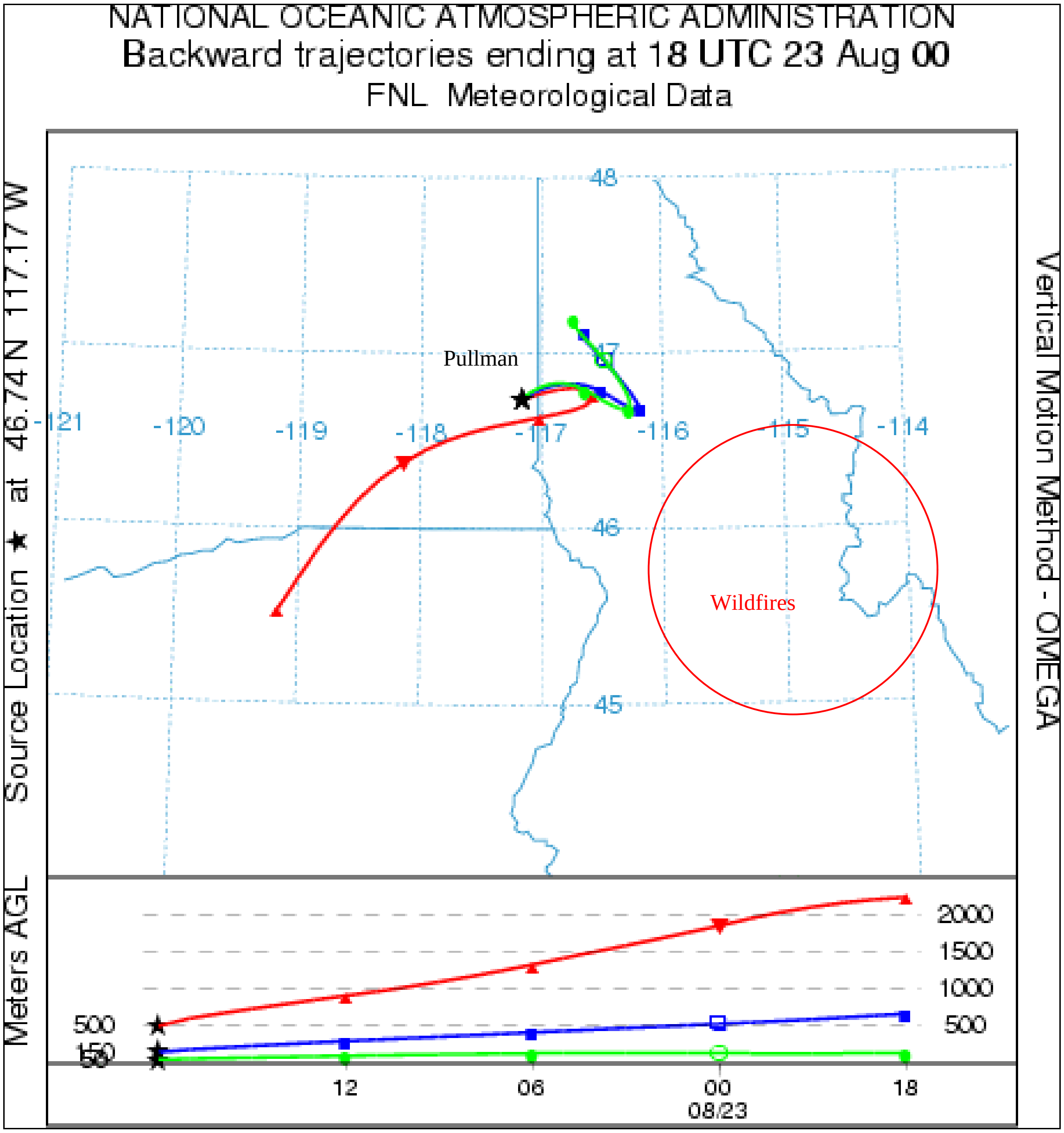
Wildfire	Location	Size (acres)	% Contained
Clear Creek Fire	Central Idaho	71,505	36
Crooked	Central Idaho	4,600	90
Burnt Flats	Central Idaho	17,000	50
Maloney Creek	Central Idaho	63,000	90
Three Bears	Central Idaho	32,500	Not contained
Elizabeth	Central Idaho	2,670	Not contained
Trail Creek	Central Idaho	23,930	15
Burgdorf Junction	Central Idaho	52,900	44
Flossie Complex	Central Idaho	40,000	Not contained
Nick	Central Idaho	2,600	40
Burley Complex	Central Idaho	28,500	90
Rankin Creek Fire	Central Idaho	6,700	80
Morse Creek Fire	Central Idaho	2,725	11
Wilderness Fires	Central Idaho	94,200	Not contained
Marling Spring Fire	North-Central Idaho	1,000	Not contained

Source: USDA Forest Service and Center for International Disaster Information (CIDI)



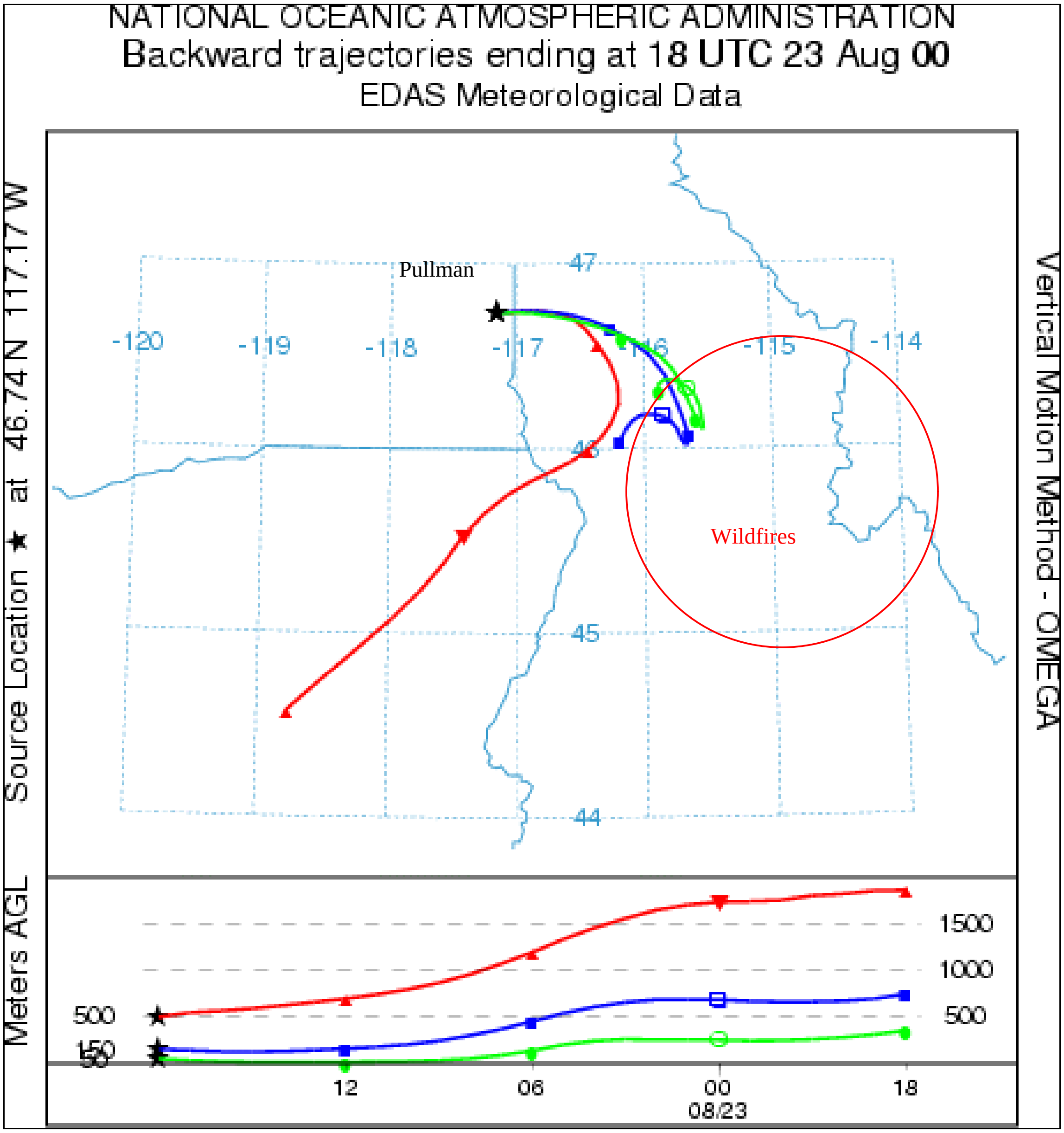
Source: http://www.osei.noaa.gov/Events/Fires/US_Northwest

Figure 3.13. Wildfire activities in Central Idaho and Western Montana captured on a satellite picture taken at 00:00 UTC on August 23, 2000 (5:00 pm PDT, August 22, 2000). The Clear Creek fire, the Ranking Creek fire, Morse Creek Fire, Wilderness Fires and Marling Spring Fire with more than 275,000 acres total. Note the smoke plume (light blue) heading toward Montana.



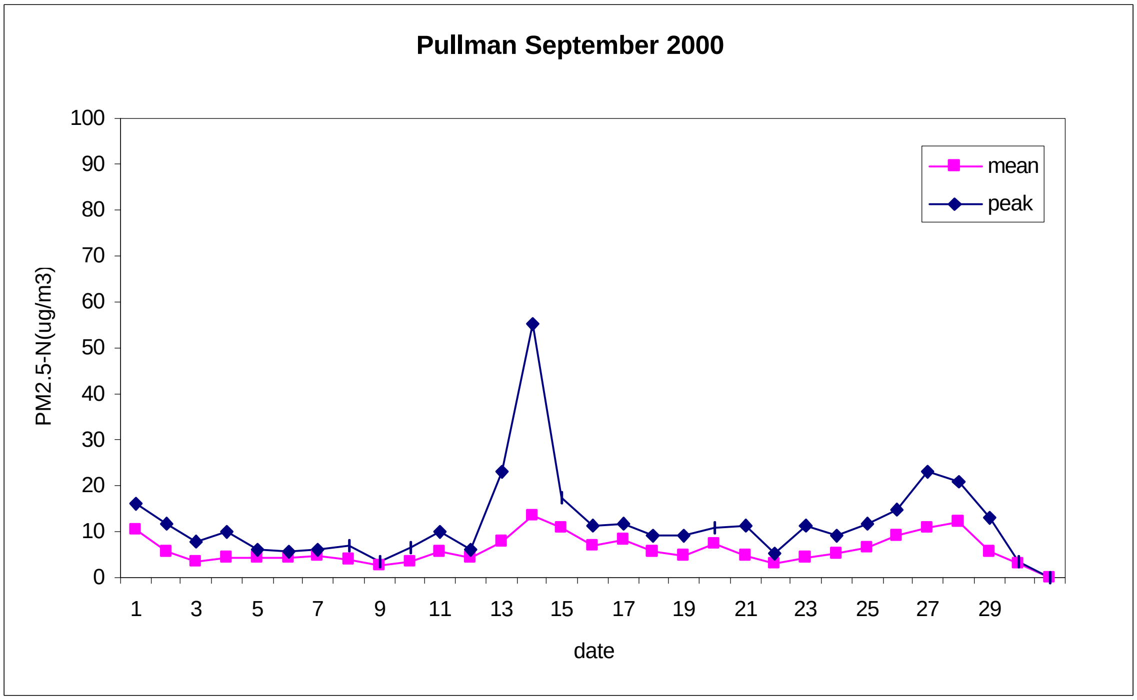
Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.14a. Backward trajectory generated from Pullman at 18 UTC on August 23, 2000 using archived FNL meteorological forecast data. The red circle points to the estimated location of the wildfires in Central Idaho. Note the descending air parcels arriving in Pullman. This descending air mass may be originated from a high pressure system moving into the area.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.14b. Backward trajectory generated from Pullman at 18 UTC on August 23, 2000 using archived EDAS meteorological forecast data. The red circle points to the estimated location of the wildfires in Central Idaho. Note the descending air parcels arriving in Pullman. This descending air mass may be originated from a high pressure system moving into the area.



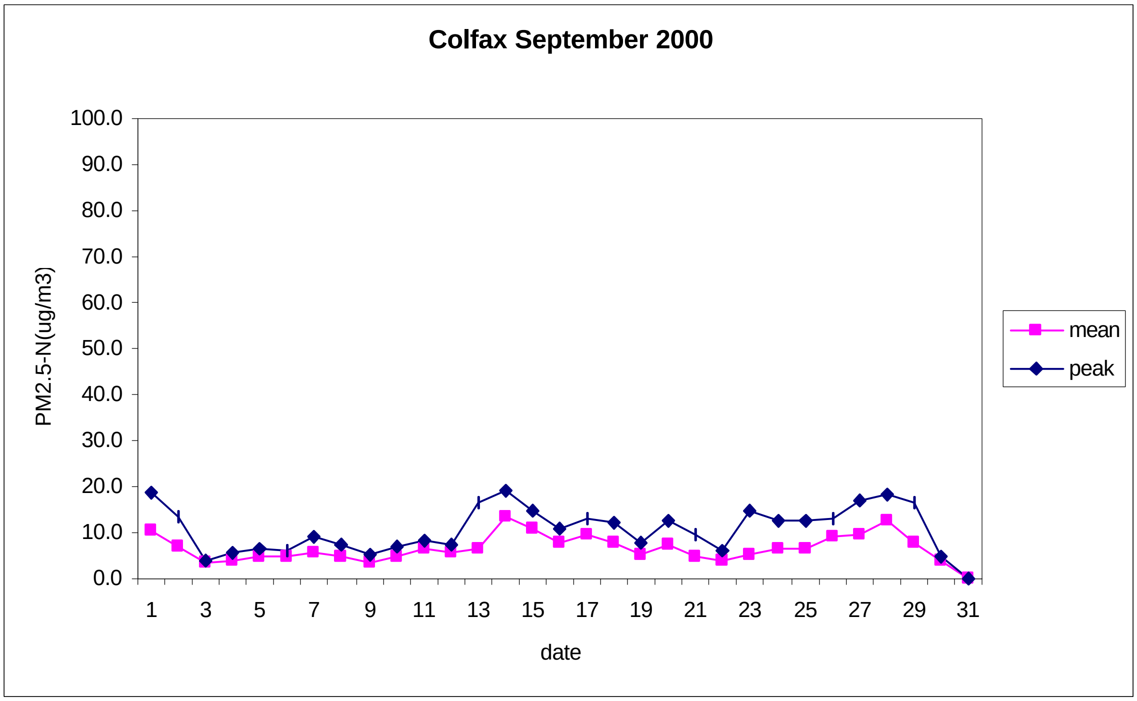


Figure 3.15. High PM levels observed on September 14, 2000 in the continuous $PM_{2.5}$ (nephelometer) instruments at Pullman site. Note that the high levels were not recorded by the instruments at Colfax site.

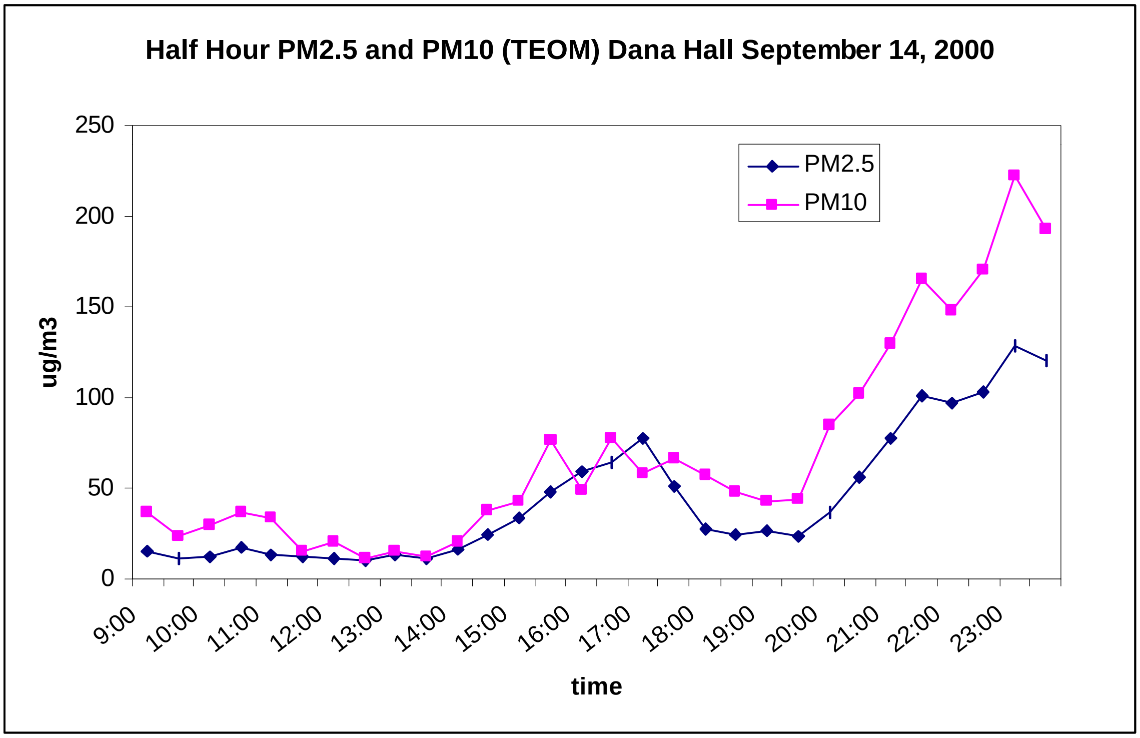


Figure 3.16. $PM_{2.5}$ (TEOM) and PM_{10} (TEOM) measurements observed at Dana Hall instruments on September 14, 2000.

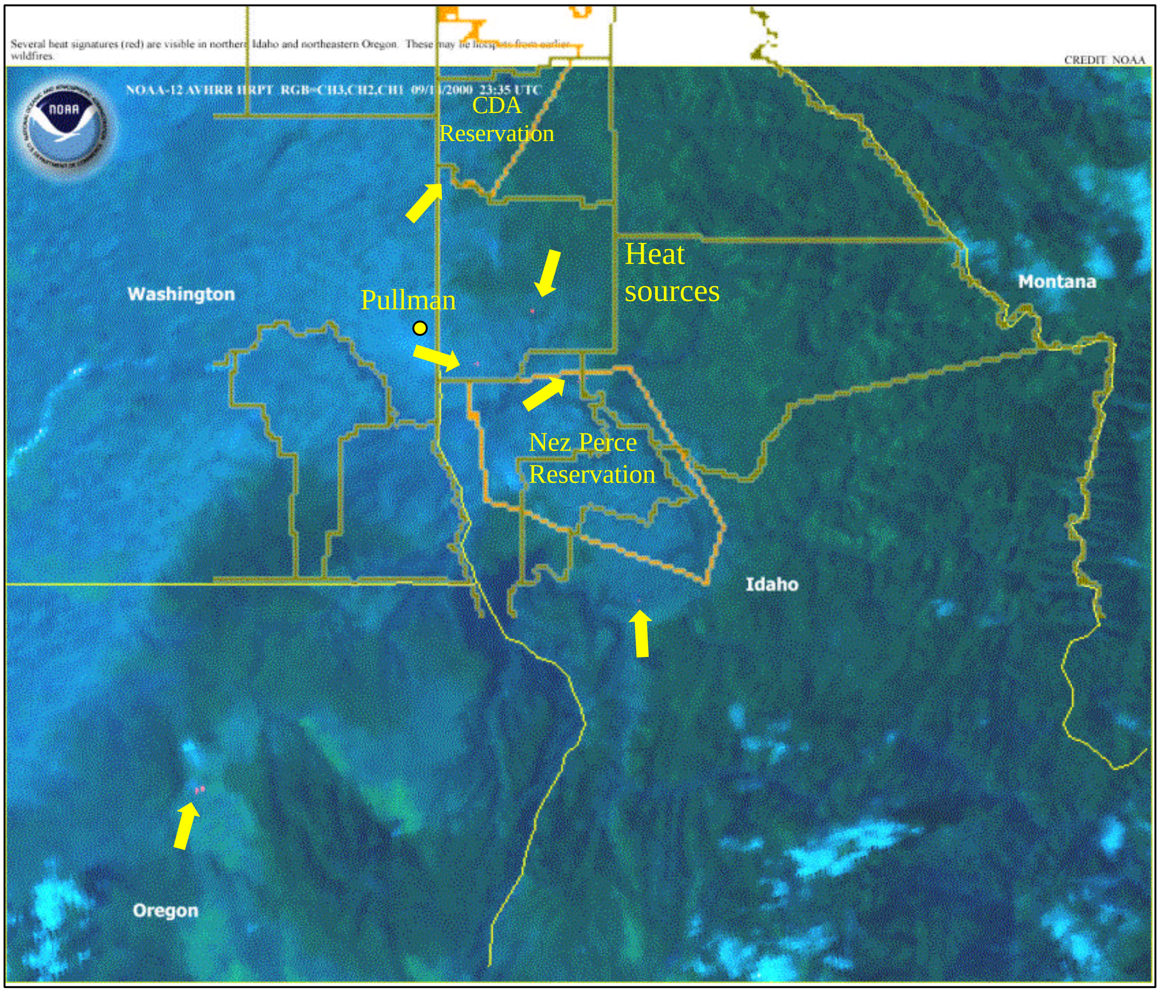
Table 3.5. Agricultural burning reported on September 14, 2000 in Eastern Washington and Northern Idaho.

Location of the fire	Number of fire sources	Reported acres burnt
Adams County, Central Washington	1	180
Columbia County, Southeast Washington	8	1,849
CDA Reservation, Northern Idaho	N/A	2,411
	Total	4,440

Source: Fall 2000 Burn Report

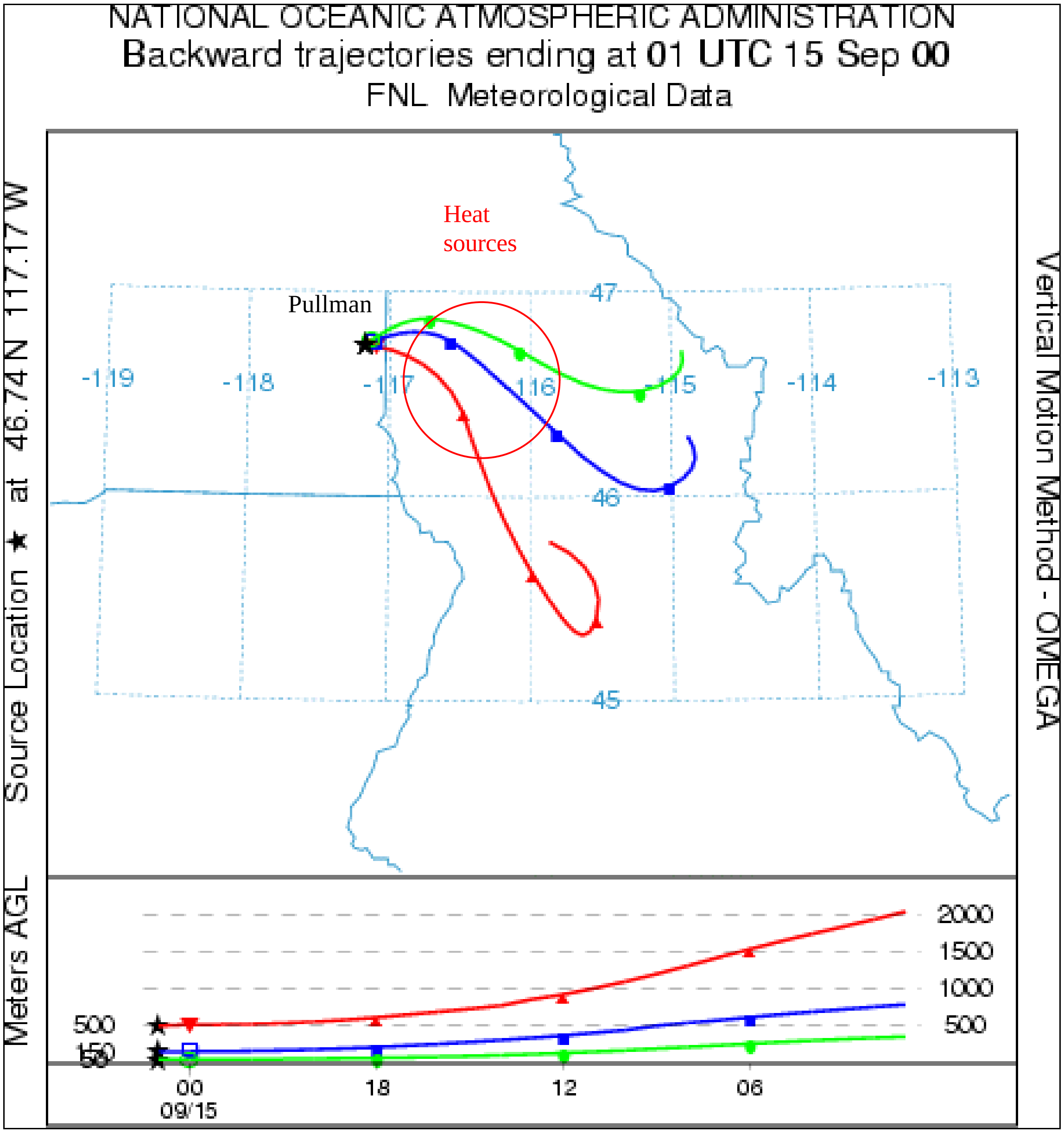
On September 14, 2000 wildfire activities were reported about 12 miles west of Salmon in Central Idaho (USDA Forest Service). The Clear Creek Complex (Clear Creek and Marlin Springs fires), which had burned for several weeks and by now involved more than 206,000 acres, was reported as 83% contained. Additionally, wildfire updates reported the Salmon-Challis wilderness fire, with approximately 180,000 acres not contained during that day. Satellite pictures available showed several heat sources (hot spots) in Idaho and Oregon (Figure 3.17). This digital image was taken at 23:35 UTC (4:35 pm PDT) on September 14, 2000 by *OSEI* from *NOAA* monitoring the fire events in the Pacific Northwest. Because of the time and location, it is most likely that some of the hotspots detected by the satellite were agricultural field burns, such as the spots in Northern Idaho located near to the border with the state of Washington, where monitoring instruments registered high levels of $PM_{2.5}$ in the air.

The trajectories generated by HYSPLIT for air parcels arriving in Pullman on September 14 at 5:00 pm PST (01 UTC September 15, 2000) are shown in Figure 3.18a and 3.18b. The backward trajectories estimated that air parcels were coming from the east, in Idaho. During that day, several hotspots (fires) were captured by satellite in North Idaho. The trajectory analysis, as predicted by HYSPLIT based upon archived meteorological forecast data, was consistent with smoke observed in Pullman during the afternoon of September 14th being linked to the fires, which occurred in North Idaho, whether they were field burns and/or wildfires.



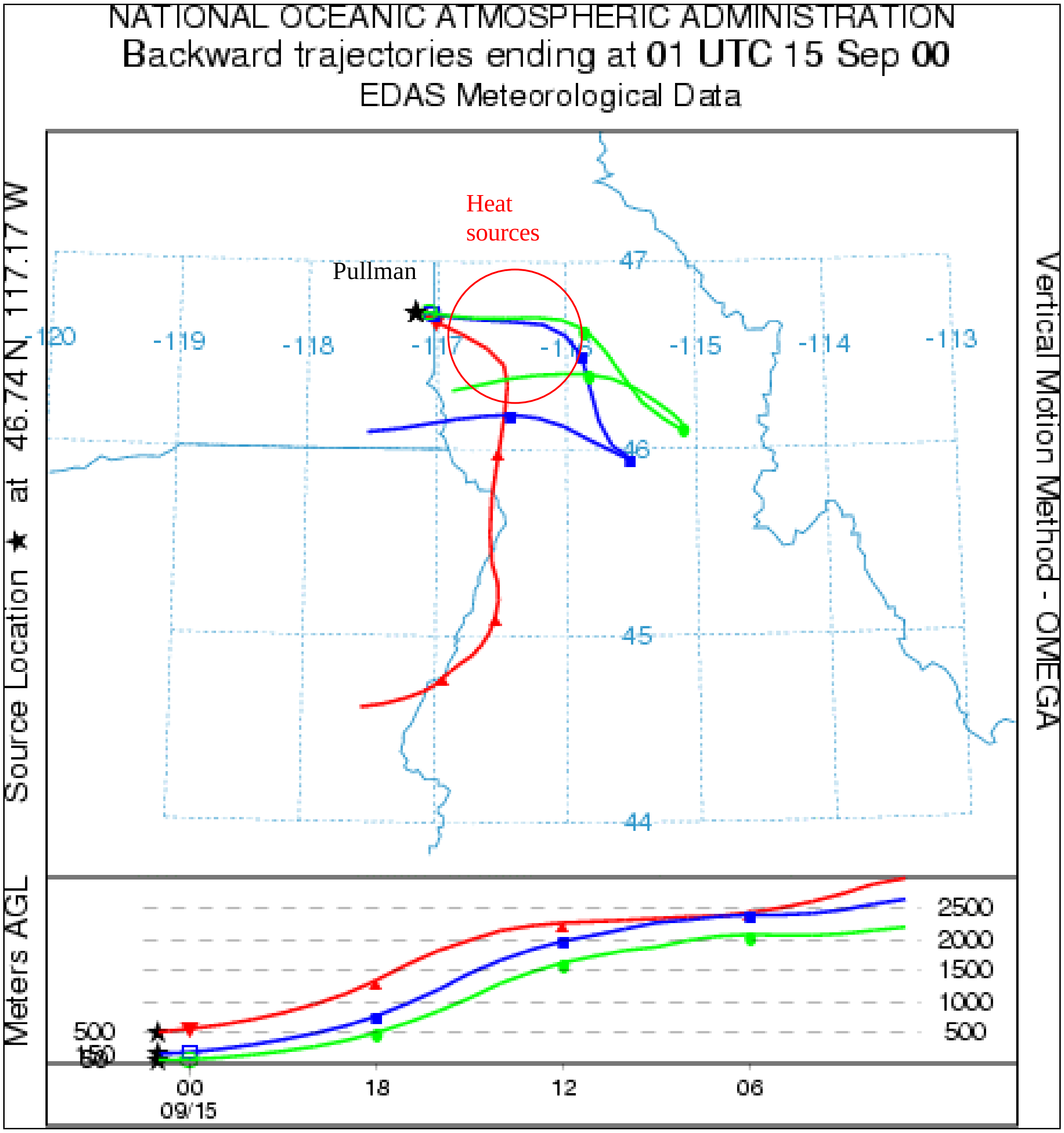
Source: http://www.osei.noaa.gov/Events/Fires/US_Northwest

Figure 3.17. Several heat sources from Northern Idaho observed in a Satellite image taken at 23:35 UTC (4:35 pm PDT) on September 14, 2000 by OSEI from NOAA. Note several heat sources (fires) in Idaho and Oregon.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.18a. Backward trajectory generated from Pullman at 01 UTC on September 15, 2000 using archived FNL meteorological forecast data. The red circle points to the estimated location of the fires in Northern Idaho.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.18b. Backward trajectory generated from Pullman at 01 UTC on September 15, 2000 using archived EDAS meteorological forecast data. The red circle points to the estimated location of the fires in Northern Idaho.

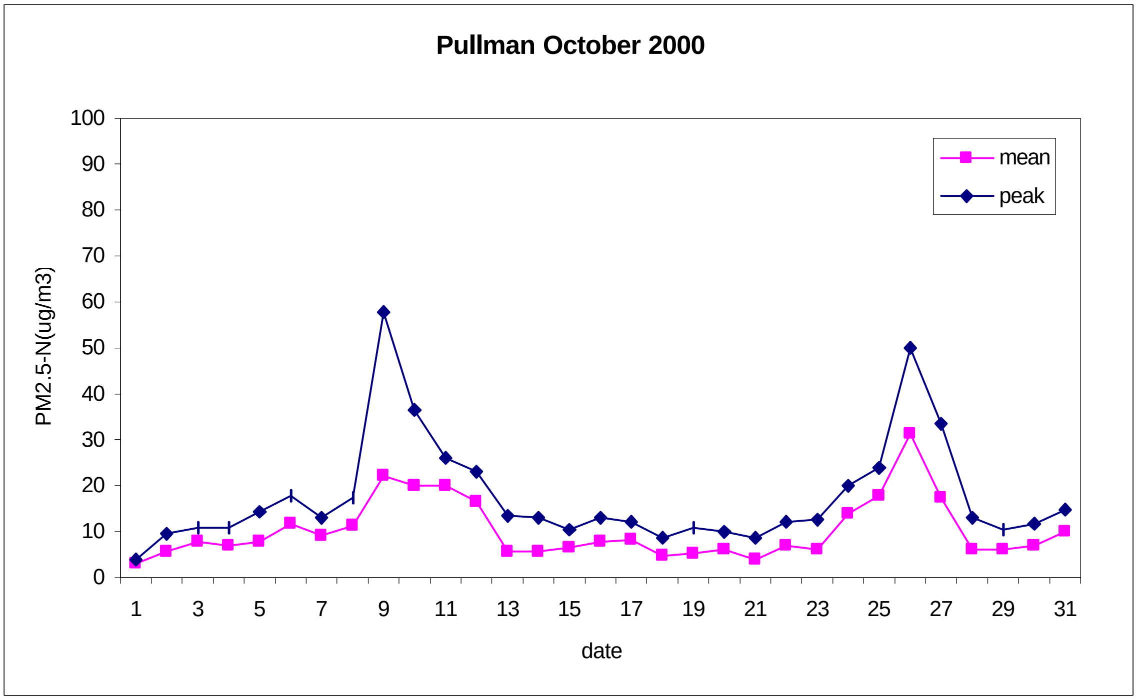
October 9, 2000. During the evening of October 9, 2000, levels of $PM_{2.5}$ greater than 65 $\mu g/m^3$ (nephelometer) were registered at the Pullman (8:00 pm PST) and Colfax (9:00 pm PST) monitoring sites (Figure 3.19). This smoke event lingered for about 3 hours. However, no complaint was registered for the episode. Field burning was authorized in some counties, and during the day more than twenty agricultural fires were reported in Columbia County (Southeast Washington), with at least 4,000 acres involved. In addition, the Clear Creek fire was still active, with more than 216,000 acres burned and reported as 90% contained for this day (Center for International Disaster Information). Satellite pictures showed heat spots (fires) in Northern Idaho (Figure 3.20). This digital image was taken at 23:35 UTC (5:49 pm PDT) on October 9, 2000 by NOAA and analyzed by the United States Department of Agriculture (USDA) Forest Service. However, this fire did not match the location of the wildfire that was reported for that day in Central Idaho (Clear Creek Complex).

The trajectories generated by HYSPLIT for air parcels arriving in Pullman on October 9th at 8:00 pm PST (04 UTC October 10, 2000) are shown in Figure 3.21a and 3.21b. The back trajectory generated using the FNL archived meteorological forecast data (Figure 3.21a) was different compared to the trajectory generated using EDAS forecast data (Figure 3.21b). This may have occurred because of the different resolution of the archived meteorological data (FNL 191 km resolution an EDAS 80 km), which is used by the HYSPLIT model.

Nevertheless, both back-trajectories estimated that air parcels arriving in Pullman during the smoke episode were coming from the southwest. For that day, several agricultural burns were reported in Columbia County (southwest of Pullman). The trajectory analysis suggested that the smoke observed in Pullman during the evening of October 9th may be linked to the field burns that occurred in Columbia County.

October 26, 2000. On the night of October 26, 2000 (11:00 pm PDT), high levels of $PM_{2.5}$ (nephelometer 50 $\mu g/m^3$) were observed from the instruments located at the monitoring sites in Pullman and Colfax (Figure 3.19). This figure also shows a high mean value for the $PM_{2.5}$ 24-hour period during this day. Possible periods of poor ventilation conditions and stagnant weather in the region may have trapped smoke and dust in the air, which contributed to those high PM values. Figures 3.22a and 3.22b show poor ventilation conditions (MM5 forecast) in the region at 12:00 pm and 4:00 pm on October 26. For that day, no wildfire in the area, agricultural burns or complaints were reported and no burn call was made in the state of Washington for that day.

The trajectories generated by HYSPLIT for air parcels arriving in Pullman on October 26 at 11:00 pm (07 UTC October 27, 2000) are shown in Figure 3.23a and 3.23b. The figures show shifts in the trajectories plotted. This may indicate some degree of stagnant weather present during that day. The backward trajectories estimated that air parcels were coming from the east (Idaho) and slightly moving within Eastern Washington. The analysis suggested that the smoke observed in Pullman was likely due to PM trapped in the air due to periods of poor ventilation and stagnant weather conditions in the area.



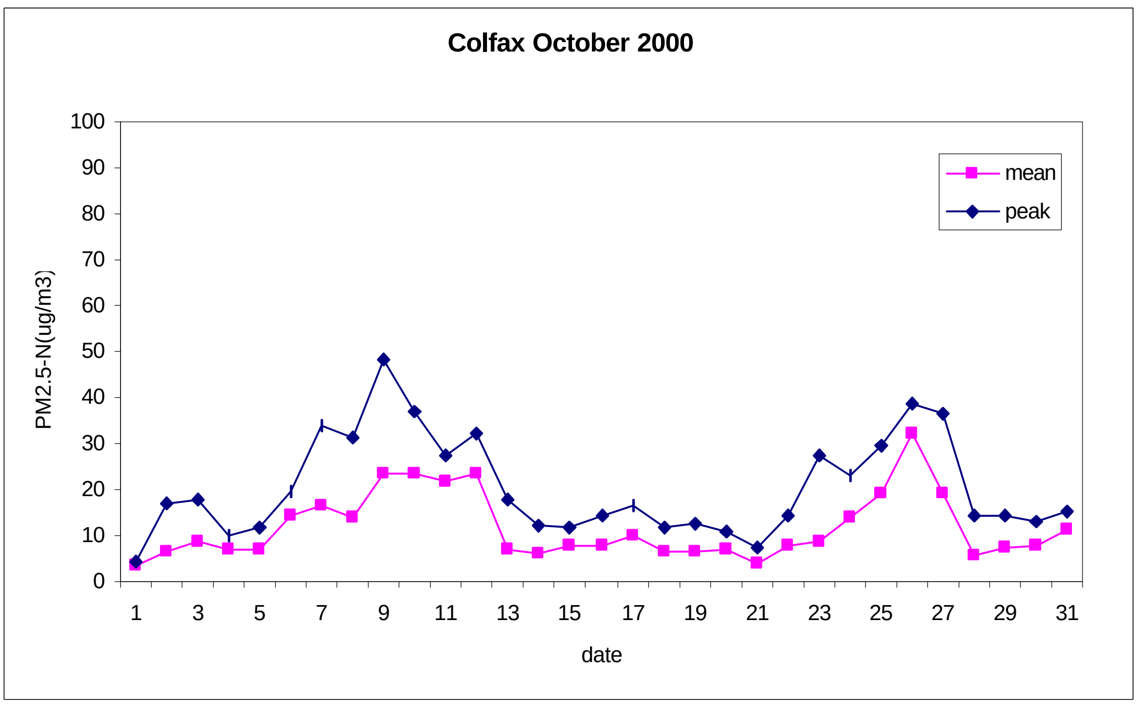
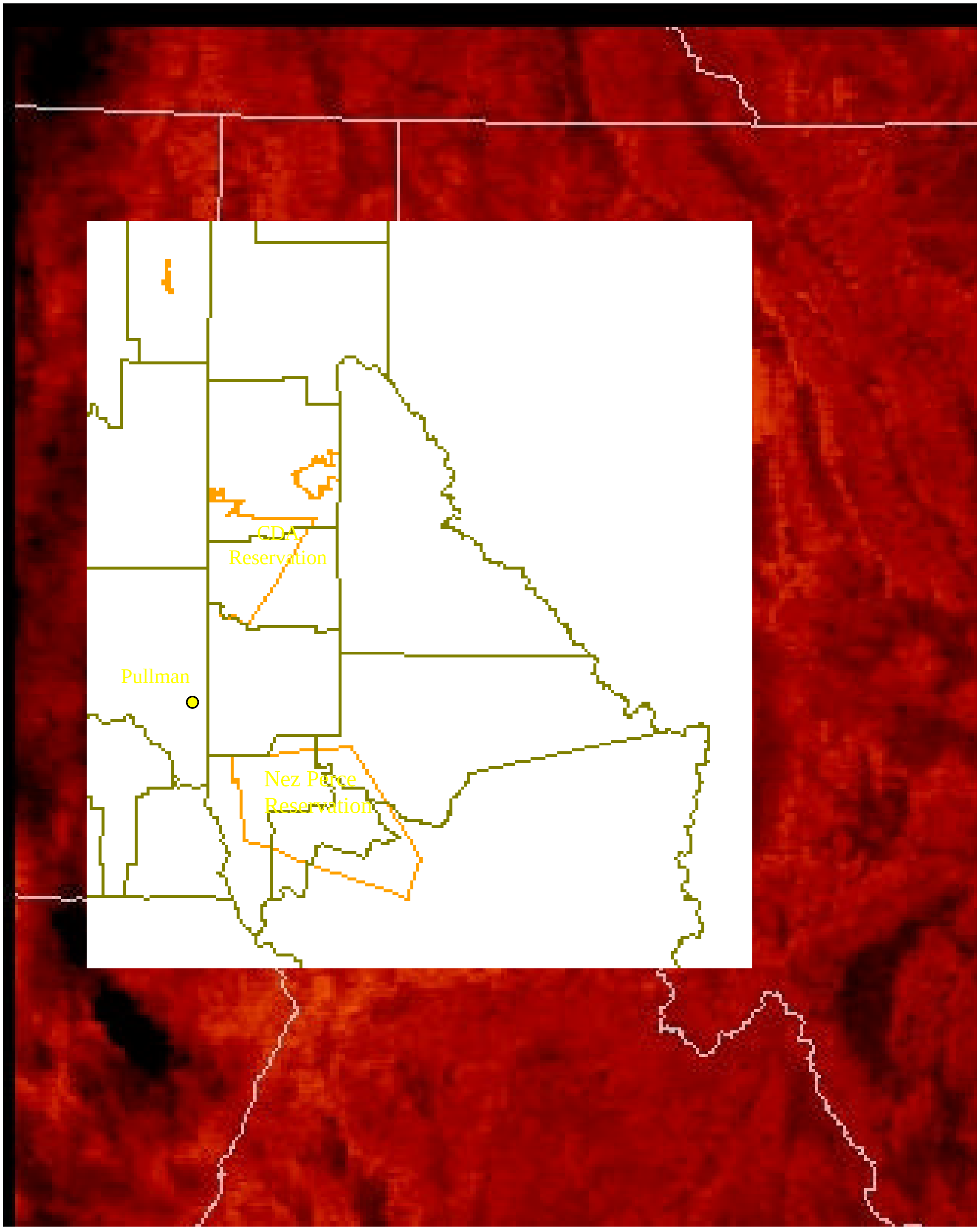
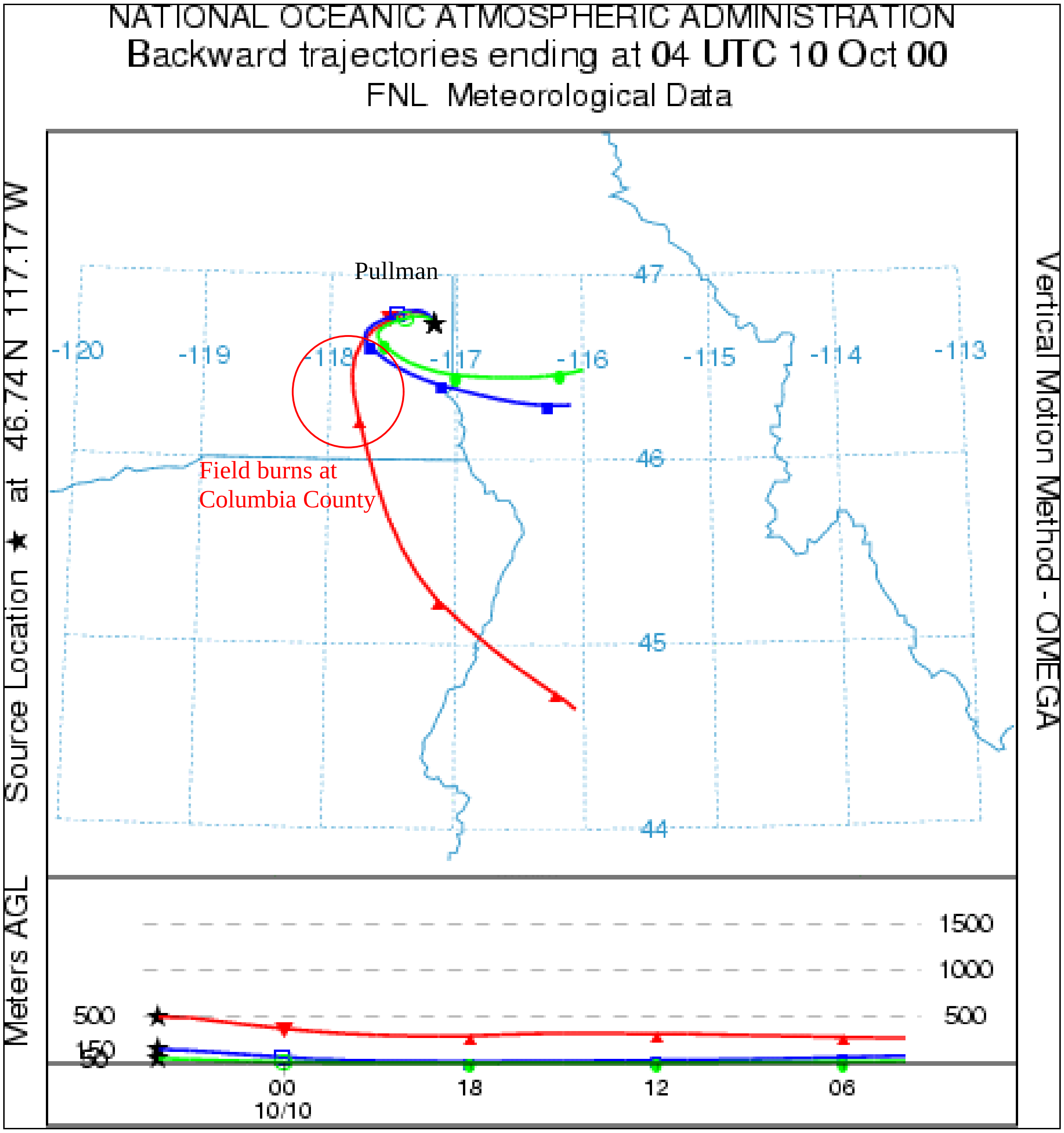


Figure 3.19. Period of atypical PM levels observed on October 9 & 26, 2000 in the continuous PM $_{2.5}$ (nephelometer) measurements registered at Pullman and Colfax sites.



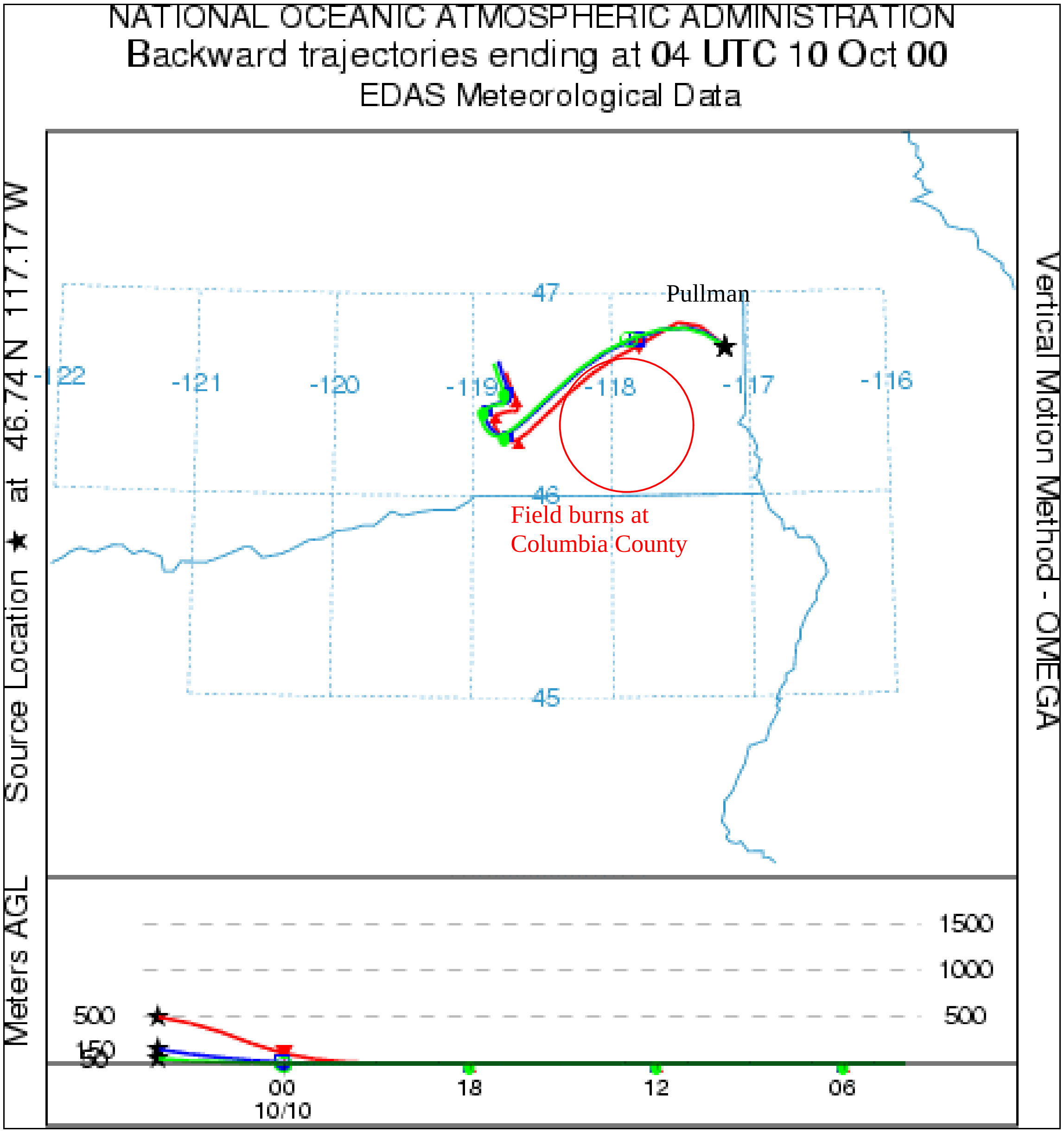
Source: http://www.fs.fed.us/r4/rsgis_fire/satellite.html

Figure 3.20. Heat sources (wildfire) in Northern Idaho observed from a Satellite image taken at 6:49 MDT (5:49 pm PDT) on October 9, 2000 by *NOAA* and analyzed by the United States Department of Agriculture (USDA) Forest Service.



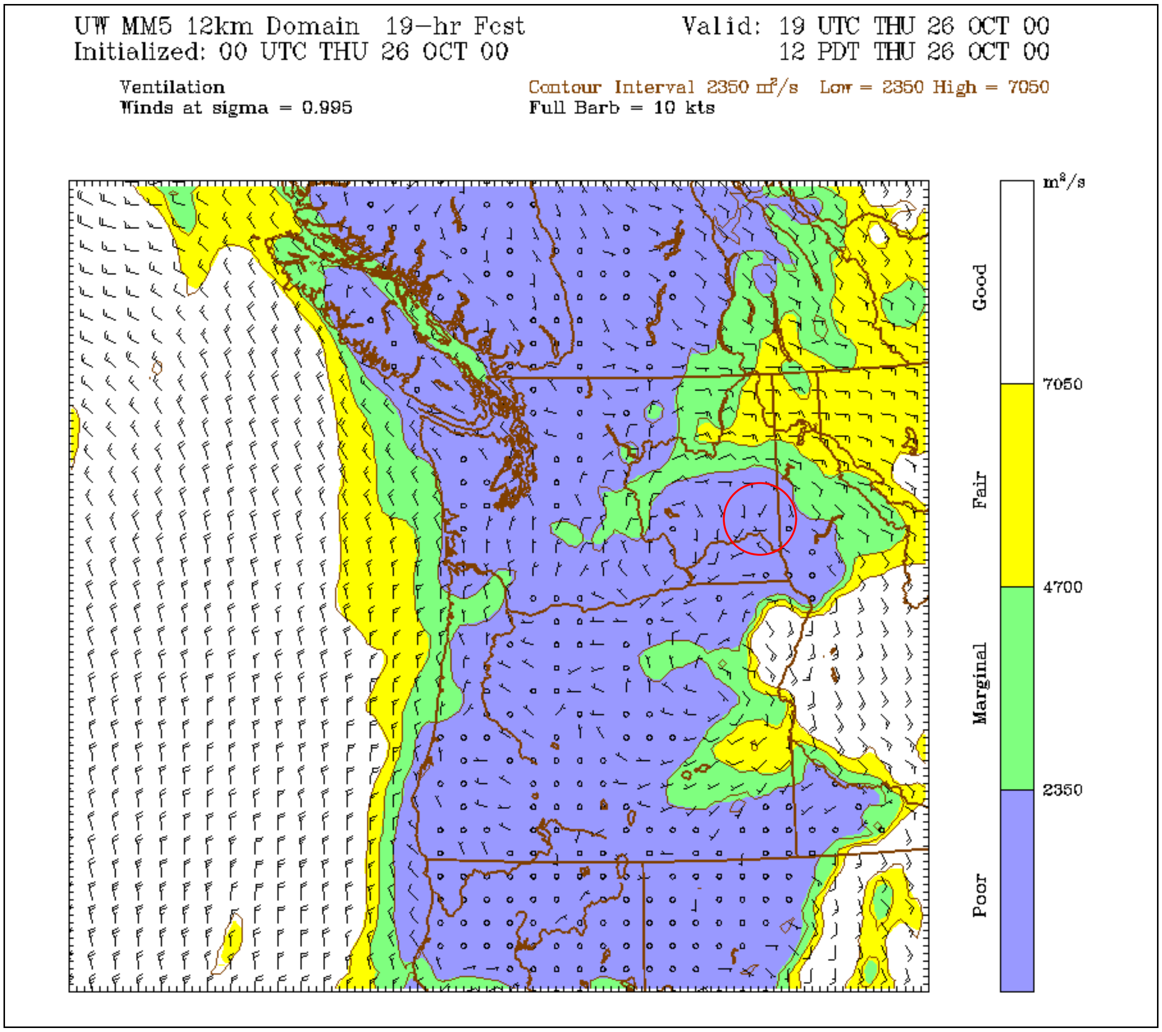
Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.21a. Backward trajectory generated from Pullman at 04 UTC on October 10, 2000 using archived FNL meteorological forecast data. The red circle points to the estimated location of the field burns in Columbia County.



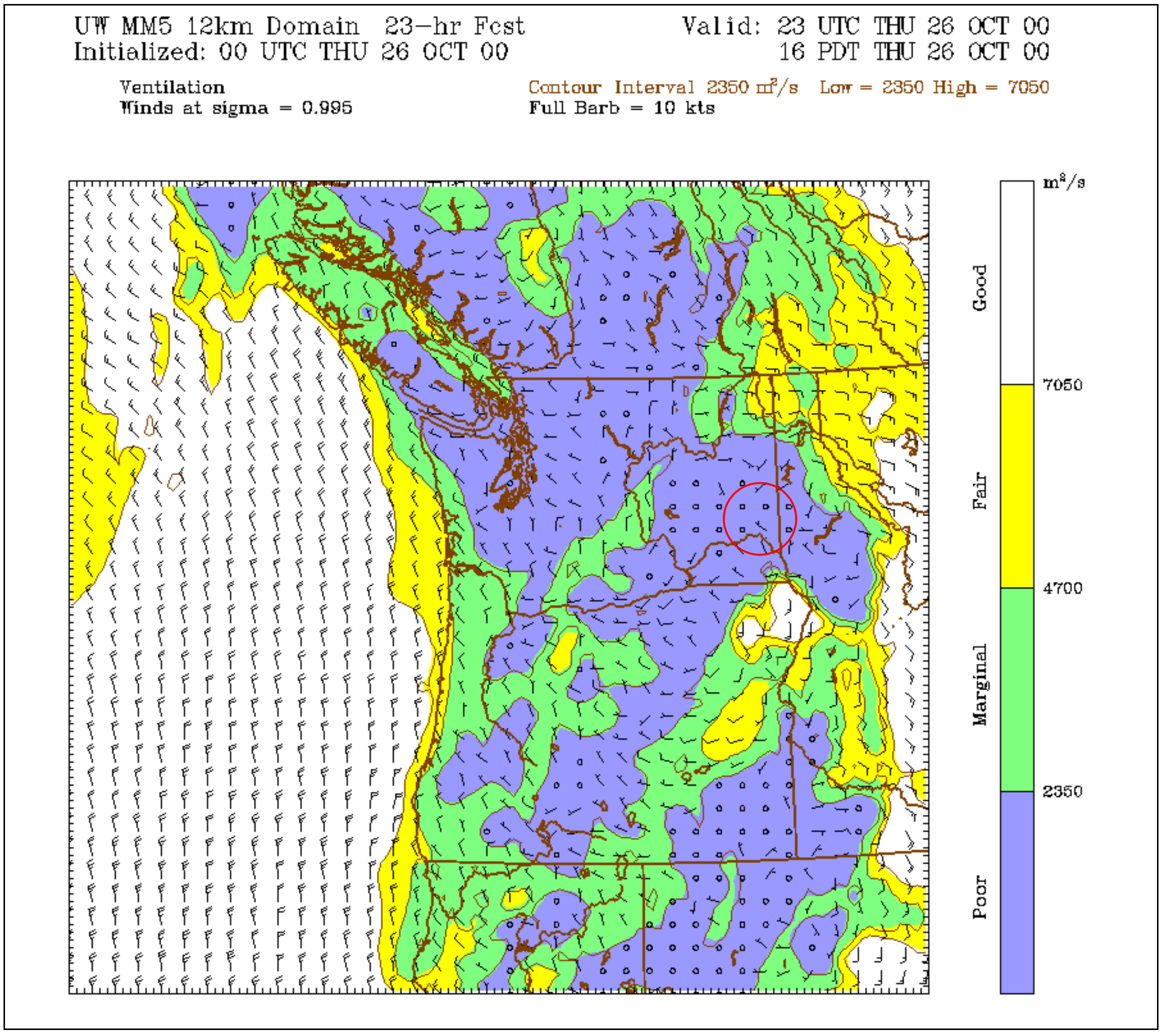
Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.21b. Backward trajectory generated from Pullman at 04 UTC on October 10, 2000 using archived EDAS meteorological forecast data. The red circle points to the estimated location of the field burns in Columbia County.



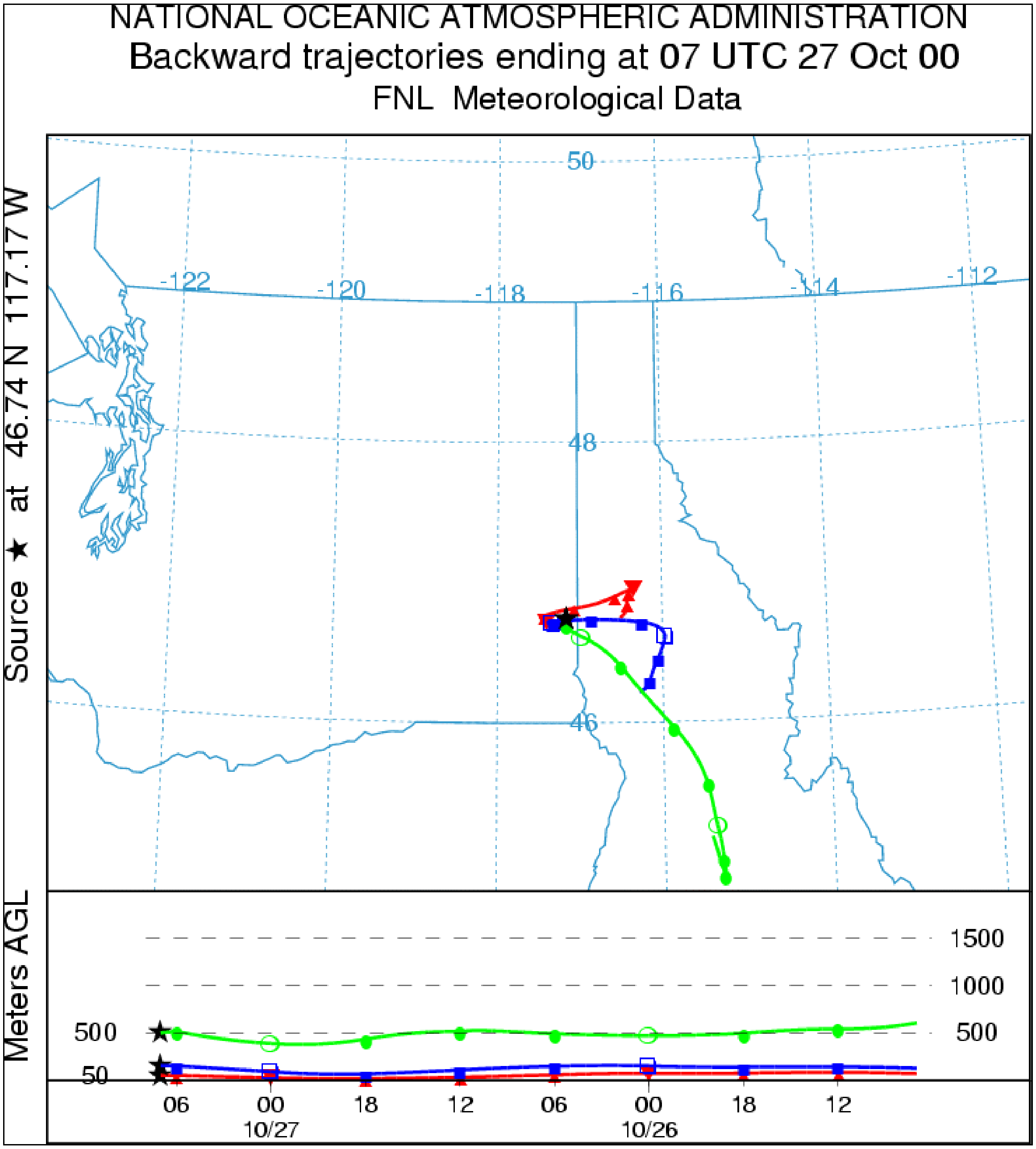
Source: Pacific Northwest MM5 Mesoscale Numerical Forecast

Figure 3.22a. Ventilation Conditions and wind direction forecasts for the Pacific Northwest Region at 12:00 pm PDT on October 26, 2000. Note the poor ventilation conditions (marked area) in the region, where monitoring instruments observed high PM levels.



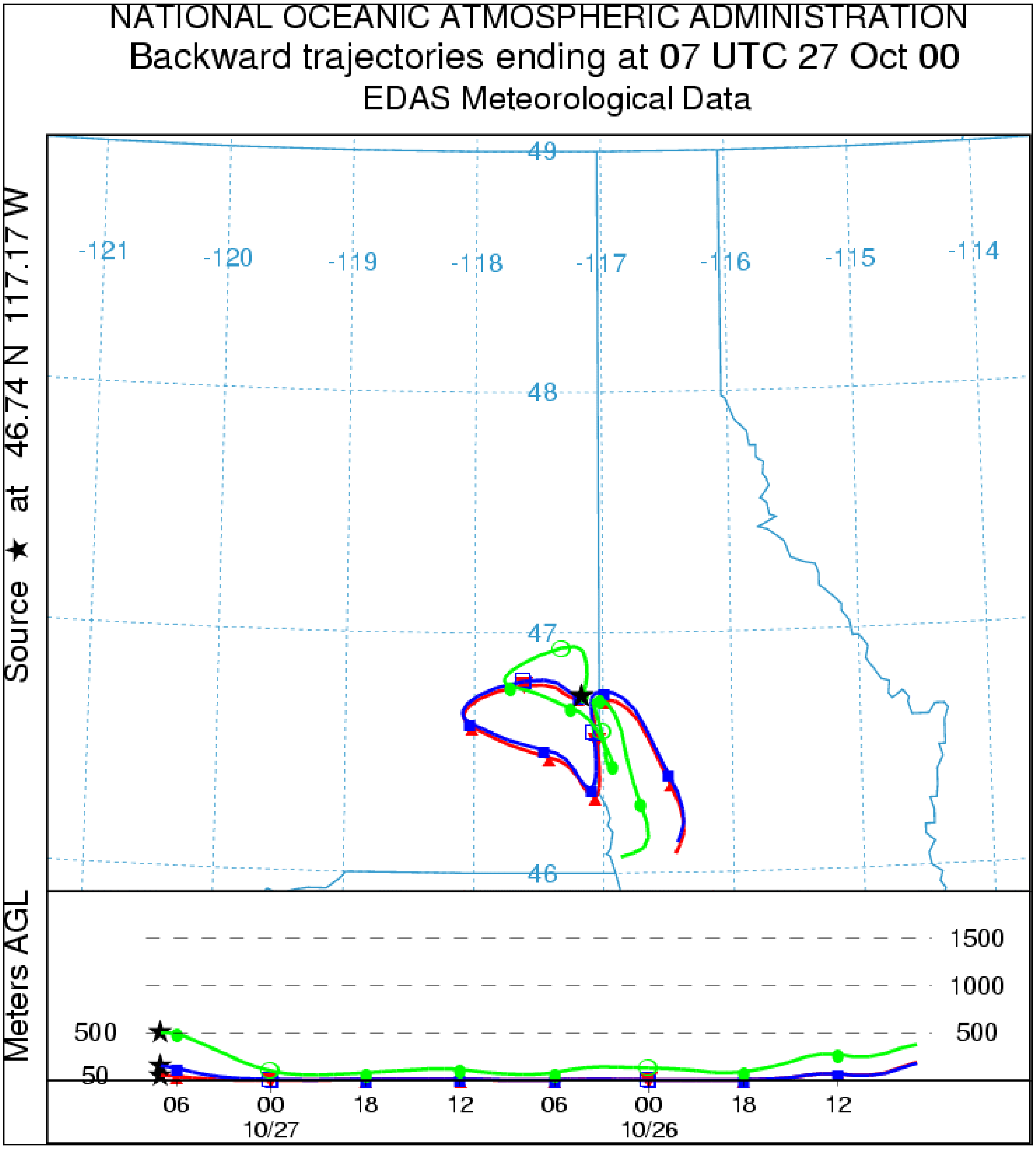
Source: Pacific Northwest MM5 Mesoscale Numerical Forecast

Figure 3.22b. Ventilation Conditions and wind direction forecasts for the Pacific Northwest Region at 4:00 pm PDT on October 26, 2000. Note the poor ventilation conditions (marked area) in the region, where monitoring instruments observed high PM levels.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.23a. Backward trajectory generated from Pullman at 07 UTC on October 27, 2000 using archived FNL meteorological forecast data. Note the shifts in the trajectory plotted. This may indicate some degree of stagnant weather present during that day.

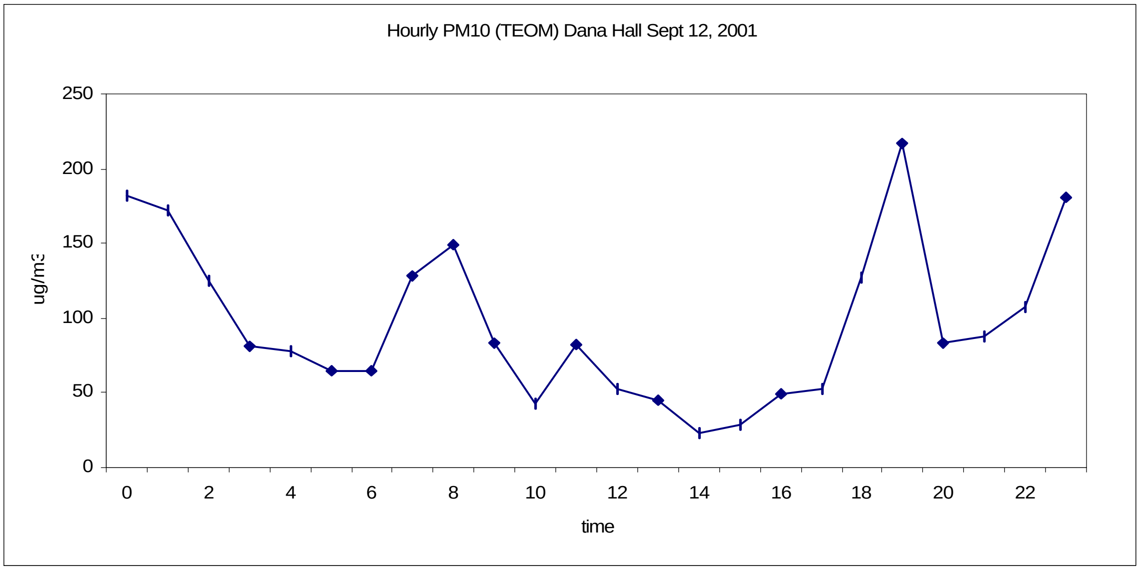


Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.23b. Backward trajectory generated from Pullman at 07 UTC on October 27, 2000 using archived EDAS meteorological forecast data. Note the several shifts in the trajectory plotted. This may indicate some degree of stagnant weather present during that day.

September 12, 2001. During the evening of September 12, 2001, high levels of $PM_{2.5}$ were observed at the Pullman (6:30 pm PDT) and Moscow (5:00 pm PDT) monitoring sites. This condition lasted for more than 3 hours. Pullman registered PM_{10} levels of 214 $\mu g/m^3$ (TEOM) and Moscow registered $PM_{2.5}$ levels of 210 $\mu g/m^3$ (TEOM) (Figure 3.24). Eight formal smoke complaints were reported for this episode, linking the smoke to agricultural field burning in Idaho. On September 12th, a no burn day was announced for the whole state of Washington. However, on the Coeur d'Alene Indian Reservation, located in Northern Idaho, a burn day was declared between 10:00 am and 3:00 pm (PDT) on September 12, 2001. Within this area, grass seed is produced in large quantities and fire is utilized regularly as part of the cropping process.

Wildfire activities were reported in North Central Washington on this day. The Chelan Lake-Sawtooth Wilderness area burned for several days with more than 50,000 acres involved. This wildfire (Rex Creek Complex) was reported as 65% contained throughout the day. Satellite pictures captured this wildfire (Figure 3.25). The digital image was taken at 00:15 UTC (5:15 pm PDT) on September 12, 2001 by *NOAA* and was analyzed by *OSEI*. In addition, heat sources from north Idaho (CDA reservation area) were captured by another satellite image. This picture was taken at 18:20 UTC on September 12, 2001 by NOAA and was analyzed by the USDA Forest Service (Figure 3.26).



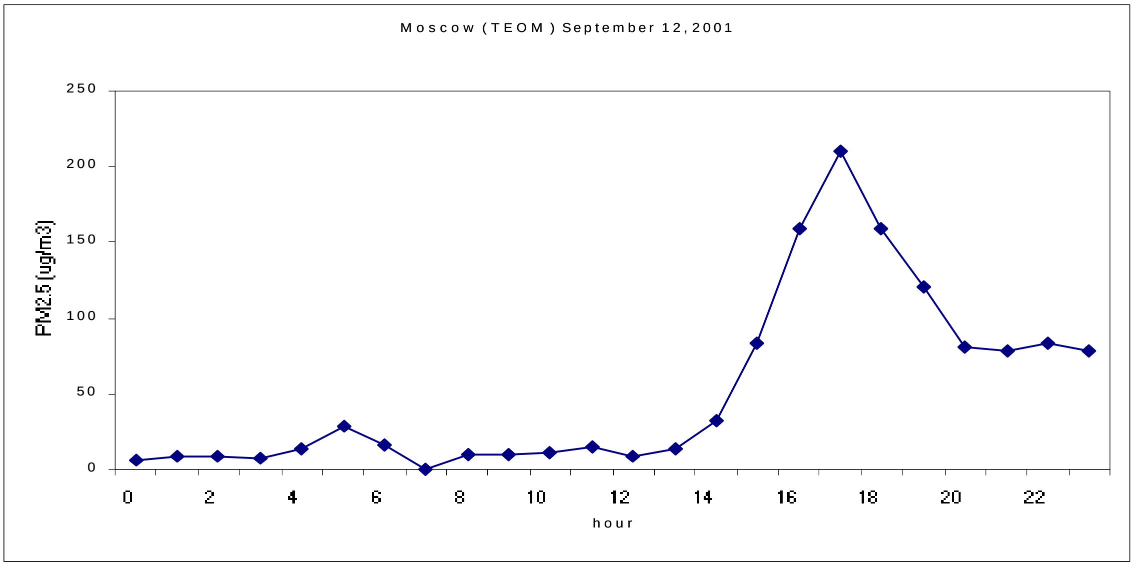
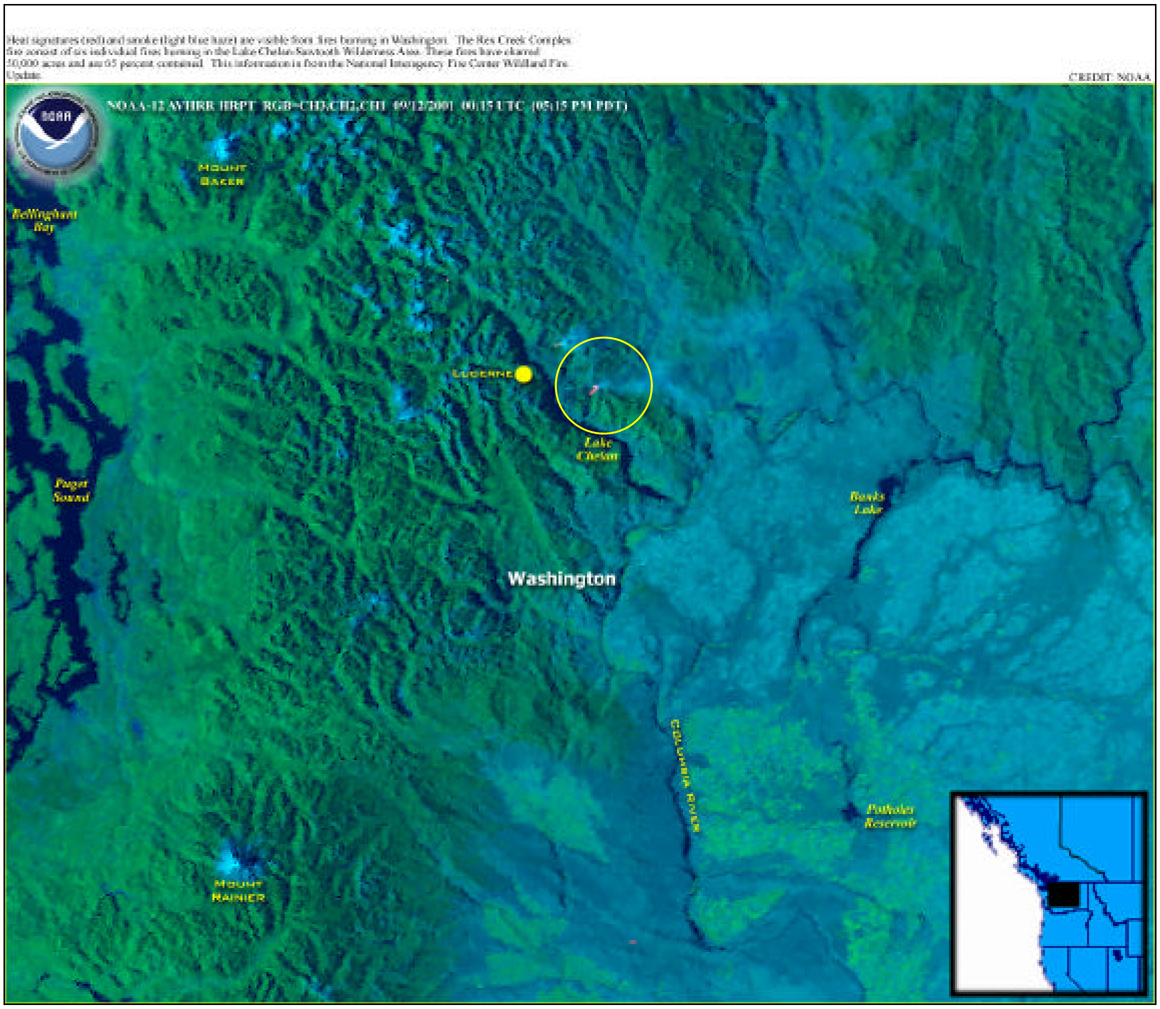
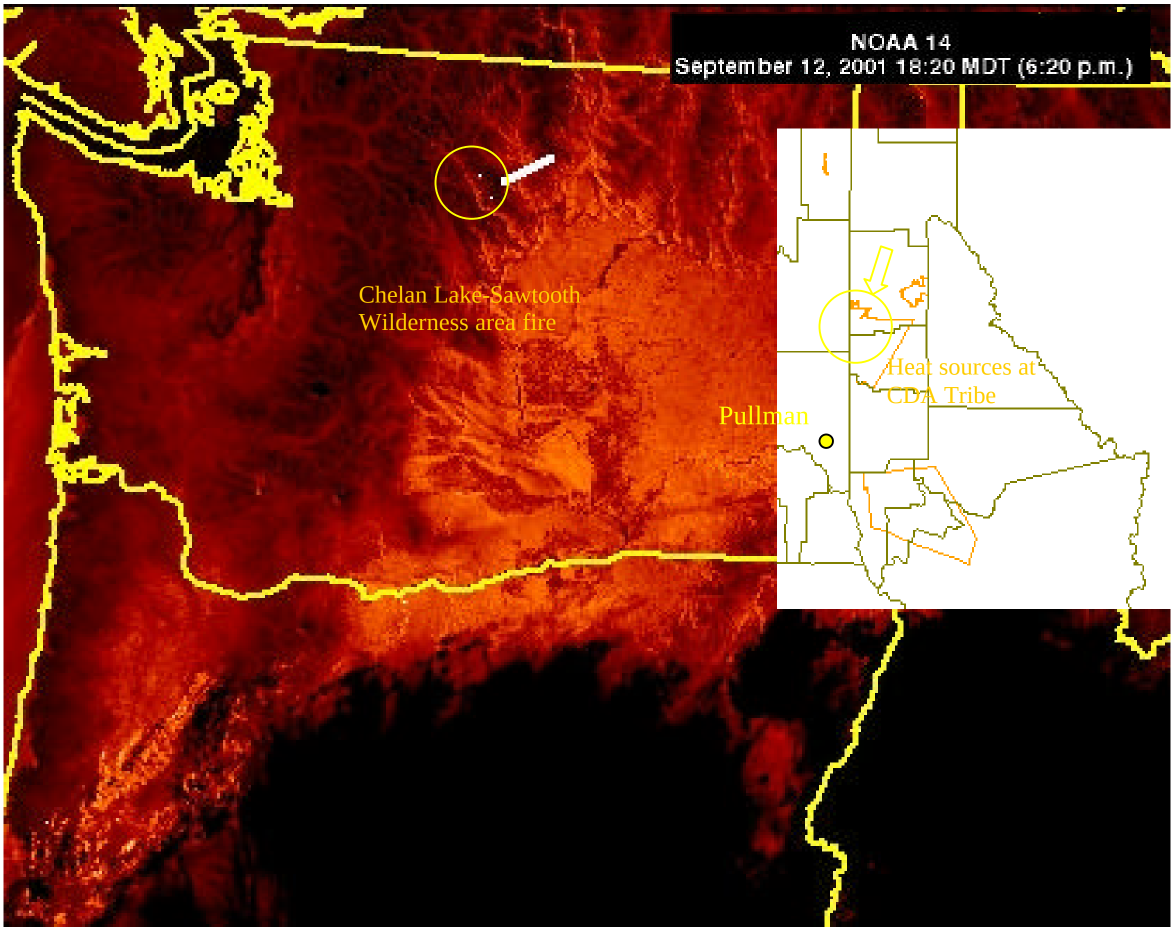


Figure 3.24. Continuous PM_{10} and $PM_{2.5}$ (TEOM) registered at Dana Hall, Pullman and Moscow, ID instruments on September 12, 2001.



Source: http://www.osei.noaa.gov/Events/Fires/US_Northwest/

Figure 3.25. Wildfire in Central Washington captured on a satellite picture taken at 00:15 UTC (5:15 pm PDT) on September 12, 2001. The yellow circle points to the Chelan Lake-Sawtooth Wilderness fire (Rex Creek Complex) approximately 50,000 acres in size and 65% contained.

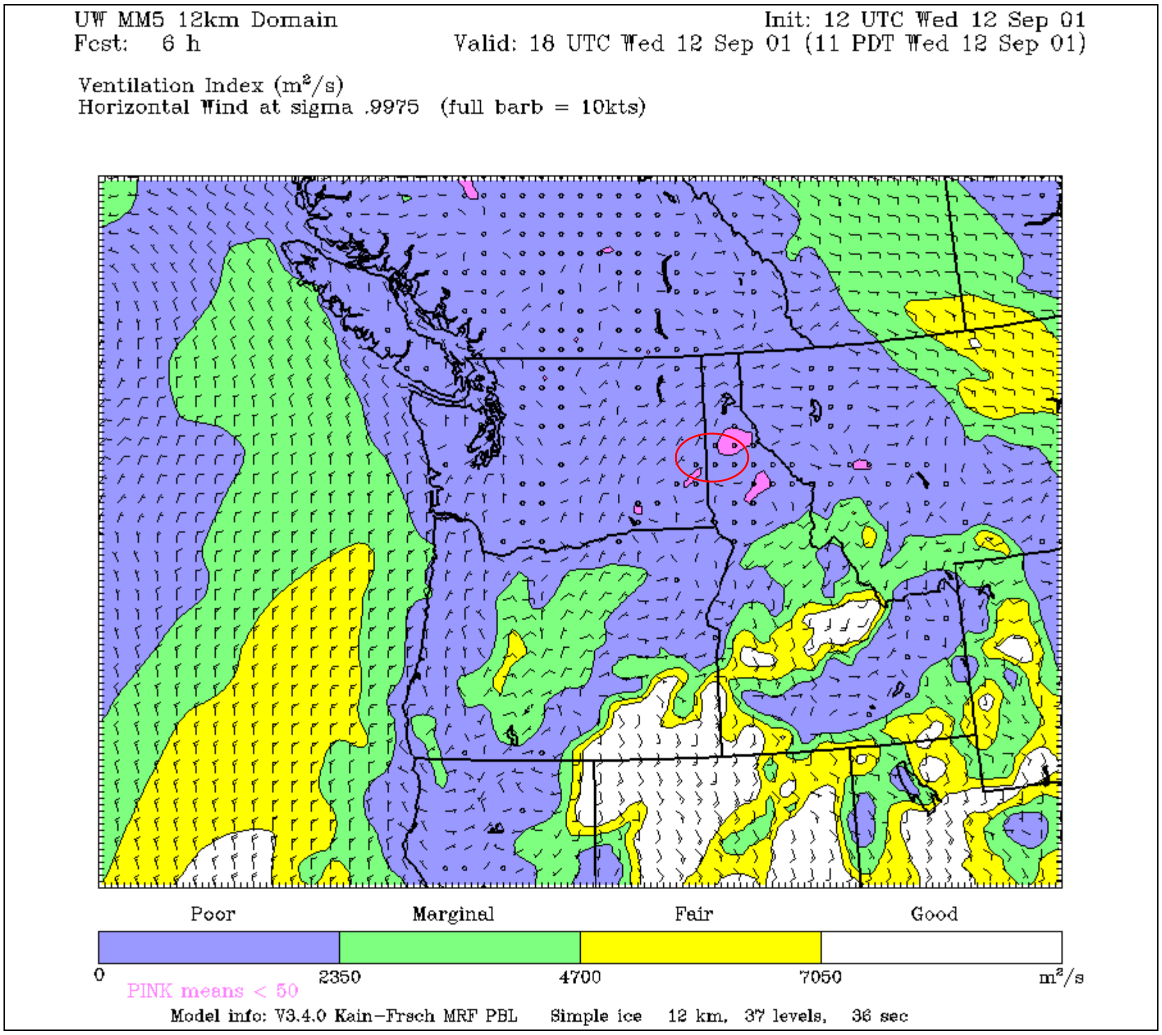


Source: http://www.fs.fed.us/r4/rsgis_fire/satellite.html

Figure 3.26. Wildfire in Central Washington and field burns captured on a satellite picture taken at 18:20 UTC on September 12, 2001 (11:20 am PDT). The yellow circles point to the Chelan Lake-Sawtooth Wilderness fire (Rex Creek Complex) 50,000 acres in size and the field burns at the CDA Indian Reservation.

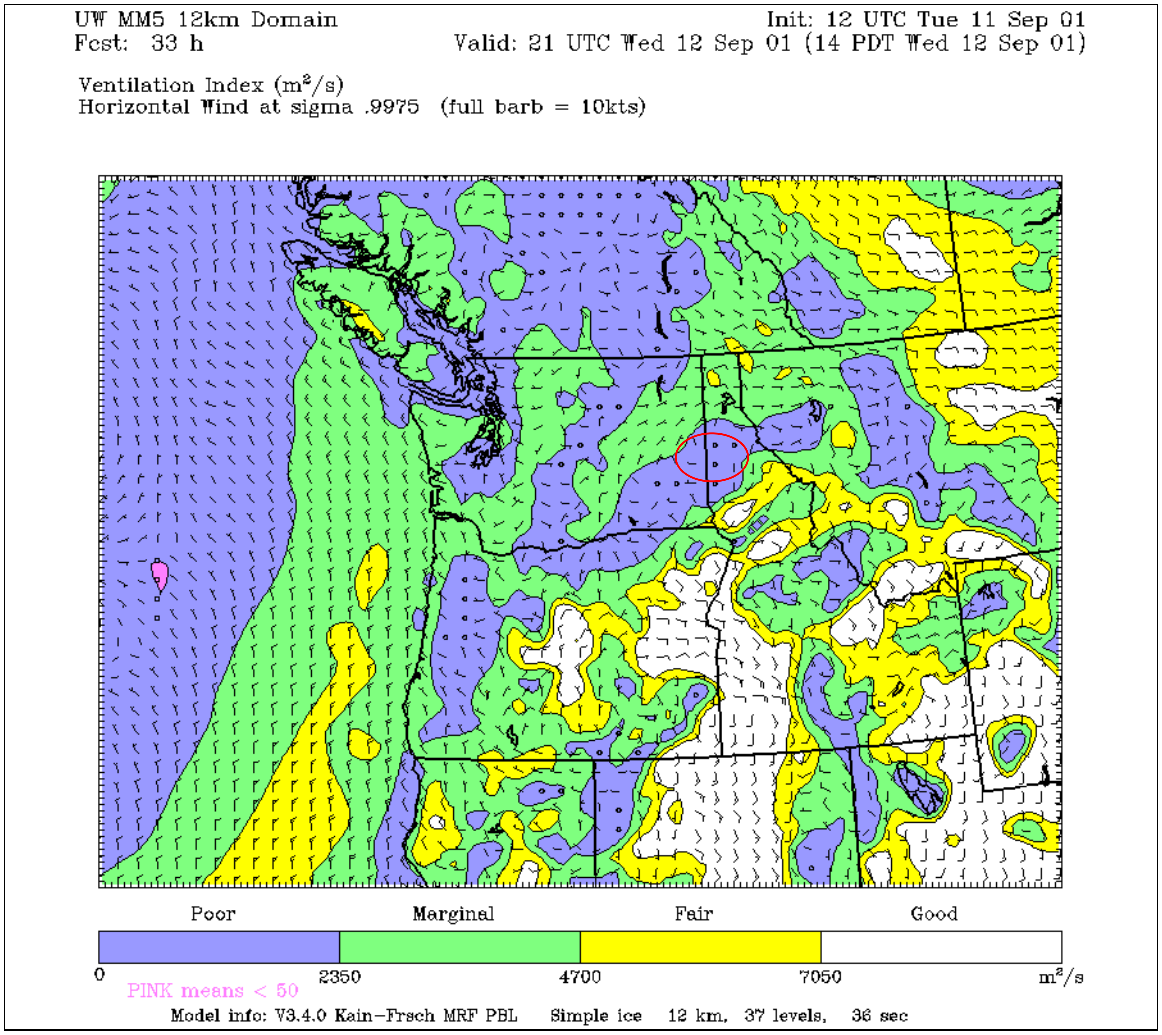
The ventilation conditions (MM5 forecasts) throughout the day were poor in the Pullman- Moscow area. The same poor conditions were present at the CDA reservation area during the period allowed for burning (Figures 3.27a and 3.27b). The surface prevailing winds in the area during the morning of September 12, 2001 were low in wind speed and were from the Northeast. Surface wind speeds less than 3 m/s were observed at the meteorological station located at the Dana Hall roof (WSU Pullman) (Figure 3.28). The wind speed remained low (less than 2 m/s) during the smoke period (6:00 pm – 8:00 pm). The forecast maps (MM5) showed a shift in wind direction from northeast in the morning to northwest in the afternoon (Figures 3.27a and 3.27b). However, the meteorological instruments located at WSU observed that the winds were from the northwest during most of the day (Figure 3.28).

The trajectories generated by HYSPLIT for air parcels arriving in Pullman on September 12th at 6:00 pm PST (02 UTC September 13, 2001) are shown in Figures 3.29a and 3.29b. The backward trajectories estimated that air parcels were coming from the northeast (Northern Idaho). During that day, field-burning activities were permitted at the Coeur d'Alene Indian Reservation located in Northern Idaho. The trajectory analysis suggested that the smoke observed in Pullman during the afternoon of September 12th originated from agricultural burning that occurred on the Coeur d'Alene Indian reservation.



Source: Pacific Northwest MM5 Mesoscale Numerical Forecast

Figure 3.27a. Ventilation Conditions and wind direction forecasts for the Pacific Northwest Region at 11:00 am PDT on September 12, 2001. Note the poor ventilation conditions at the marked area.



Source: Pacific Northwest MM5 Mesoscale Numerical Forecast

Figure 3.27b. Ventilation Conditions and wind direction forecasts for the Pacific Northwest Region at 2:00 pm PDT on September 12, 2001. Note the poor ventilation conditions at the marked area, where Pullman is located.

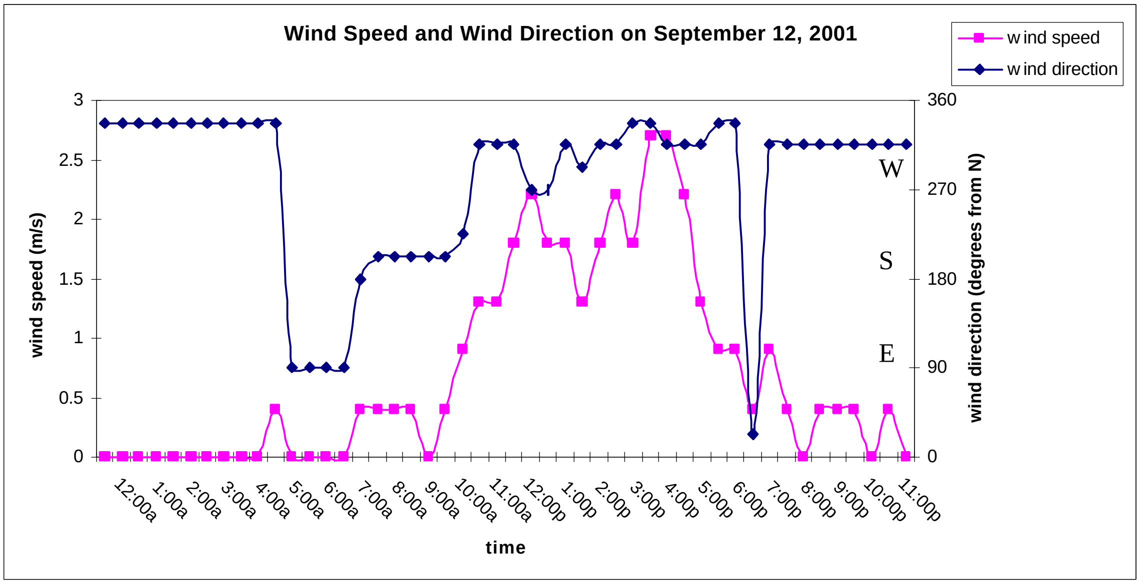
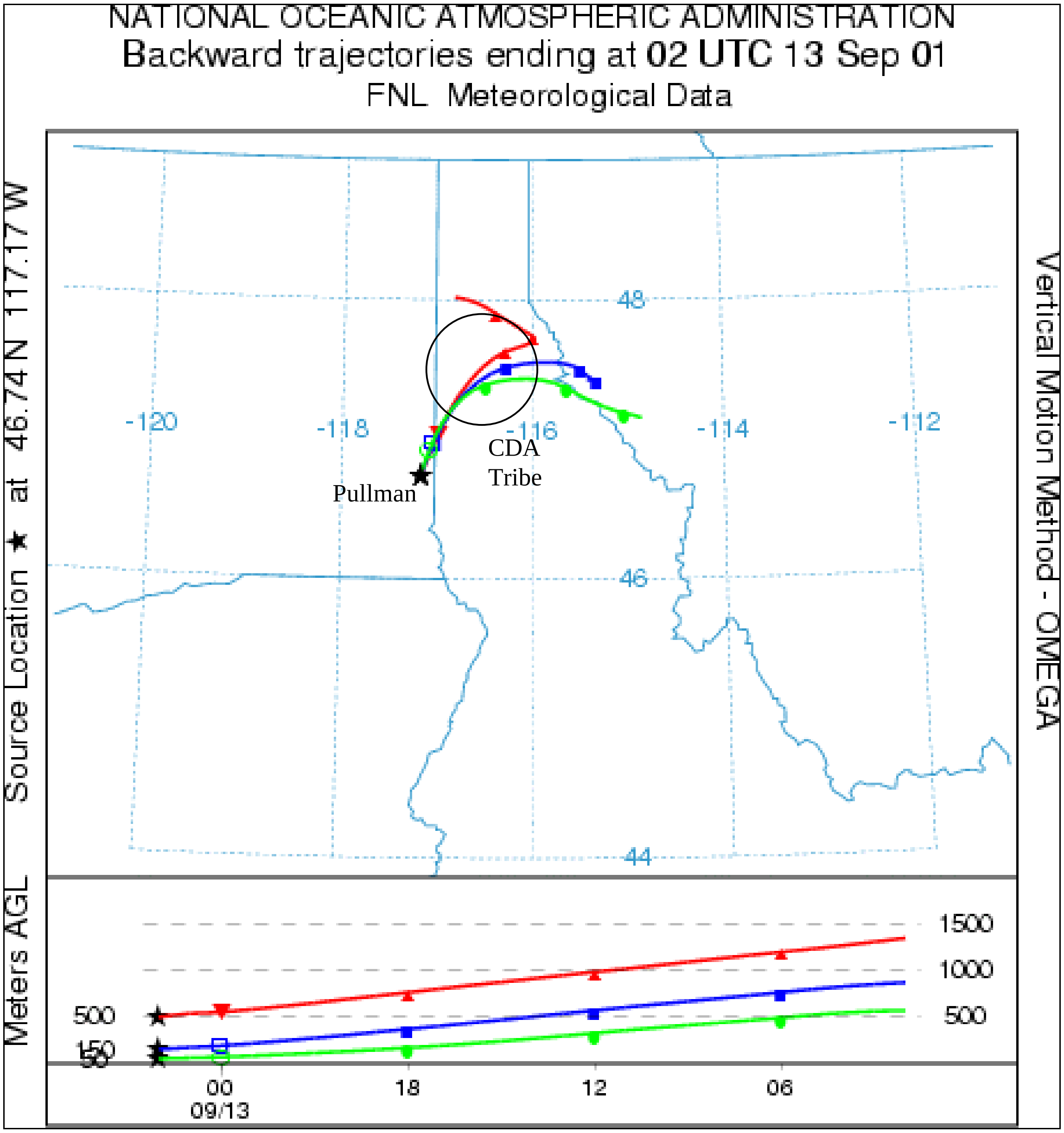
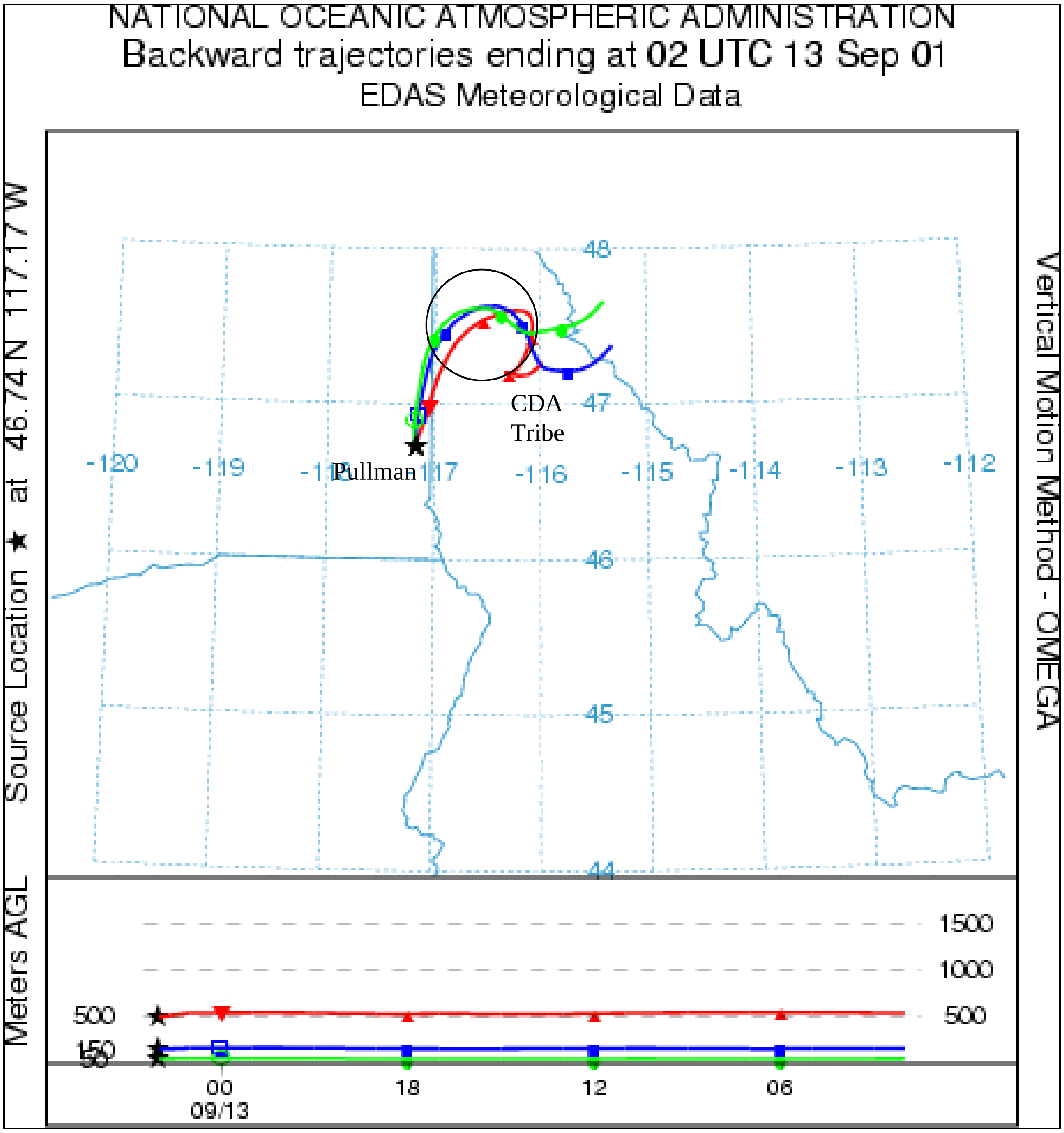


Figure 3.28. Observed wind speed and wind direction at Dana Hall meteorological instruments on September 12, 2001.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.29a. Backward trajectory generated from Pullman at 02 UTC on September 13, 2001 using archived FNL meteorological forecast data. The area marked points to the location of the Coeur d' Alene Indian Reservation, where field burns were performed.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.29b. Backward trajectory generated from Pullman at 02 UTC on September 13, 2001 using archived EDAS meteorological forecast data. The area marked points to the location of the Coeur d' Alene Indian Reservation, where field burns were performed.

September 19, 2001. The prevailing winds on the early morning (12:30 am PDT) of September 19, 2001 were moderate in speed (less than 7 m/s) and were coming from the southwest (Figure 3.30). High levels of PM_{10} (200 $\mu g/m^3$ TEOM) in the air were registered at WSU in Pullman and $PM_{2.5}$ levels above 60 $\mu g/m^3$ at the Moscow instruments (TEOM) (Figure 3.31). The smoke episode lingered for no more than two hours. Nevertheless, eleven formal smoke complaints were registered protesting the poor air quality conditions. Furthermore, respiratory problems enhanced by the smoke were reported. Two complaints linked the problem to agricultural burning activities.

Burning activities are allowed only throughout the daytime in the state of Washington. The burn decision approved for September 18th (day before) permitted a limited number of acres to be burned in certain areas. In Whitman County, less than 100 acres were permitted and in Walla Walla, less than 75 acres. However, a wildfire started during the late afternoon, when a Walla Walla wheat farmer lost control of a field burn. Enhanced by high winds, the fire grew rapidly overnight, burning pine trees, tall grass and wheat fields. The fire became 5,000 acres in size along the western front of the Blue Mountains.

The ventilation conditions (MM5 forecasts) on September 18 were fair to marginal throughout the afternoon and evening at the wildfire area in Walla Walla County. Good ventilation conditions were observed at the Pullman- Moscow area during the same time period (Figures 3.32a-d), when burning a limited number of acres was allowed (less than 100 acres) in Whitman County.

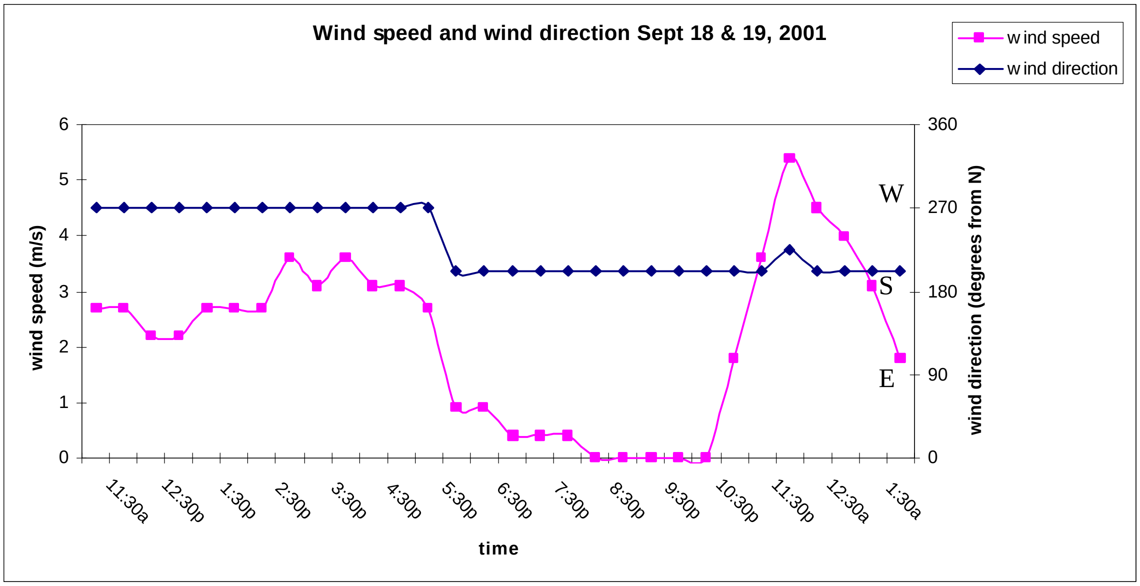


Figure 3.30. Observed wind speed and wind direction at Dana Hall meteorological instruments on September 18 & 19, 2001.

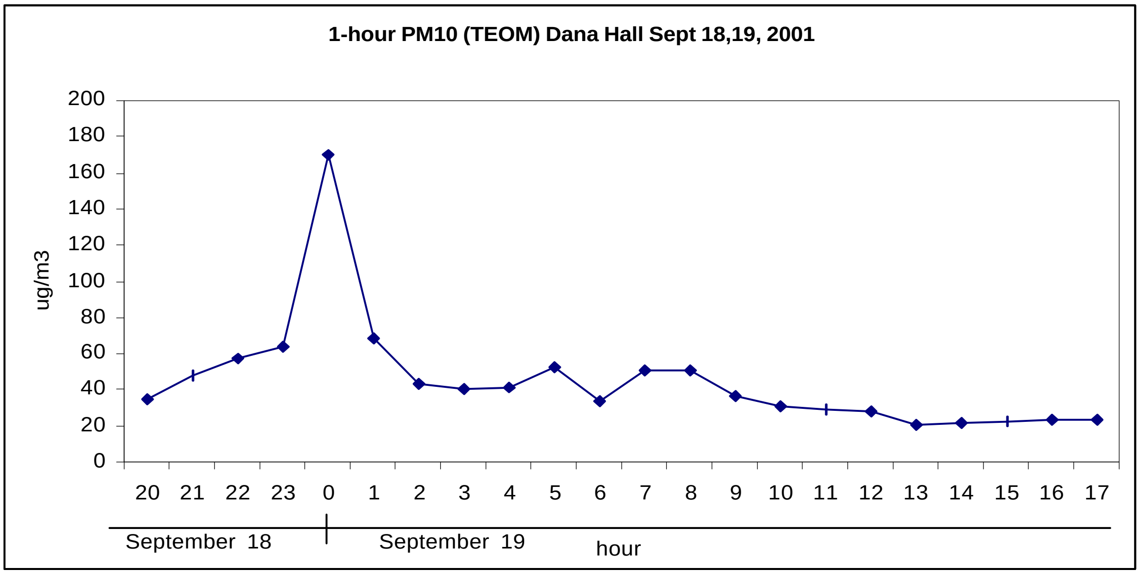
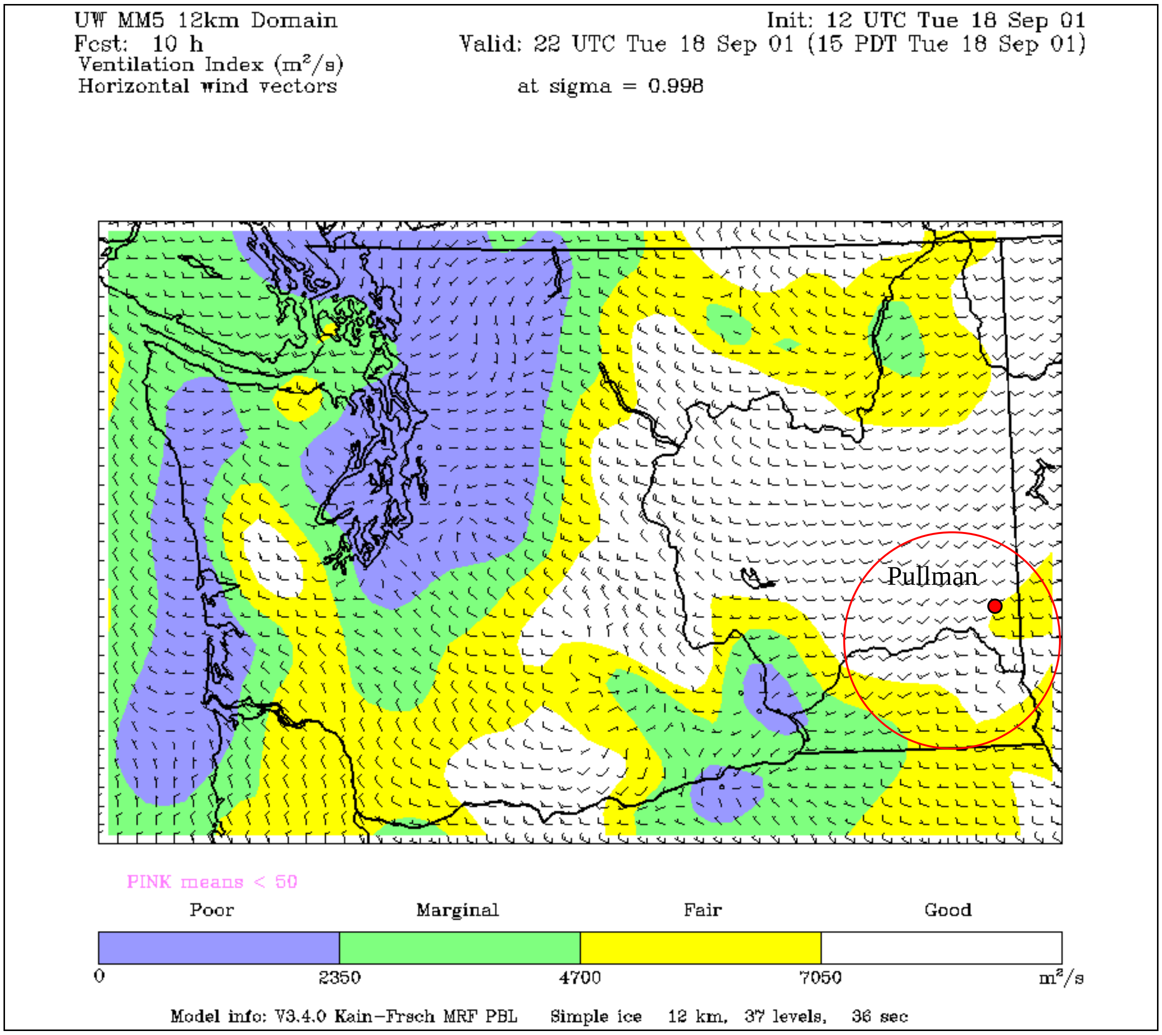


Figure 3.31. Continuous PM10 and PM 2.5 (TEOM) registered at Pullman and Moscow air quality monitoring stations on September 18 & 19, 2001.

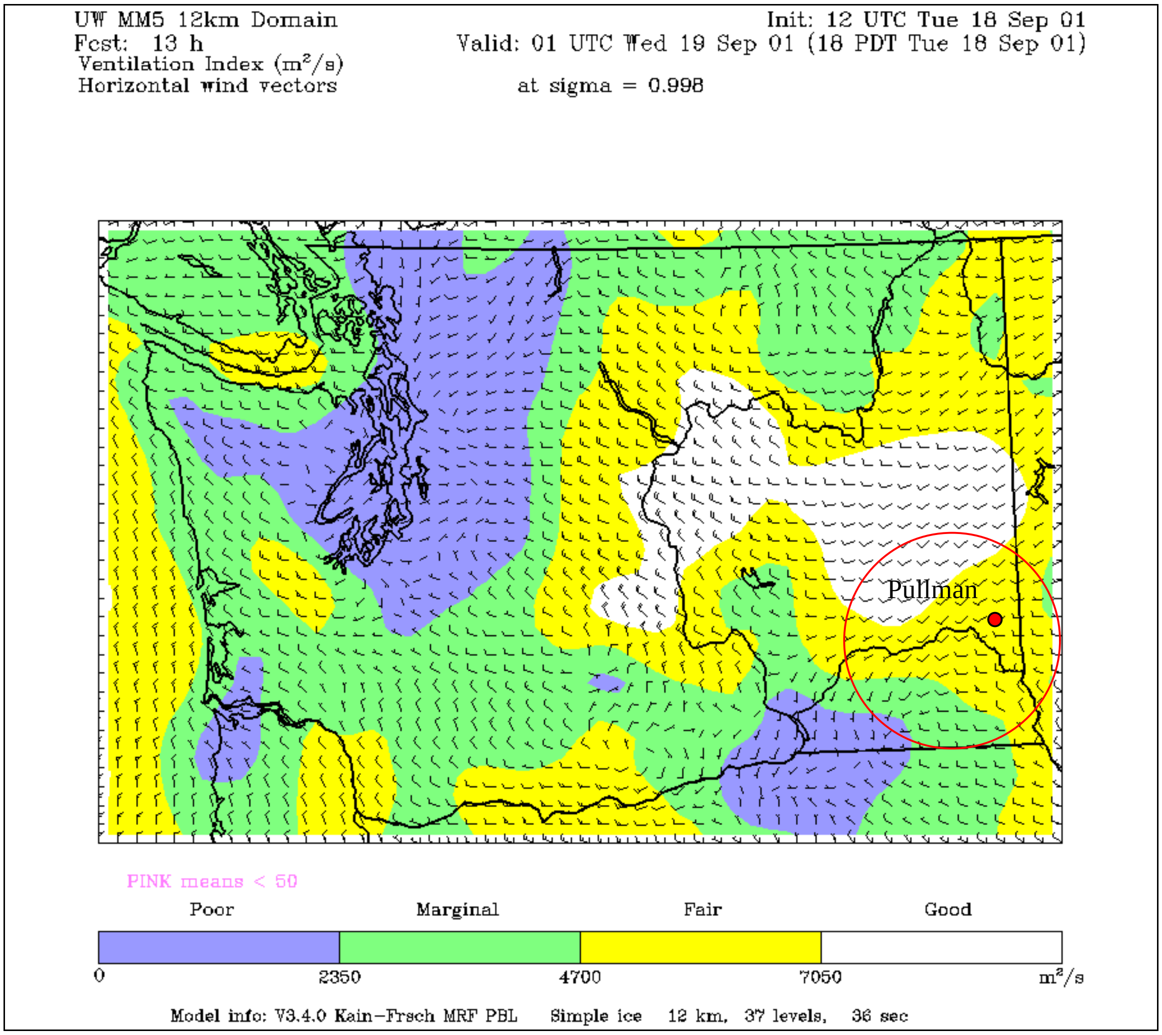
The favorable conditions declined late in the evening, and were poor overnight. The surface prevailing winds in the fire area were moderate in wind speed and from the southwest during the afternoon of September 18. A meteorological station located in Walla Walla City recorded wind speeds less than 7 m/s during that time. The forecast maps (MM5) showed surface winds moving from the southwest toward the east-northeast throughout the evening and overnight. (Figure 3.32b, 3.32d). During the smoke period (12:00 am – 1:00 am PDT) on September 19, 2001, the observed wind speed remained moderate (less than 6 m/s) and from the southwest (also in Figure 3.30).

Wildfire activities were also reported in North Central Washington. The Chelan Lake Sawtooth Wilderness fire had more than 50,000 acres burnt and was reported as 70% contained during that day. Satellite pictures available for the day showed this wildfire (Figure 3.33). In addition, a heat source coming from southeast Washington was captured by this image. The fire matched the location of the wildfire reported in Walla Walla County. The digital image was taken at 20:34 MDT (7:34 pm PDT) on September 18, 2001 by *NOAA* and was analyzed by the USDA Forest Service.



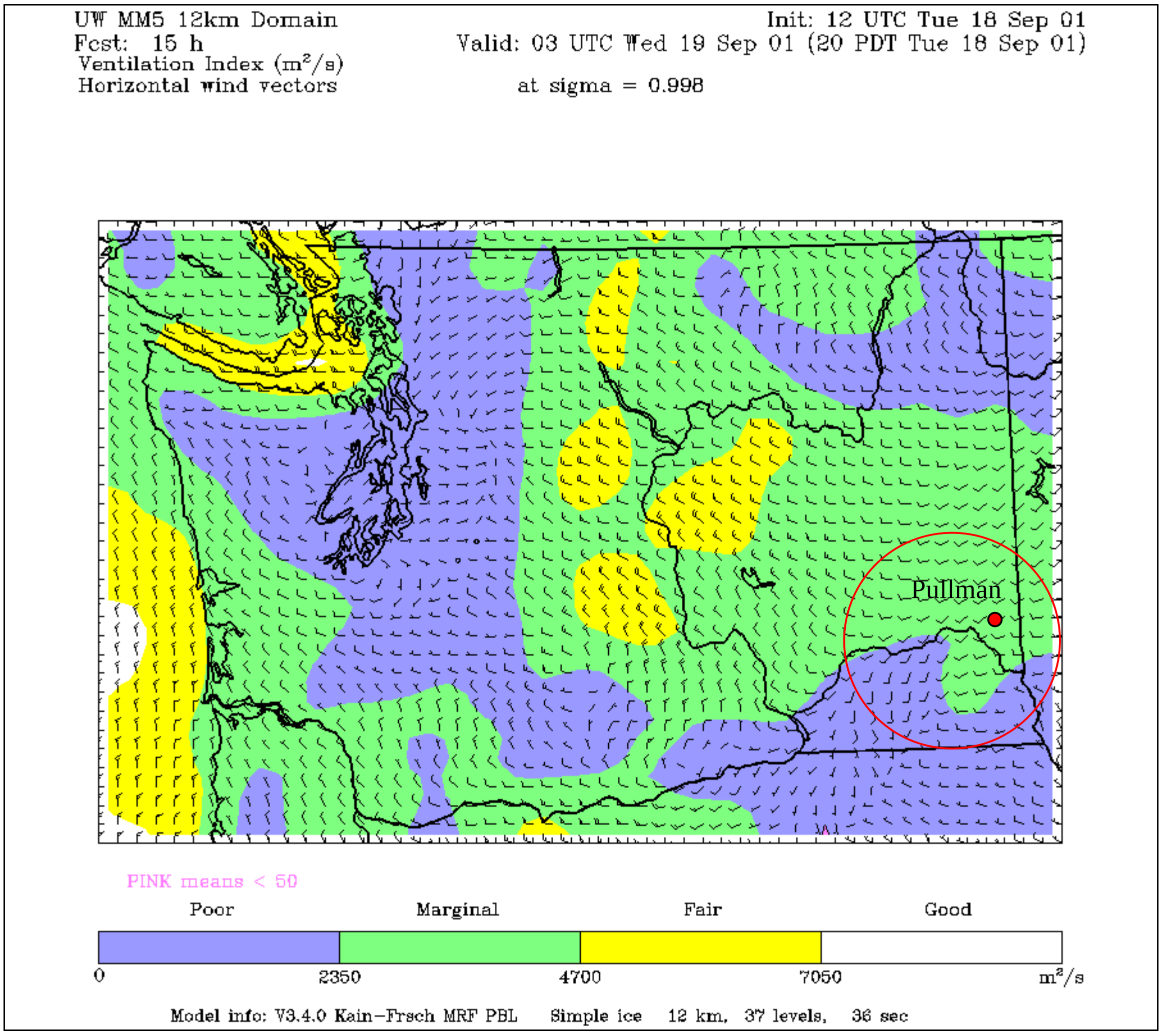
Source: Pacific Northwest MM5 Mesoscale Numerical Forecast

Figure 3.32a. Ventilation Conditions and wind direction forecasts for the Pacific Northwest Region at 3:00 pm PDT on September 18, 2001. Note the good ventilation conditions in the marked area.



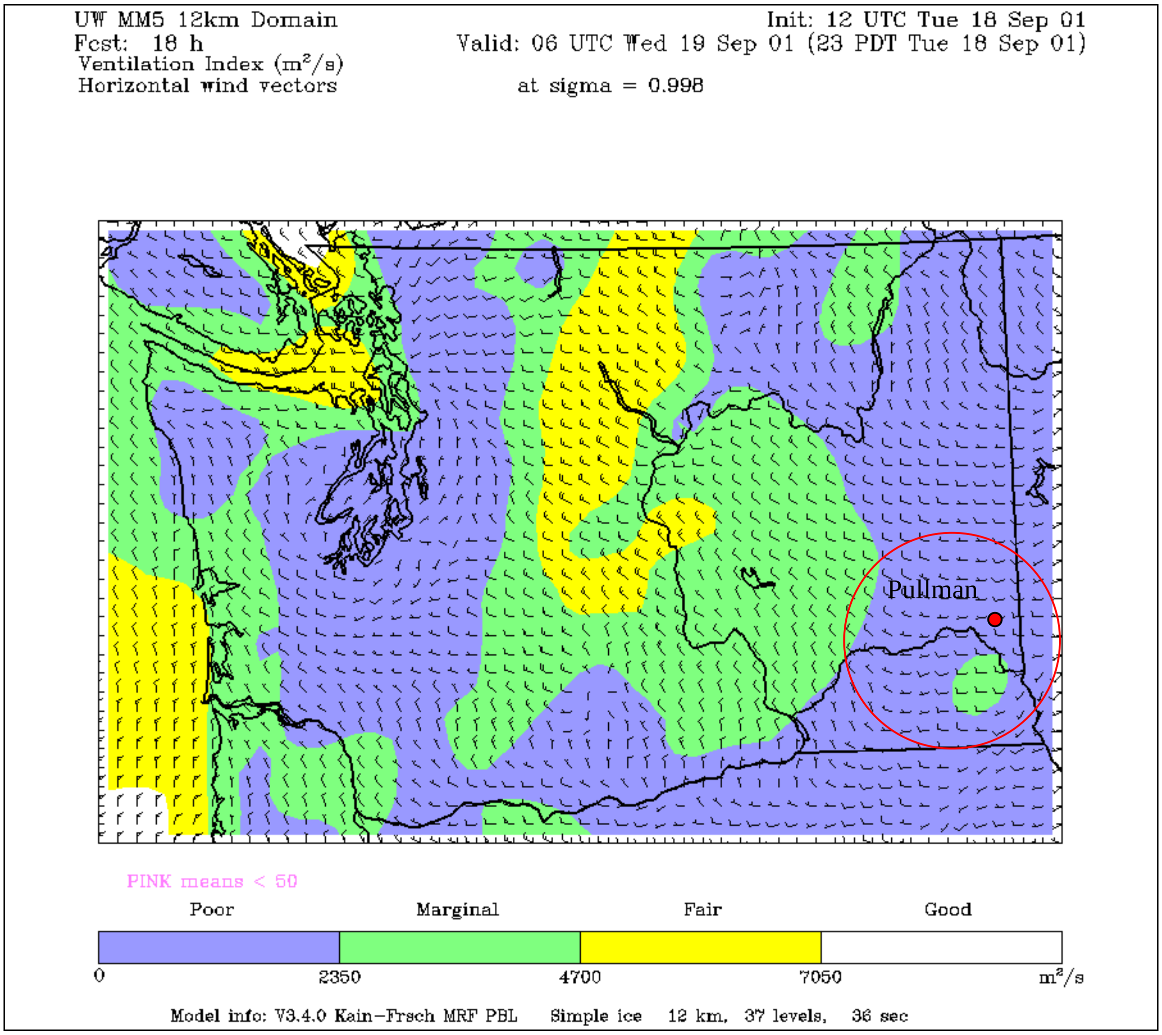
Source: Pacific Northwest MM5 Mesoscale Numerical Forecast

Figure 3.32b. Ventilation Conditions and wind direction forecasts for the Pacific Northwest Region at 6:00 pm PDT on September 18, 2001. Note the ventilation gradually declining in the marked area.



Source: Pacific Northwest MM5 Mesoscale Numerical Forecast

Figure 3.32c. Ventilation Conditions and wind direction forecasts for the Pacific Northwest Region at 8:00 pm PDT on September 18, 2001, also note winds moving from the southwest toward the east-northeast in the selected area. Note the marginal ventilation conditions in the marked area.



Source: Pacific Northwest MM5 Mesoscale Numerical Forecast

Figure 3.32d. Ventilation Conditions and wind direction forecasts for the Pacific Northwest Region at 8:00 pm PDT on September 18, 2001. Note the poor ventilation conditions in the marked area; also note winds moving from the west toward the east-northeast in the selected area.

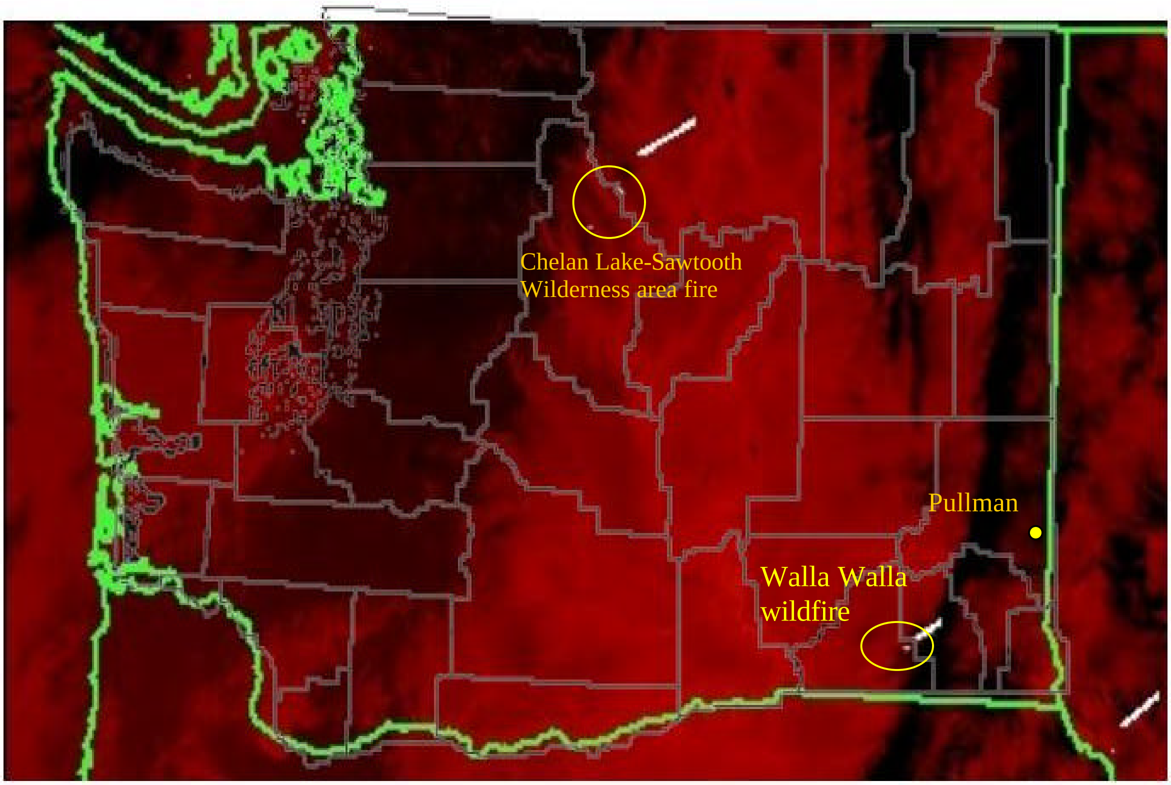
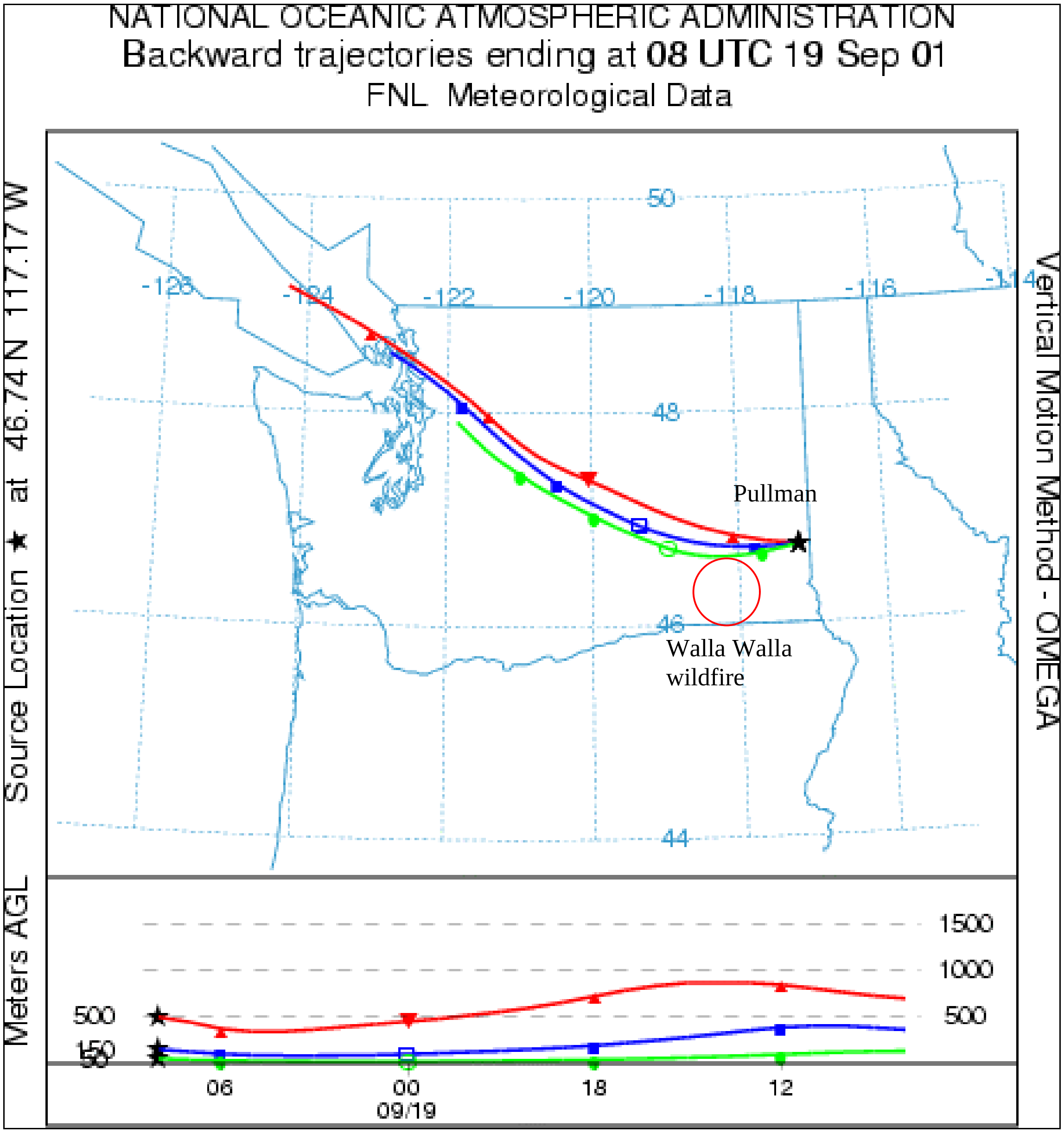


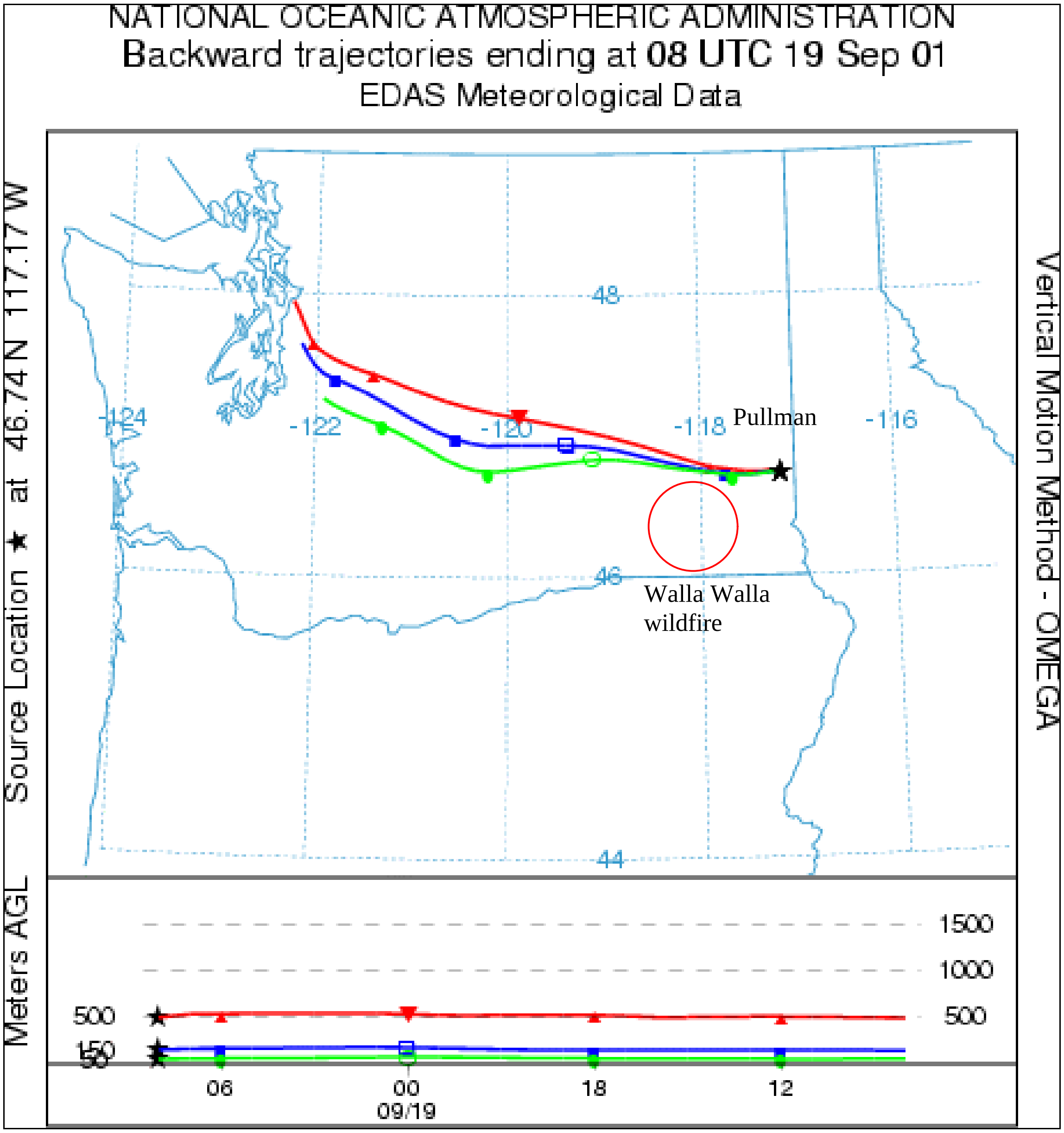
Figure 3.33. Wildfire in Central and Southeast Washington captured on a satellite picture taken at 20:34 MDT (7:34 pm PDT) on September 18, 2001. The yellow circle points to the Chelan Lake-Sawtooth Wilderness fire (Rex Creek Complex) 45,700 acres in size (85% contained), and the Walla Walla fire 5,000 acres in size.

The trajectories generated by HYSPLIT for air parcels arriving in Pullman on September 19th at 12:00 am PST (08 UTC September 19, 2001) are shown in Figure 3.34a and 3.34b. The backward trajectories estimated that air parcels were coming from the west, but were not consistent with the smoke source being due to the wildfire in Walla Walla (southwest Pullman). On the other hand, moderate wind speeds (less than 5 m/s) occurred and came mainly from the southwest, which were observed in Pullman throughout the night (see Figure 3.30). A backward trajectory analysis was hand-calculated (Figure 3.35) using the wind speed and wind direction observed in Pullman. These results suggested that the agricultural wildfire in Walla Walla was likely the source of the smoke. However, the hand-trajectory analysis only considered the surface wind profiles in a fixed location.



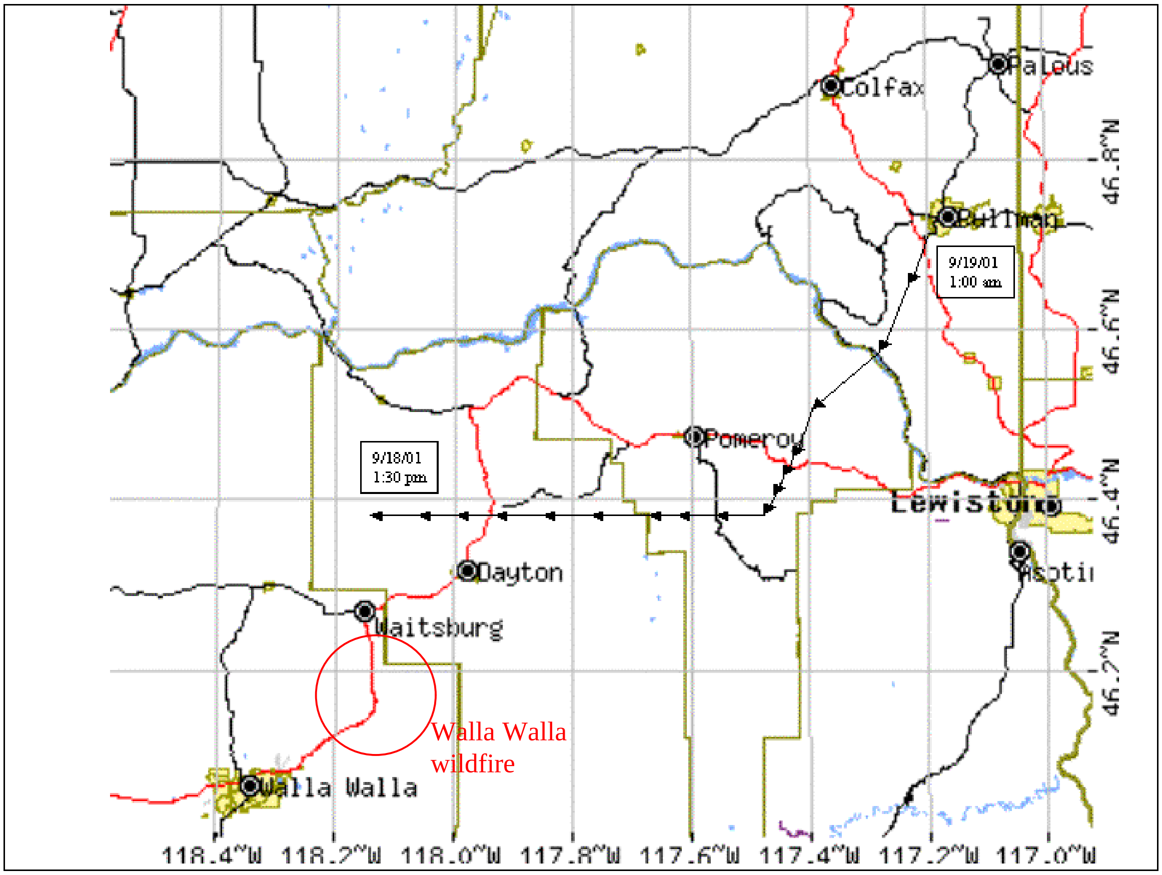
Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.34a. Backward trajectory generated from Pullman at 08 UTC on September 19, 2001 using archived FNL meteorological forecast data. The red circle points to the location of the fire in Walla Walla.



Source: HYSPLIT4 (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model.
Web address: http://www.arl.noaa.gov/ready/hysplit4.html,
NOAA Air Resources Laboratory, Silver Spring, MD

Figure 3.34b. Backward trajectory generated from Pullman at 08 UTC on September 19, 2001 using archived EDAS meteorological forecast data. The red circle points to the location of the fire in Walla Walla and Pullman.



Source of map: http://tiger.census.gov/cgi-bin/mapbrowse

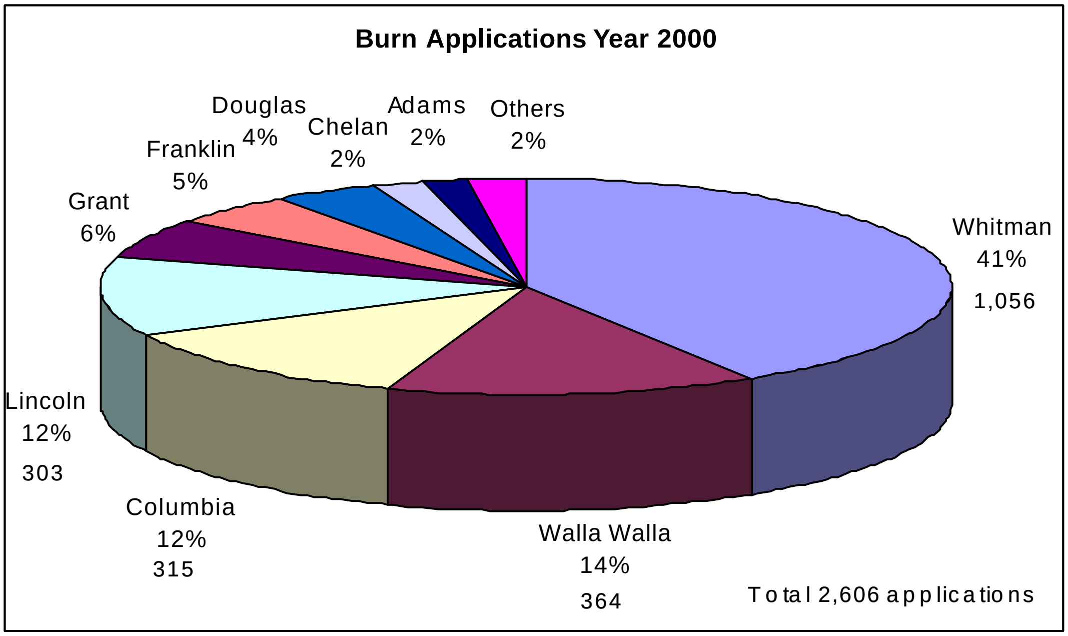
Figure 3.35. Hand- calculated backward trajectory generated from wind speed and wind direction observed in Pullman on September 18 & 19, 2001.

3.4.2 Burn permits, Burn calendar and Post-Burn reports

Over 1,500 burning applications were filed for the year 2000. These applicants consisted of independent farmers and businesses. They applied for, in total, 2,606 burn authorizations to perform field burning, which involved more than 190,000 acres. Whitman, Walla Walla and Columbia Counties had most of the burn applications (67%) and the number of acres applied for (84%) (Figure 3.36).

From the total burn applications, 2,599 applications (99.7%) were approved and only 7 (0.3%) were denied. Only 115 acres (0.06%) were not approved. Therefore, more than 96,000 acres were approved for burning during the Spring 2000 season and another 96,000 acres for the Fall season of the same year. However, not all of the acreage was eventually cleared using fire. From the permit fee refunded during the same period, a better approximation of the acreage burned was estimated. In total, less than 166,000 acres (86 % acres applied) were burned during the same year, as is shown in more detail in Figure 3.37.

The Post-Burn Report for the Fall 2000 registered 297 burning activities (22 % of the applications) with a total of 38,966 acres involved (41% of total acres applied). The Fall 2000 burning distribution in Eastern Washington showed that most of the burning activities occurred in a short period of time. Most of the field burning was performed from early September through late October, as shown in Figure 3.38. However, this



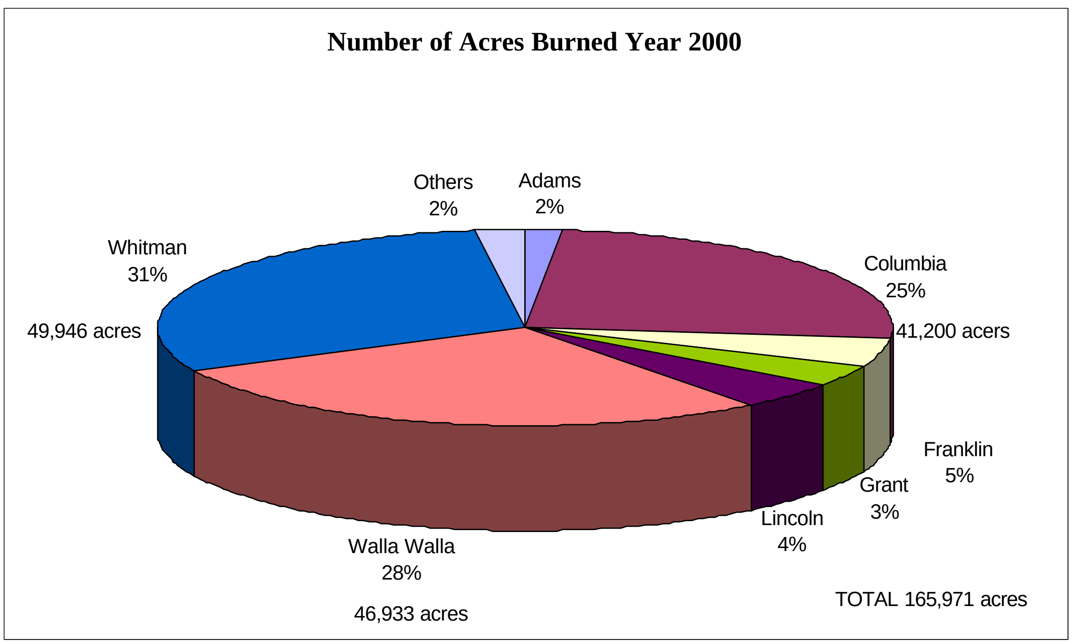


Figure 3.36. Burn applications and number of acres approved per county in Washington state for the year 2000.

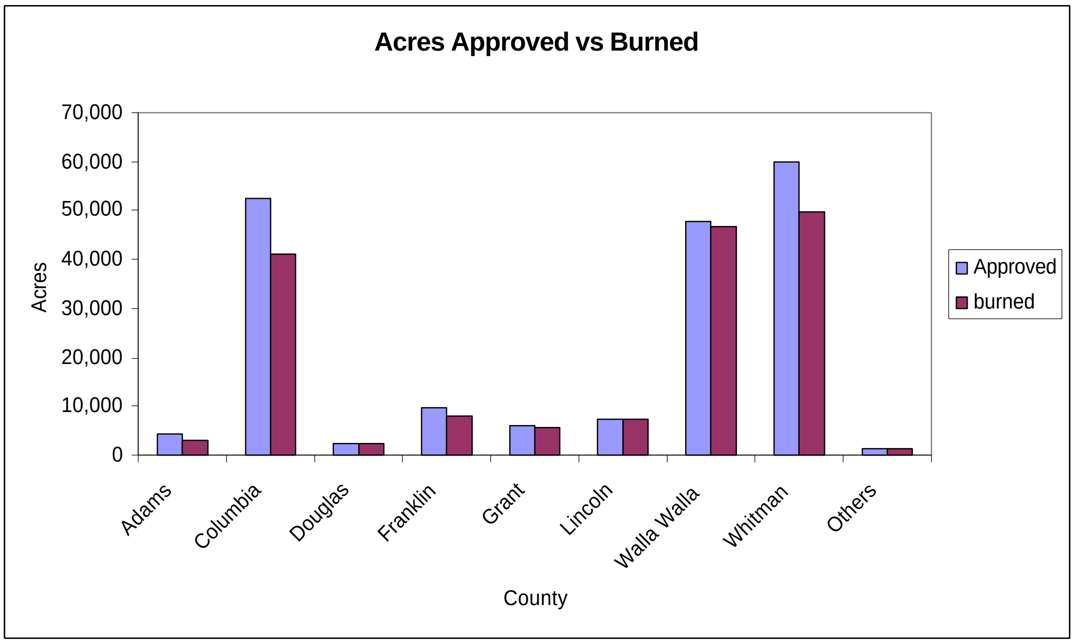


Figure 3.37. Number of acres burned compared to the amount of acres applied for burning activities in each county in Eastern Washington during the year 2000.

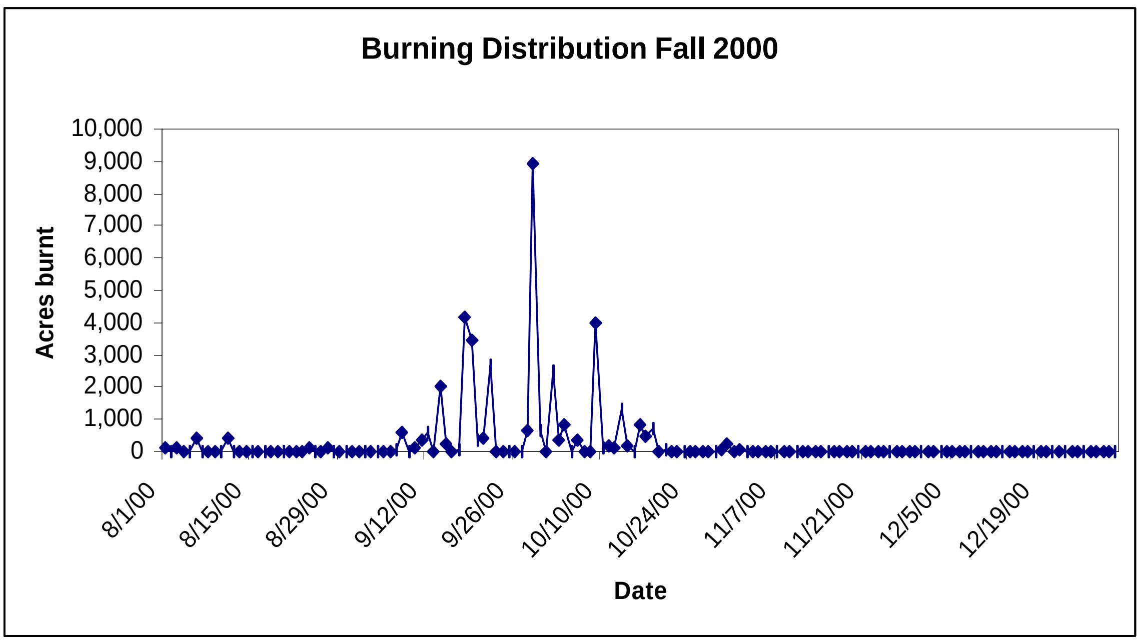


Figure 3.38. Agricultural burning distribution in Eastern Washington during the Fall season 2000.

analysis only included the post burn reports voluntarily submitted, which was 41% of the total number of acres applied for during the same period of time.

More complete information was obtained from the Spring and Fall 2001 burning seasons. The Spring 2001 reported 939 field-burning activities with more than 99,000 acres involved. Whitman, Walla Walla, Columbia and Garfield Counties reported most of the acreage burned (95 % total acres reported), as is shown in Figure 3.39. The temporal distribution of the burning activities suggested that most of the fires were set between the period March - May (Figure 3.40). On the other hand, during the Fall 2001, 363 field burns were reported with more than 26,000 acres involved (more than 30% reduction from Fall 2000 to 2001) (Figure 3.41). The distribution of the burn activities throughout the Fall season suggested that most of the fires occurred between late August through October (Figure 3.42).

Throughout the year 2000, the burn calendar in the state of Washington allowed an average of 97 days (27 % of the year) to perform burning activities, which included agricultural burning. Most of the burn days were allowed in the Spring season (70 days) and only 27 days were allowed for the Fall. Figure 3.43 shows the spatial distribution of burn days in Washington for both seasons. The Fall 2000 burning season registered the same number of acres involved in field-burning activities as the Spring season for the same year. In addition, counties such as Columbia, Whitman and Walla Walla, with the largest number of acres approved for burning, did not have the largest number of burn days. This situation was noticed in some counties with an increased ratio between the total acres approved and the burn call days in the Fall. Figure 3.44 shows this relationship, per county, and per season in the year 2000. However, this analysis only considered the approved burns, which did not equal the total amount of acres actually burned. The ratio between the number of acres burned and the number of burn call days was only determined for Fall 2000. Figure 3.45 shows this ratio from the information voluntarily reported.

The burn calendar for the year 2001 registered an average of 89 burn call days (8.2 % less than the past period) for the entire year. The Spring burn season also had the greater number of burn days (70 days) compared to the 22 days allowed for burning in the Fall. The spatial distribution of burn days is shown in Figure 3.46 for Eastern and Central Washington. The year 2001 had a smaller number of acres burned during the Fall (26,652 acres) compared to the Spring of the same year (99,633 acres). Because of the fewer number of days for which burning was allowed, in some counties, the number of acres burned per day was high. In Whitman County, this ratio was over 700 acres per burn day (Figure 3.47). Based on this, a high number of complaints might be expected in the Fall, especially in Whitman County.

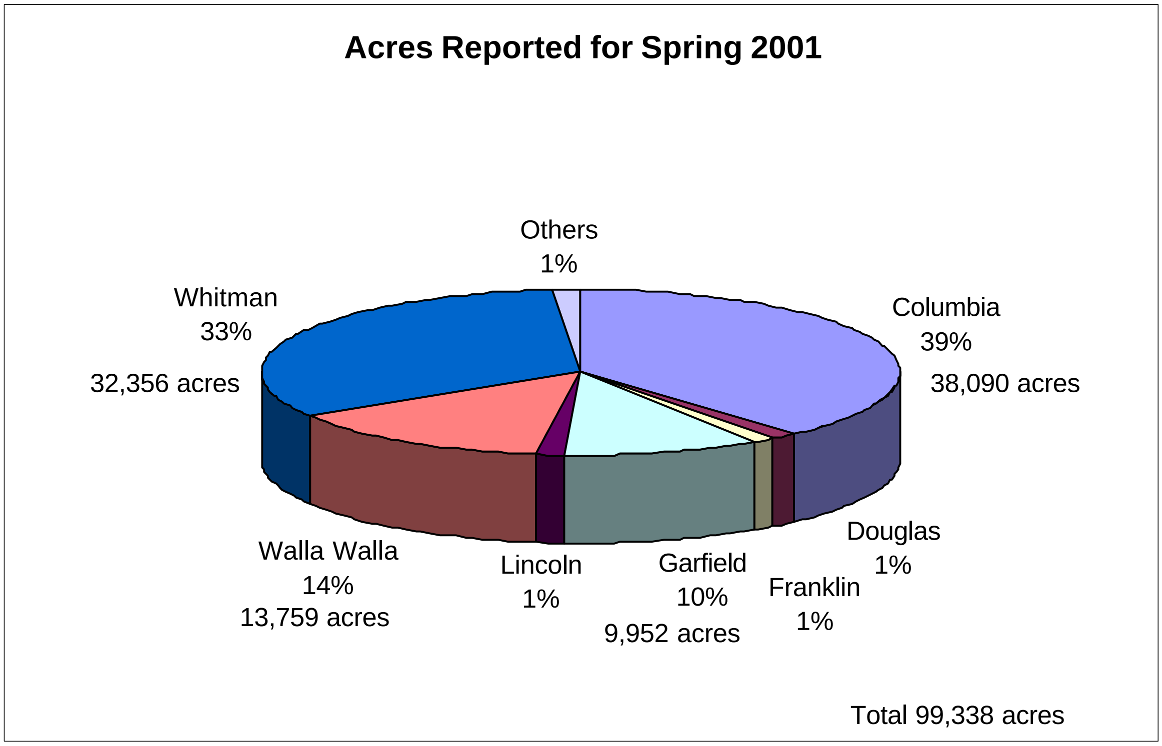


Figure 3.39. Spatial distribution of field burns in Eastern Washington in the Spring 2001 burning season.

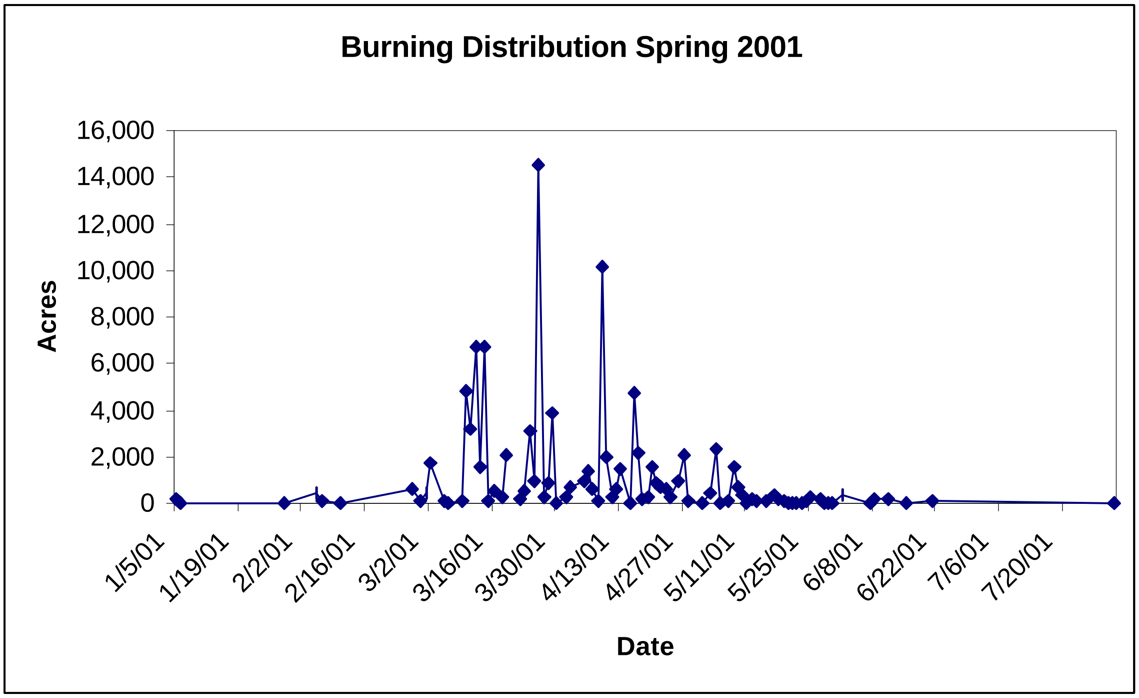


Figure 3.40. Temporal distribution of field burns in Eastern Washington during the Spring 2001 burn season.

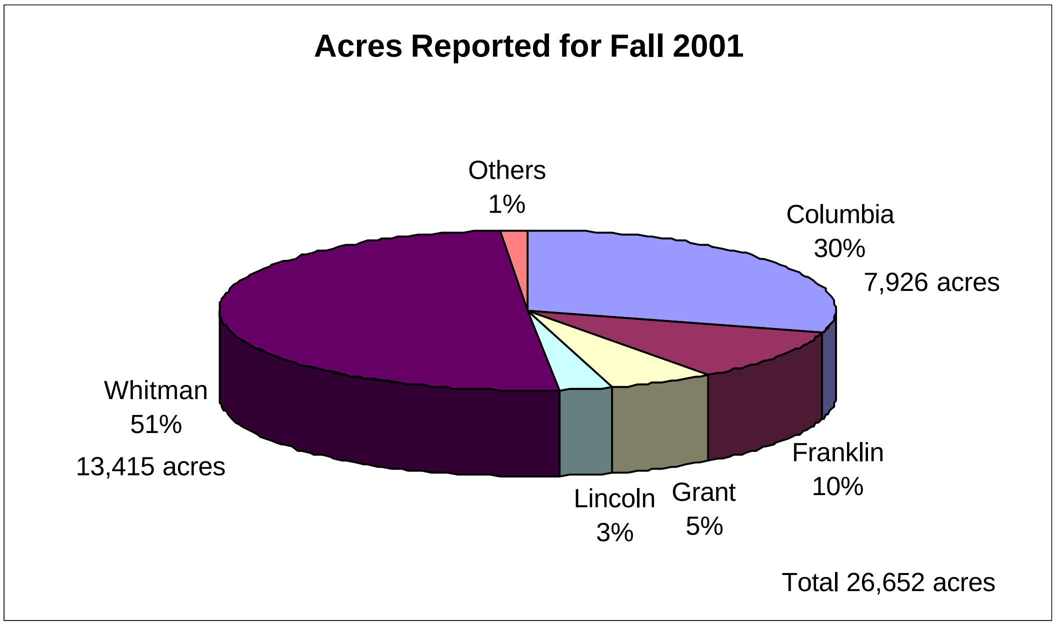


Figure 3.41. Spatial distribution of field burns in Eastern Washington in the Fall 2001 burning season.

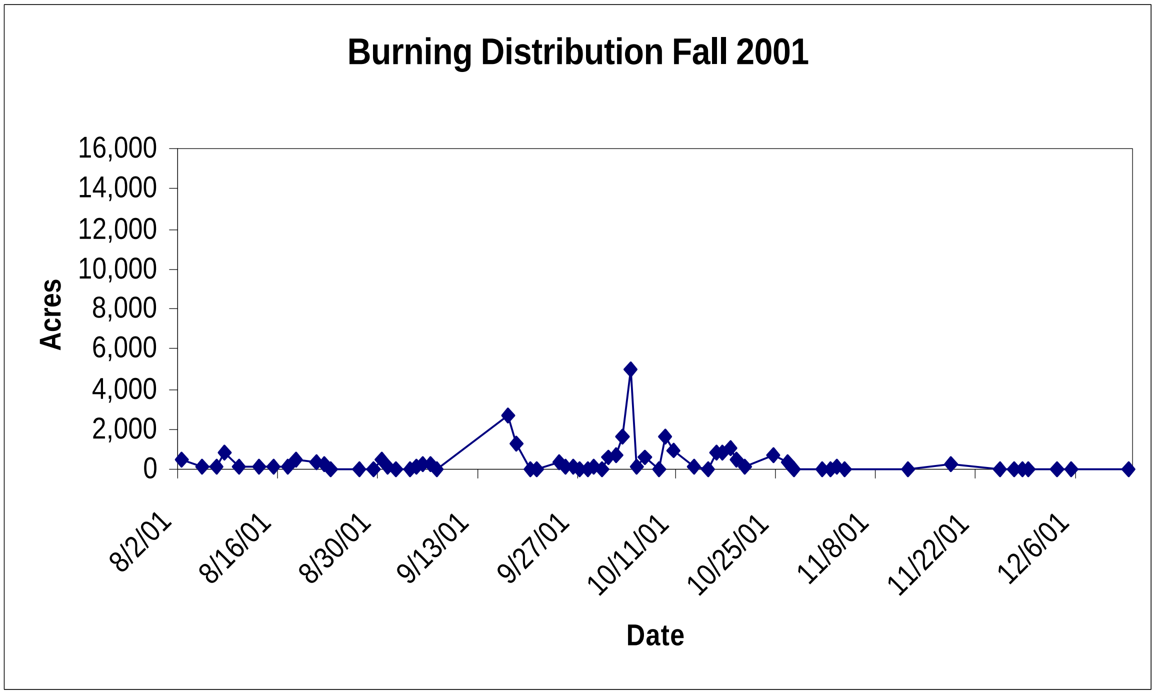


Figure 3.42. Temporal distribution of field burns in Eastern Washington during the Fall 2001 burn season.

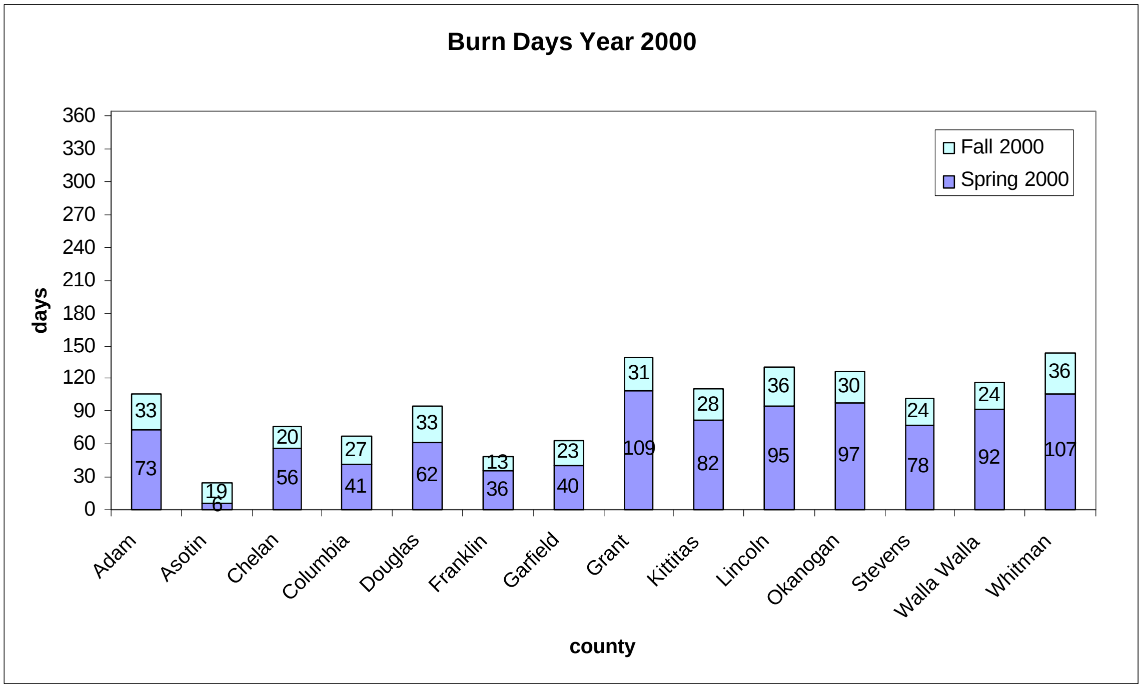


Figure 3.43. Spatial distribution of burn call days in the state of Washington during the year 2000.

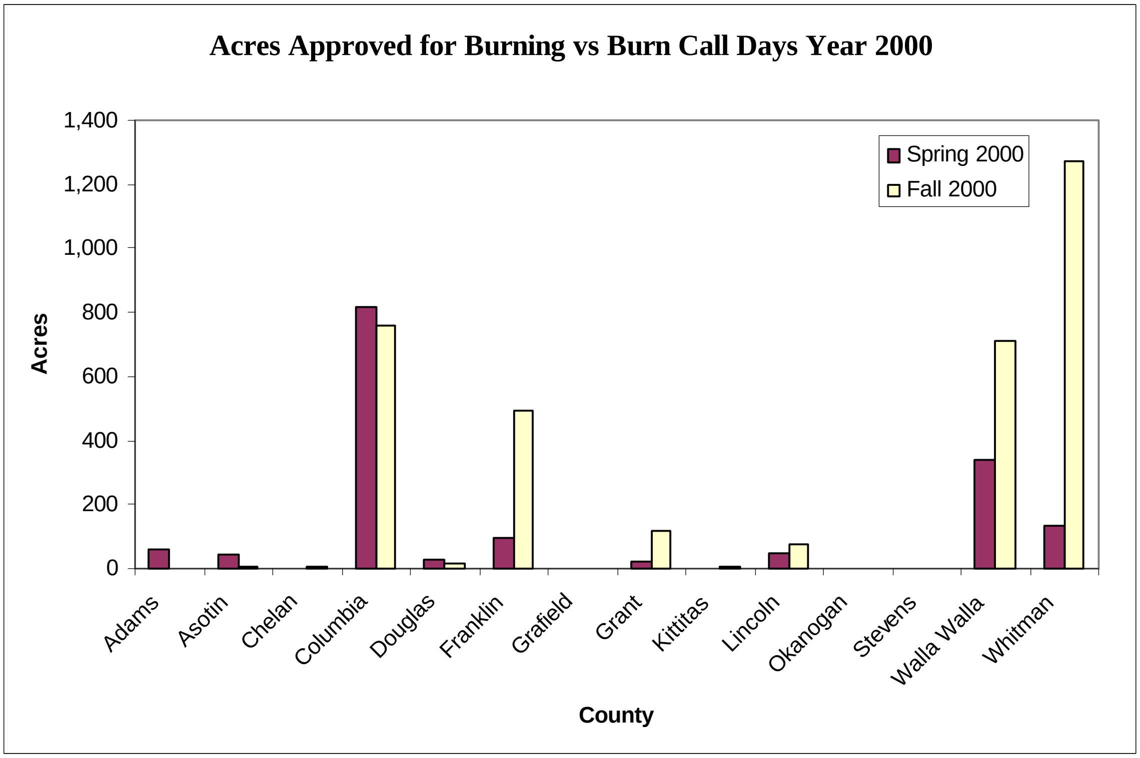


Figure 3.44. Relation between the number of acres approved for burning and the number of burn call days, per county, and per season in the state of Washington during the year 2000.

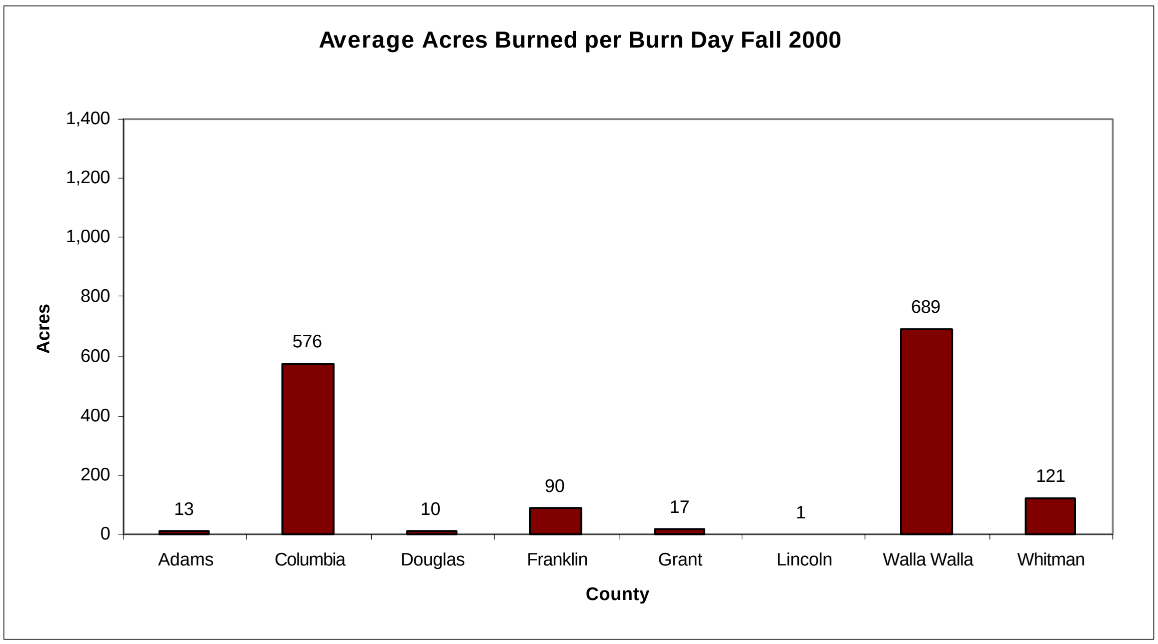


Figure 3.45. Ratio between the number of acres burned and the number of burn call days, per county in the state of Washington during the Fall 2000.

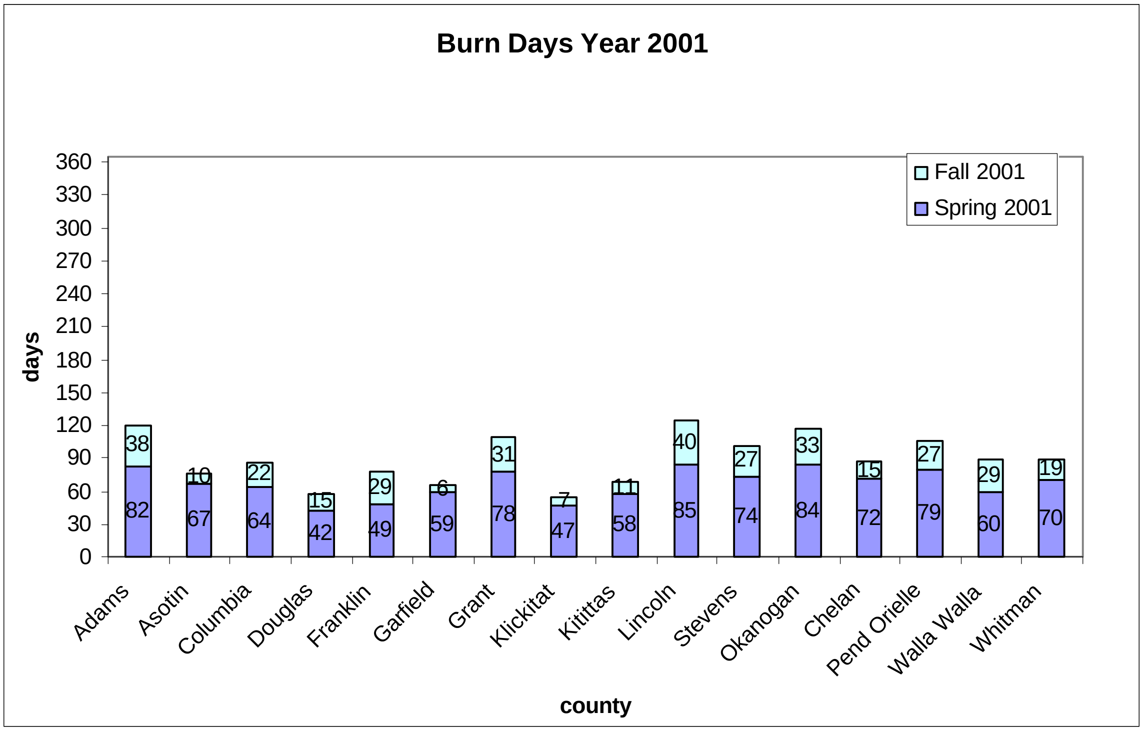


Figure 3.46. Spatial distribution of burn call days in the state of Washington during the year 2001.

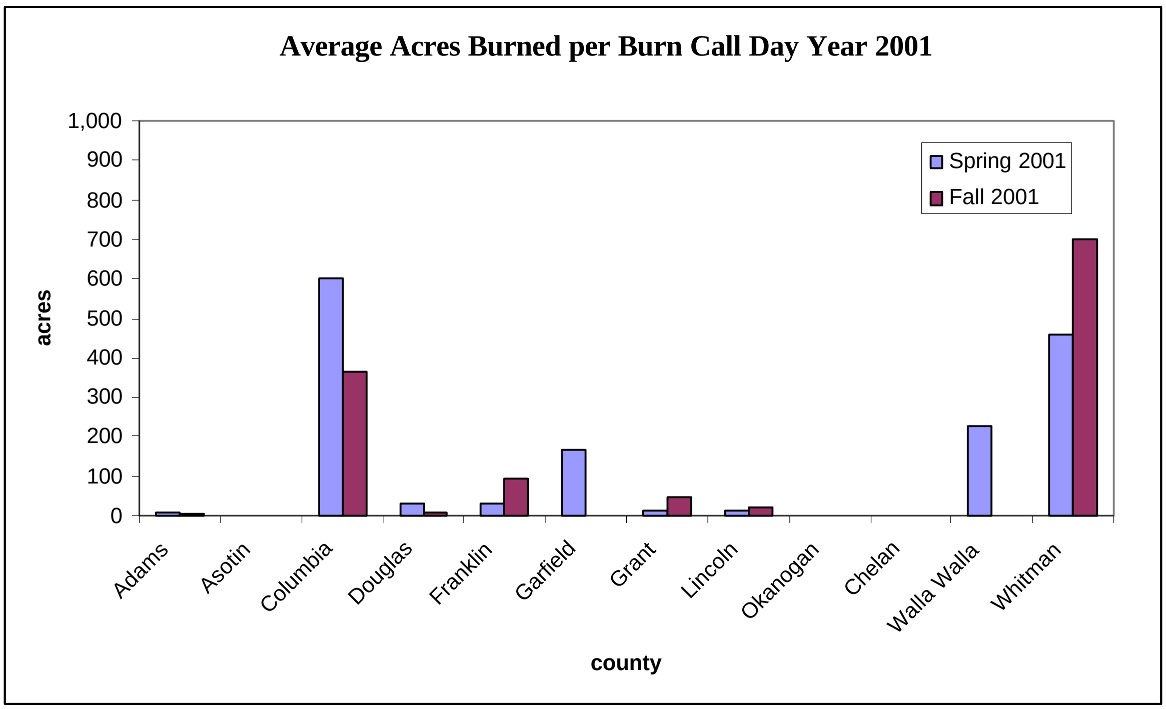


Figure 3.47. Ratio between the number of acres approved for burning and the number of burn call days, per county, and per season in the state of Washington during the year 2001.

3.4.3 Complaint log

For a better understanding of the data, the complaint log was separated into three categories based on the comments and testimony registered by each complaint as follows:

- *Burning activities*: included all complaints related to people that visually observed and reported burning activities.
- *Bad air quality:* included all complaints related to smoke in the air and poor air conditions.
- *Other/ not relevant*: included all unknown complaints and/or complaints not related to air quality or burning problems.

In 2000, seventy-six formal complaints were registered in Eastern Washington. The complaints were related to different types of sources, such as agricultural (20 complaints), orchard (14 complaints), open burning (39 complaints) and other categories (3 complaints). The complaint log registered calls (17 calls in the spring and late summer, and fifty-nine calls in the fall) from twelve different counties. Franklin, Whitman and Stevens Counties reported 60% (46 calls) of the total complaints in 2000 (Figure 3.48). The twenty-six complaints reported from Franklin County were anonymous and did not specify the source and the reason for the protest. Whitman County reported eleven complaints during the year. Four complaints reported bad air quality conditions (smoke in the air) and five reported burning activities. Figure 3.49 shows the temporal distribution of the complaints in the region during the year 2000. The figure suggested that most complaints were triggered in the fall, between the months of September and November.

The sources reported for those complaints included nine complaints related to agricultural burning, one to dust, and one related to an open type of burning. In Stevens County, nine complaints were reported during the year 2000. Seven calls specified burning activities and four calls protested about bad air quality conditions. The majority of the complaints (7 calls) were for open burning activities, such as trash, debris and other types of materials.

Finally, from the total number of complaints (76 calls) registered during the year 2000 in the state of Washington, thirty-one complaints reported burning activities and sixteen reported some air quality problems. But, from those complaints linked to agricultural sources (20 calls), fifteen complaints reported agricultural burnings and seven linked smoke impacts to agricultural burnings. Table 3.6 summarizes this analysis by category and source of complaint.

In 2001, one hundred thirty-five formal complaints were registered (77.6 % more calls than the year 2000) in the state of Washington. The complaints were related to different types of sources, such as agricultural (23 complaints), orchard (11 complaints), open burning (46 complaints), general (35 complaints) and other categories (20 complaints). The complaint calls (50 calls in the spring and late summer and 85 calls in the fall) came from eighteen different counties. Whitman, Spokane and Stevens Counties reported 61% of the total complaints (82 calls) during the year 2001 (Figure 3.50). Whitman County registered thirty-nine complaints during the year (triple the number of calls from the year 2000). From these calls, thirty-two complaints reported bad air quality conditions (smoke in the air) and nine accounted for burning activities. Figure 3.51 shows the temporal distribution of the complaints in Central and Eastern Washington in the year 2001. The figure suggested that most complaints were also triggered in the Fall, mostly in the month of September. The sources reported for those complaints included twenty general complaints for bad air quality, fifteen complaints related to an agricultural source and four related to an open type of burning.

Spokane County registered twenty-two complaints in 2001. Eighteen calls specified bad air quality conditions (smoke in the air) and nine calls specified some type of burning activity. The majority of the complaints were related to poor air quality conditions. Fifteen were general smoke complaints and some of them (6 calls) were linked to wildfires and others (2 complaints) were attributed to woodstoves. Only two calls protested about smoke related to agricultural burning. However, in Stevens County twenty-one complaints were reported during the year and fifteen calls specified burning activities and six calls protested about bad air quality conditions. The majority of the calls (19 calls) reported some type of local burning of trash, debris and/or another sort of material (open burning).

Finally, from the total number of complaints (135 calls) received during the year 2001 in the state of Washington, fifty-five complaints reported burning activities and seventy-two accounted for a report of some air quality problems. From those complaints linked to agricultural sources (23 calls), eleven complaints reported agricultural burnings and seventeen calls reported smoke impacts from agricultural burning. Table 3.7 summarizes this analysis by category and source of complaint.

Poor air quality conditions observed in Pullman were sometimes correlated with numerous complaints in the area. Figures 3.52a-d and 3.53a-c show the complaint response along with the $PM_{2.5}$ observed in Pullman for the months of April, August, September and October 2000, March, April and September, 2001, respectively. Complaints in the Spring, for both years, seem to be less correlated to poor air quality conditions compared to those in the Fall. This relation was clear in the two smoke episodes that occurred in Pullman on September 2001 (Figure 3.53c). Those short-term high $PM_{2.5}$ levels occurred on two different days (September 12 & 19), and triggered an increased complaint response to the poor air quality conditions. On the other hand, several complaints (3) were reported on March 26, 2001, but high $PM_{2.5}$ levels were not observed at the monitors (Figure 3.53a). These complaints were triggered by smoke blowing across the highway north of Pullman from prescribed field burning, smoke which did not affect the air quality in Pullman.

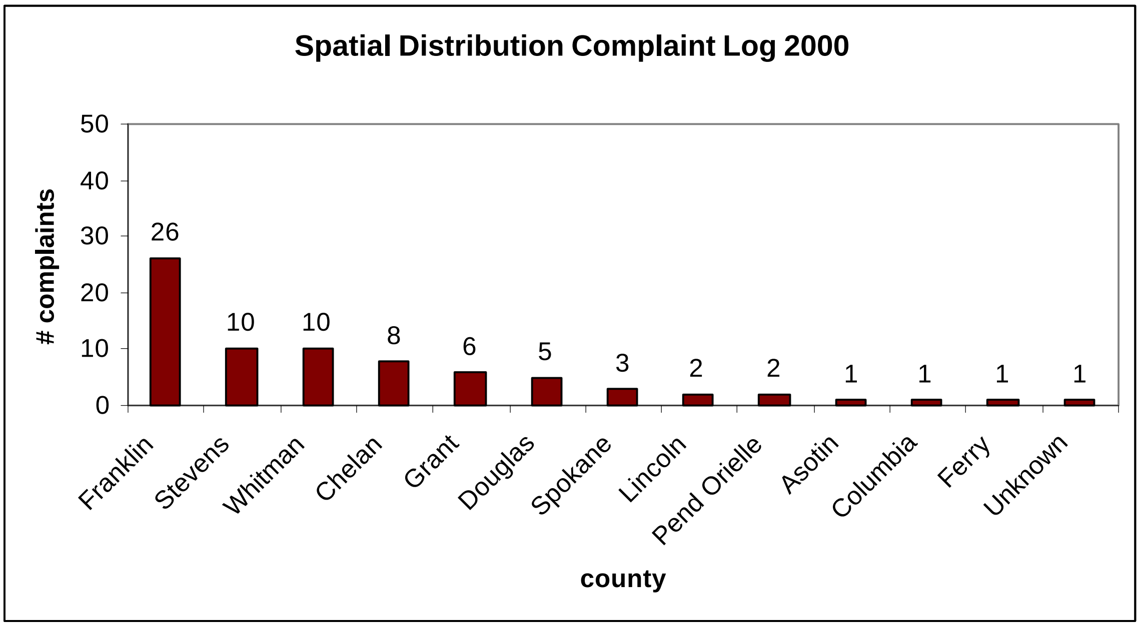


Figure 3.48. Spatial distribution and number of complaints registered during the year 2000 in the state of Washington.

Table 3.6. Source and characteristic of the complaints reported during the year 2000.

Report / Source	**Open**	**Agricultural/ orchard**	**Other**
Burning activities	15	15	1
Bad air quality (smoke)	8	7	1
Other/ not relevant	21	12	1

Source:

- *Open*: included all outdoor burning excluding agricultural related burns.
- *Agricultural/ orchard*: included agricultural field burnings and orchard burnings.
- *Other*: not relevant and/or unknown source.

Category:

- *Burning activities*: included all complaints related to people that visually observed and reported burning activities.
- *Bad air quality:* included all complaints related to smoke in the air and poor air conditions.
- *Other/ not relevant*: included all unknown complaints and/or complaints not related to air quality or burning.

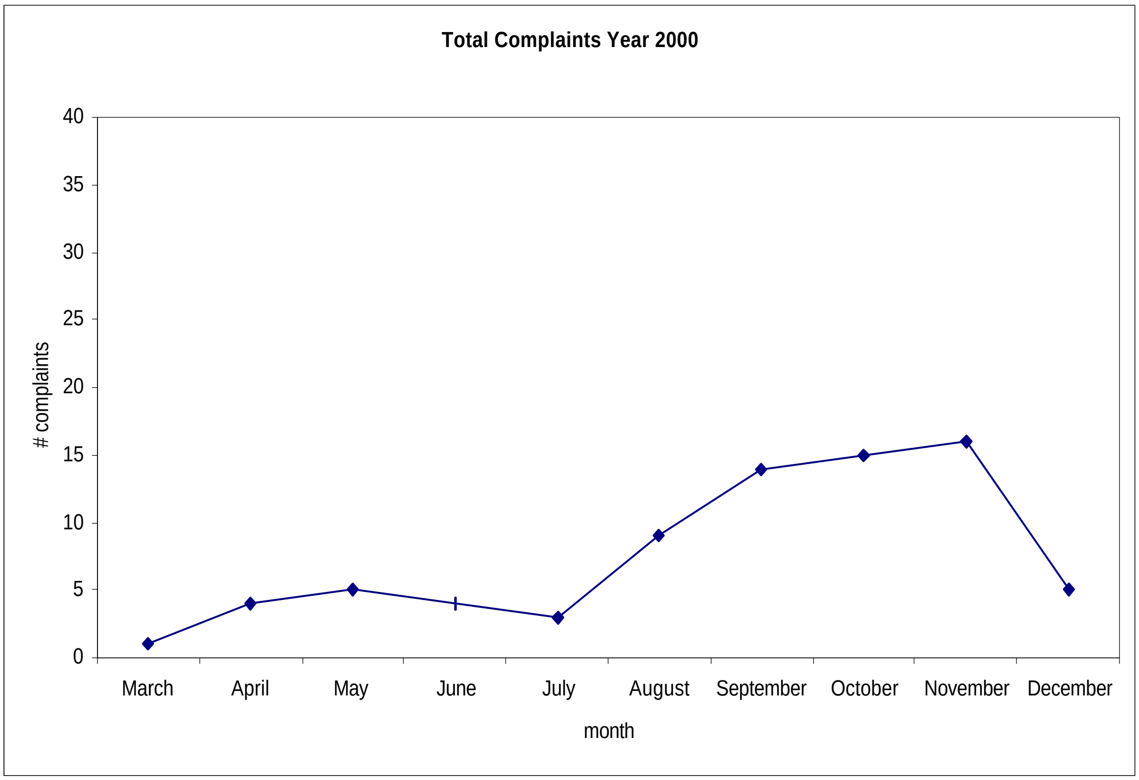


Figure 3.49. Temporal distribution of complaints in Central and Eastern Washington State in the year 2000.

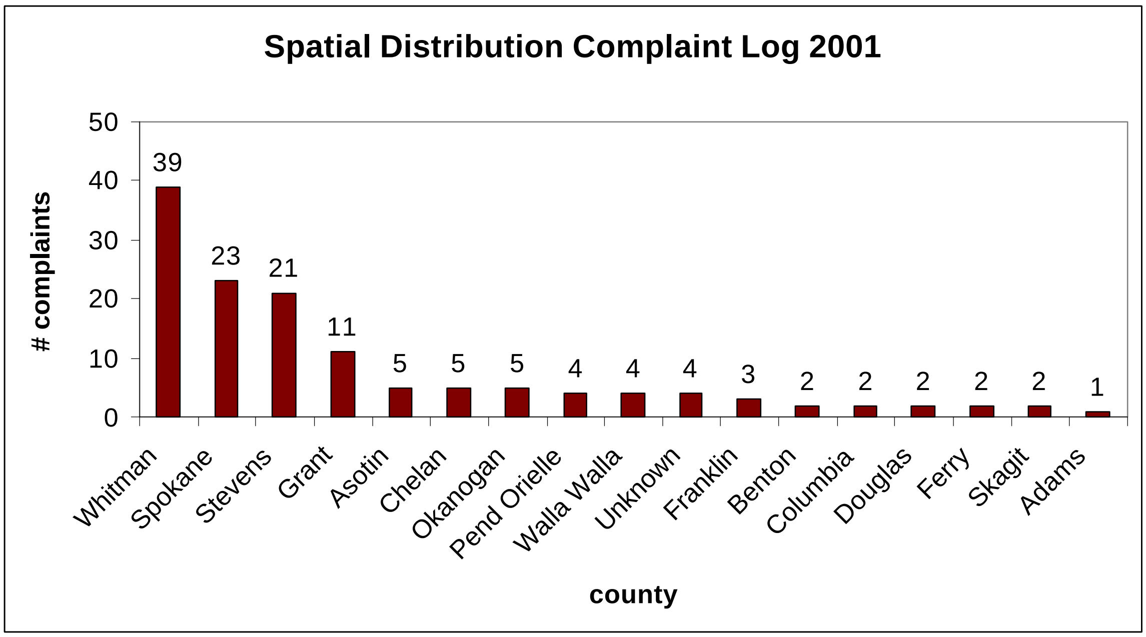


Figure 3.50. Spatial distribution and number of complaints registered during the year 2001 in the state of Washington.

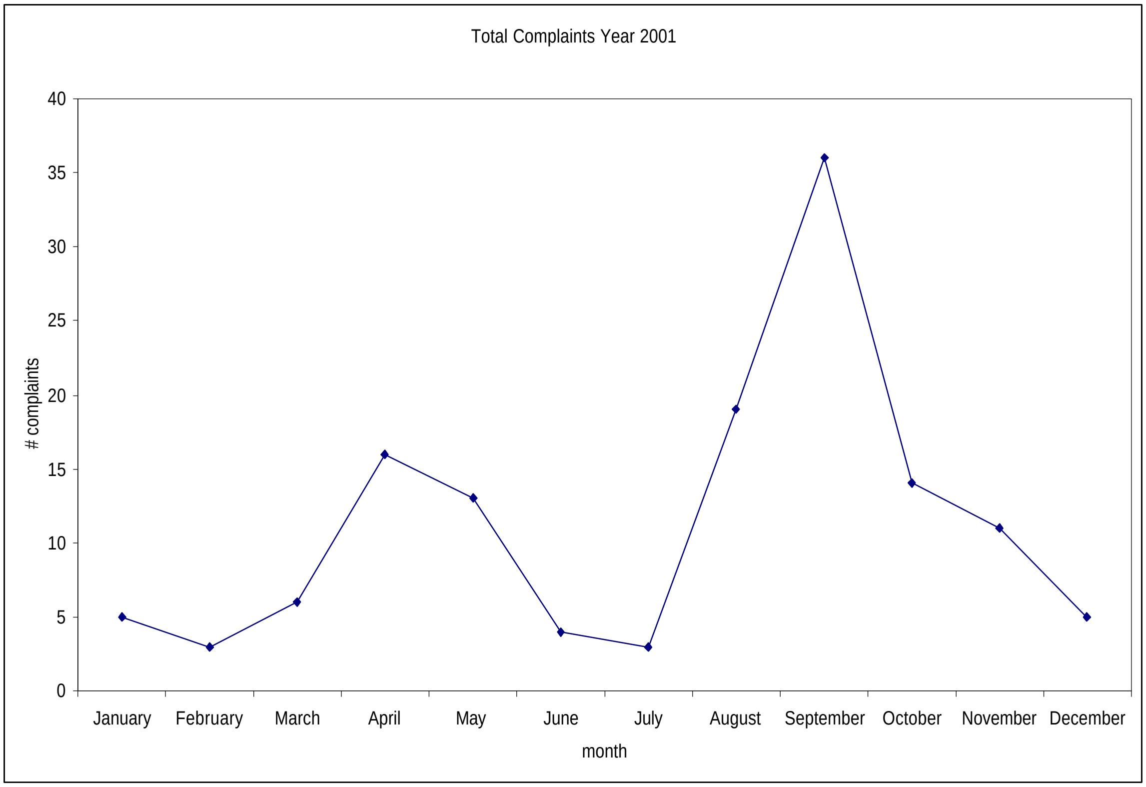


Figure 3.51. Temporal distribution of complaints in Central and Eastern Washington State in the year 2001.

Table 3.7. Source and characteristic of the complaints reported during the year 2001.

Report / Source	Open	Agricultural/ orchard	Other
Burning activities	40	11	4
Bad air quality (smoke)	11	17	44
Other/ not relevant	3	3	9

Source:

- *Open*: included all outdoor burning excluding agricultural related burns.
- *Agricultural/ orchard*: included agricultural field burnings and orchard burnings.
- *Other*: not relevant and/or unknown source.

Category:

- *Burning activities*: included all complaints related to people that visually observed and reported burning activities.
- *Bad air quality:* included all complaints related to smoke in the air and poor air conditions.
- *Other/ not relevant*: included all unknown complaints and/or complaints not related to air quality or burning.

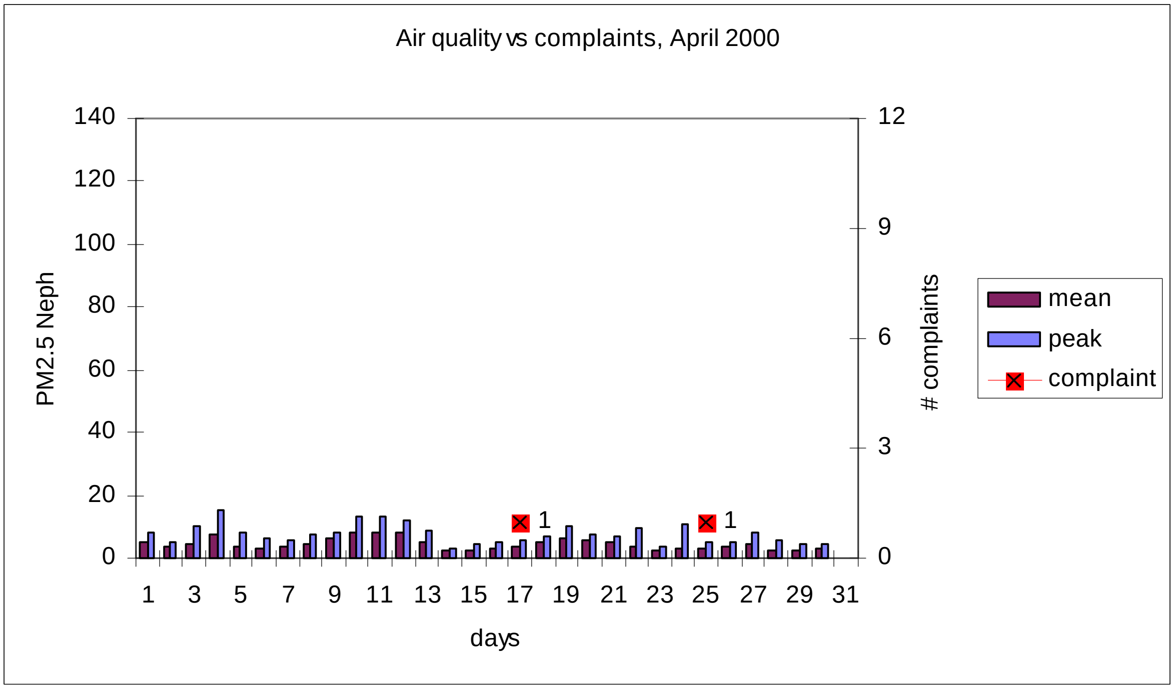


Figure 3.52a. Complaint response to poor air quality conditions observed in Pullman on April 2000. The complaints were not linked to the PM levels. The complaints from Whitman County reported garbage burning (April 17) and field burning (April 25). However, no smoke intrusion in the air quality observation was noticed.

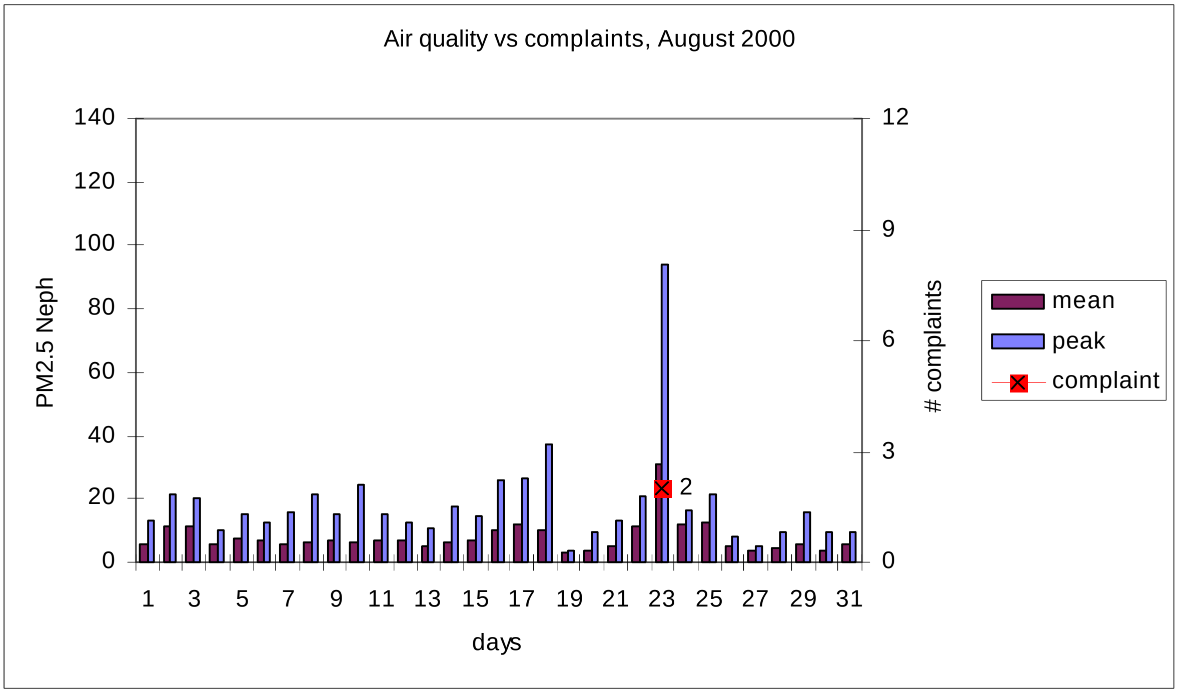


Figure 3.52b. Complaint response to poor air quality conditions observed in Pullman on August 2000. The complaint response was linked to the high PM levels observed on August 23. Two complaints from Whitman County (Pullman) reported smoke in the air during this day.

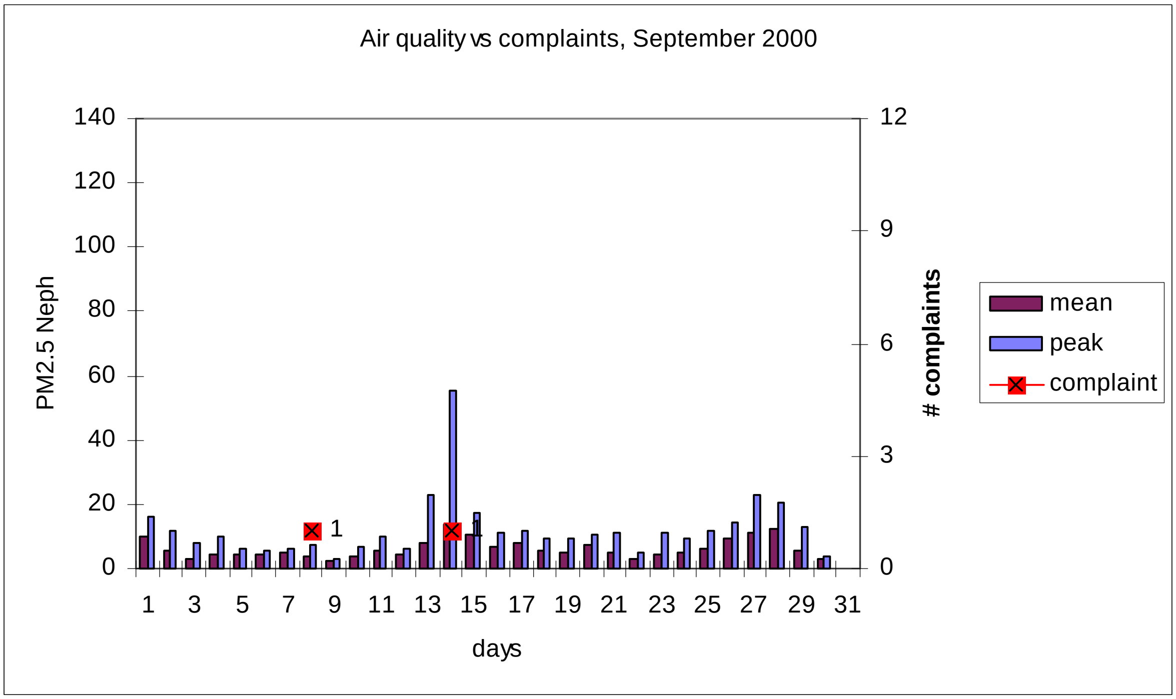


Figure 3.52c. Complaint response to poor air quality conditions observed in Pullman on September 2000. On September 14, high PM levels were observed and one complaint was reported in Whitman County.

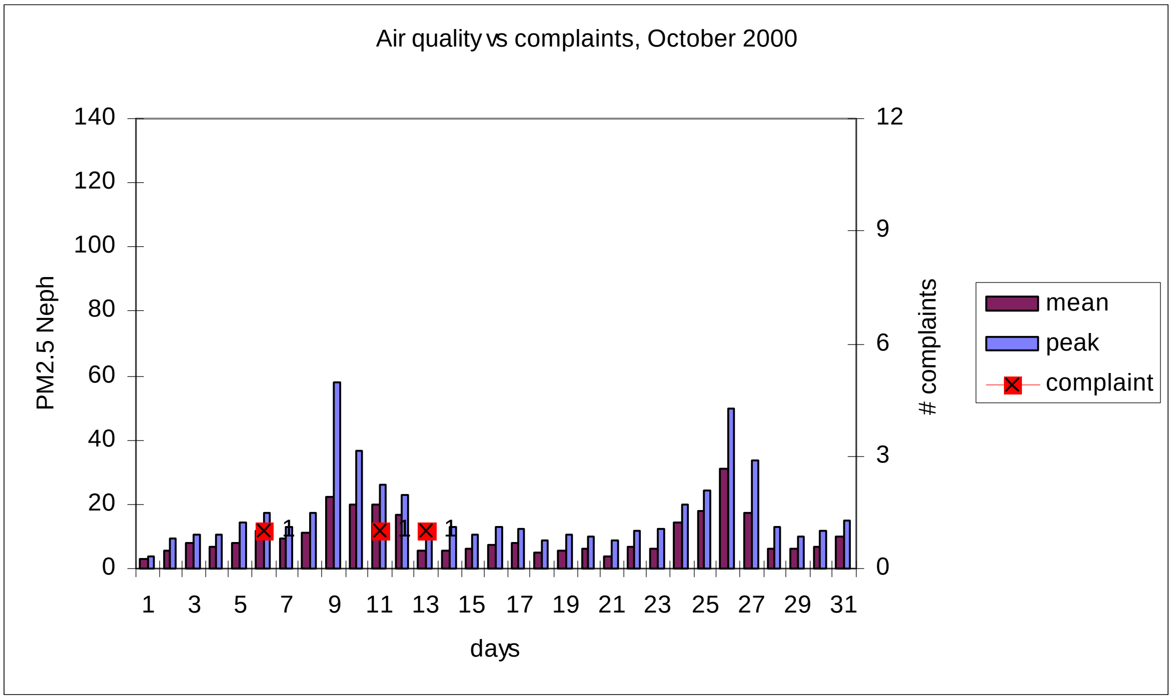


Figure 3.52d. Complaint response to poor air quality conditions observed in Pullman on October 2000. The complaint response may be linked to high PM levels observed. Two complaints from Pullman (October 6 and 13) reported some degree of poor air quality conditions.

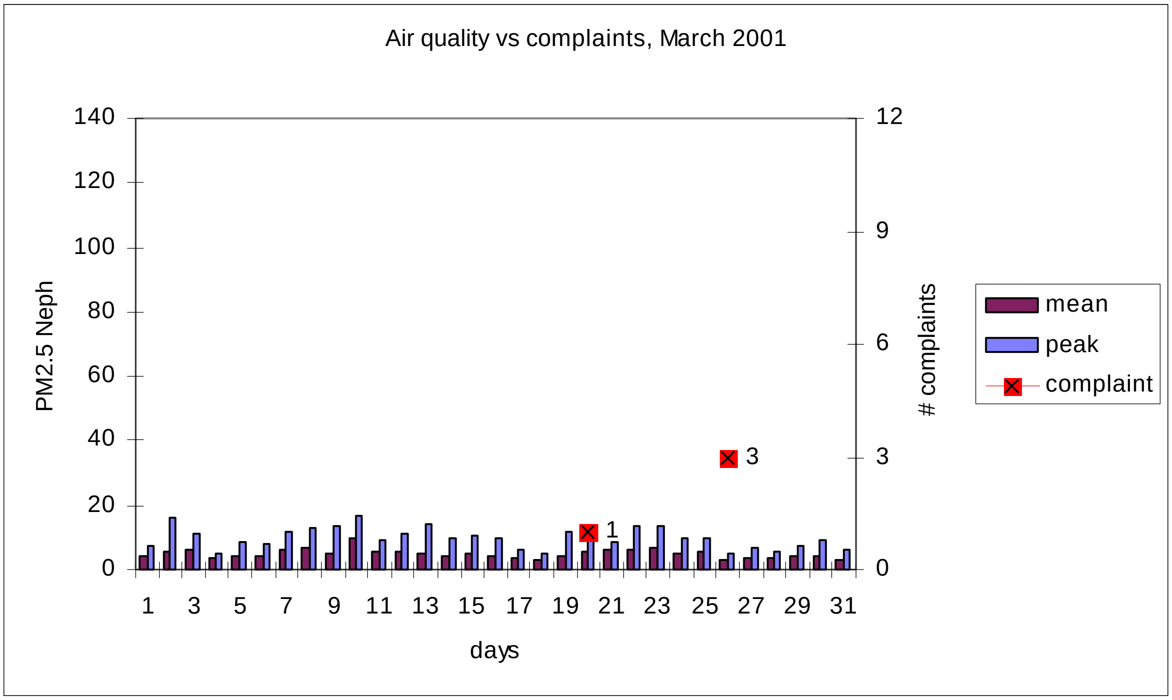


Figure 3.53a. Complaint response to poor air quality conditions observed in Pullman on March 2001. The complaints are not linked to high PM levels. The complaints from Whitman County (Pullman) on March 26 were triggered by smoke blowing across the highway north of Pullman from field burning. However, no smoke intrusion in the air quality observation was noticed at the monitors.

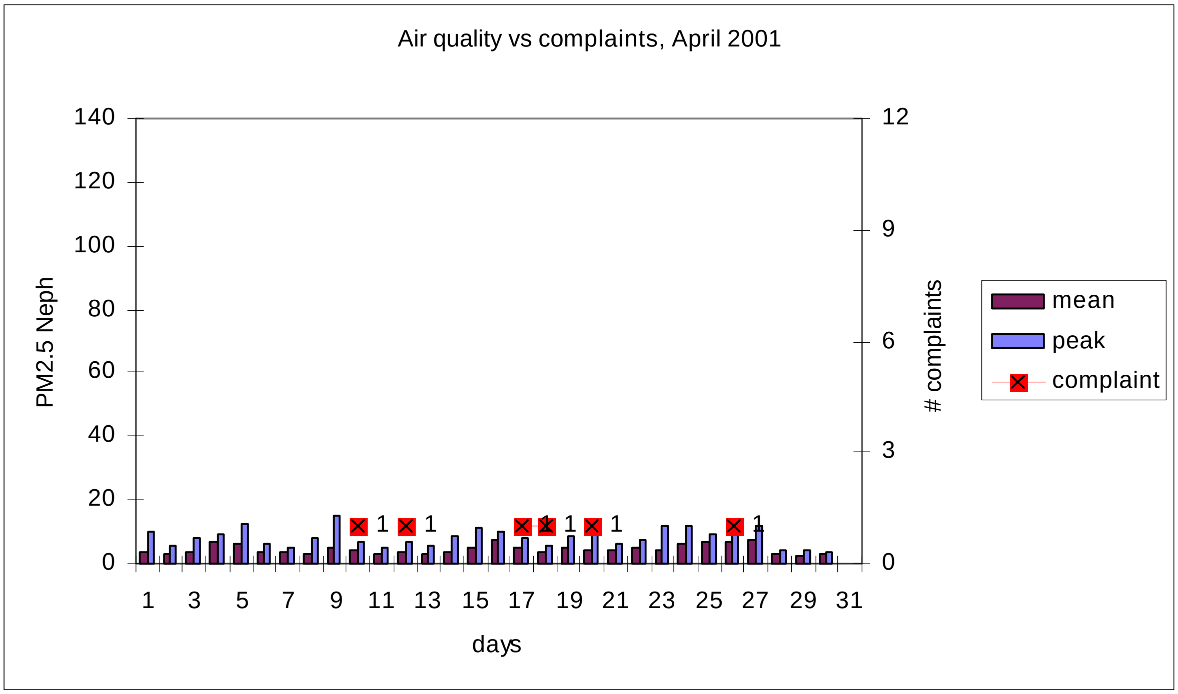


Figure 3.53b. Complaint response to poor air quality conditions observed in Pullman on April 2001. The complaints are not linked to high PM levels. The complaints from Whitman County were triggered by visual observation of field burning in the area.

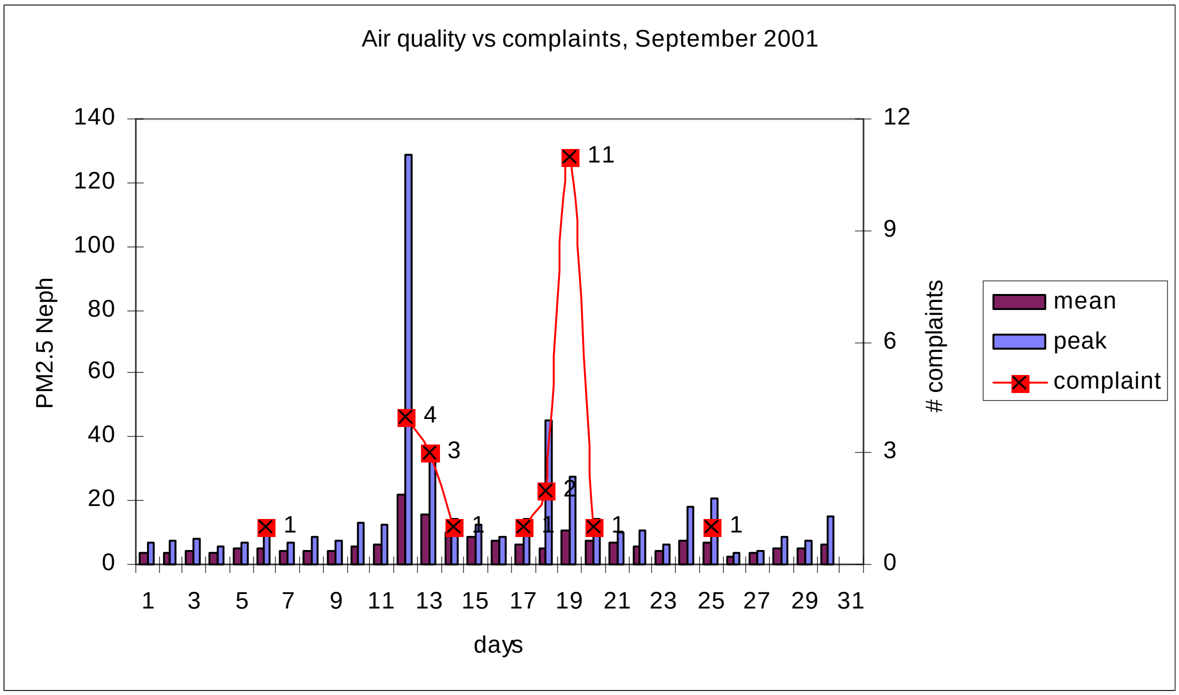


Figure 3.53c. Complaint response to poor air quality conditions observed in Pullman on September 2001. The complaint response was linked to the PM levels observed on September 12 and 19. Numerous complaints from Whitman County (Pullman) reported smoke in the air during this day.

3.5 Summary and Conclusions

Eight smoke episodes were identified as occurrences of smoke intrusion in Pullman, WA in the years 2000 and 2001. In 2000, conditions in the Northwest were such that many wildfires burned during the summer, especially in Central Idaho, which complicated the source attribution of the smoke episodes that occurred during the Fall burning season. Back trajectories using the HYSPLIT model were used to attribute the smoke to its source. This model calculated the origin of air parcels arriving at Pullman during the episodes using archived meteorological forecast data. For four of these days, agricultural burns were most likely responsible for the smoke observed in Pullman, but only two of them were field burns in Washington (one was a field burn out of control in Walla Walla). The other two smoke episodes could be attributed to agricultural field burns that occurred in Idaho, including the Coeur d’ Alene Indian Reservation.

Smoke intrusion in the air quality observations was noticed on days when agricultural burning was not allowed due to poor ventilation and/or regional burn bans. The correlation between complaints and stubble burning showed that the majority of the complaints were not related to agricultural field burning. Open types of burning activities were frequently responsible for the poor air quality conditions observed in rural communities in Eastern Washington. Whitman County reported most of the complaints linked to agricultural field burning, but not all of the protests were related to smoke impacts in the air quality. Several complaints protested the actual farming practices and reported field burning that occurred in the area, even though negative air quality impacts as measured by $PM_{2.5}$ were not observed in Pullman. In addition, air quality conditions and frequency of complaints were interrelated. The study found that periods of poor air quality conditions observed in the fall in Pullman triggered complaints in the area. This correlation was most obvious during the two smoke episodes that occurred in Pullman during September 2001.

In both years, the Fall burn season had fewer days to burn compared to the Spring season. However, in 2000, the amount of acres applied for burning were the same for both burn seasons, so that the average number of acres burned per day is higher in the Fall than in the Spring. Thus, smoke impacts in populated areas in Eastern Washington and Northern Idaho are most likely to occur during the Fall. This problem is exacerbated as the Fall burn period overlaps with the wildfire season.

The implementation of a regulatory program to decrease emissions from cereal crop burning in Eastern Washington and mandatory participation of growers in reporting their burns, provides reliable data for quantitative analysis and documentation. Consistent with this, the analysis showed a reduction in the acreage burned in the year 2001 compared to the year 2000. Daily burn decisions made by WDOE's Smoke Management Program, based on forecasted ventilation conditions, worked well considering the amount of authorized burns and smoke impacts observed in Pullman. The study found that in only two cases field burns that occurred in Washington were most likely responsible for the smoke observed in Pullman, including the documented case of the field burn out of control in Walla Walla that occurred on September 18, 2001. Thus, under certain atmospheric conditions and depending on the amount of acres, smoke from fires in Columbia and Walla Walla County can potentially be observed in Pullman.

A real understanding of a shared airshed between Eastern Washington and Northern Idaho will eliminate undesirable smoke episodes such as the one that occurred in Pullman and Moscow on September 12, 2001. In addition, a better coordination between Washington Department of Ecology, Idaho Department of Environmental Quality and Native Americans' Smoke Management Programs will eventually maintain field burning as a suitable tool for farming practices in the region.

Trajectory analyses and dispersion models based upon updated forecasts, as well as, more air quality data from continuous monitoring instruments could aid in reducing air quality impacts in the rural areas of Eastern Washington. These tools will help to prevent potential smoke episodes by improving the actual smoke management program, and will provide a better understanding of smoke behavior downwind from the field burn.

Further analysis of local meteorological conditions, smoke dispersion and chemical reactions within the smoke plume from field burning will reduce the uncertainties associated with pollutant dilution and transport to urban areas. Developing trajectory and dispersion models, for well-documented cases, will provide a better understanding of the spatial and temporal behavior of smoke in the air from stubble burning. Finally, this approach will help to reduce some uncertainties and tension created between farmers and people living in the community.

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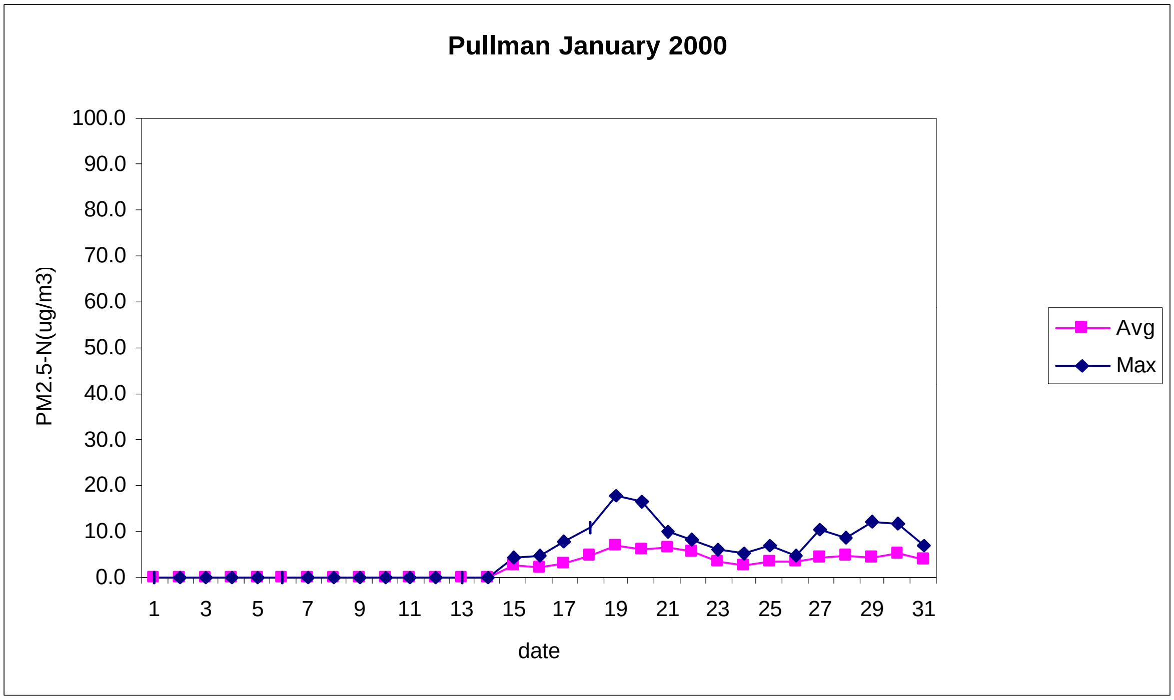
APPENDIX A

AIR QUALITY DATA OBSERVED IN DOWNTOWN PULLMAN IN 2000-2001 (NEPHELOMETER)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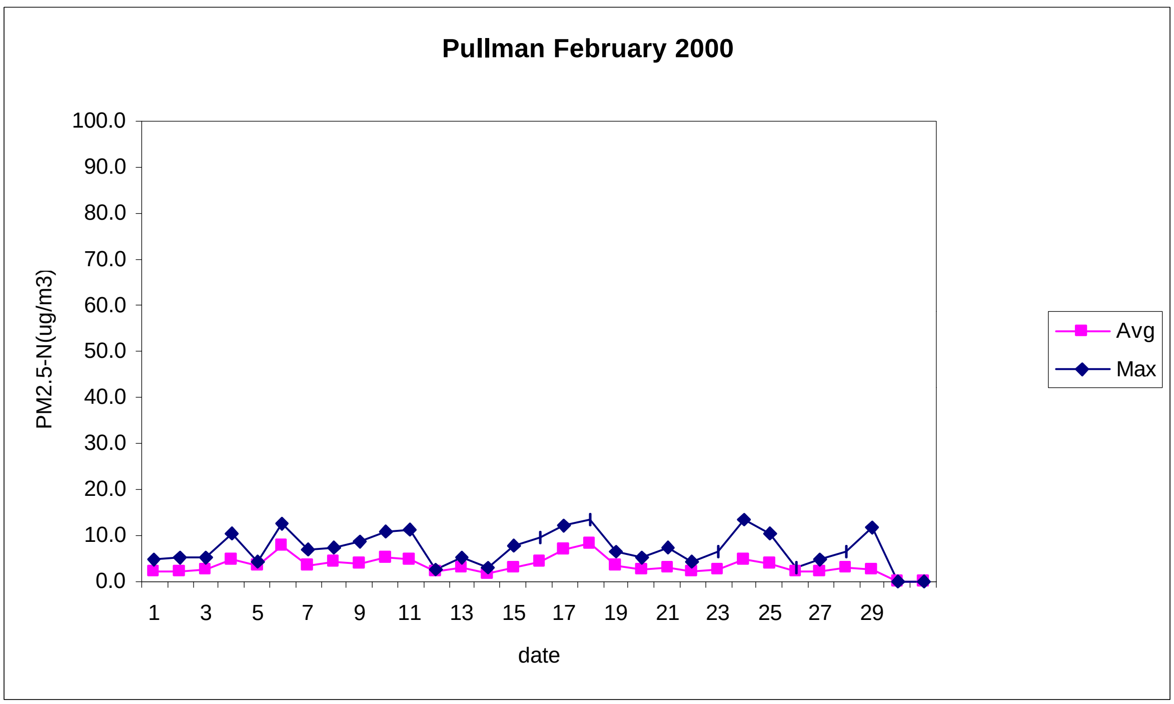
Avg
Max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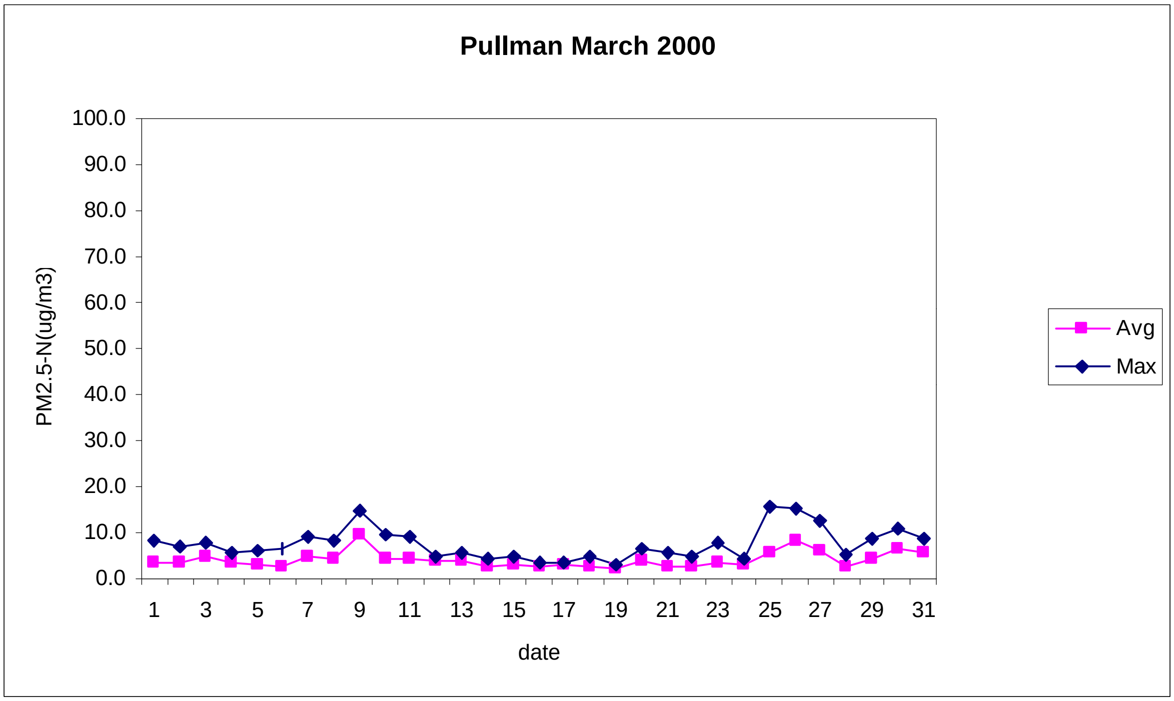
date
Avg
Max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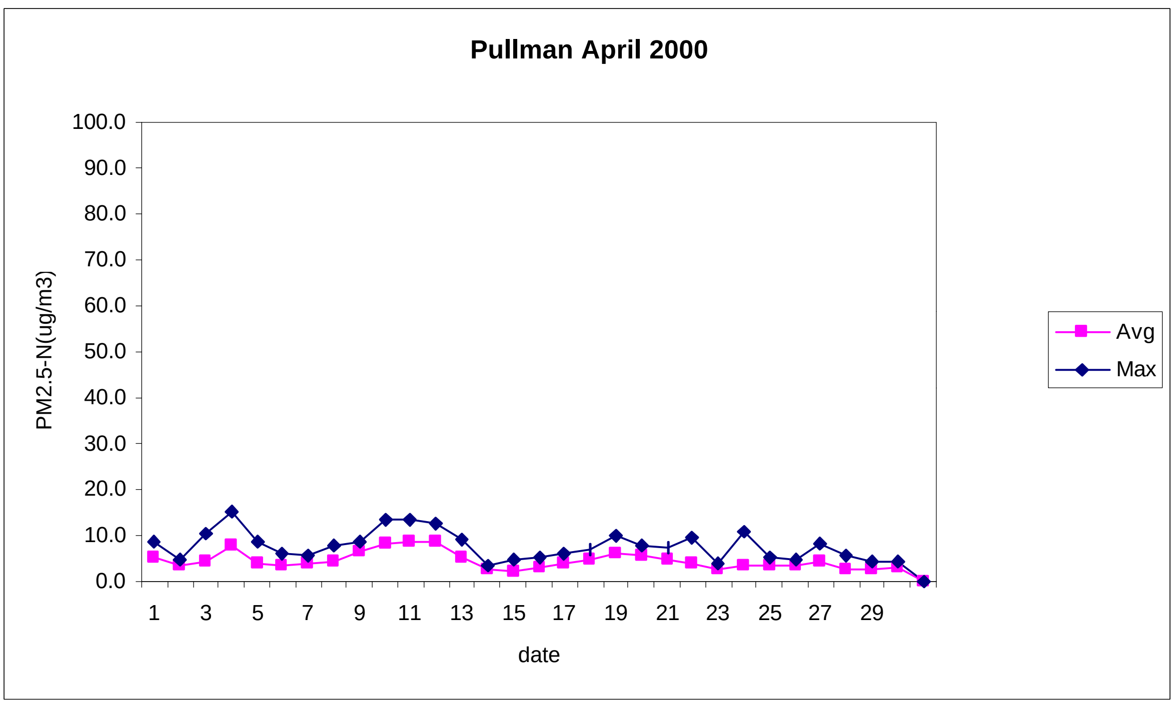
31
date
Avg
Max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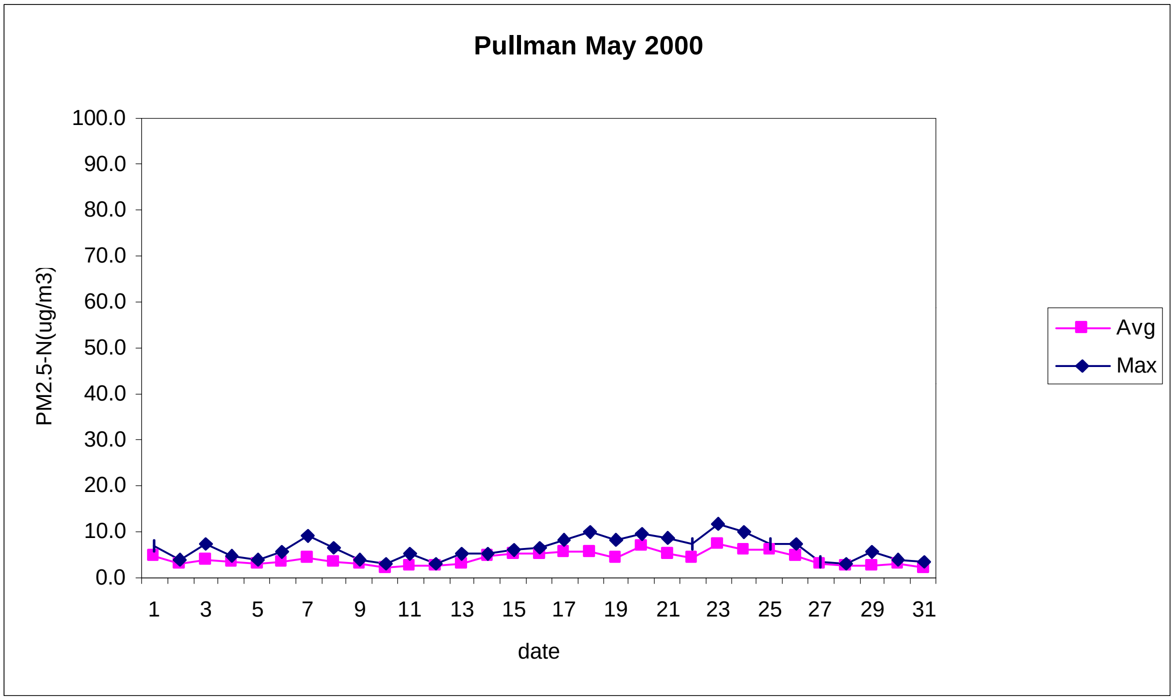
Avg
Max



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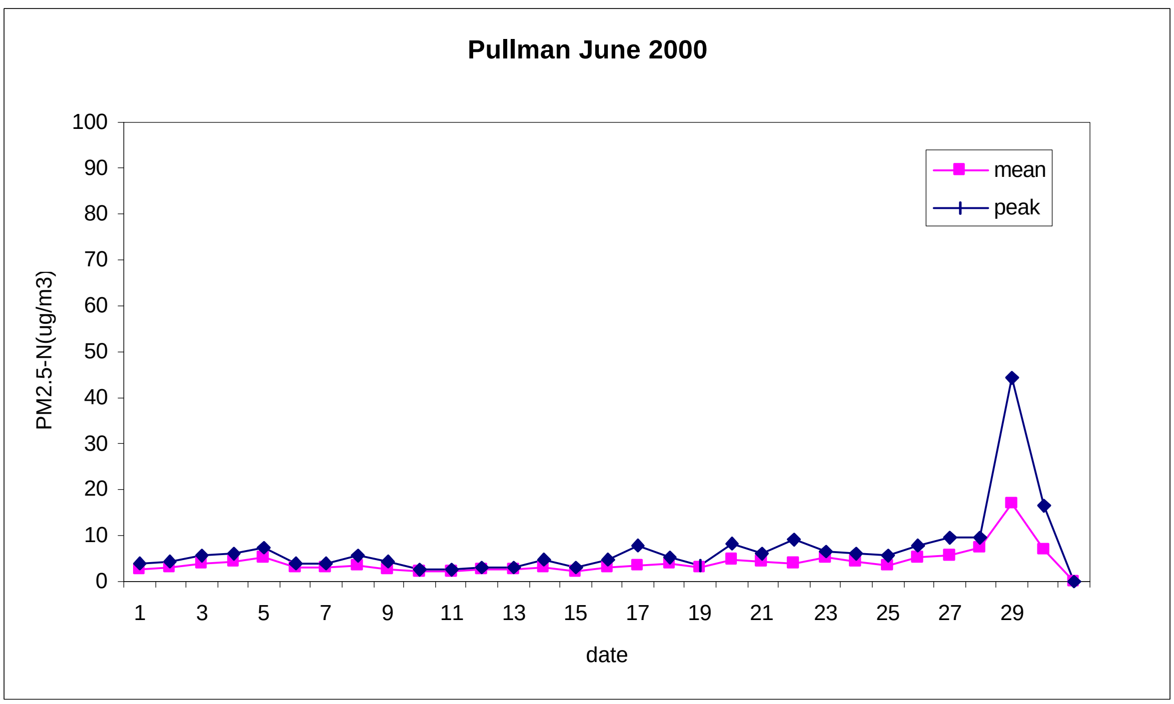
Avg
Max



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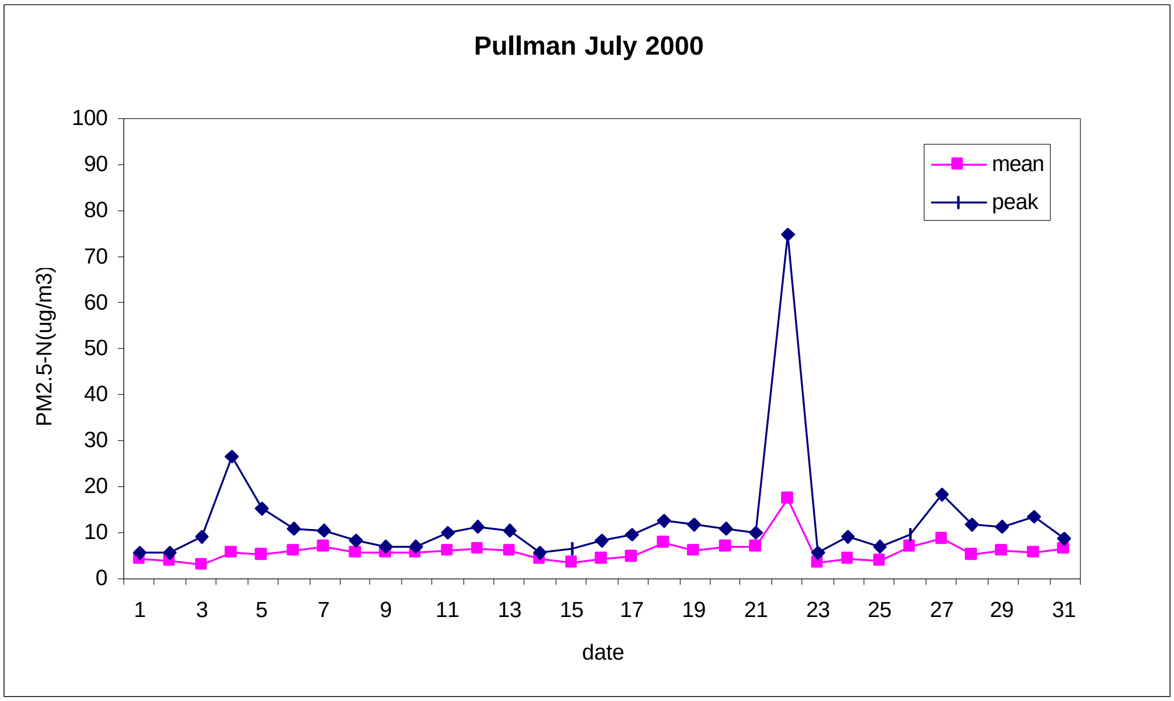
mean
peak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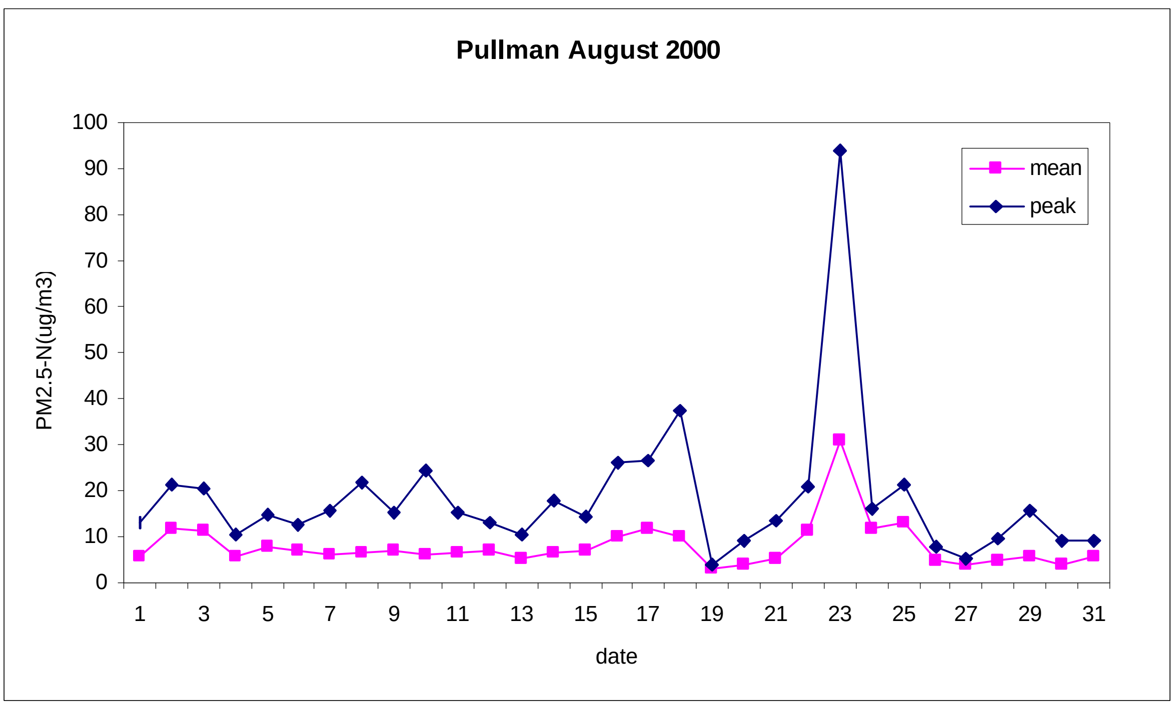
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20
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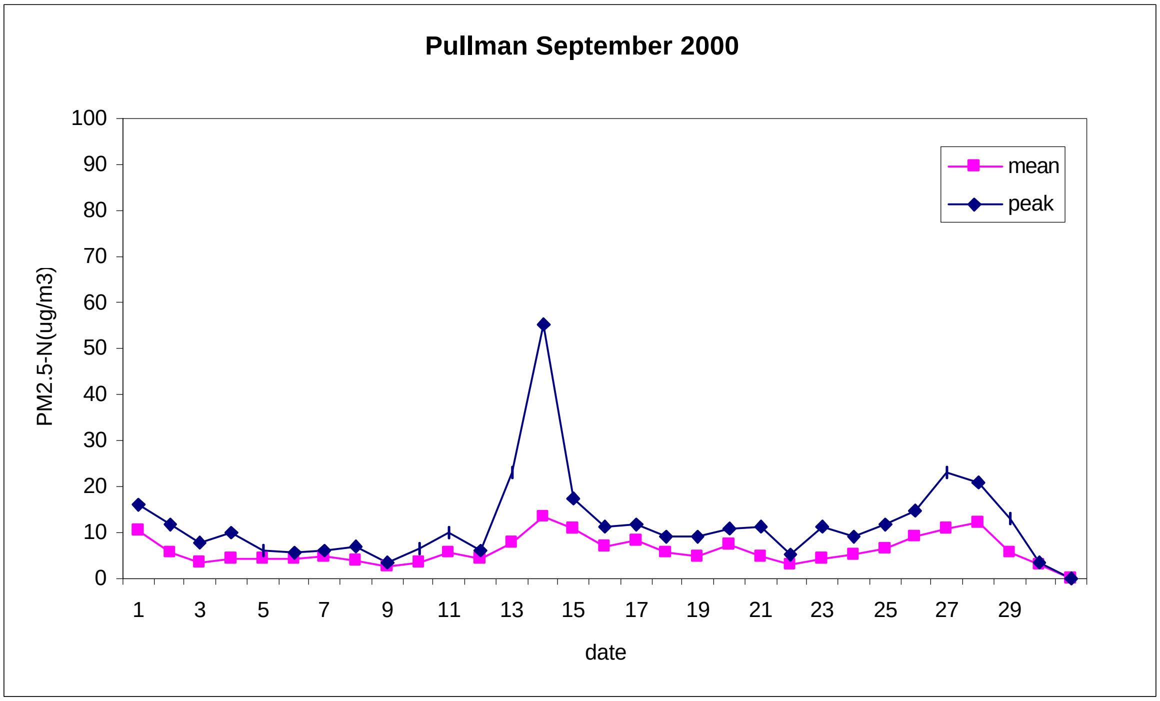
date
mean
peak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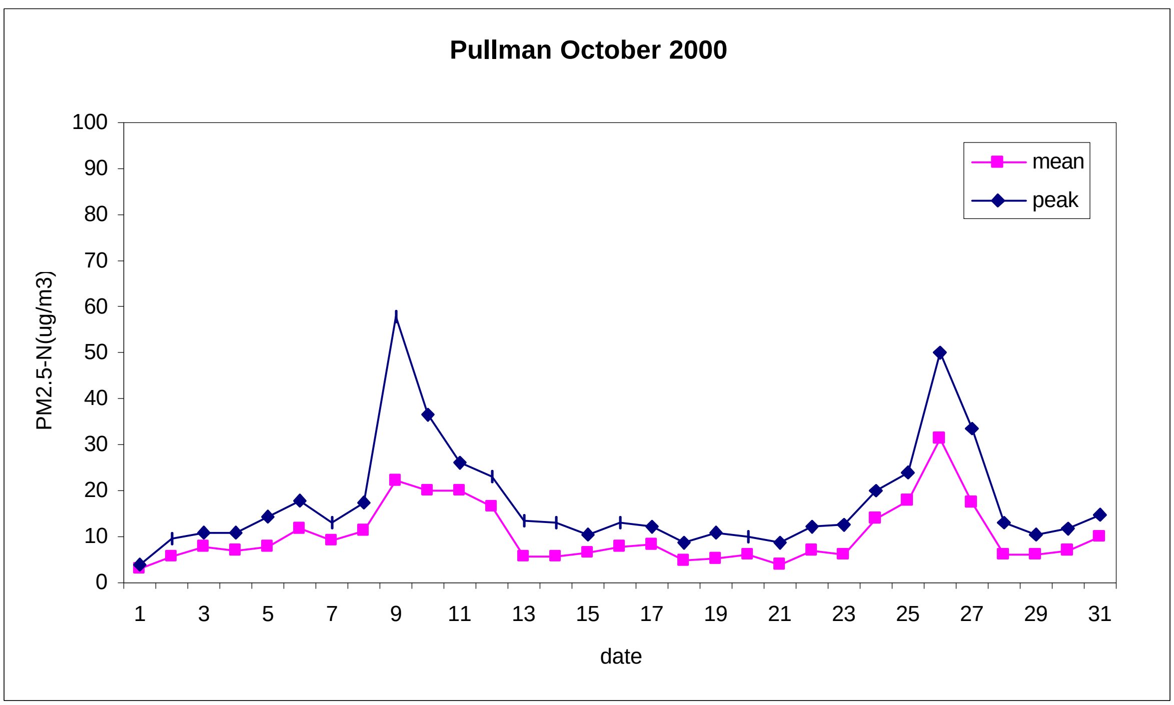
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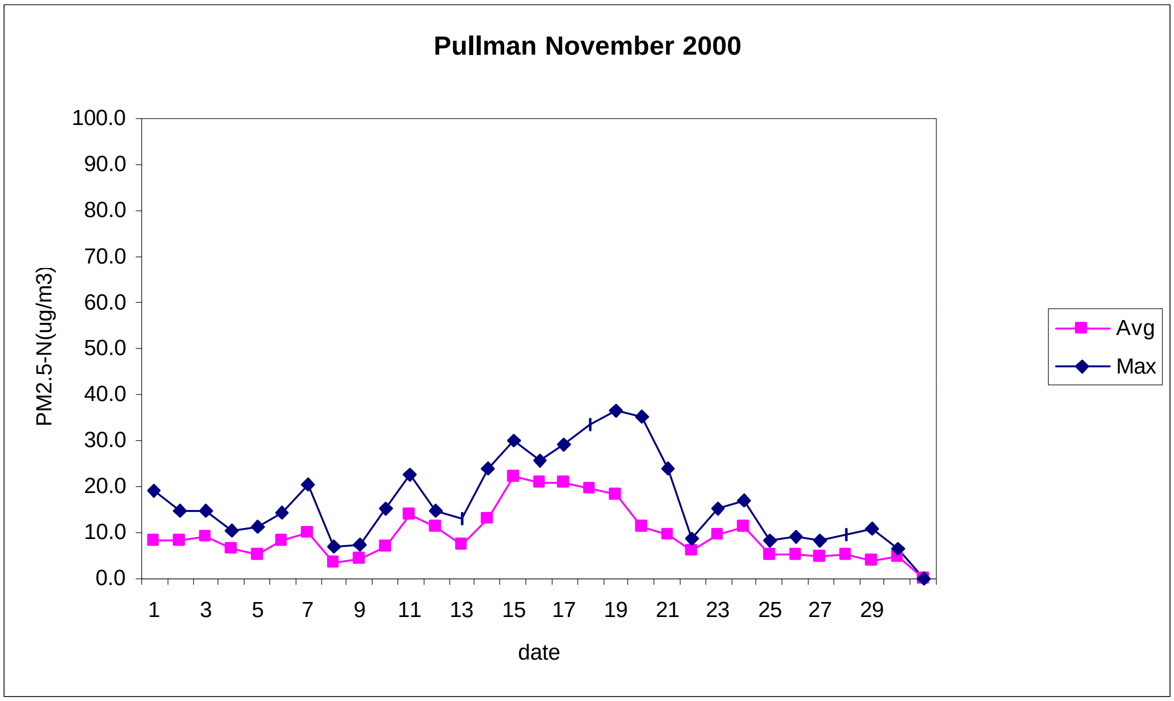
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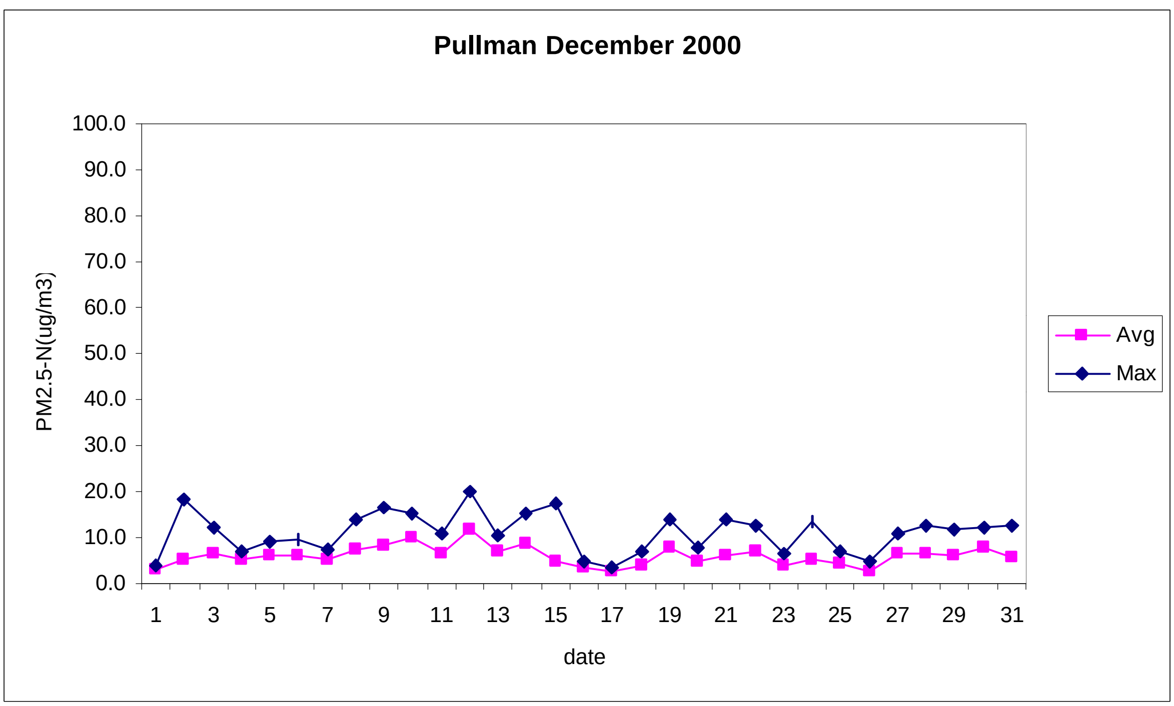
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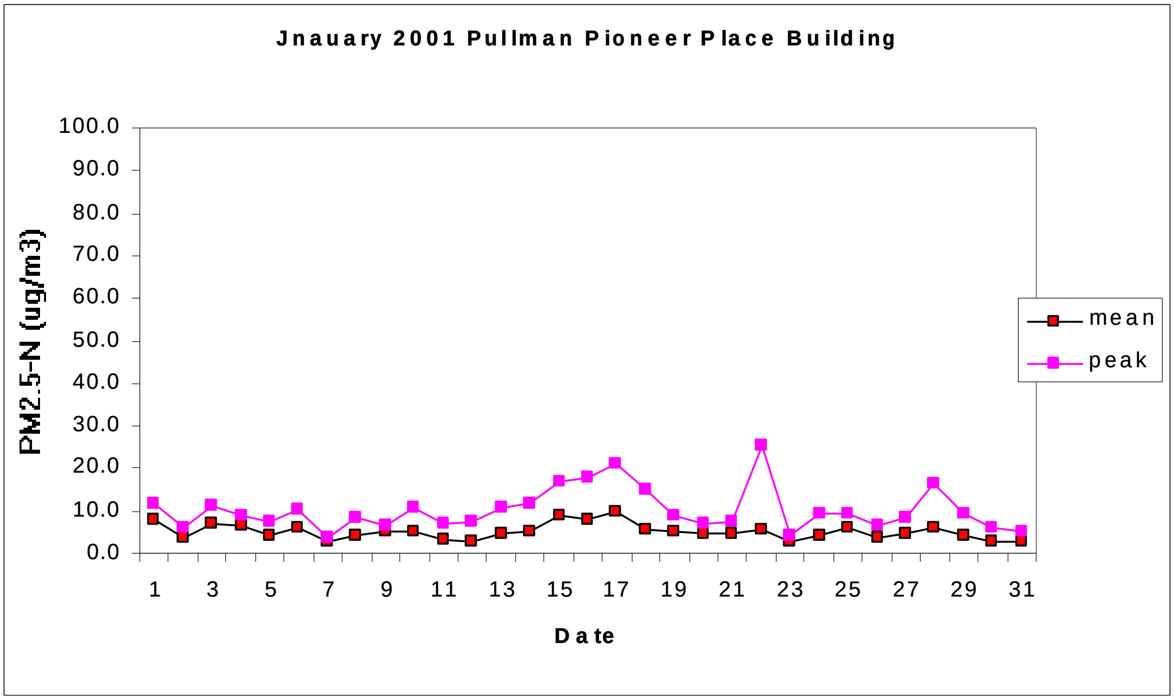
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Date
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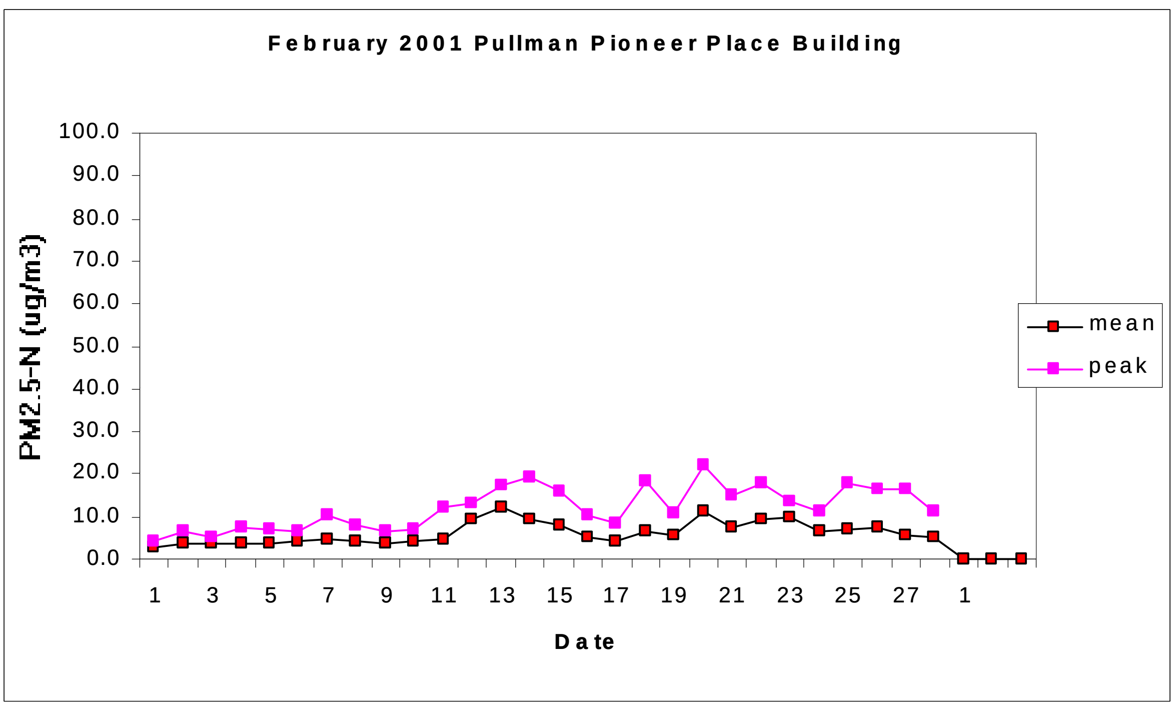
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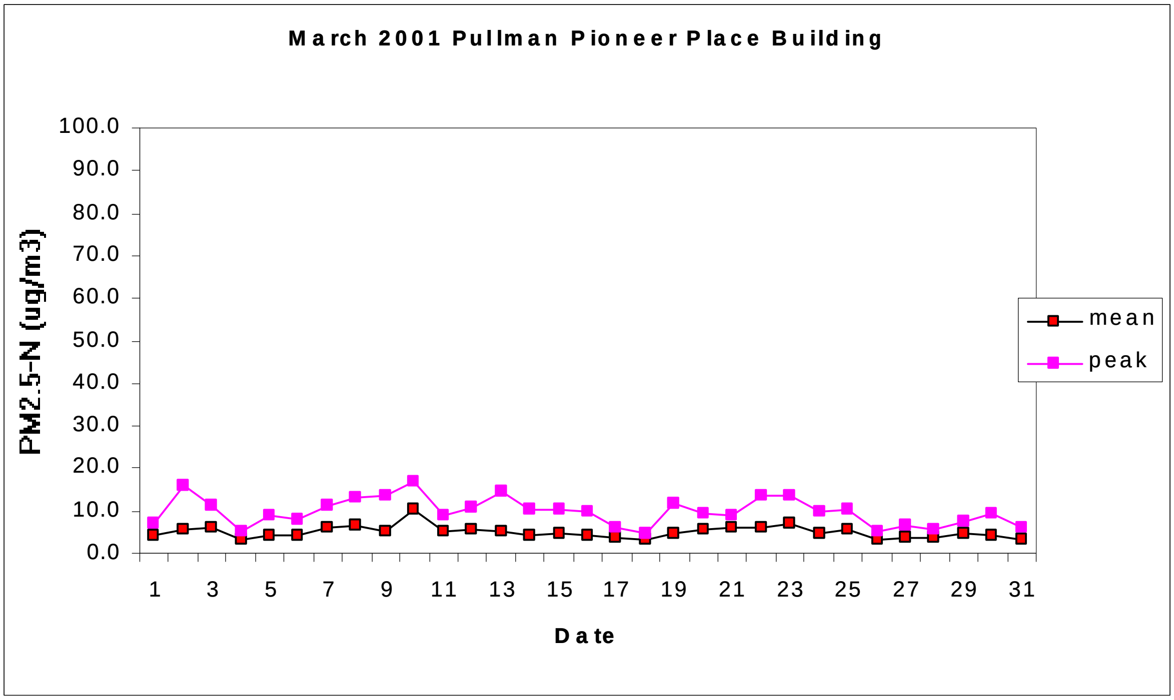
Date
mean
peak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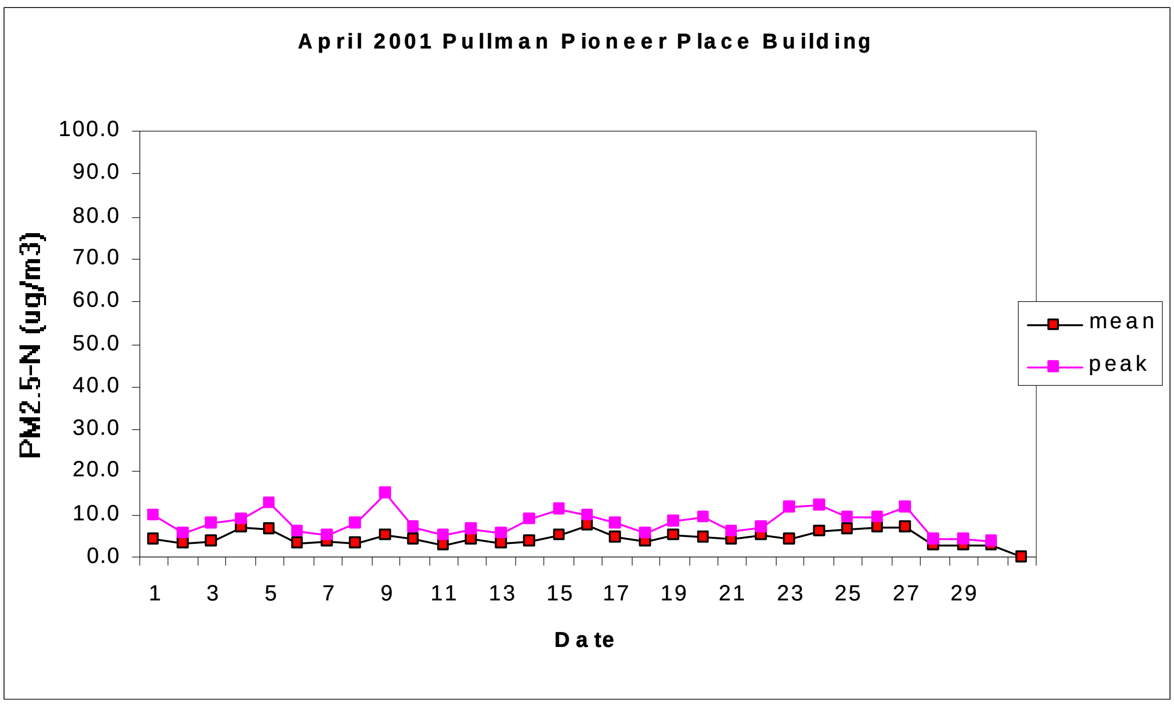
Date
mean
peak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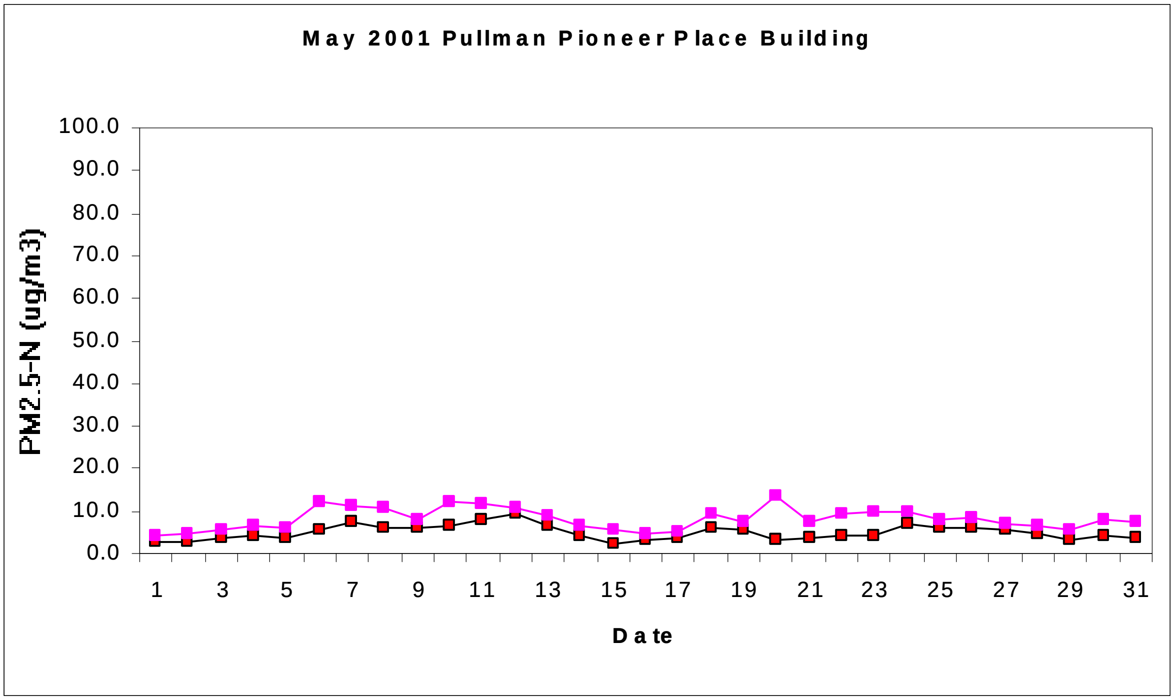
Date
mean
peak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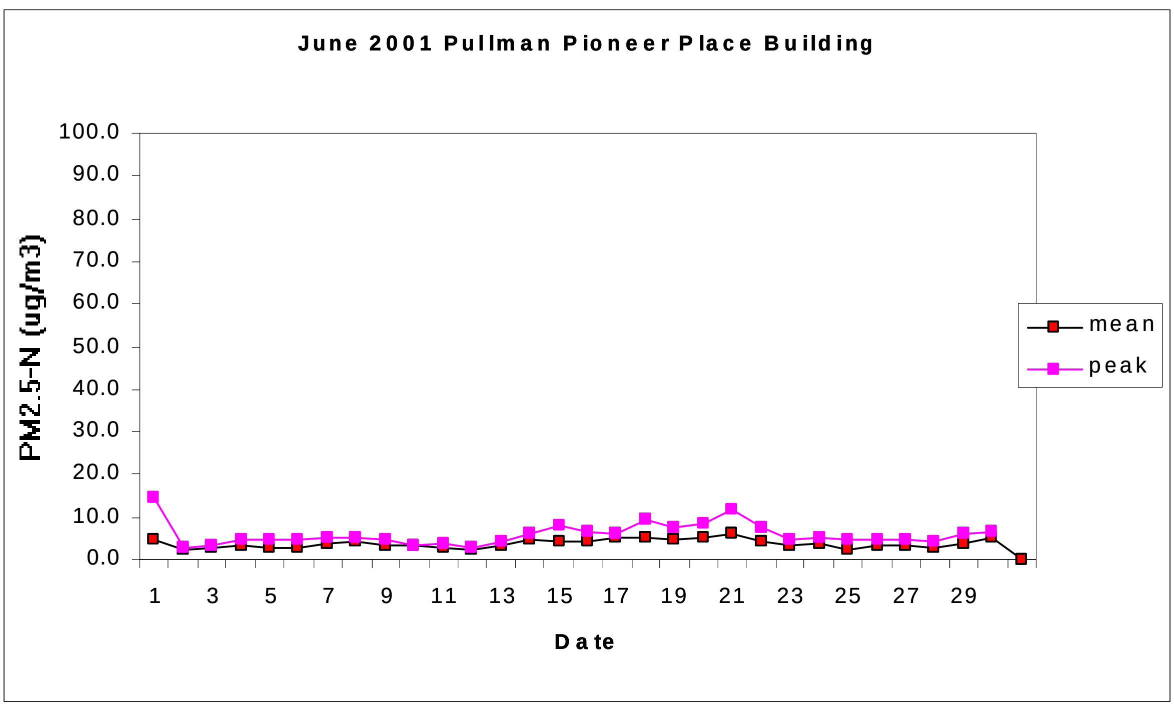
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mean
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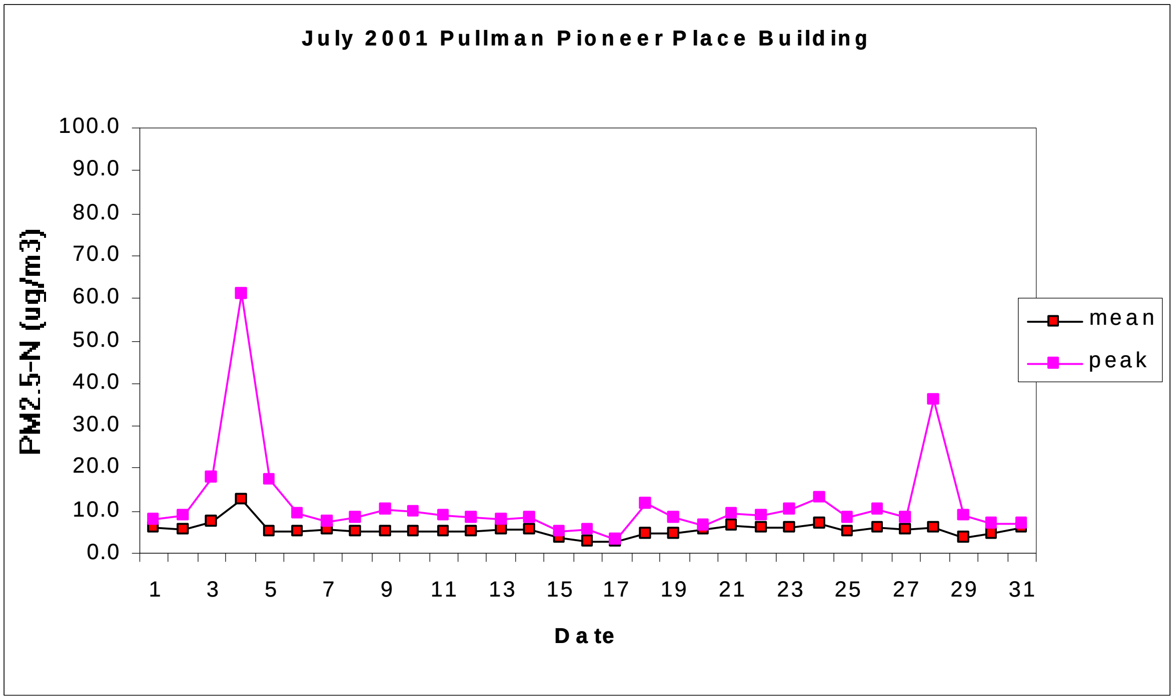
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Date
mean
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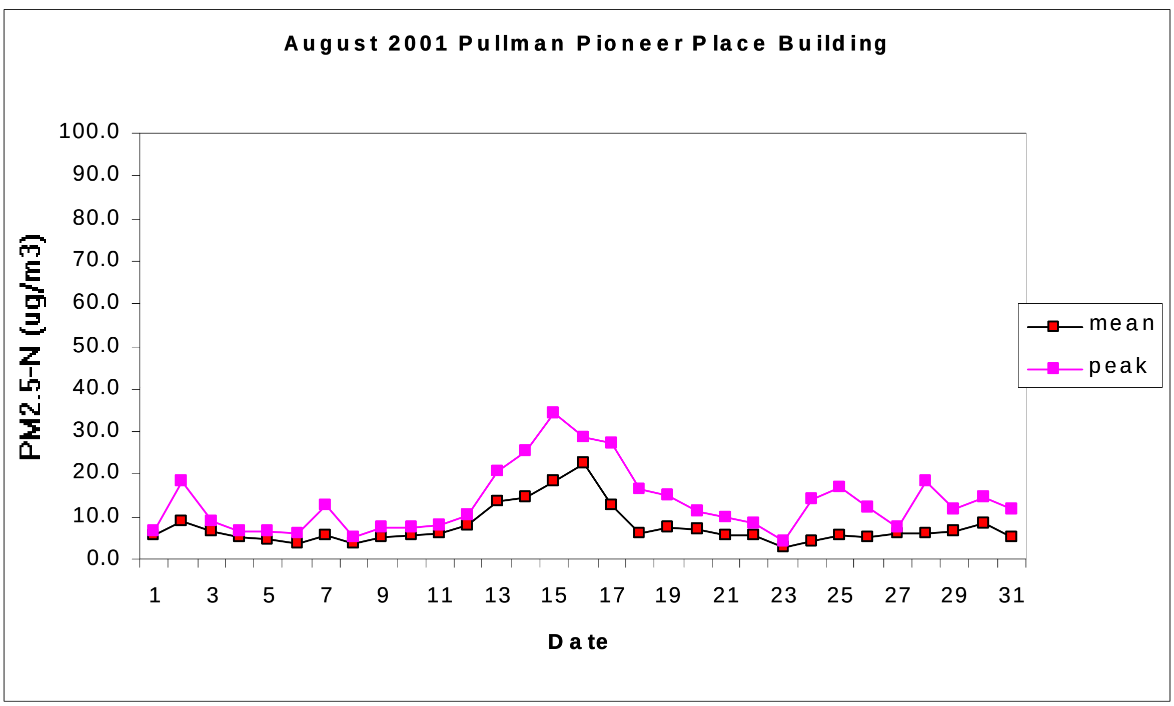
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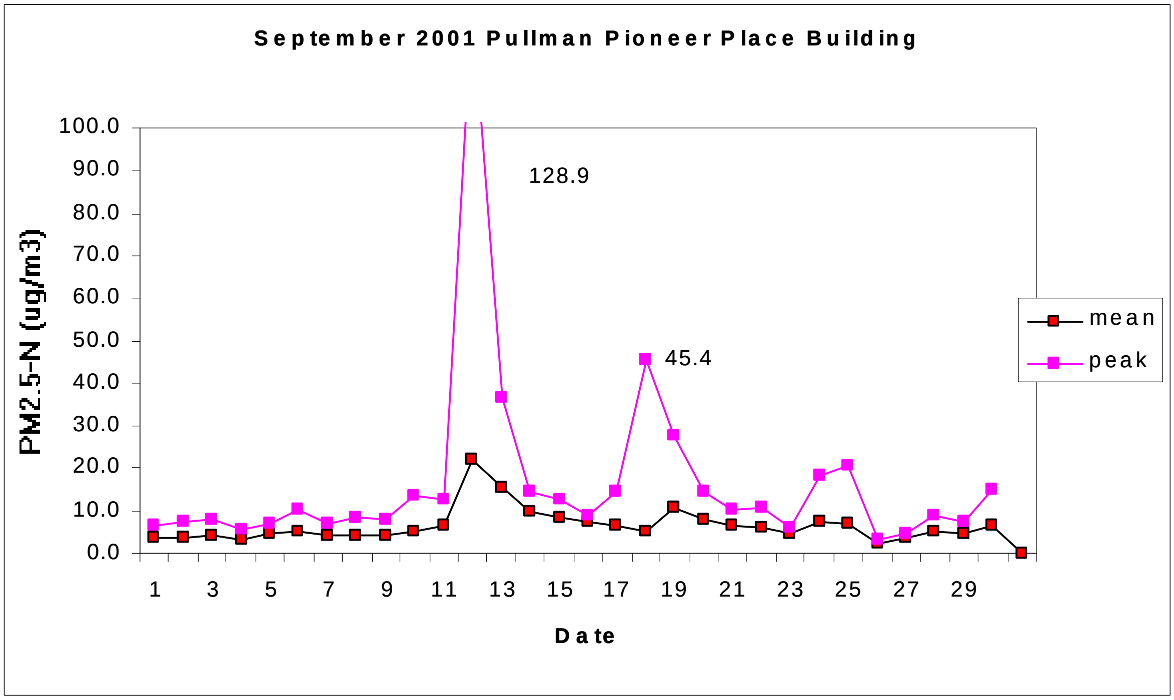
Date
mean
peak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45.4
mean
peak
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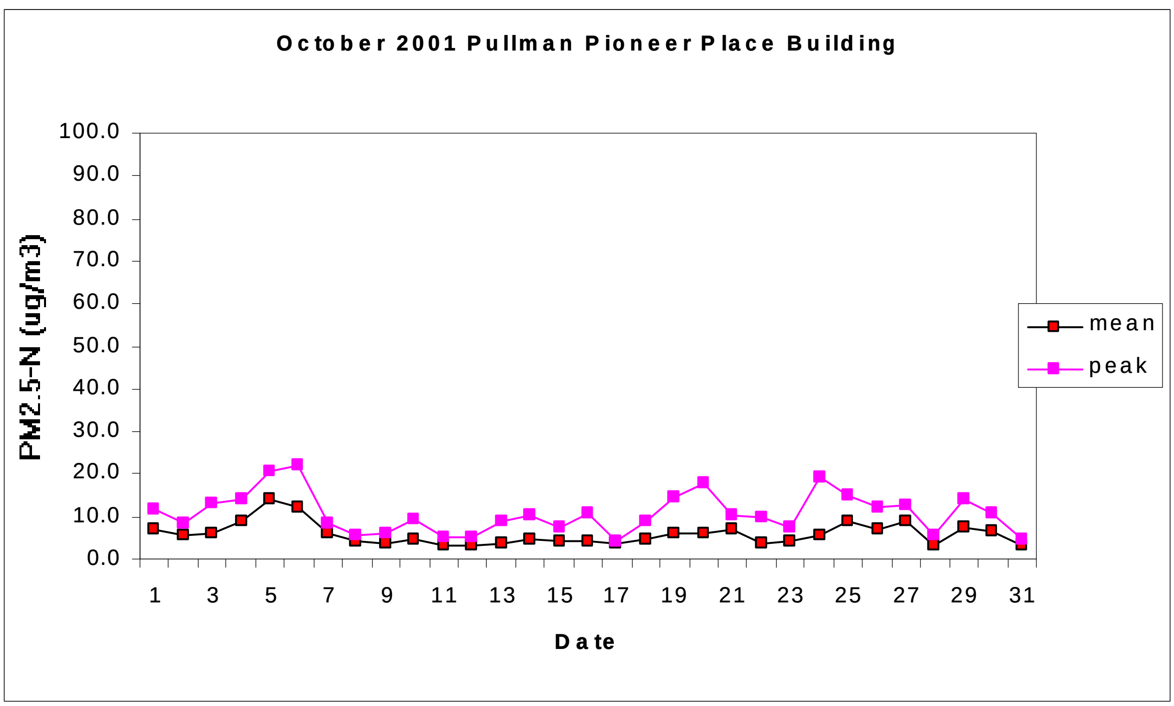
Date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peak
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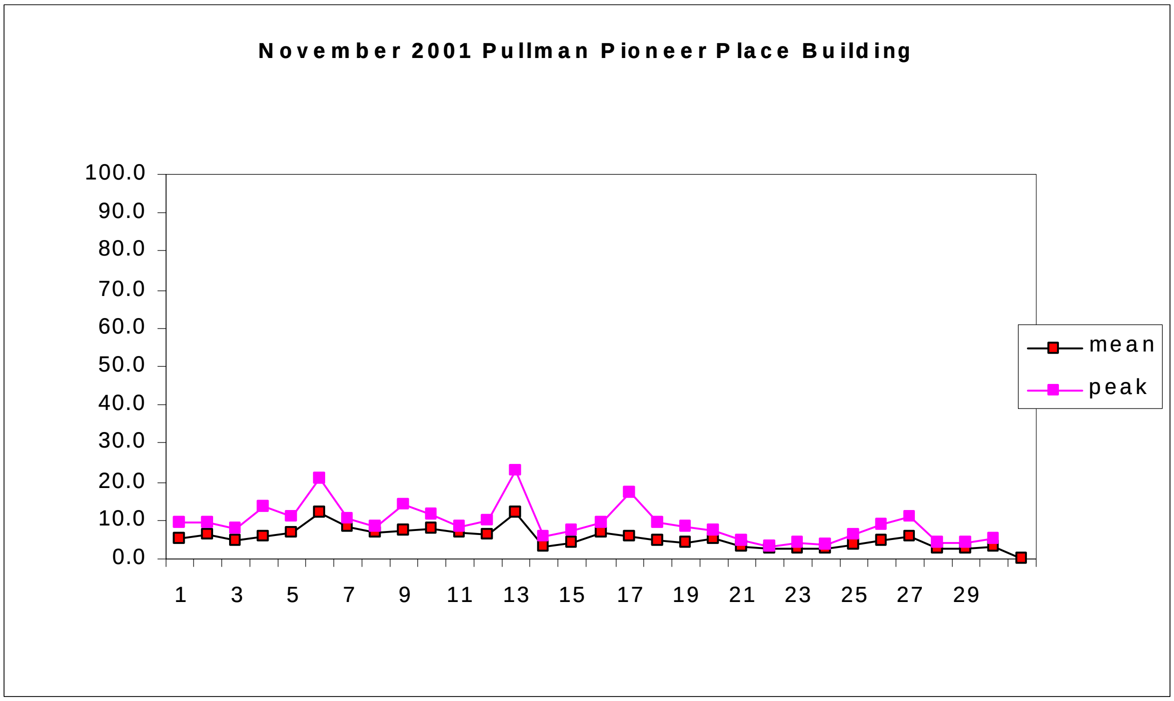
Date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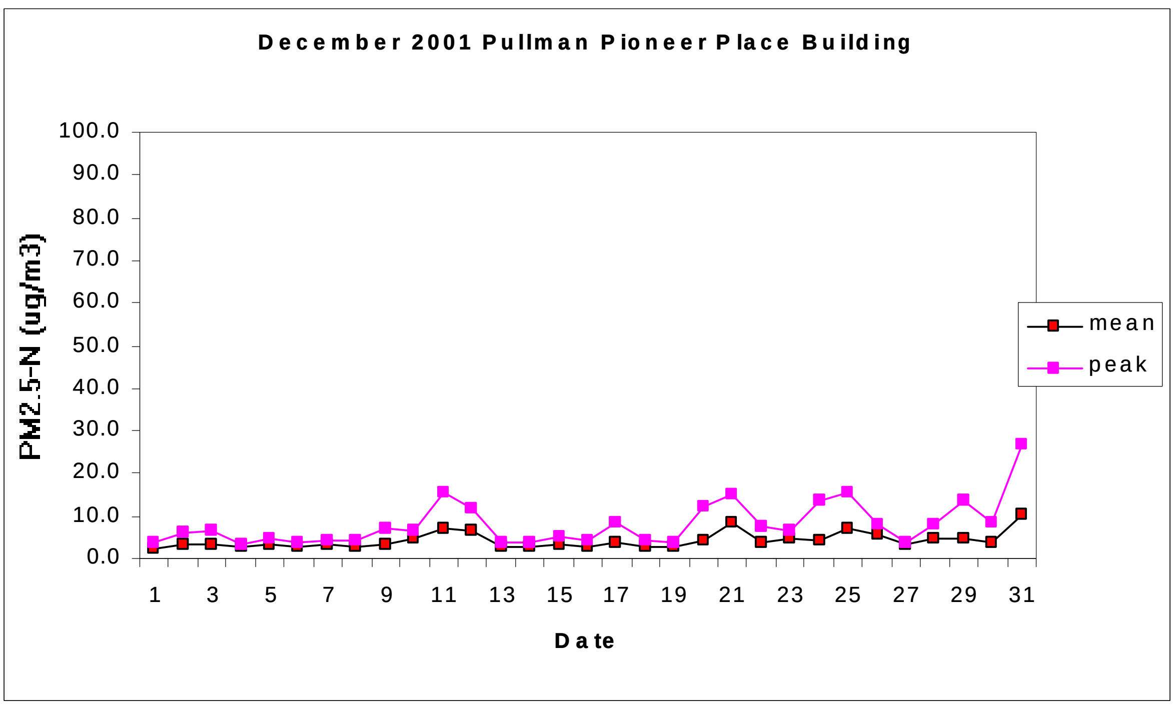
mean
peak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10.0
0.0
1
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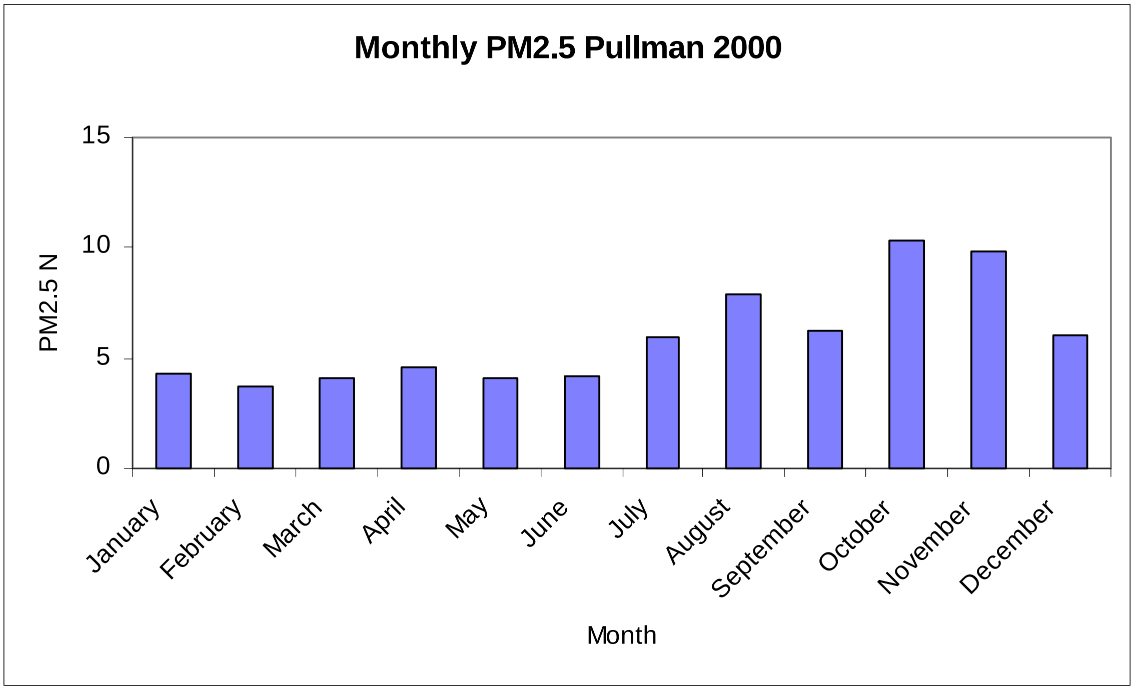
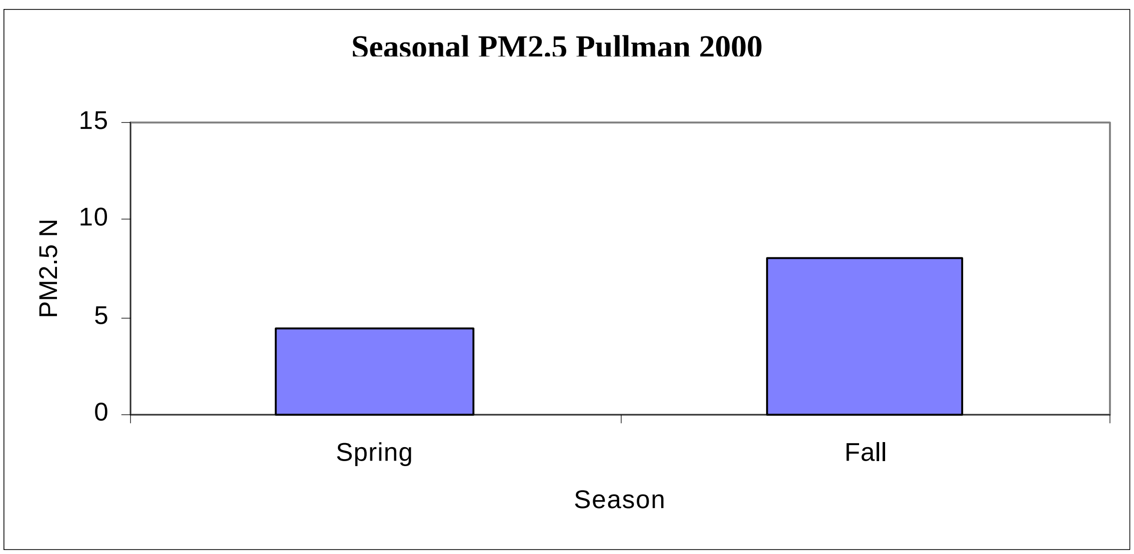
31
Date
mean
peak

APPENDIX B

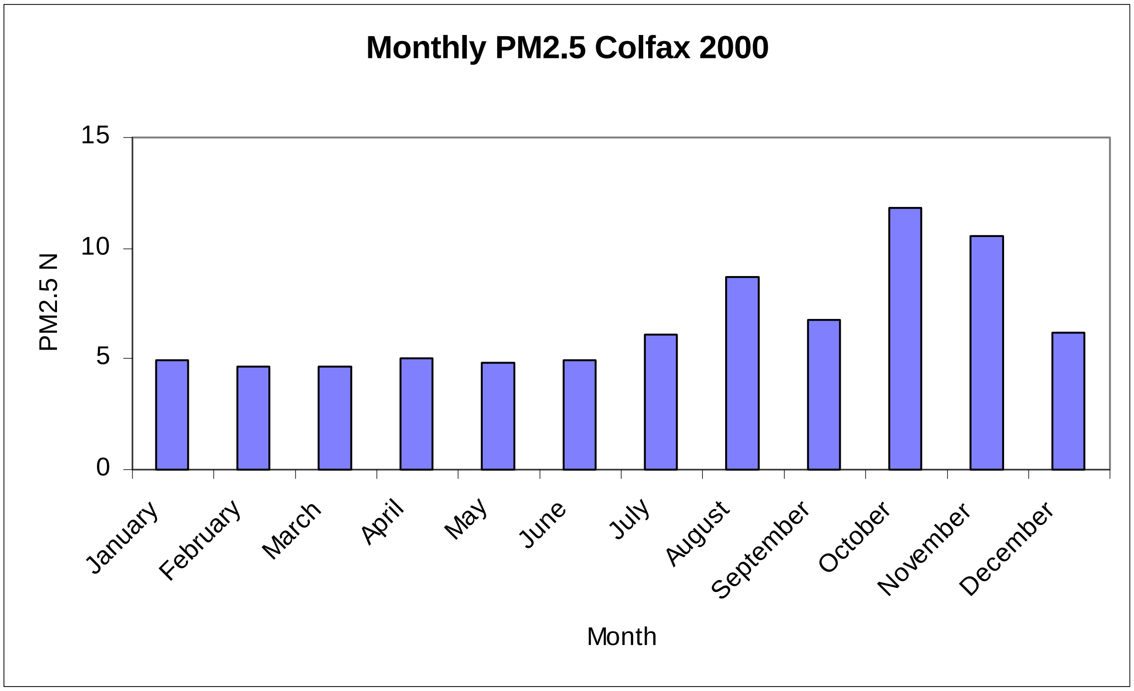
SEASONAL PARTICULATE MATTER OBSERVED IN EASTERN WASHINGTON IN 2000-2001

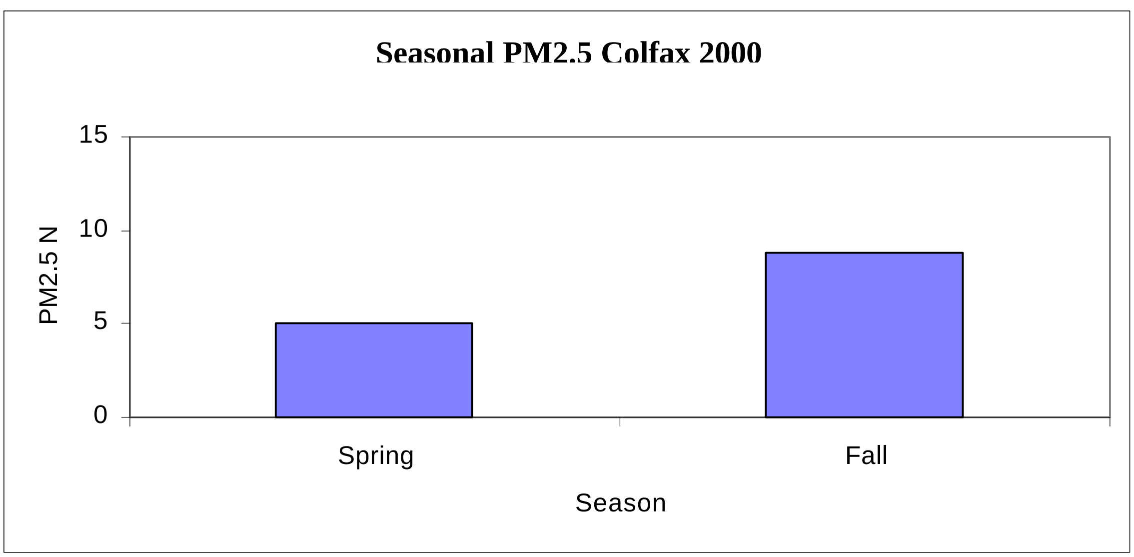


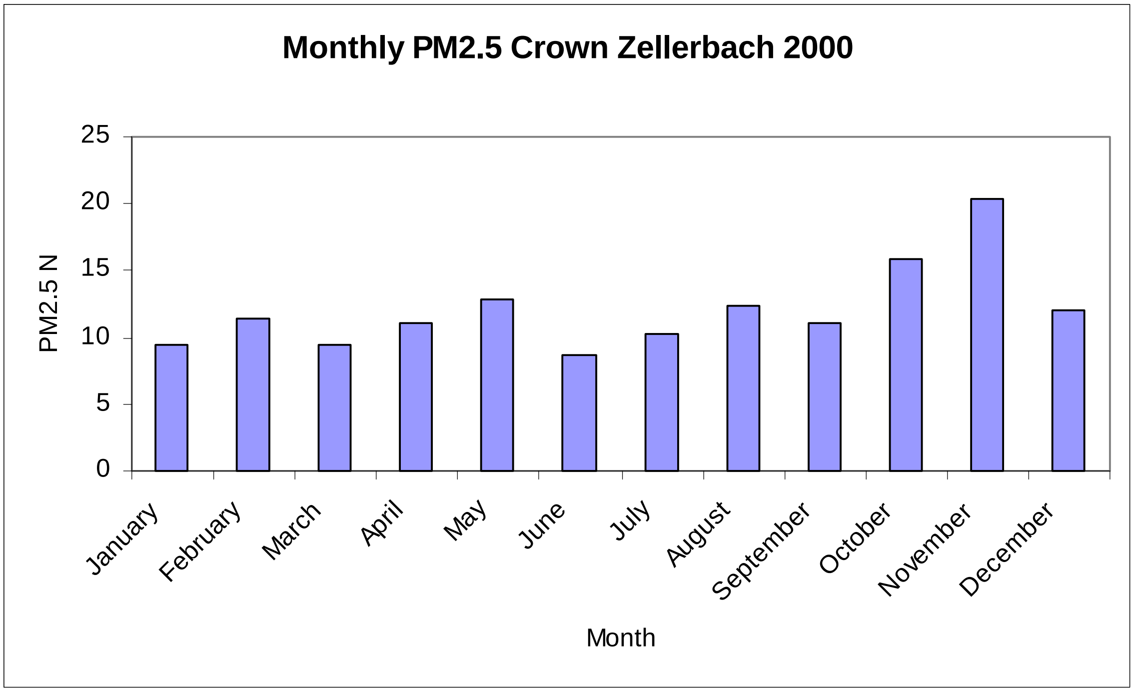
Monthly PM2.5 Pullman 2000
PM2.5 N
15
10
5
0
January
February
March
April
May
June
July
August
September
October
November
December
Month

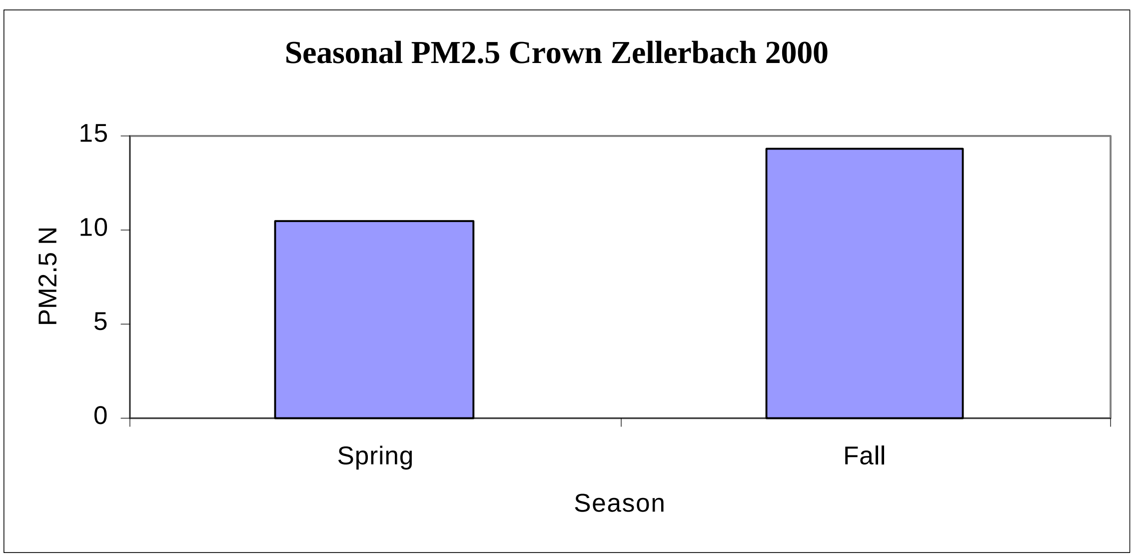


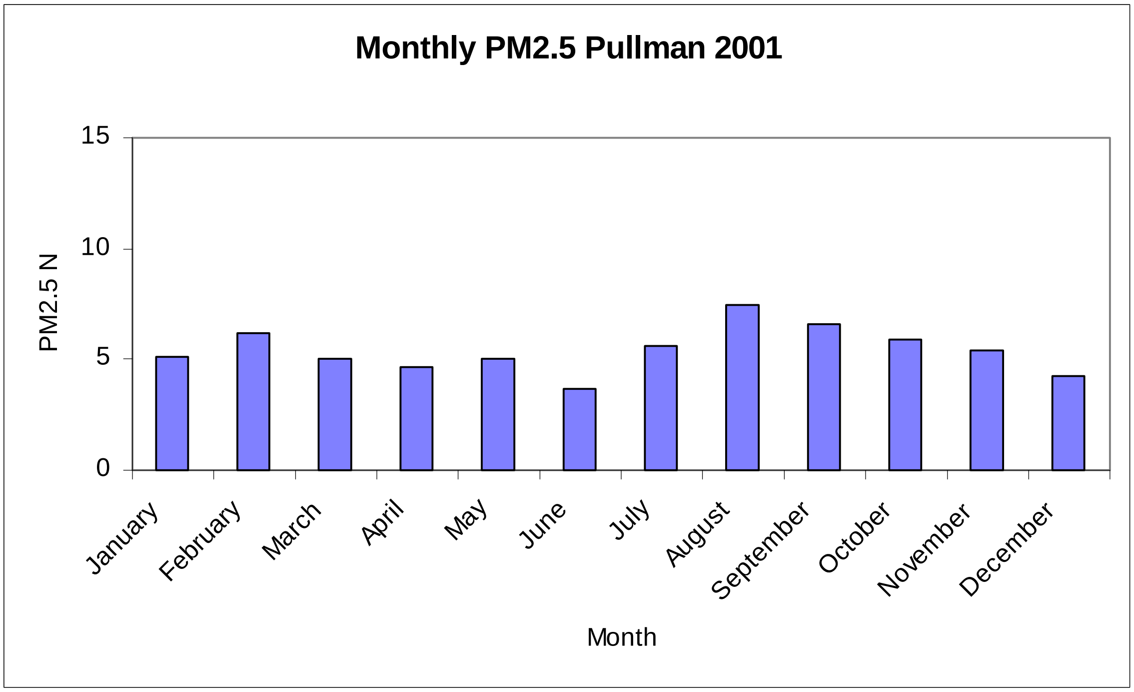
Seasonal PM2.5 Pullman 2000
PM2.5 N
15
10
5
0
Spring
Fall
Season

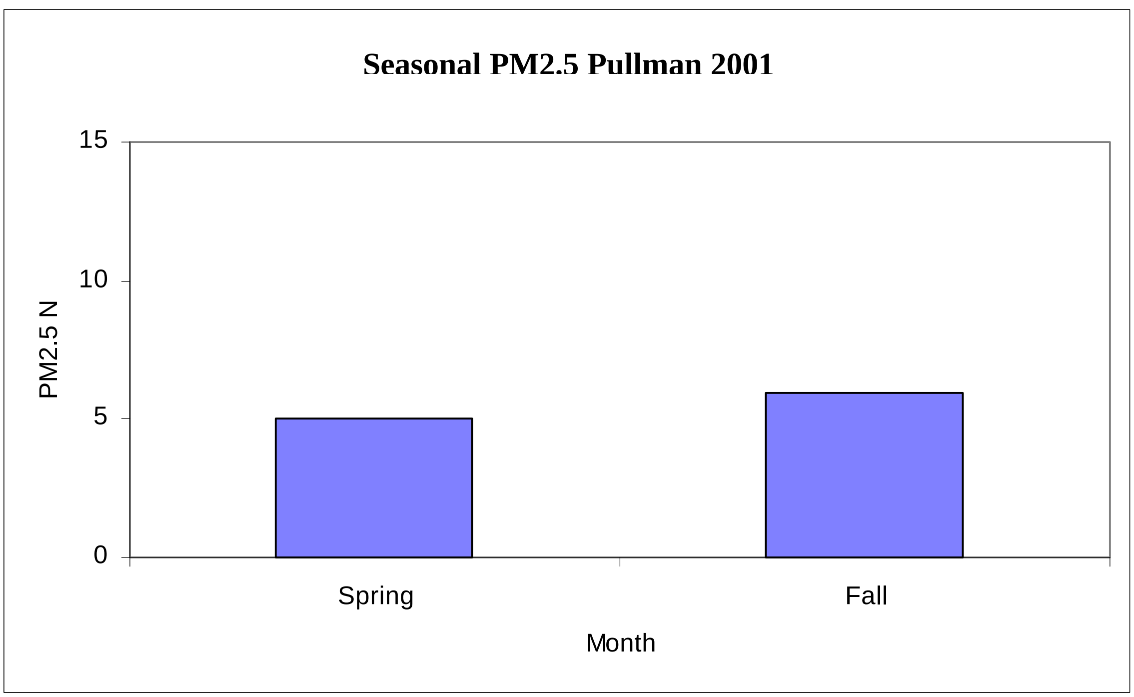

Monthly PM2.5 Colfax 2000
PM2.5 N
15
10
5
0
January
February
March
April
May
June
July
August
September
October
November
December
Month

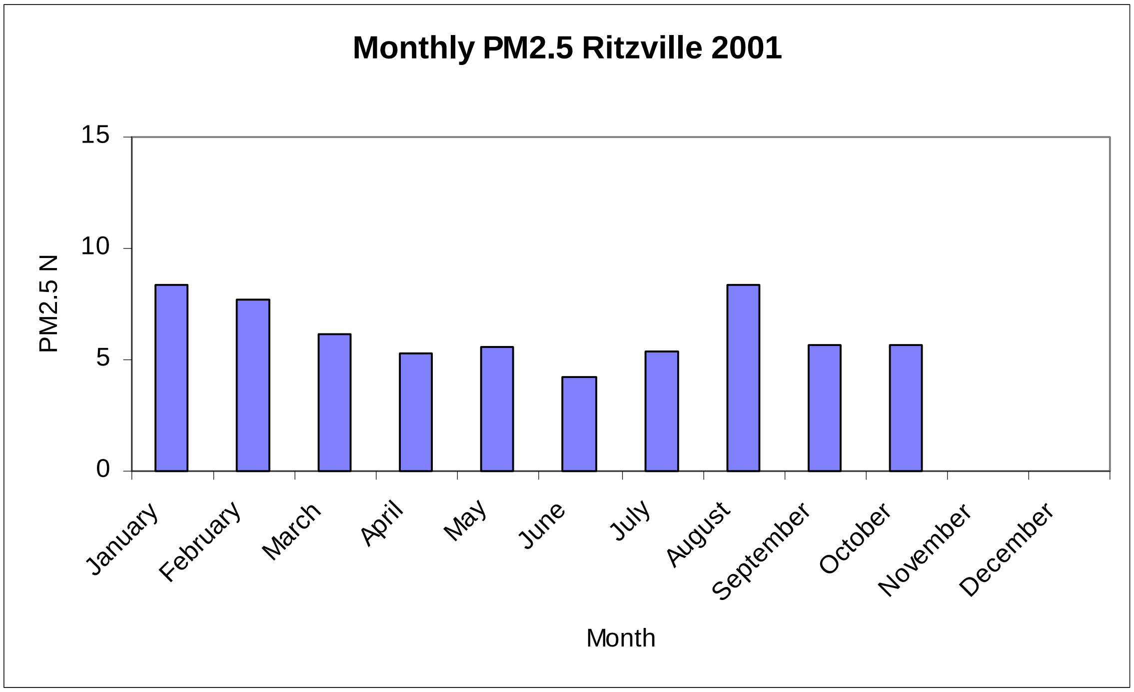

Seasonal PM2.5 Colfax 2000
PM2.5 N
15
10
5
0
Spring
Fall
Season

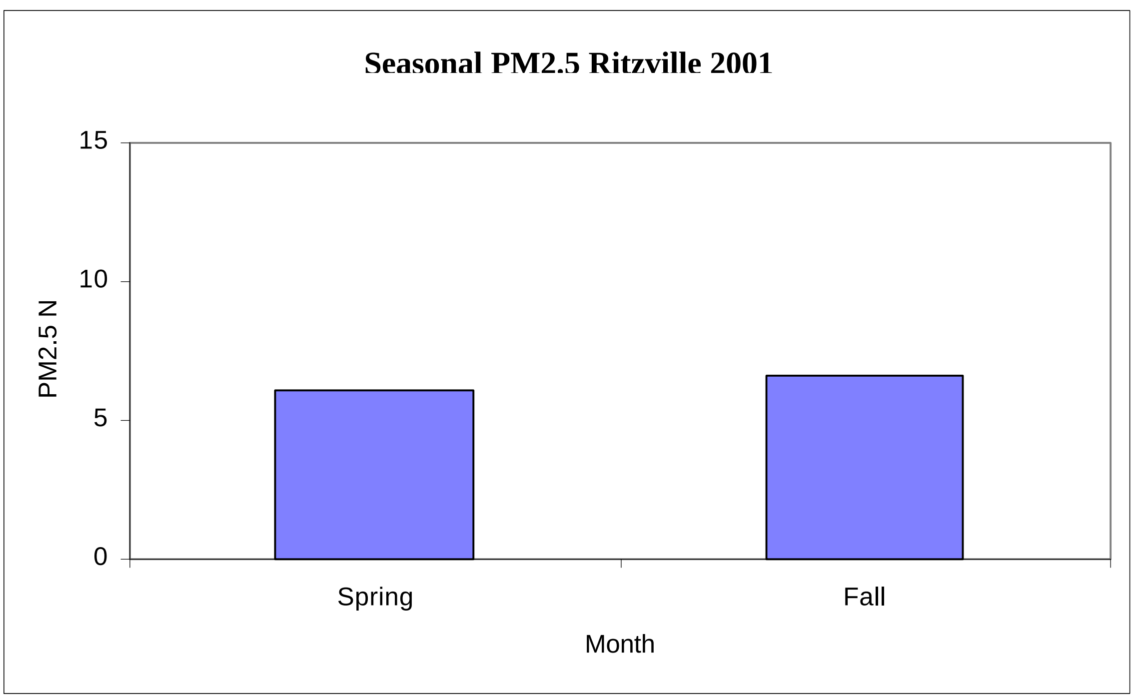

Monthly PM2.5 Crown Zellerbach 2000
25
20
15
10
5
0
PM2.5 N
January
February
March
April
May
June
July
August
September
October
November
December
Month


Seasonal PM2.5 Crown Zellerbach 2000
15
10
5
0
PM2.5 N
Spring
Fall
Season


Monthly PM2.5 Pullman 2001
15
10
5
0
PM2.5 N
January
February
March
April
May
June
July
August
September
October
November
December
Month

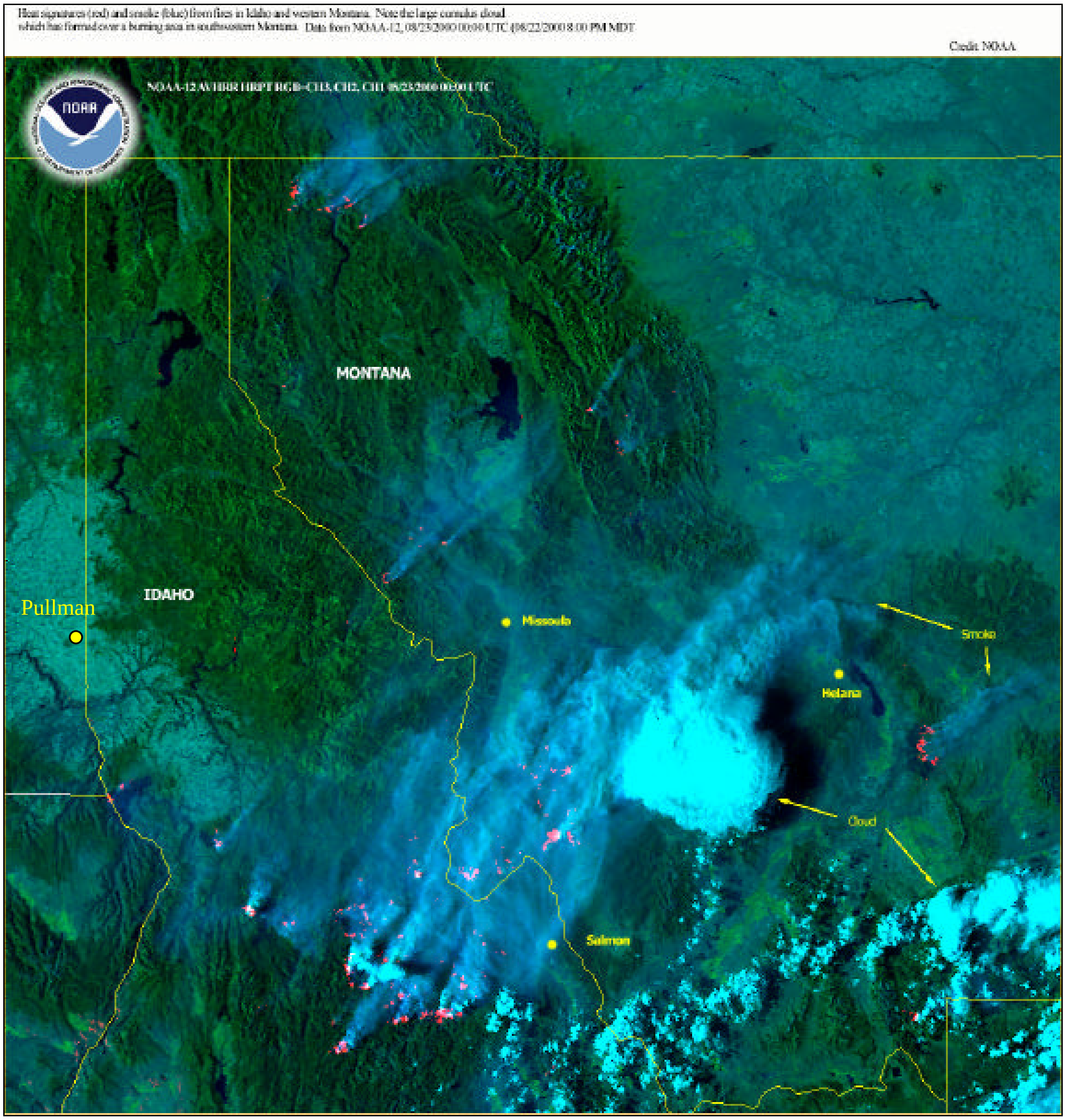

Seasonal PM2.5 Pullman 2001
15
10
5
0
PM2.5 N
Spring
Fall
Month


Monthly PM2.5 Ritzville 2001
15
10
5
0
PM2.5 N
January
February
March
April
May
June
July
August
September
October
November
December
Month


Seasonal PM2.5 Ritzville 2001
15
10
5
0
PM2.5 N
Spring
Fall
Month

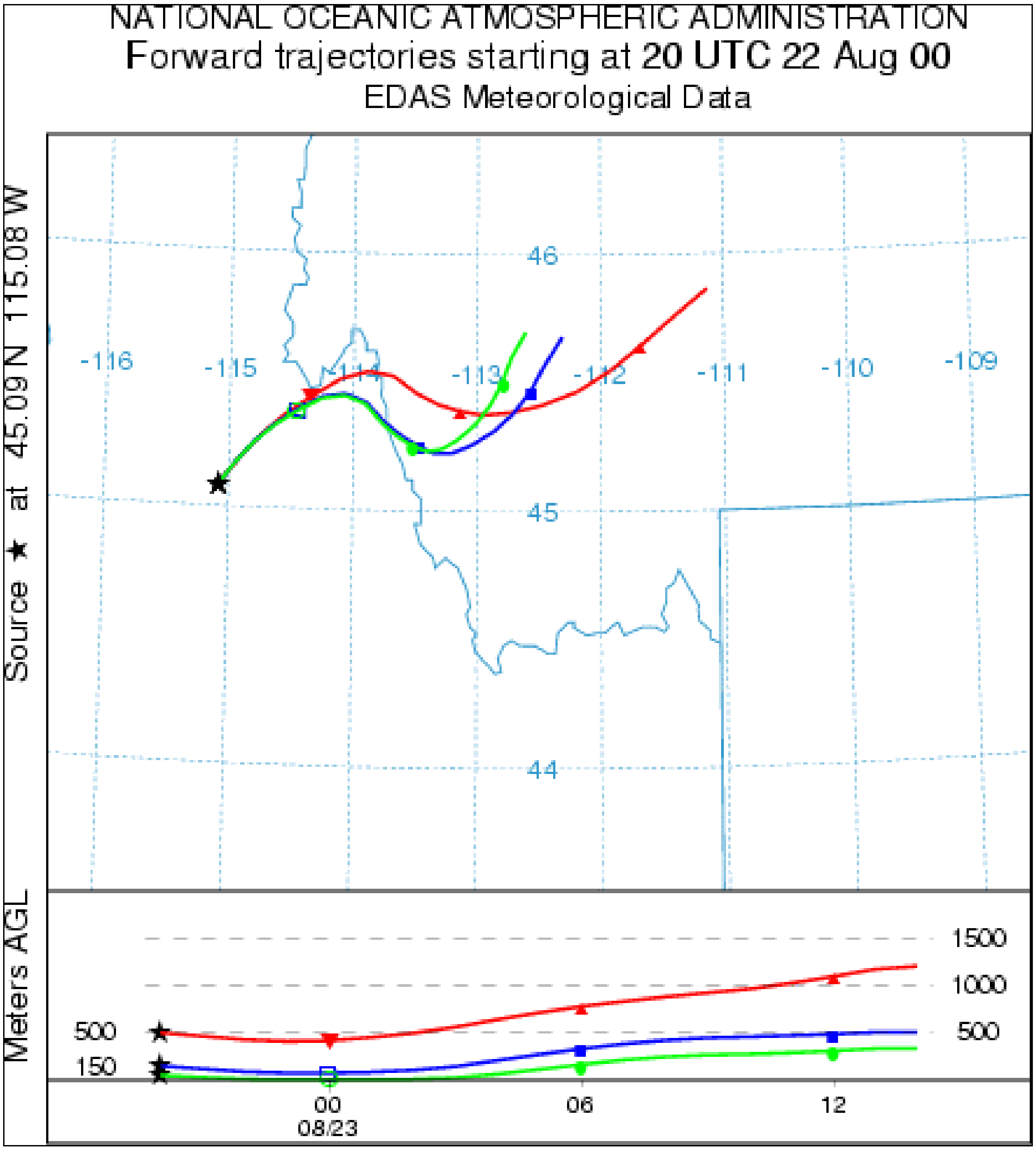
APPENDIX C

ANALYSIS OF CONSISTENCY BETWEEN HYSPLIT TRAJECTORIES AND SMOKE PLUME OBSERVATIONS FROM SATELLITE IMAGE

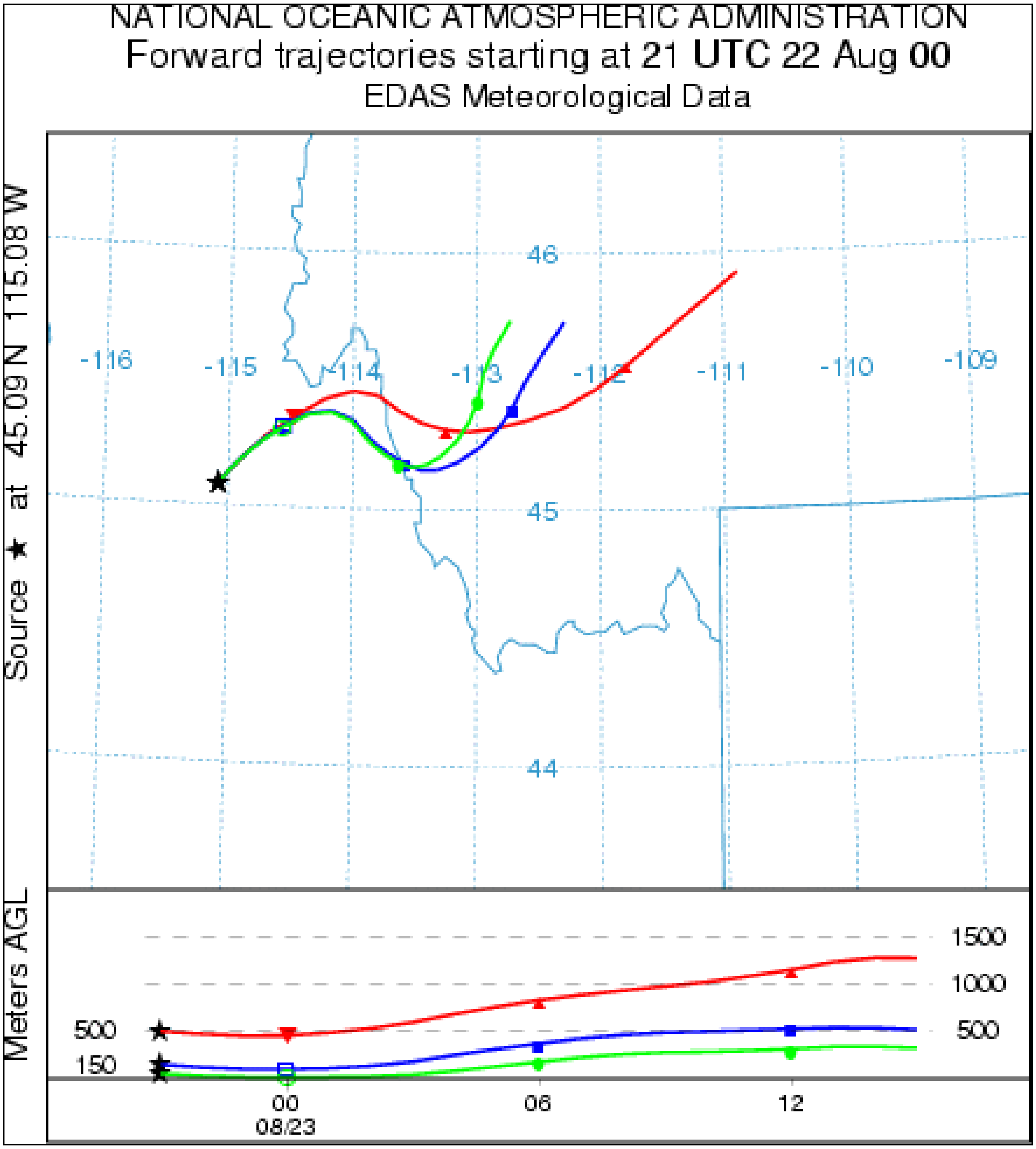


Source: http://www.osei.noaa.gov/Events/Fires/US_Northwest

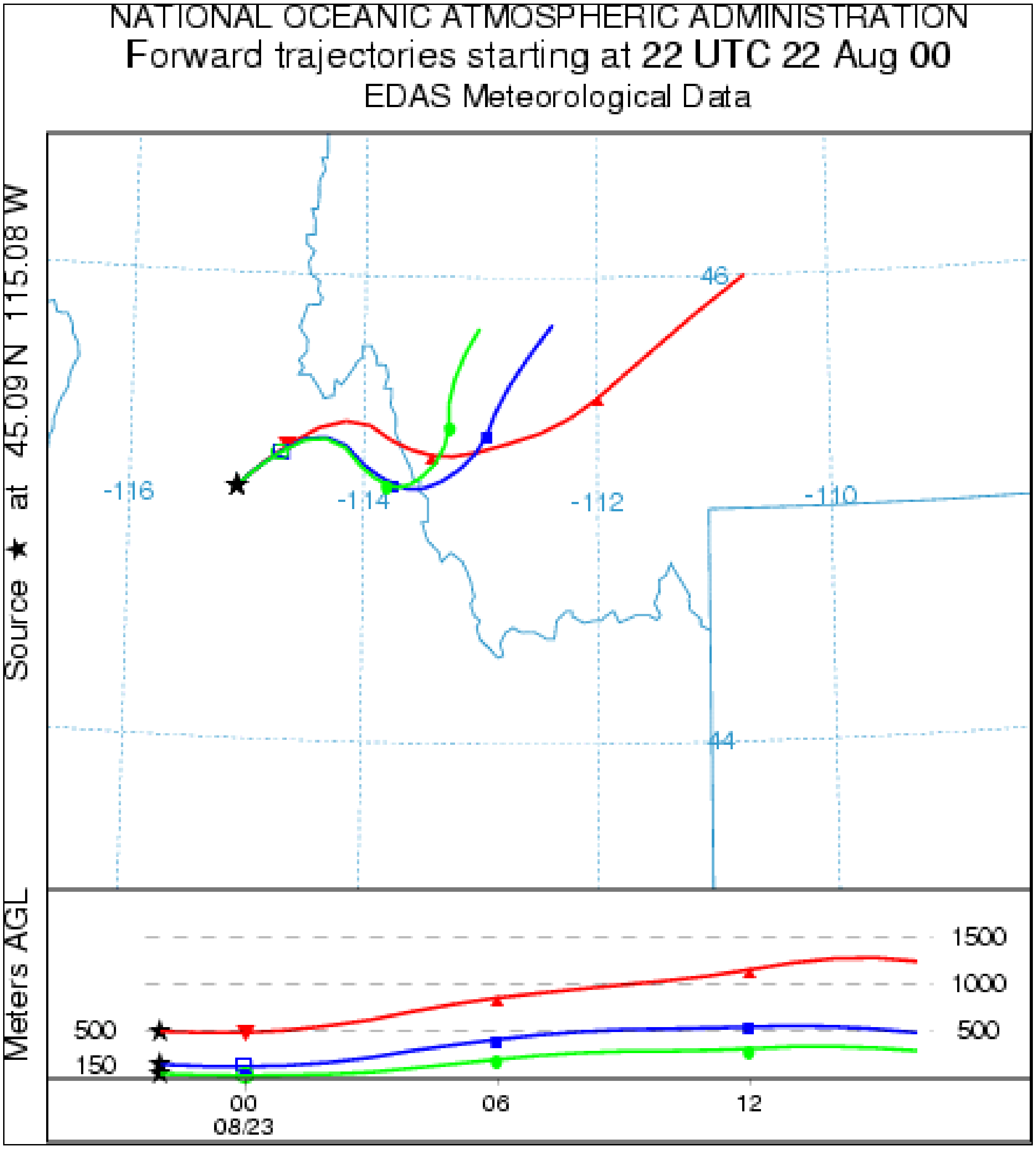
Wildfire activities in Central Idaho and Western Montana captured on a satellite picture taken at 00:00 UTC on August 23, 2000 (5:00 pm PDT, August 22, 2000). The Clear Creek fire, the Ranking Creek fire, Morse Creek Fire, Wilderness Fires and Marling Spring Fire with more than 275,000 acres total. Note the smoke plume (light blue) heading toward Montana.



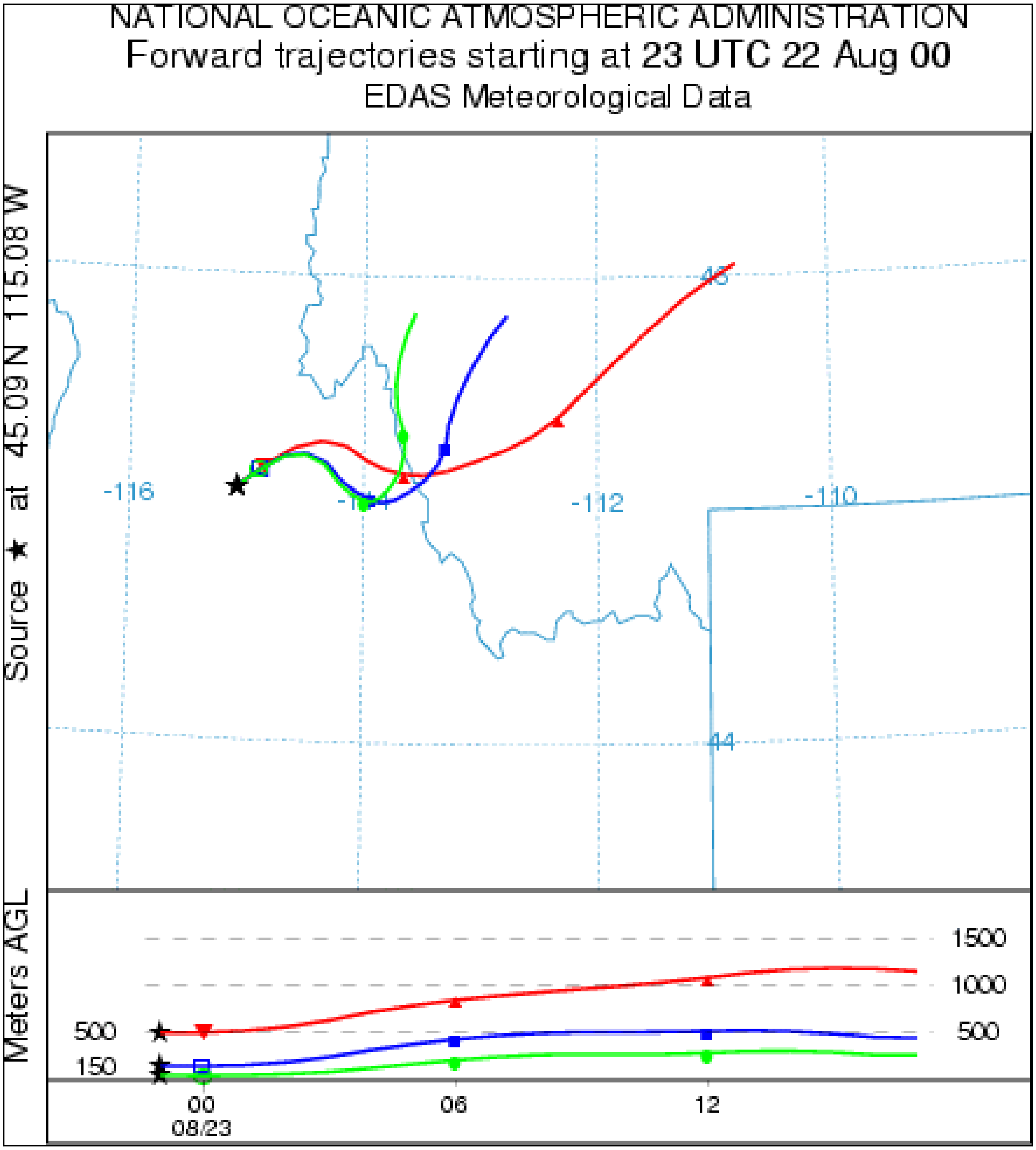
Forward trajectory generated by HYSPLIT from the wildfires in Central Idaho at 20 UTC on August 22, 2000 using archived EDAS meteorological forecast data. Note consistency between the smoke observed in the satellite image and the trajectories generated by the model.



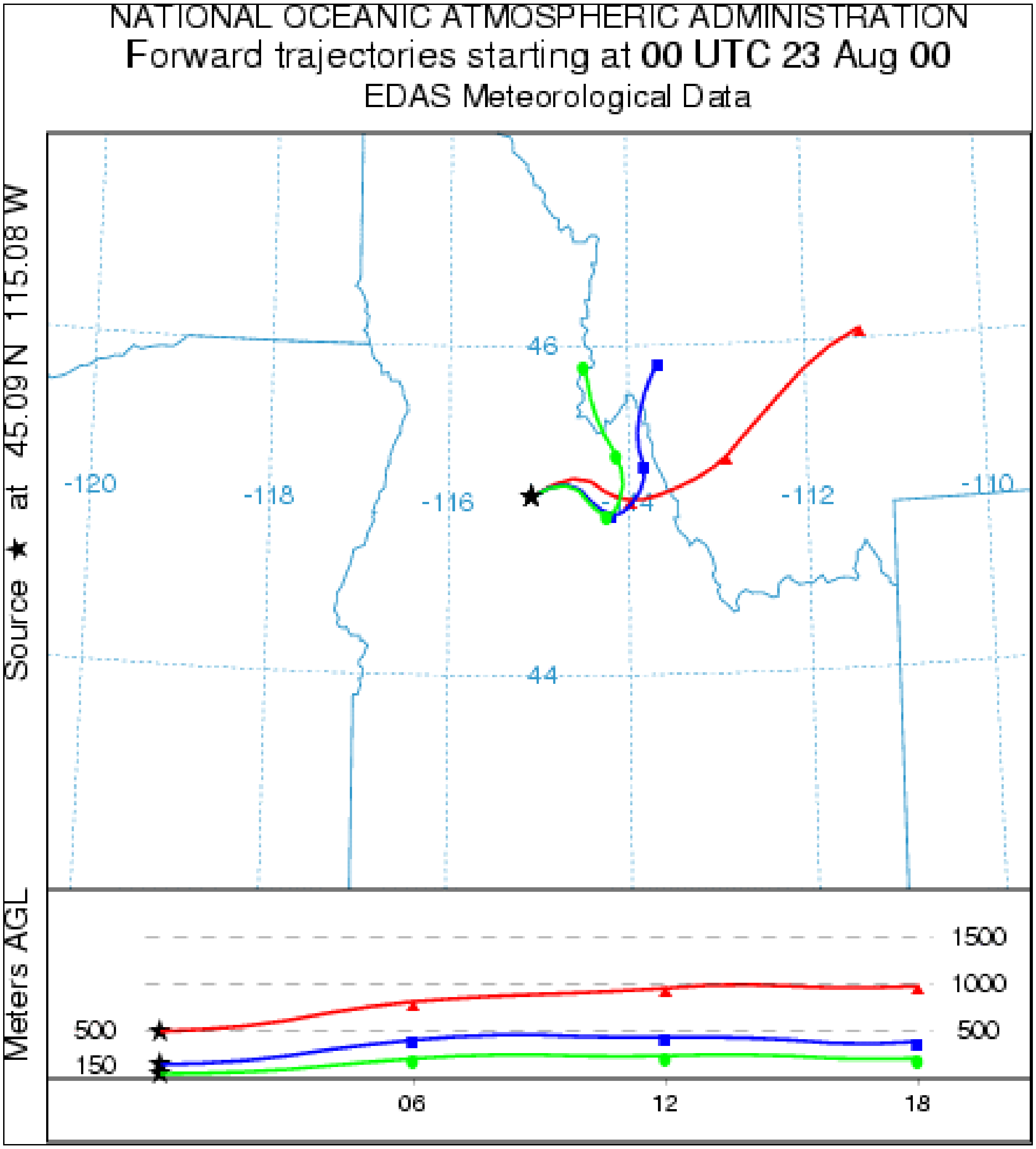
Forward trajectory generated by HYSPLIT from the wildfires in Central Idaho at 21 UTC on August 22, 2000 using archived EDAS meteorological forecast data.



Forward trajectory generated by HYSPLIT from the wildfires in Central Idaho at 22 UTC on August 22, 2000 using archived EDAS meteorological forecast data.



Forward trajectory generated by HYSPLIT from the wildfires in Central Idaho at 23 UTC on August 22, 2000 using archived EDAS meteorological forecast data.



Forward trajectory generated by HYSPLIT from the wildfires in Central Idaho at 00 UTC on August 23, 2000 using archived EDAS meteorological forecast data.