DENVER EARLY ACTION OZONE COMPACT
Wildfire Emission Inventory

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Introduction

Emissions estimates for wildfires were estimated using methodology developed by the Fire Emissions Joint Forum (FEJF) at the Western Regional Air Partnership (WRAP). This methodology is described in the document, "DRAFT FINAL REPORT –1996 Fire Emission Inventory (December 2001)" by Air Sciences, Inc. Fire characteristic data were processed as point sources following the methodology used by the WRAP.

Spatial Distribution of Wildfires

Wildfires were located using heat detection images from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite system. The location, along with other fire characteristic information, was confirmed using data from National Interagency Coordination Center (NICC) Fire Incidence Reports.

Figures 1 and 2 show the location of all wildfires in 2002 for the modeling domain. Light shaded dots on Figures 1 and 2 show the location of active wildfire during the June 25-July 1 ozone episode and the July 18-21 episode respectively. The symbols on figures 1 and 2 are not to scale but do represent the daily location of the wildfires. In order for the fires to appear on satellite imagery, the fires are usually about 100 acres in size.

Wildfire Activity Data

National Interagency Coordination Center (NICC) Fire Incidence Reports contained the name and other characteristics of the various fires that were not contained in the MODIS data sets.

Wildfires were reported as individual fires and as the total number of fire days. Thus, a wildfire that burned over three days was reported as one fire, referred to as a fire event, and as three fire days. The source data of wildfire activity contained both the total acreage of a fire as well as acreage consumed on a daily basis. The latter was calculated as the difference in fire size on that day and the fire size the day before. If no fire growth occurred during that period, the daily acreage was set to zero. Total fuel consumption was calculated as:

Equation 1: Daily Wildfire Emissions Calculation

$$\text{Daily emission (tons)} = \frac{\text{Acreage burned (acres)} * \text{Fuel load (tons/acre)} * \text{Emission factor (lbs/ton)}}{2000\ \text{(lbs/ton)}}$$

Equation 2: Smoldering Factor

$$\text{Emission}_{\text{total day 2}} = \text{Emission}_{\text{day 2}} + \left(\text{Emission}_{\text{day 1}} * 0.17\right)$$

Figure 1: Location of fines during the June 25-July 1 episodes (yellow areas are active)

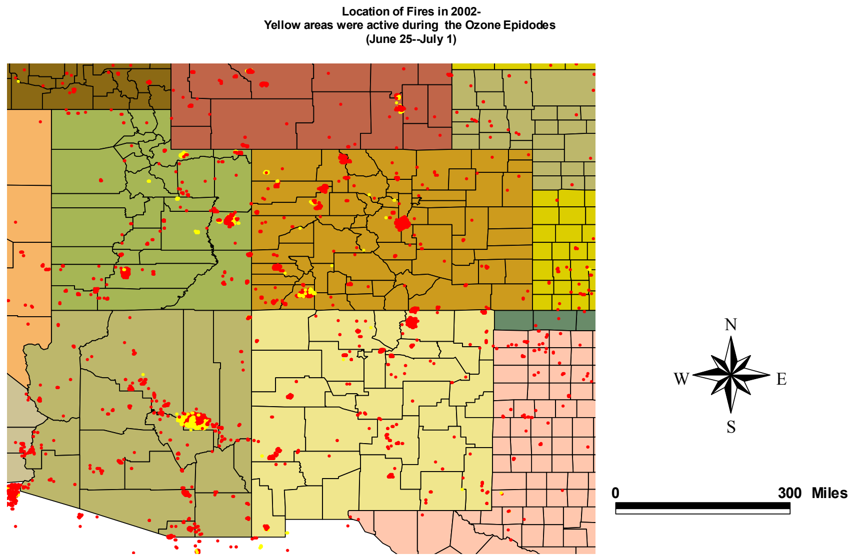
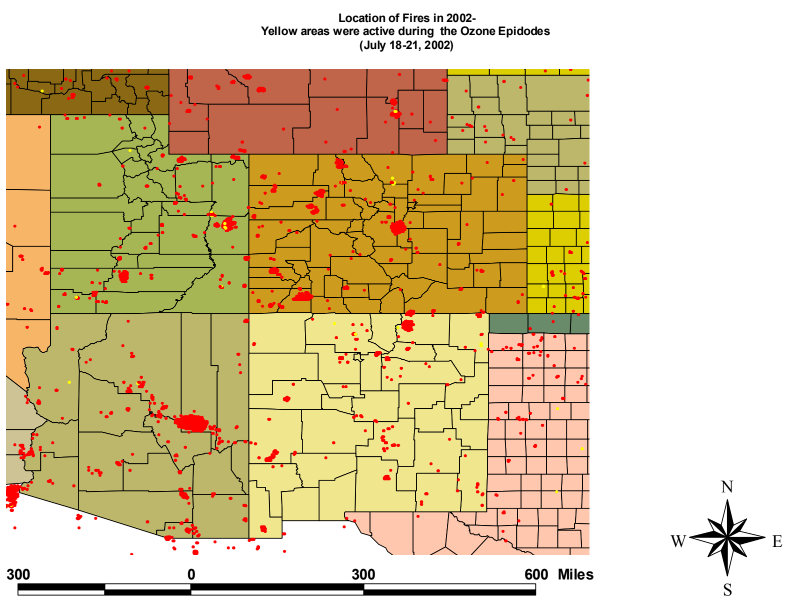


Figure 2: Location of fires during the July 18-21, episode (yellow areas are active)



Wildfire Characteristics

ENVIRON developed software for use with the EPS2x emission inventory system to assign a plume profile for each daily fire event. The plume values include: the top and bottom of the plume (PTOP and PBOT, respectively; both expressed in meters above ground elevation), and the percent of emissions entrained within the surface layer of the atmosphere (LAY1F), defined as the first 80 meters above the ground. These three plume parameters are established and assigned for each of the 24 hours of each daily fire event. All of the plume values were assigned based on the limited information available for each fire event, including fire size (or fire area grown per day) and either a reported fuel loading or the National Fire Danger Rating System (NFDRS) fuel model.

Estimates of buoyant efficiency and entrainment efficiency were derived from methods described by the WRAP FEJF.

The following steps were taken to assign plume characteristics to each of the normalized fires in the 2002 inventories:

1. Estimate the hourly emissions rate for each fire using a standard diurnal consumption template that was formulated based on expert opinion. The WRAP Emissions and Modeling Forums requested hourly rates of fire emissions. To satisfy this temporal requirement, daily emissions for each wildfire and prescribed fire event in the inventory were apportioned to hourly emissions using the standard diurnal consumption template presented in Table 1

Table 1: Standard Diurnal Consumption Template Used to Distribute Fire-Total Heat Production and Emissions

Hour	1	2	3	4	5	6	7	8	9	10
% per hr	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	2.00
Hour	13	14	15	16	17	18	19	20	21	22
% per hr	10.00	13.00	16.00	17.00	12.00	7.00	4.00	0.53	0.53	0.53

2. Calculate daily virtual fire acreages to normalize the virtual plume diameter based on fuel loading (or spatial fuel density) including crown fuels consumed. The virtual acreage was calculated by multiplying the actual fire size by the square root of the normalized pre-burn fuel loading. This was done in order to relate fuel loading to the characteristic "stack" diameter of the plume. For wildfire and prescribed fire days, the total fuel loading was normalized to 13.8 tons per acre, which is the total surface loading plus crown biomass for NFDRS fuel model U (western pines).

Equation 3:

$$\text{Acreage}_{\text{virtual}} = \text{Acreage}_{\text{actual}} \cdot \sqrt{\text{Fuel Loading} / 13.8}$$

Days added to model smoldering for the day after an original activity day also had a virtual acreage computed. For wildfires, an additional 13.5 percent of the acres the day before were assumed to smolder the following day (see above). To model the heat release for these smoldering-adjusted events, the acreage for that day was set as 13.5 percent of the *original* acreage of the day before.

Equation 4:

$$\text{Wildfire Acreage}_{\text{virtual}} = \text{Acreage}_{\text{day before}} * 0.135 * \sqrt{\text{Fuel load} / 13.8}$$

For the purpose of assigning a specific plume profile to each fire event, five virtual acreage size classes were established. The virtual acreage size classes are shown in Table 2.

Table 2: Virtual Acreage Size Classes

Class	1	2	3	4	5
Size (acres)	0 – 10	>= 10 – 100	>= 100 – 1,000	>= 1,000 – 5,000	>= 5,000

3. Calculate the vertical plume profile (i.e., the height, in meters above ground elevation, at the top and bottom of the plume) for a perfectly buoyant energy source for each hour for each fire based on virtual daily fire acreage.

For each virtual size class, the following variables were encoded: size-related buoyant efficiency (BEsize), the maximum possible top of plume, and the minimum possible bottom of plume. All were expressed as a function of virtual acres. The hourly table contains a buoyant efficiency (BEhour) that varies with the time of day during the fire. The values for these variables are shown in Table 3 (showing variables as a function of fire size) and Table 4 (showing BEsize as a function of hour of day).

Table 3 Fire-Related Parameters as Function of Fire Size Classes

Class	1	2	3	4	5
Size (virtual acres)	0 – 10	>= 10 – 100	>= 100 – 1,000	>= 1,000 – 5,000	>= 5,000
BE_{size}	0.4	0.6	0.75	0.85	0.9
P_{top} max (m)	160	2,400	6,400	7,200	8,000
P_{bot} min (m)	0	300	800	1,600	1,600

Table 4: Buoyant Efficiency as Function of Hour of Day

Hour	1	2	3	4	5	6	7	8	9	10	11	12
BE_{hour}	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.06	0.10	0.2	0.4
Hour	13	14	15	16	17	18	19	20	21	22	23	24
BE_{hour}	0.7	0.8	0.9	0.95	0.99	0.8	0.7	0.4	0.06	0.03	0.03	0.03

Equations were used to calculate Ptop, Pbot as a function of time of day and size of the fire (again, expressed in terms of virtual acres). Note that the calculations use an hourly value for buoyant efficiency and heat release value based on fire size, also referred to as a normalized fire growth.

The hourly top of the plume was calculated as follows:

Equation 5:

$$Ptop_{hour} = (BE_{hour})^2 * (BE_{size})^2 * Ptop_{max}$$

where BE is the buoyant efficiency looked up from the hourly or size class tables. The hourly bottom of plume was similarly calculated as:

Equation 6:

$$Pbot_{hour} = (BE_{hour})^2 * (BE_{size})^2 * Pbot_{min}$$

4. Lastly, an equation was used to calculate LAY1F, the proportion of emissions fumigated into the first atmospheric layer (below 80 m). LAY1F was calculated as the arithmetic inverse of the hour specific buoyant efficiency multiplied by the size specific buoyant efficiency.

Equation 7

$$Lay1F_{hour} = 1 - (BE_{hour} * BE_{size})$$

Using equations 5 through 7, the bottom and top of the atmospheric plume as well as the proportion of the plume fumigated into the first atmospheric surface layer were all scaled to fire size, fuel loading (incorporated in virtual acres calculation) and hour of the day. Figures 4.2 through 4.5 illustrate the relationships described above.

Figure 3: The relationship between buoyancy efficiency and time of day

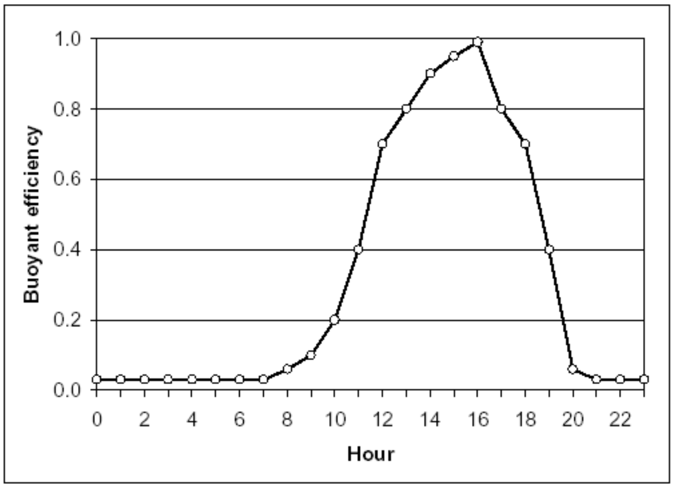


Figure 4: The projected top of the atmospheric plume (m) as a function of time of day and fire size. Fire sizes represent the upper cutoff of the fire size categories. The lowest line represents the 10 acres cutoff. Note the logarithmic scale on the y-axis.

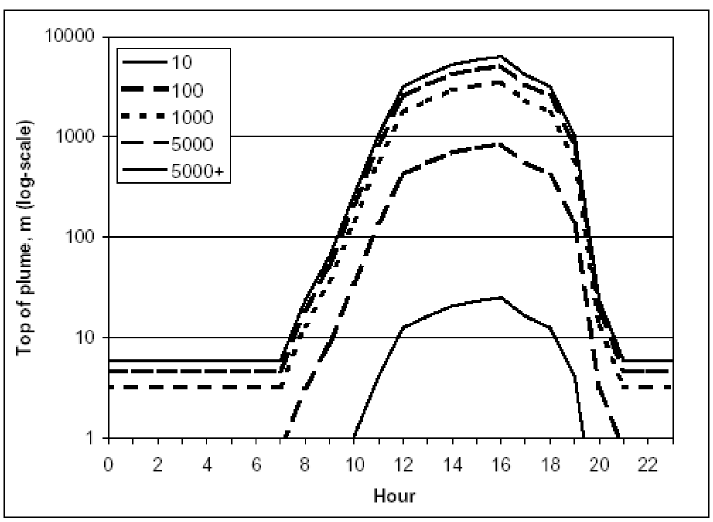


Figure 5: The projected bottom of the atmospheric plume (m) as a function of time of day and fire size. Fire sizes represent the upper cutoff of the fire size categories. The line representing the 10 acres cutoff is constant at a value of zero.

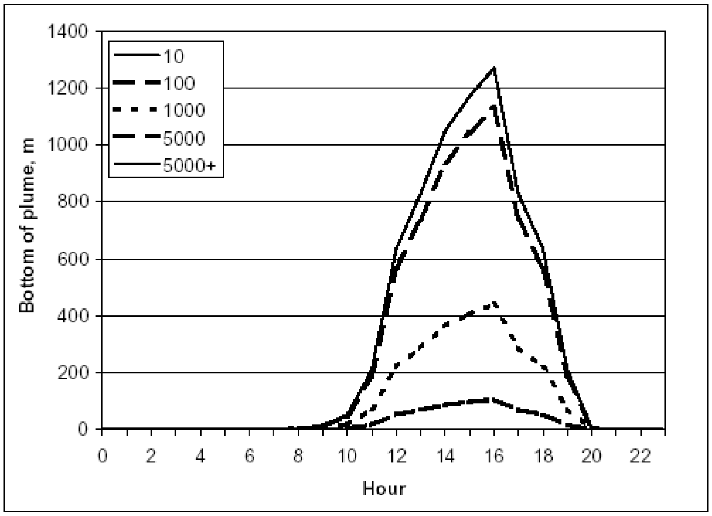
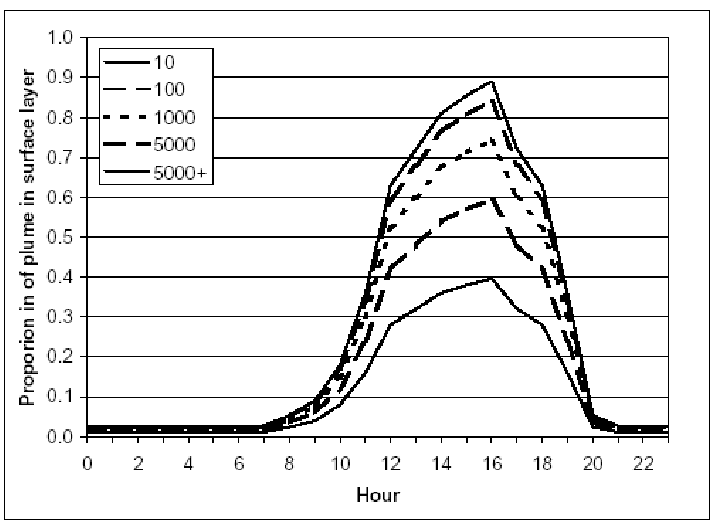


Figure 6: The proportion of the plume fumigation to the atmospheric surface layer (<80 m) as a function of time of day and fire size. Fire sizes represent the upper cutoff of the fire size categories. The lowest line represents the 10 acres cutoff.



Emissions Summary

Table 5 presents a daily average of total emission by domain for July-August 2002. Table 6 presents a summary of wildfire emissions over the entire domain in tons/day. The entire domain includes, the Denver ozone nonattainment area, the rest of Colorado and the other States within the modeling domain. Table 6 presents a daily average of total emission by domain for July-August 2002. Figure 7 and 8 presents emissions from wildfires within the state and along the front range. As seen in Figures 7 and 8, most of the emissions from wildfires occurred in early June 2002 before the episodes. Fairly minimal activity occurred with the state and along the front range during this time period. However, during the June25-July 1 episode, there was some reported smoke along the Front Range on June 29 and June 30.

Table 5:Average Daily Emission from Wildfires by Domain for July-August 2002

Domain	VOC (tpd)	NOx (tpd)	CO (tpd)
Front Range	15	7	323
Colorado	1414	654	29675
Whole Domain	2230	1016	47382

Table 6: Summary of Wildfire Emission Over the Entire Modeling Domain (TPD)

	Wildfire Emissions Summary (tons/day)		
Date	NOx	VOC	CO
6/4/02	35.35	77.56	1648.03
6/5/02	61.98	135.99	2889.69
6/6/02	65.48	143.67	3053.09
6/7/02	21.30	46.73	992.99
6/8/02	3062.92	6719.79	143000.00
6/9/02	732.38	1606.96	34100.00
6/10/02	1261.78	2768.25	58800.00
6/11/02	1071.52	2350.87	50000.00
6/12/02	400.09	877.81	18700.00
6/13/02	207.44	455.14	9671.41
6/14/02	143.72	315.30	6700.18
6/15/02	337.27	739.96	15700.00
6/16/02	371.52	815.06	17300.00
6/17/02	140.27	307.78	6539.71
6/18/02	246.38	540.55	11500.00
6/19/02	1042.43	2287.08	48600.00
6/20/02	947.45	2078.62	44200.00
6/21/02	1393.21	3056.56	65000.00
6/22/02	1648.12	3616.15	76800.00
6/23/02	3697.70	8112.82	172000.00
6/24/02	2401.81	5269.53	112000.00
6/25/02	1237.10	2714.12	57700.00
6/26/02	1495.87	3281.90	69700.00
6/27/02	1591.24	3491.05	74200.00
6/28/02	1045.22	2293.18	48700.00
6/29/02	1181.59	2592.33	55100.00
6/30/02	1951.80	4282.18	91000.00
7/1/02	1120.90	2459.29	52300.00
7/2/02	970.32	2128.78	45200.00
7/3/02	1040.66	2283.16	48500.00
7/4/02	763.81	1675.79	35600.00
7/5/02	235.43	516.51	11000.00
7/6/02	134.64	295.38	6277.16
7/7/02	125.97	276.39	5873.18
7/8/02	96.11	210.89	4481.53
7/9/02	39.54	86.77	1844.06
7/10/02	25.11	55.09	1170.86
7/11/02	48.32	106.00	2252.37
7/12/02	82.57	181.14	3849.39
7/13/02	183.21	401.93	8541.42
7/14/02	595.91	1307.33	27800.00
7/15/02	353.34	775.20	16500.00
7/16/02	806.12	1768.59	37600.00
7/17/02	498.13	1092.92	23200.00
7/18/02	160.32	351.70	7473.30
7/19/02	88.17	193.43	4110.65
7/20/02	49.64	108.91	2314.63
7/21/02	7.07	15.53	329.68

Figure 7: Time series of Front Range VOC Emissions from Wildfire. The black lines with bullets represent the modeled episodes.

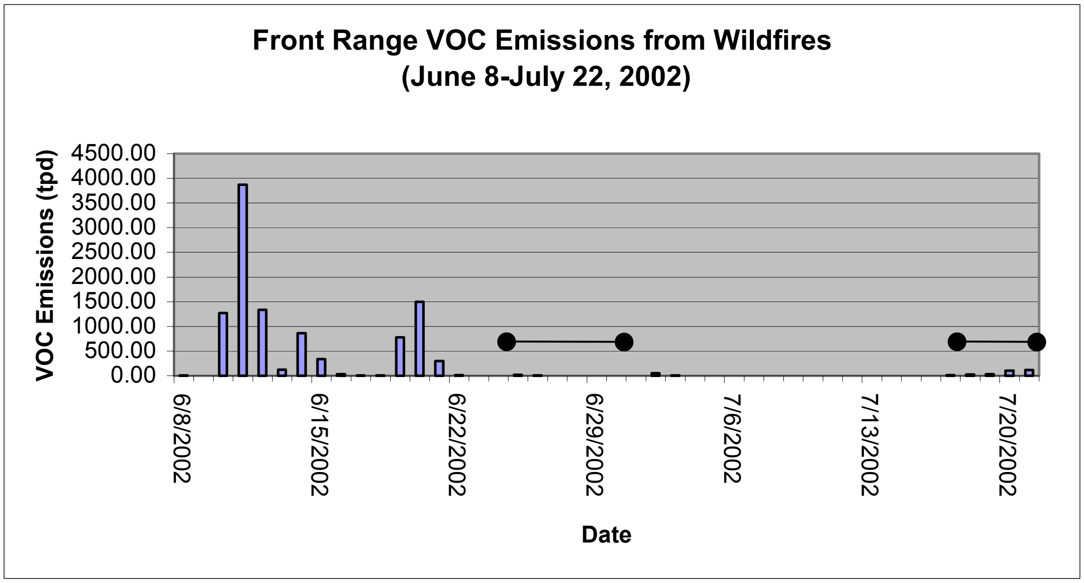


Figure 8: Time series of statewide VOC emissions from Wildfires. The black lines with bullets represent the modeled episodes.