Development of Version 2 of the Wildland Fire Portion of the National Emissions Inventory

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ABSTRACT

Emissions from wildland fires represent a large fraction of the total mass of particulate matter emitted in the United States. We present the methods and results for the national-scale processing of version 2 of the 2008 wildland fire National Emissions Inventory (NEI). The version 2 NEI was produced using fire activity data from SmartFire 2 (SF2) and emissions processing in the BlueSky smoke modeling framework. Additionally, guidance and feedback from experts were utilized in determining input data sets and processing streams. This is important because both BlueSky and the newly redesigned SF2 are frameworks that contain multiple modeling processing pathways and options. Wildland fire emissions of $PM_{2.5}$ were estimated at 1,716,000 tons, which represents 28% of the total $PM_{2.5}$ from the NEI.

INTRODUCTION

Wildland fires, including wildfires and prescribed burning, represent a significant fraction of the total emissions of fine particles, both globally and nationally.[1] Unfortunately, there is still significant uncertainty in wildland fire emission estimates.[2] In spite of this, the United States Environmental Protection Agency (EPA) must produce an inventory for wildland fires every three years as part of the National Emissions Inventory (NEI), which is used for regulatory modeling and analysis. Therefore, it is important to continually improve methods to estimate wildland fires in the U.S.

Emissions from wildland fire can be thought of in terms of the classic formula of Seiler and Crutzen (1980):

$$\text{Emission}_i = A \times B \times \text{CE} \times e_i \qquad \textbf{(1)}$$

where

A = area burned
B = biomass available (or fuel loading)
CE = combustion efficiency (or consumption)
e_i = an emission factor for pollutant or group i

Equation 1 is commonly used in developing biomass burning emissions estimates; however, the equation masks considerable complexity. The area burned term can be derived from remote sensing of active fires, remote sensing of burn scars, ground-based reporting, or some combination. These methods of estimating area burned do not necessarily yield similar results. Biomass available for burning within the burned area (known as the fuel loading) can be of a variety of different vegetation types and estimated from several different mappings and methodologies. Combustion efficiency is a function of how much of the fuel loading is consumed, which is estimated by consumption models that take into account the fuel types, forest structure, and fuel loadings along with fuel moisture and type of fire. These complex dynamic or empirical consumption models include Consume,[3] and the First Order Fire Effects Model.[4]

This paper presents methods and results for the 2008 national wildland fire emissions inventory that serves as the basis for the wildland fire component of the 2008 NEI (version 2). Wildland fire includes wildfires and prescribed burns, but does not include agricultural burning, which is estimated separately. The final 2008 NEI version 2 published by the EPA differs from what is presented here in that the NEI also contains data submitted by several states (sometimes in lieu of the data presented here and sometimes in combination with the data presented here). Despite this, wildland fire emissions estimates for most states in the final NEI come from this analysis. Though the NEI includes estimates for several pollutants, we focus on $PM_{2.5}$, the pollutant for which wildland fires represent the largest fraction of the overall U.S. inventory.

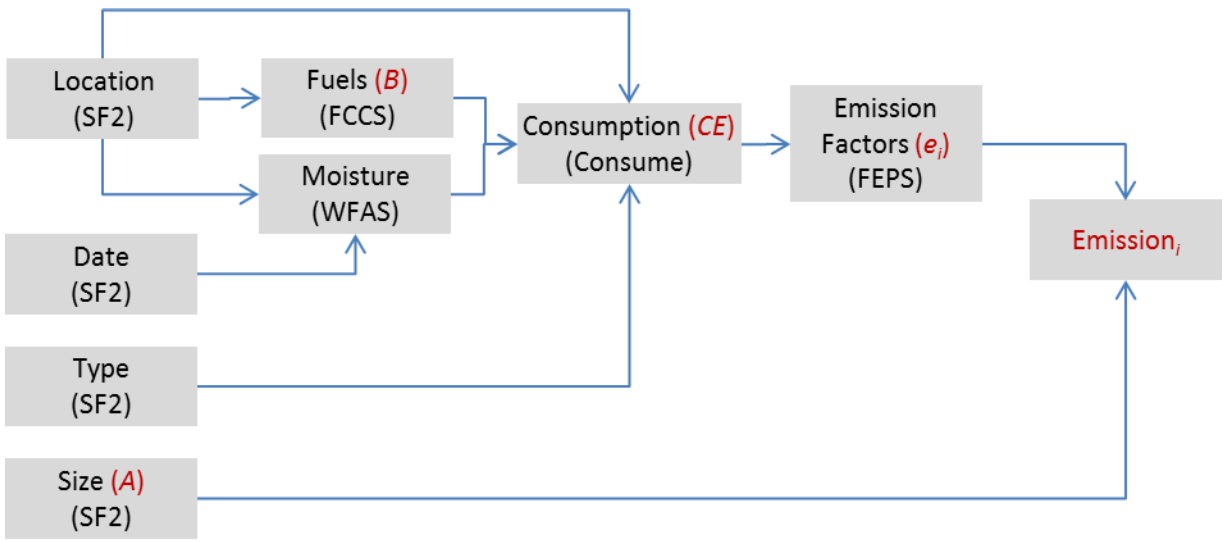
METHODS

We present the overall methods used in the NEI (version 2) national scale processing below. For additional details, please refer to the full General Technical Report, which can be found at http://airfire.org/emissions.

The flow of data elements used to produce the terms in Equation 1 is shown in Figure 1. Fire activity information (location, date, type, and size of fires) is provided by SmartFire version 2.0 (SF2). Although SF2 shares some features with the original SmartFire system, SF2 has been comprehensively redesigned to be more flexible, expandable, and accurate. SF2 is a modular framework that can combine an indefinite number of fire information data sets (ground reports, satellite-based detection, helicopter perimeters, etc.) into a best estimate of fire activity.

The remaining elements are calculated using models or data sets within the BlueSky framework,[5] including LANDFIRE-mapped fuelbeds from the Fuel Characteristic Classification System,[6] Consume, and the Fire Emissions Production Simulator,[7] and fuel moisture calculations from the Wildland Fire Assessment System (WFAS) archive. Each processing step is outlined below.

Figure 1. Data element process flow for SF2-BlueSky emissions inventory processing. Terms of Equation 1 are shown in red, and models or systems used to derive each element are shown in parentheses.



Activity Data

Wildland fire activity data (i.e., fire locations, sizes, types, and timings) were generated within SF2. SF2 can ingest and reconcile information from an arbitrary number of multiple activity data sets. For this inventory, three fire activity data sets (sources) were used.

Monitoring Trends in Burn Severity (MTBS). The MTBS project has produced burn scar information from large fires for 2008.[8] This inventory used the burn perimeter outlines that were generated for each MTBS fire. The MTBS project seeks to analyze all fires in the U.S. greater than 1,000 acres in the West and 500 acres in the East.[9] Therefore, MTBS perimeters are available for those large fires only. Both wildfires and prescribed burns are included in the data set.

Incident Command Summary Reports (ICS-209). Though it is not their primary purpose, ICS-209 reports contain fire activity information that can be used in emissions inventories. ICS-209 reports are created for all fires for which there is a federal response, which could include monitoring only. Though all fire types are represented in the ICS-209 database, the vast majority of ICS-209 fires are wildfires.

Hazard Mapping System (HMS). The National Oceanic and Atmospheric Administration's (NOAA) HMS is an operational effort to collect, assess, and provide human quality control to fire detection data from several satellite-based remote sensors. HMS includes automated detections from geostationary (e.g., GOES) and polar-orbiting (e.g., MODIS) instruments. HMS also includes manually detected fires, where a trained analyst observes smoke plumes in visible satellite imagery. Though the HMS data includes many fires, the likelihood of detection of a specific fire depends on many parameters, including size, intensity, land type, timing, and cloud cover.

Association and Reconciliation

SF2 works by first associating data between input data sources that are likely to represent the same actual real-world fire. SF2 then reconciles the associated data into a single coherent information stream using a variety of options and user-adjustable weightings. The association and reconciliation steps are done to (1) avoid double counting fires that appear in multiple data sources and (2) allow for utilizing the best data sources for each piece of information required (e.g., location, size, fire type).

In this inventory, data were associated using spatio-temporal overlap of the data with assumed uncertainty bounds set for each data source, and associated data were reconciled using simple precedence. For each key element, each data source was assigned a rank. For a given fire, the data source with the highest rank in an element provided the estimate for that element. Table 1 shows the ranks that were assigned to each data source for each data element. We note that each of the data sources included fires that were not present in any other data source.

Table 1. Data source precedence for the key data elements estimated by SF2.

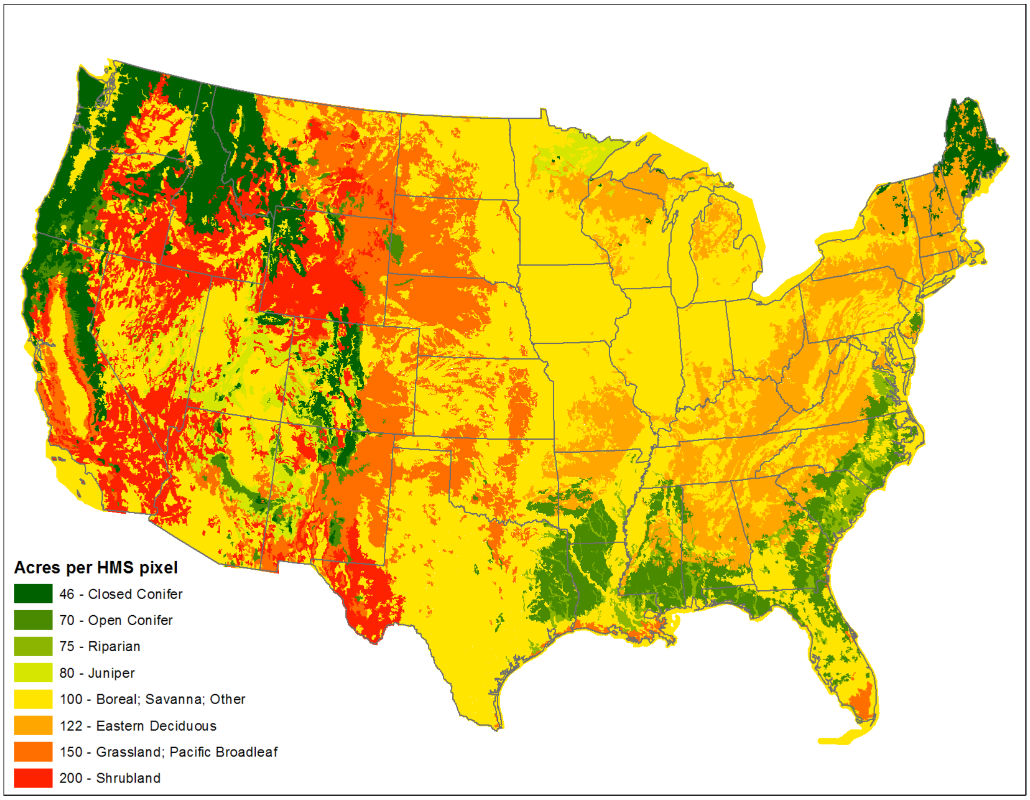
Data Element	First Choice	Second Choice	Third Choice
Location/shape	MTBS	HMS	ICS-209
Final size	MTBS	ICS-209	HMS
Daily growth[a]	HMS	ICS-209	MTBS
Fire type (WF/Rx)	ICS-209	MTBS	climatology[b]
Name	ICS-209	MTBS	unique ID assigned[c]
Start date	First reported		
End date	HMS	ICS-209	MTBS

[a] results are scaled to final size so daily growth is relative
[b] a climatology of prescribed fire vs. wildfire seasonality was used where no other type information was available (see below)
[c] for fires not in the ICS or MTBS datasets, a unique name was assigned based on their HMS satellite detects

<u>Final Size from HMS</u>

"Final size" represents the total burned area of the fire. For fires with other information for final size, HMS satellite detects were aggregated into an estimate of final fire size. HMS hot spot pixels do not provide information on area burned intrinsically, so final size must be inferred. Final size was estimated by assigning an area burned per pixel (A_p) and multiplying by the number of pixels in the fire. The value of A_p depends on the ecosystem because the same fire size will result in heat release, smoldering length, and timing differences in different ecosystems and therefore result in different satellite detection probabilities. To develop the area-per-pixel relationships, MTBS burn perimeters for 2003-2008 were intersected with the FCCS 1-km resolution map (http://www.fs.fed.us/pnw/fera/fccs/maps.shtml). Each FCCS fuelbed and each MTBS perimeter was assigned to one of 12 broad vegetation classes. Linear area-per-pixel relationships were developed for fires that were less than 10,000 acres and for all fires. Figure 2 shows how A_p varies spatially.

Figure 2. Mapped values of A_p used for the determination of final size from HMS data.

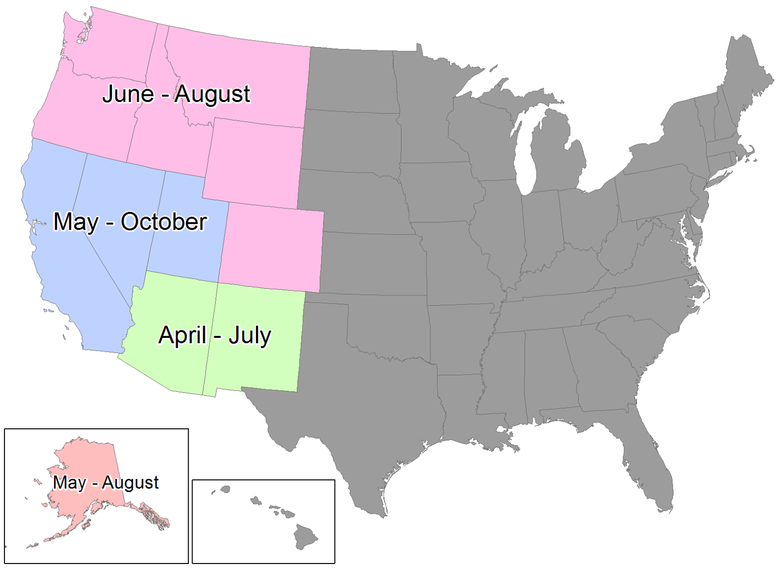


Fire Type from Climatology

Where no other information on fire type is available, a fire type climatology was developed to designate fires as either wildfire or prescribed burn depending on the state and month of the burn (Figure 3). Fires were presumed to be prescribed burns unless they fell within the "distinct wildfire season" for the state. The fire season map was developed by analyzing the MTBS data set for the years 1984-2006 to determine the typical wildfire season for each state and analyzing the Forest Service Activity Tracking (FACTS) prescribed burn data set for one year (10/1/2009 to 9/30/2010) to estimate the prescribed burning season. For many states in the West, the seasonal patterns of wild and prescribed fires were distinct and separable. In other states, particularly in the southeastern United States, the seasons were not separable. For those states, fires lacking other information are presumed to be prescribed burns. Fires only found in the

HMS data source were presumed to be prescribed burns by default because wildfires were more likely to be represented in the other data sets as well.

Figure 3. Default wildfire assignment map. If a fire with no type information fell within the states and months shown, it was designated as a wildfire. Otherwise, it was assumed to be a prescribed burn.



Emissions Processing

The fire activity data produced by the SF2 processing described above provided inputs to emissions modeling within BlueSky. SF2 was used to produce reconciled fire activity output in the BlueSky standard file format. The following steps were applied:

1) Segregate agricultural fires (based on the USGS National Land Cover Dataset)
2) Assign fuel moistures (via the USFS Wildland Fire Assessment System)
3) Process emissions through BlueSky:
    a) Fuel loading (LANDFIRE-FCCS 1-km database)
    b) Consumption (Consume 4.0)
    c) Emissions (FEPS emissions factors)
4) Post-process (duff consumption adjustment)

Duff consumption for prescribed fires was adjusted as a post-process step because of a known issue in the current Consume 4.0 model where unrealistically large duff consumption can occur in areas of large duff depths. Because this issue was flagged by regional experts working with the National Wildfire Coordinating Group's Smoke Committee, a post-processing limitation was imposed on prescribed fire duff consumption of 20 tons/acre in the western U.S. and 5 tons/acre in the eastern U.S. No limitations were imposed on wildfire duff consumption.

RESULTS

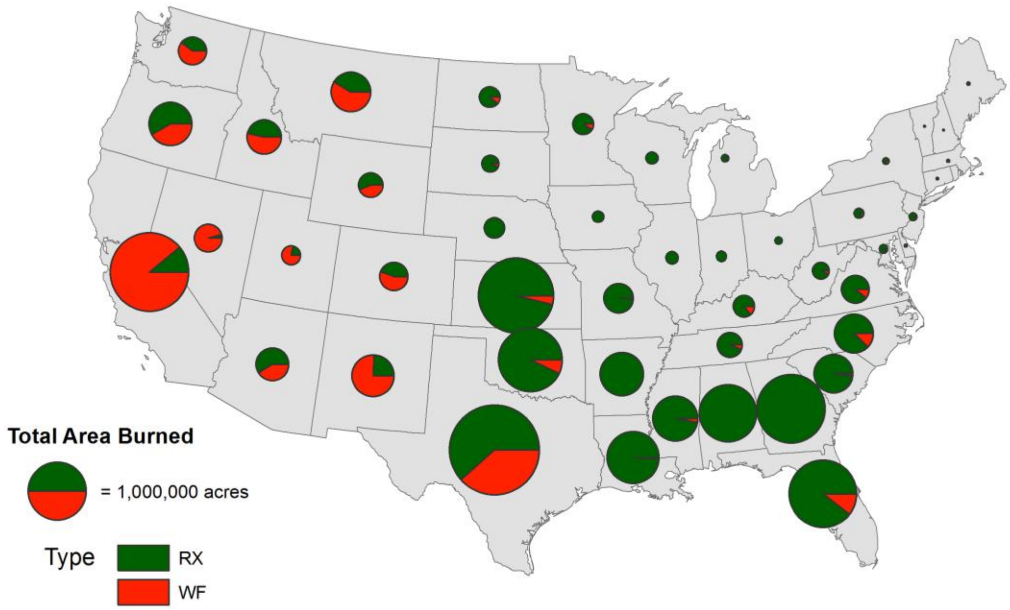
The total 2008 $PM_{2.5}$ from wild and prescribed fires was estimated at about 1,716,000 tons. Table 2 compares this total with the overall $PM_{2.5}$ in the 2008 NEI. Together, wild and prescribed fires comprise 28% of the total U.S. $PM_{2.5}$ inventory, with wildfires contributing 16% and prescribed burning contributing 12%.

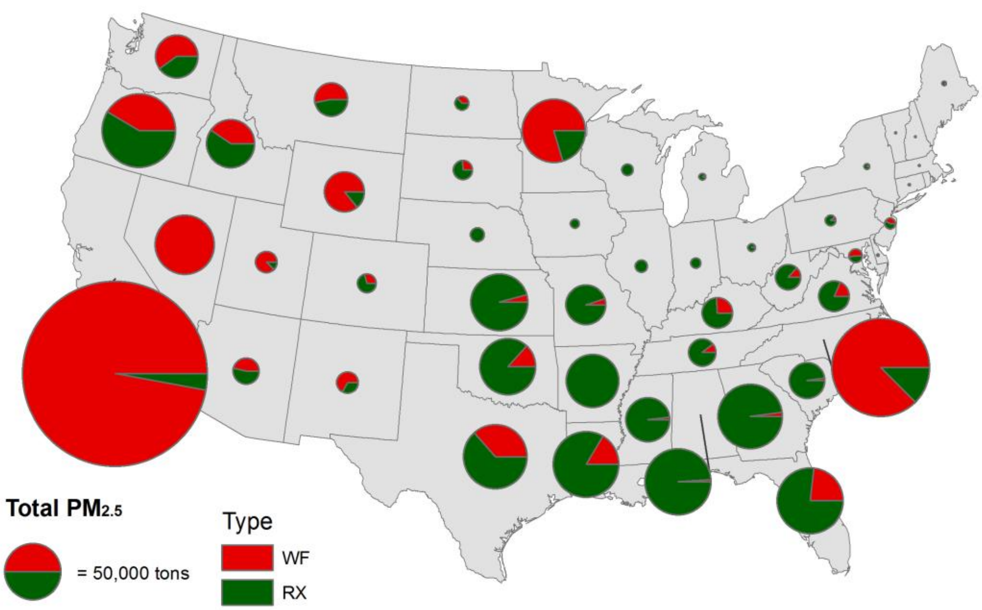
Table 2. Total $PM_{2.5}$ emissions in the 2008 NEI and this study.

Sector	$PM_{2.5}$ emissions (tons)	Percent of Total
2008 NEI v2 (all sectors)	6,066,086	100
This study (wild and prescribed fire)	1,715,962	28
This study (wildfire)	994,292	16
This study (prescribed fire)	721,670	12

Area burned and $PM_{2.5}$ results by state and fire type are presented in Figure 4. Large area burned totals are present throughout the southeast, the southern plains, and in California. With the exception of California, area burned state totals are dominated by prescribed burning. Conversely, the emissions pattern is dominated by wildfires, particularly in California, which had a record wildfire season, and North Carolina, where a single wildfire burned deep into the organic ground layer and produced significant emissions.

Figure 4. State totals of area burned (top) and $PM_{2.5}$ emitted (bottom) by fire type. Pie sizes are proportional to state totals. Each pie consists of two components: prescribed fire (green) and wildfire (red).





The monthly patterns of area burned are shown in Figures 5 and 6. In this inventory, the peak season for area burned is late winter/early spring, but the $PM_{2.5}$ emissions peak is in the summer. This difference is a result of the offset between the prescribed and wildfire burning seasons and the larger relative emissions per area burned for wildfires. In particular, the intense California Wildfires of June, July, and August dominate the 2008 inventory.

Figure 5. Monthly area burned by fire type. Red indicates wildfires and green indicates prescribed burns.

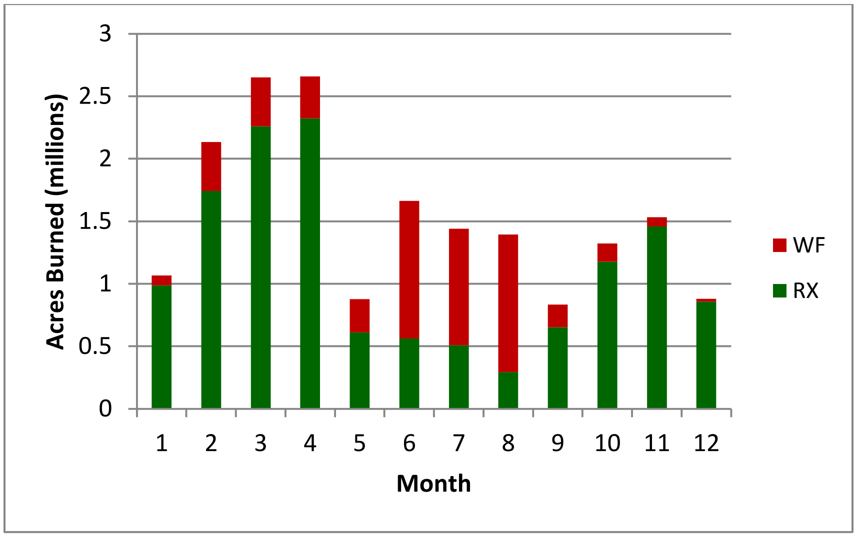
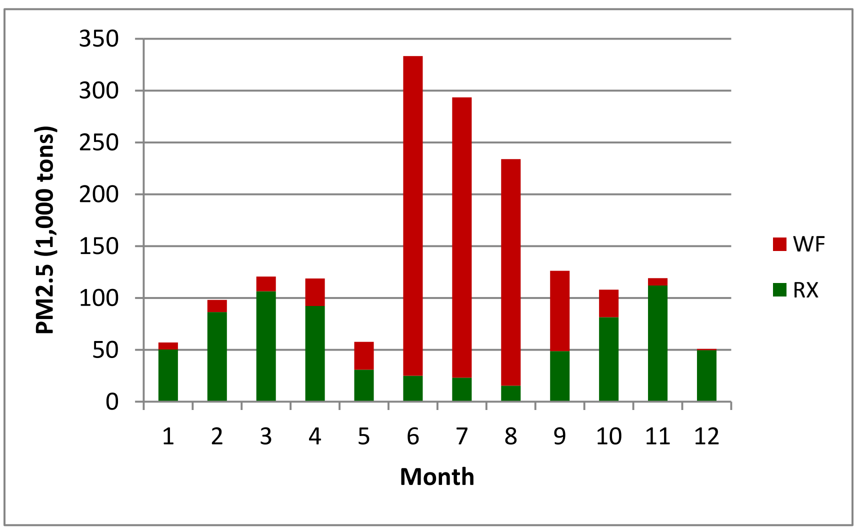


Figure 6. Monthly $PM_{2.5}$ emitted by fire type. Red indicates wildfires and green indicates prescribed burns.



DISCUSSION

While we believe this work represents an improvement over past fire emissions inventories, issues remain that can and should be addressed in future inventory development. Due to their large effect on emissions totals, the duff consumption issues in Consume are perhaps most important. Current versions of Consume calculate unrealistically high duff consumption for fuelbeds with high duff depths for prescribed fires. To account for this issue in the current inventory, an arbitrary cap based on expert judgment was applied. Future versions of Consume are expected to address this concern.

Fire information from prescribed burns is lacking in the 2008 inventory. Some burn areas are captured by MTBS, but estimates for most prescribed burn areas must rely on satellite data. To produce a more accurate inventory, local ground-based data are needed. EPA typically depends on state air quality agencies for NEI input data; however, only ten state air quality agencies submitted both wildfire and prescribed burn emissions data to the NEI. Most state air quality agencies do not track or collect such information. The state forestry agency may have this information, but they are not part of the EPA NEI process. Federal fire activity databases are another potential source of ground-based prescribed fire information. This federal data may or may not be captured in state databases. EPA and federal and state agencies need to work together to improve how fire information is reported to the NEI.

Emissions inventories of wildland fires remain highly uncertain. According to the Smoke Emissions Model Intercomparison Project (SEMIP), critical areas of uncertainty include fire activity information, fuel loading maps, and consumption.[2] Further work is needed to validate and improve all aspects of the smoke emissions modeling chain.

CONCLUSION

A new methodology, taking advantage of the latest versions of SmartFire and the BlueSky framework, was used to produce a wildland fire emission inventory for the contiguous U.S. for 2008. We estimate that 16% of U.S. $PM_{2.5}$ emissions come from wildfires and 12% of these emissions come from prescribed burns. While there was far more prescribed fire area burned than wildfire area, emissions from wildfires were higher. The historically large wildfires in California represent 31% of the total estimated fire emissions. These totals may not be typical, as wildfire activity exhibits strong inter-annual variability. Future inventories should focus on improving known issues with duff consumption and acquiring additional information on area burned from prescribed burns.

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KEY WORDS

Emission Inventory
SmartFire
BlueSky
Smoke
Wildfire
Prescribed Burn
$PM_{2.5}$
NEI