Impact of Wildland Fire Combustion Phase on PM and VOC Speciation and EPA's National Emissions Inventory

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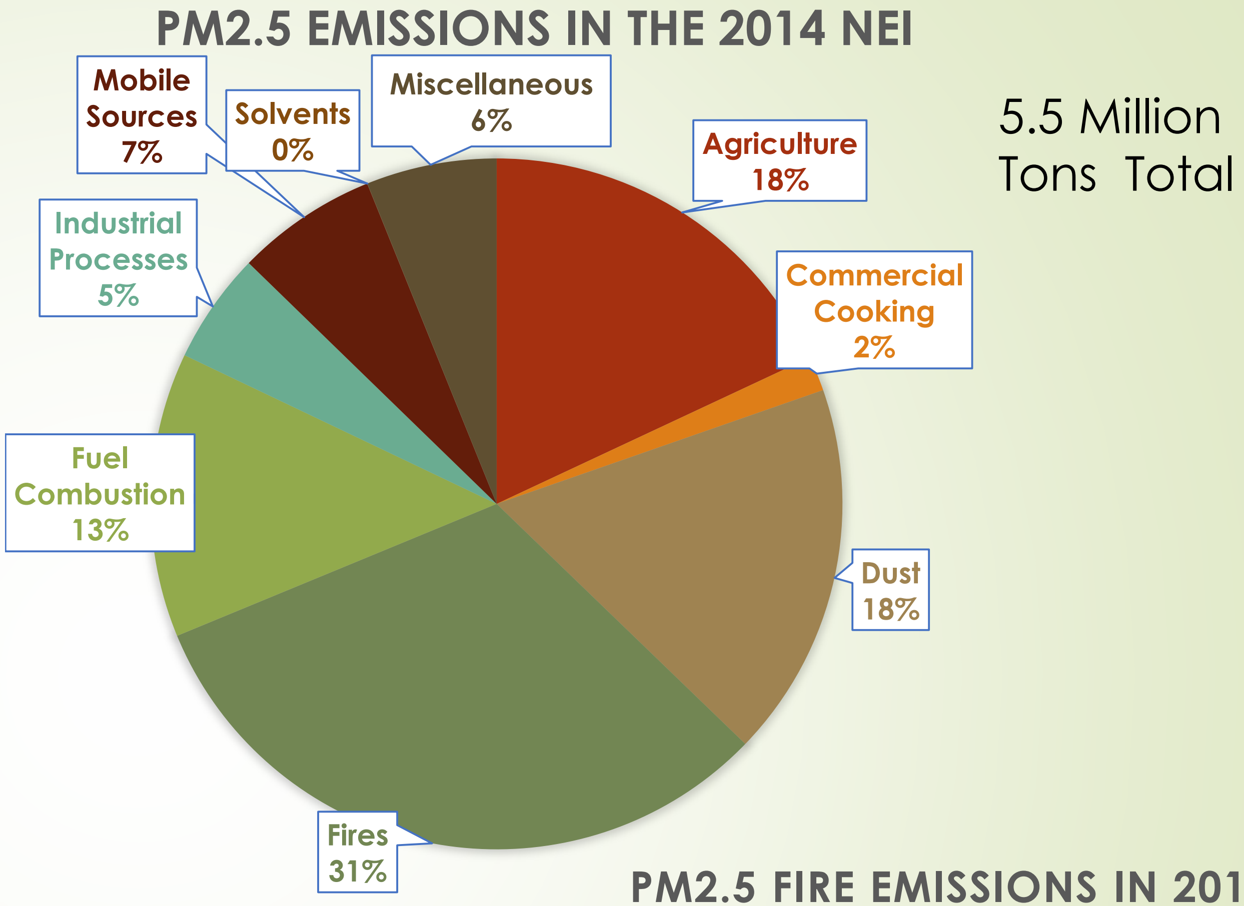
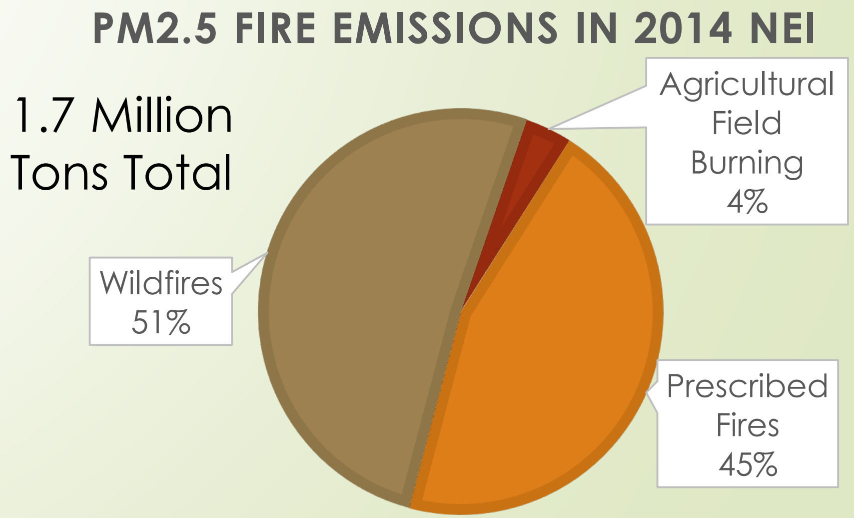
Topics to be covered

- Development of Wildland Fire (WLF = Prescribed and Wild Fires) emission estimates for the National Emissions Inventory (NEI)
  - 2014 is the most recent NEI available to the public
  - Methods, challenges, and needed improvements
- Why did we initiate an Emission Factors (EFs) testing program for WLFs?
  - Current EFs used for estimating emissions out-of-date
  - Recent studies do not always include EFs for all criteria, hazardous air pollutants and ozone precursors
  - Limited composition information by combustion phase in the literature for particulate matter (PM) and volatile organic compounds (VOCs)
- Initial results and potential impacts

NEI Basics

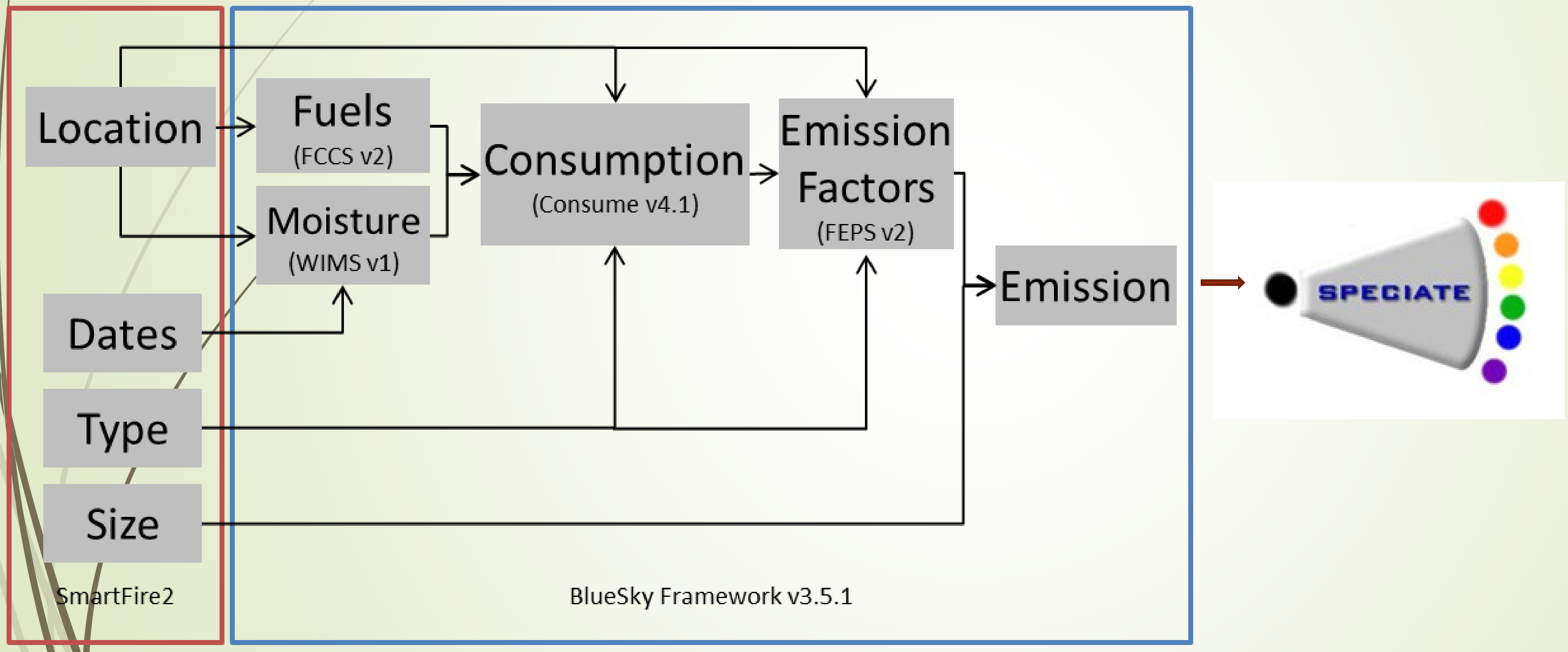
- The full NEI is on a 3-yr cycle (e.g. 2008, 2011, 2014)
- EPA works with the SLTs (States/Locals/Tribes) to complete the NEI
- There are many uses of NEI data: NAAQS assessments, international reporting, driver for air quality models, public outreach, and assessing risks from air toxics
- WLFs are significant contributors to PM, CO, VOCs and many hazardous air pollutants. PM2.5 is shown on the right as an example in the 2014 NEI





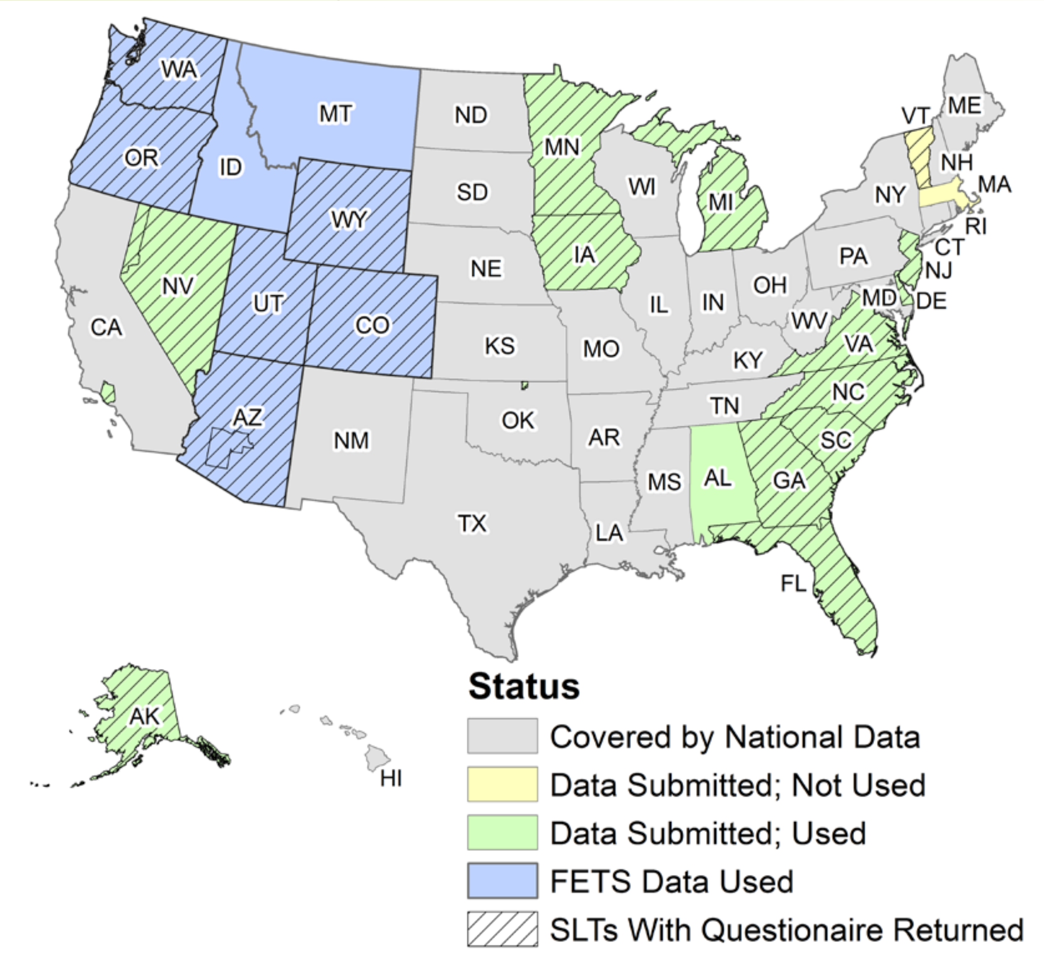
NEI Wildland Fire Emissions – Data Systems/Models

For fires in the contiguous United States and Alaska, the BlueSky (BS) framework is used to estimate smoke emissions.



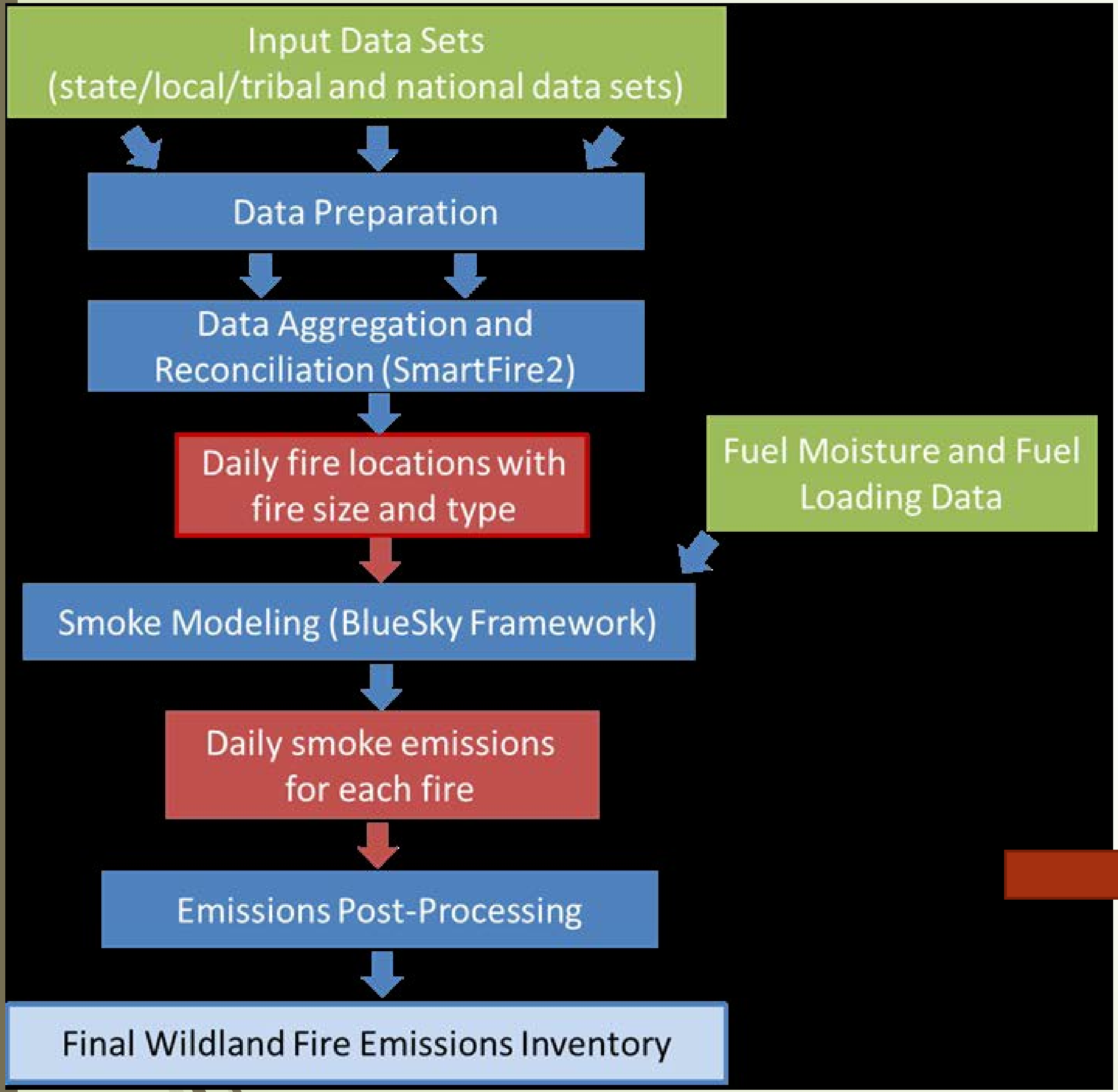
Elemental Carbon (EC)
Organic Carbon (OC)
SO_4
NO_3

We work with the SLTs, and collect as much local activity data as possible in constructing emission estimates (2014 NEI example)



- A total of 54 fire occurrence/activity datasets received; 32 of these were directly usable
- WLF questionnaire used to help EPA determine completeness of fires data
- Final data sources included data from 22 states and one Indian Nation
- FETS = Fire Emissions Tracking System from Western Air Partnership that includes several western states

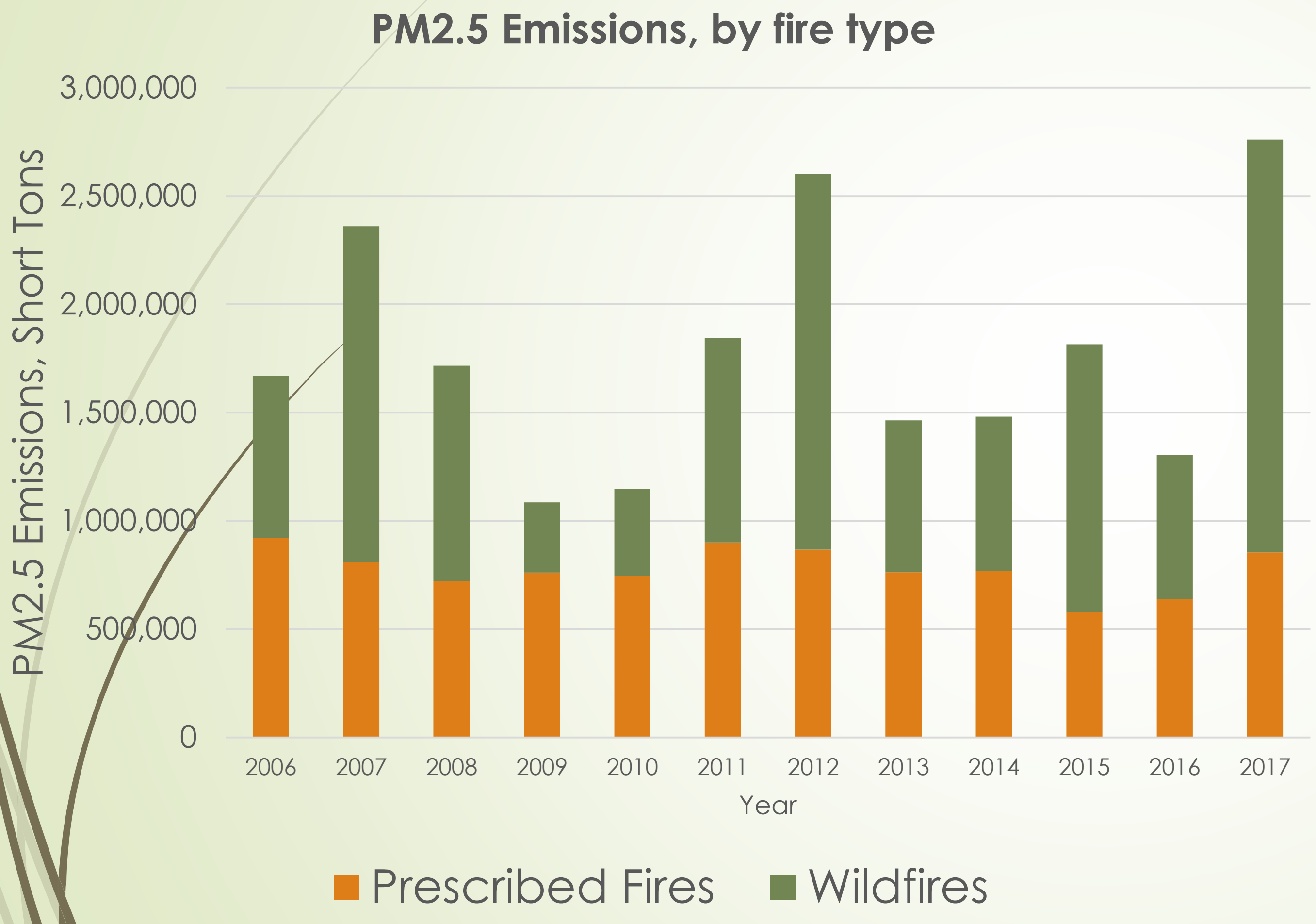
WLF Emissions Estimate methods - Overview



New in the 2014 NEI was to differentiate emissions by smoldering and flaming phases. This is important because these emissions have different PM and VOC compositions as well as different plume rise characteristics.

Results in day-specific, fire type-specific, emission estimates by combustion phase

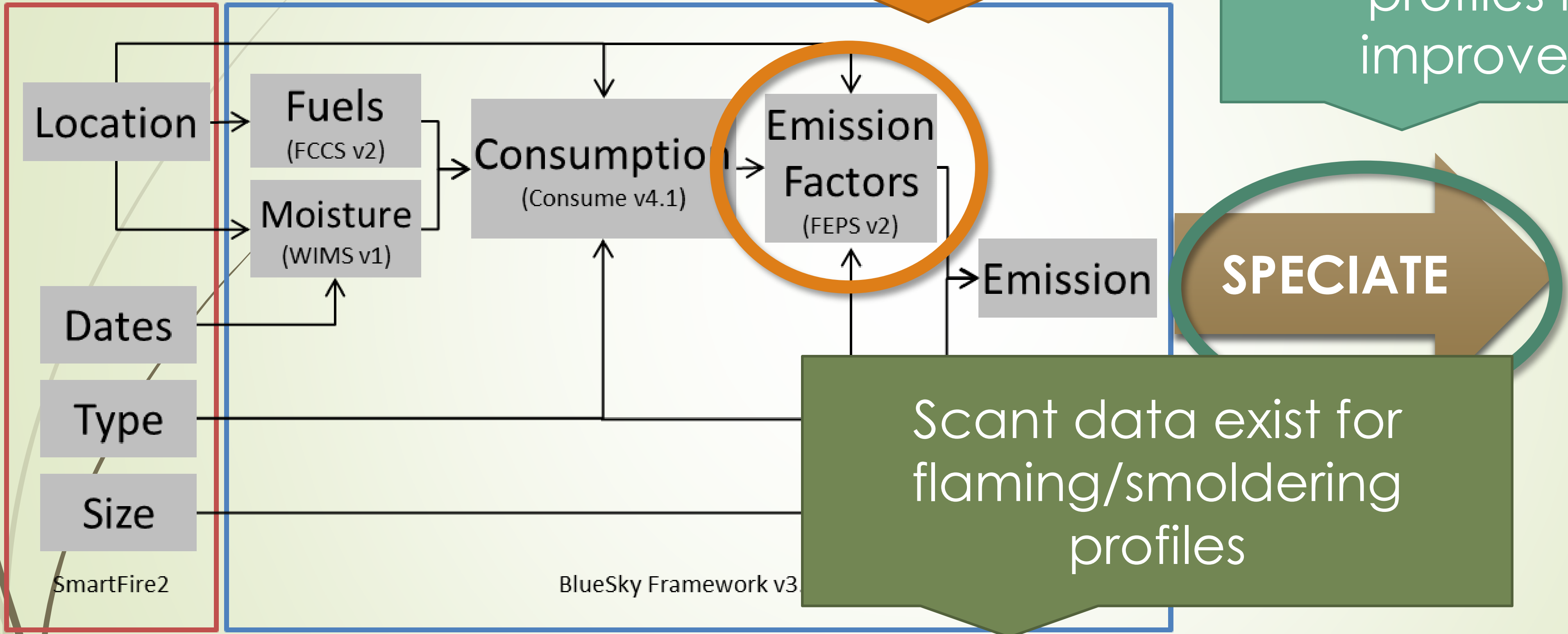
Wildfire and Prescribed Fire PM2.5 Emissions 2006 to 2017



The year-to-year variation in total PM2.5 emissions is primarily driven by changing levels of wildfire activity

2016 and 2017 estimates are draft

Why do we need more testing on EFs and speciation from fires?



Source of emission factors is not transparent

SPECIATE wildfire PM profiles need improvement

Scant data exist for flaming/smoldering profiles

Elemental Carbon, Organic Carbon, SO4, NO4

NEI 2014 reports emissions based on flaming and smoldering combustion phases of wildland fires (wild and prescribed fires).

Study Motivation

NEI 2014 reports emissions based on flaming and smoldering combustion phases of wildland fires (wild and prescribed fires).

Scant data on PM speciation by combustion phase exists and what is available in the literature had surprisingly high EC fractions.

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ATMOSPHERIC ENVIRONMENT

Particulate and gas sampling of prescribed fires in South Georgia, USA

CrossMark

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Table 3

$PM_{2.5}$ major components (as wt.%) and metals ratios to total $PM_{2.5}$ (mg g^{-1} of total $PM_{2.5}$) in flaming and smoldering stages, averaged over two prescribed fires.

Major components units (% of total $PM_{2.5}$)	Flaming		Smoldering	
	Avg.	St. Dev.	Avg.	St. Dev.
Other	27%	0.9%	29%	0.29%
OC	55%	1.8%	58%	0.59%
EC	11%	1.0%	10%	0.74%
Acetate	0.40%	0.16%	0.79%	0.62%
Nitrate	1.45%	0.76%	1.55%	1.36%
Sulfate	0.48%	0.08%	0.61%	0.49%
Oxalic acid	0.35%	0.34%	0.27%	0.21%
Ammonium	0.86%	0.22%	0.81%	0.07%
$PM_{2.5}$ (μg m^{-3})	**327.15**	**148.32**	**48.52**	**9.45**

Our objective was to validate these PM speciation profiles by combustion phase reported in the literature

Emission Factor Research Project Overview

Objective: Determine composition and emission factors for wildland fires in the United States for both PM and VOC

Approach: Use combined field measurements and laboratory simulations to fill in gaps in our understanding of the effect of fuels and fire behavior on emissions

Field Efforts: Most realistic, but there are limited opportunities, expensive, and limited range of conditions and fuels

Laboratory Efforts: Controlled conditions allow for study of a range of fuels and conditions, but does not always agree with field measurements

Experimental Methods: Laboratory Measurements

Open burn test facility (burn hut) = 60 m^3 cinder block room, clad with stainless steel

1 m^2 burn pan on top of an electronic balance

- **Teflon Filters**: Gravimetric, ion Chromatography, X-ray Fluorescence, Inductively Coupled Plasma – Mass Spectrometry
- **Quartz Filters**: Thermal Optical Analysis (IMPROVE protocol)
- **Summa Cannisters**: EPA TO-15
- **DNPH Cartridges**: EPA TO-11A

Experimental Methods: Field Measurements

‘Flyer’ sampler package mounted to the roof of an ATV. Maneuver sampler into the plume and target different types of combustion (back burn, heading fire, residual smolder)

Flyer Measurements:

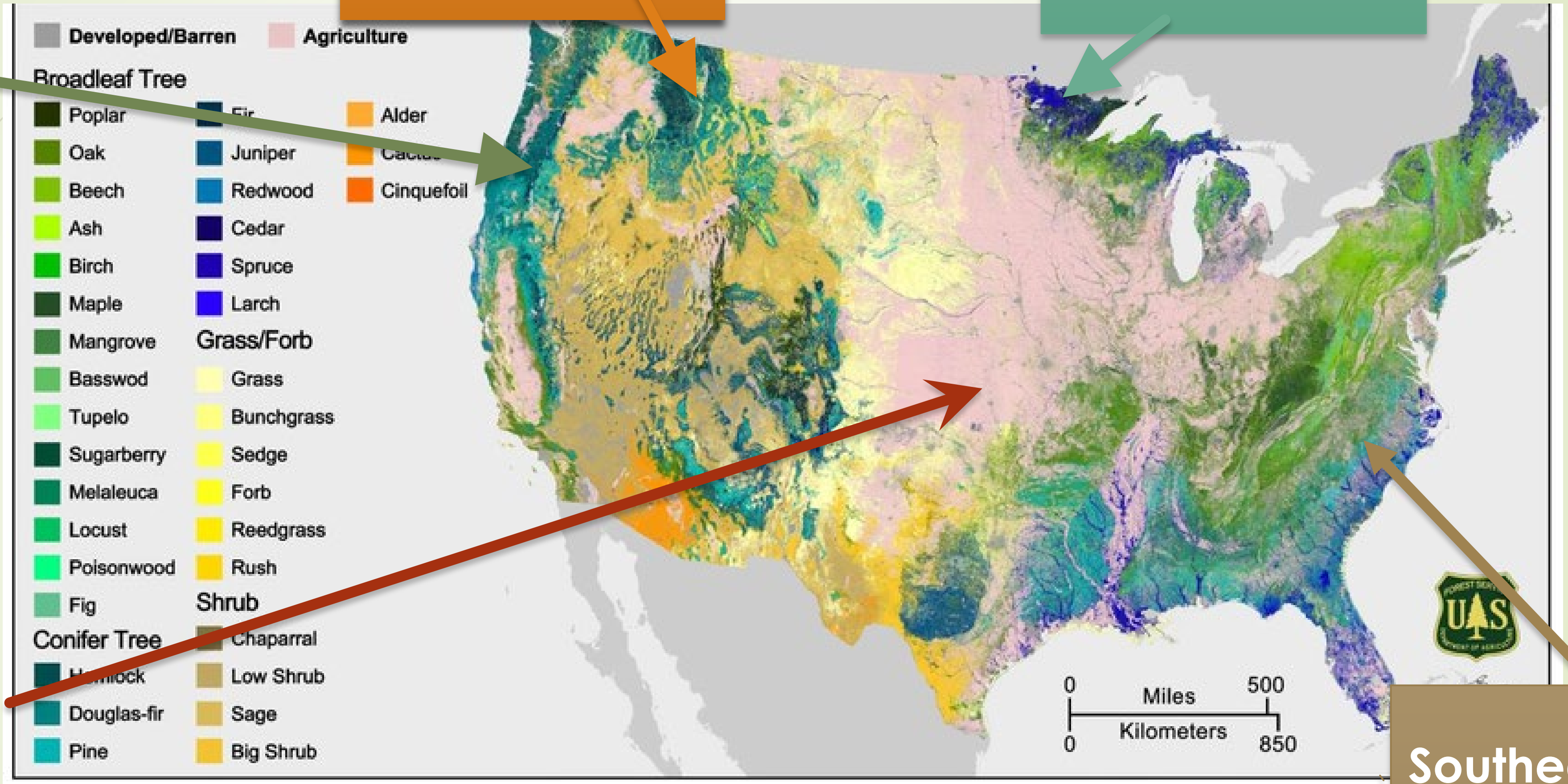
- CO_2, CO sensors
- PM light scatter
- Black carbon
- PM2.5 Teflon & Quartz filters

Fuel Source Regions

Northwestern forest litter
Fall 2018

Mosses & Peat
Spring 2019

Sycan Marsh, OR
Grassland, forest litter
Fall 2017

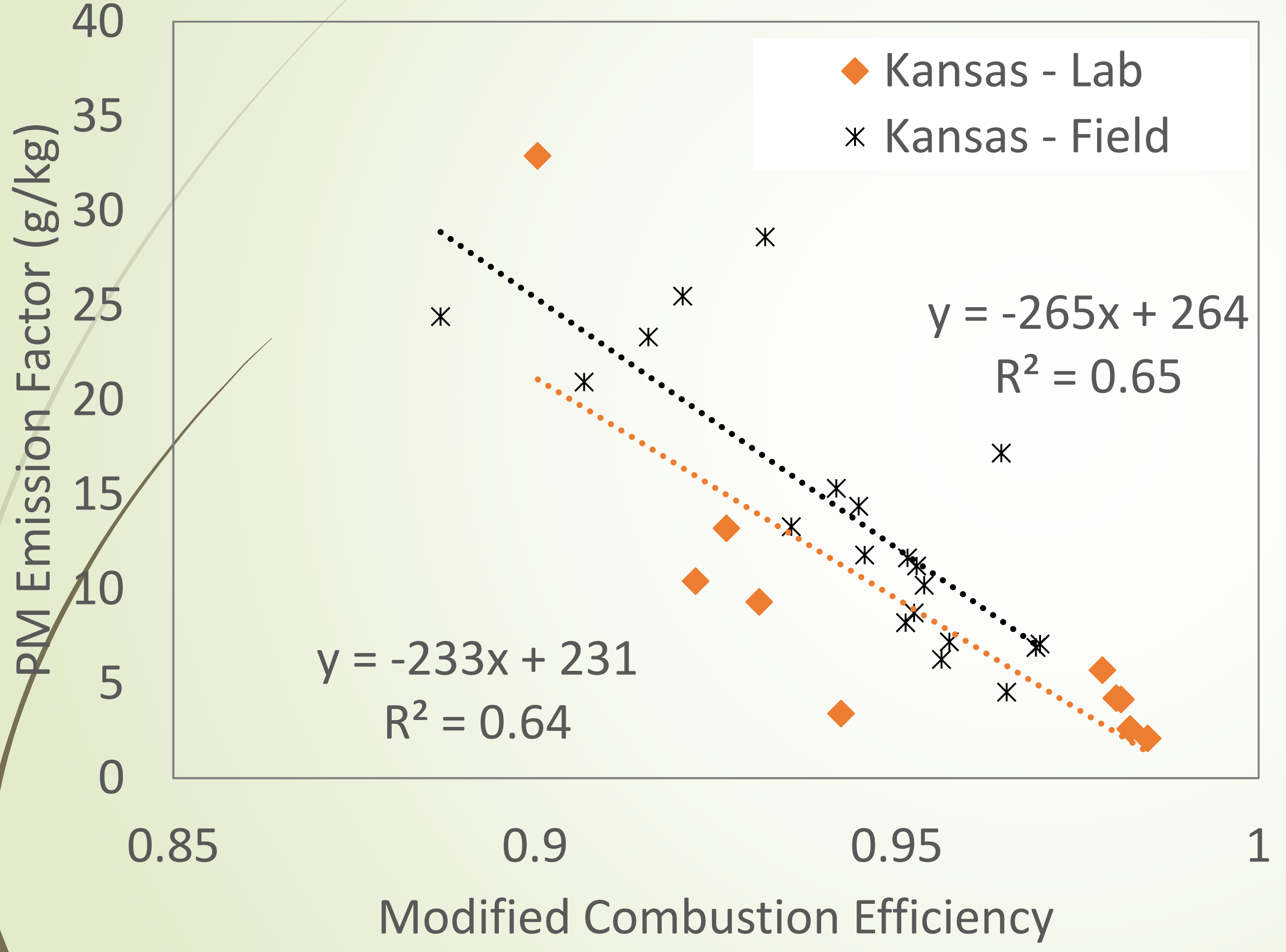


Flint Hills, KS
Tallgrass
November 2017, April 2019

Source: A US national fuels database and map for calculating carbon emissions from wildland and prescribed fire, Proceedings of the 4th Fire Behavior and Fuels Conference 2013

Southeastern forest litter
Spring 2016, Fall 2017

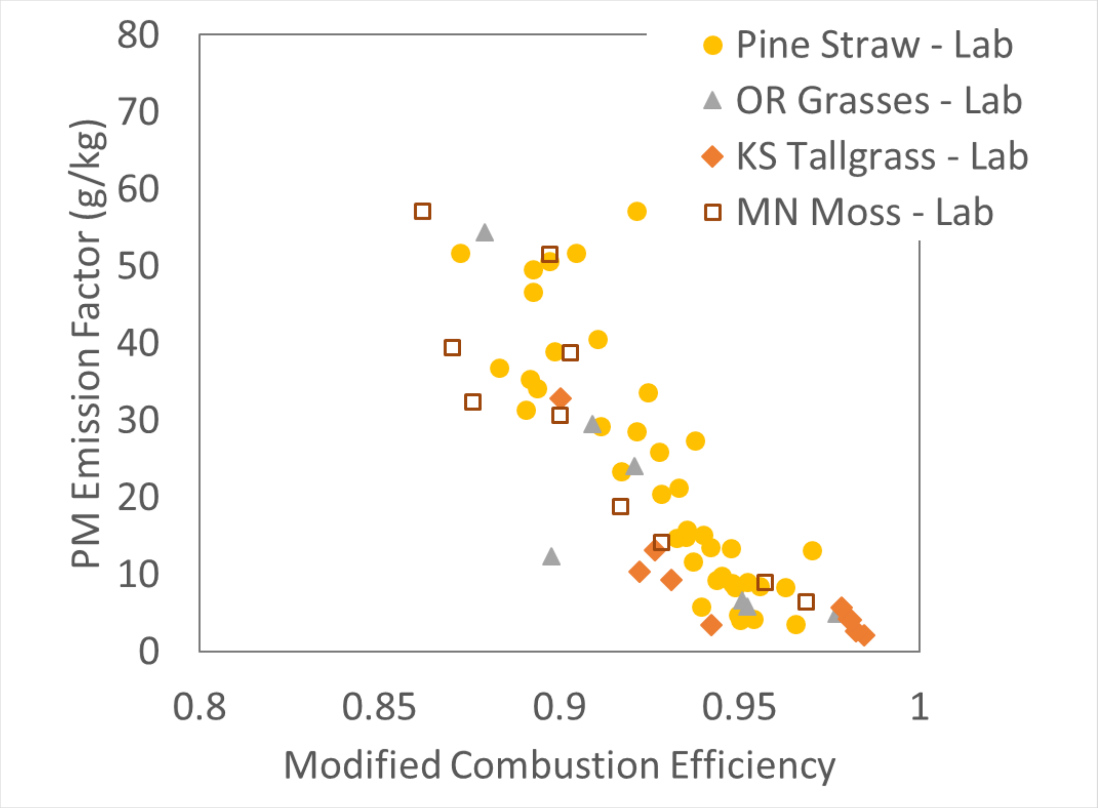
Results – PM emission factors show reasonable agreement between lab and field measurements

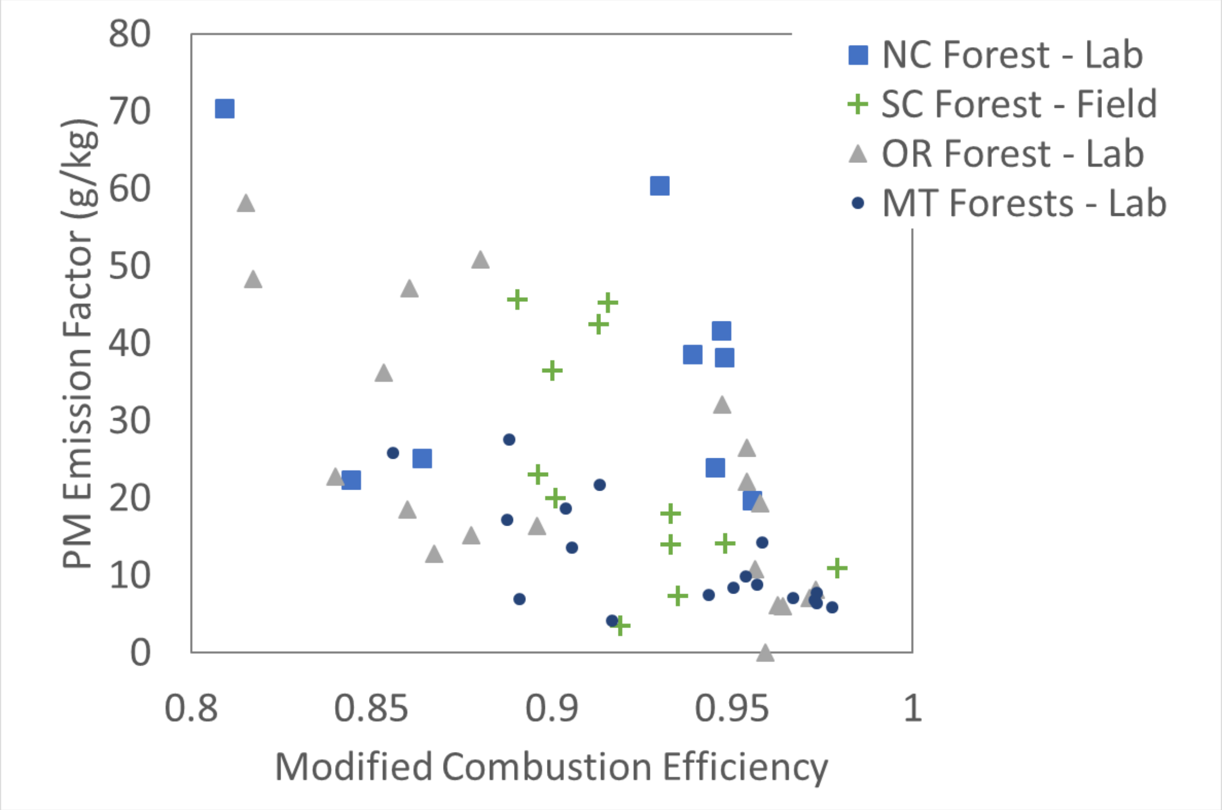


- With the same fuel type and moisture conditions, lab simulations can approximate conditions found in the field
- PM EFs generally decrease with increasing modified combustion efficiency

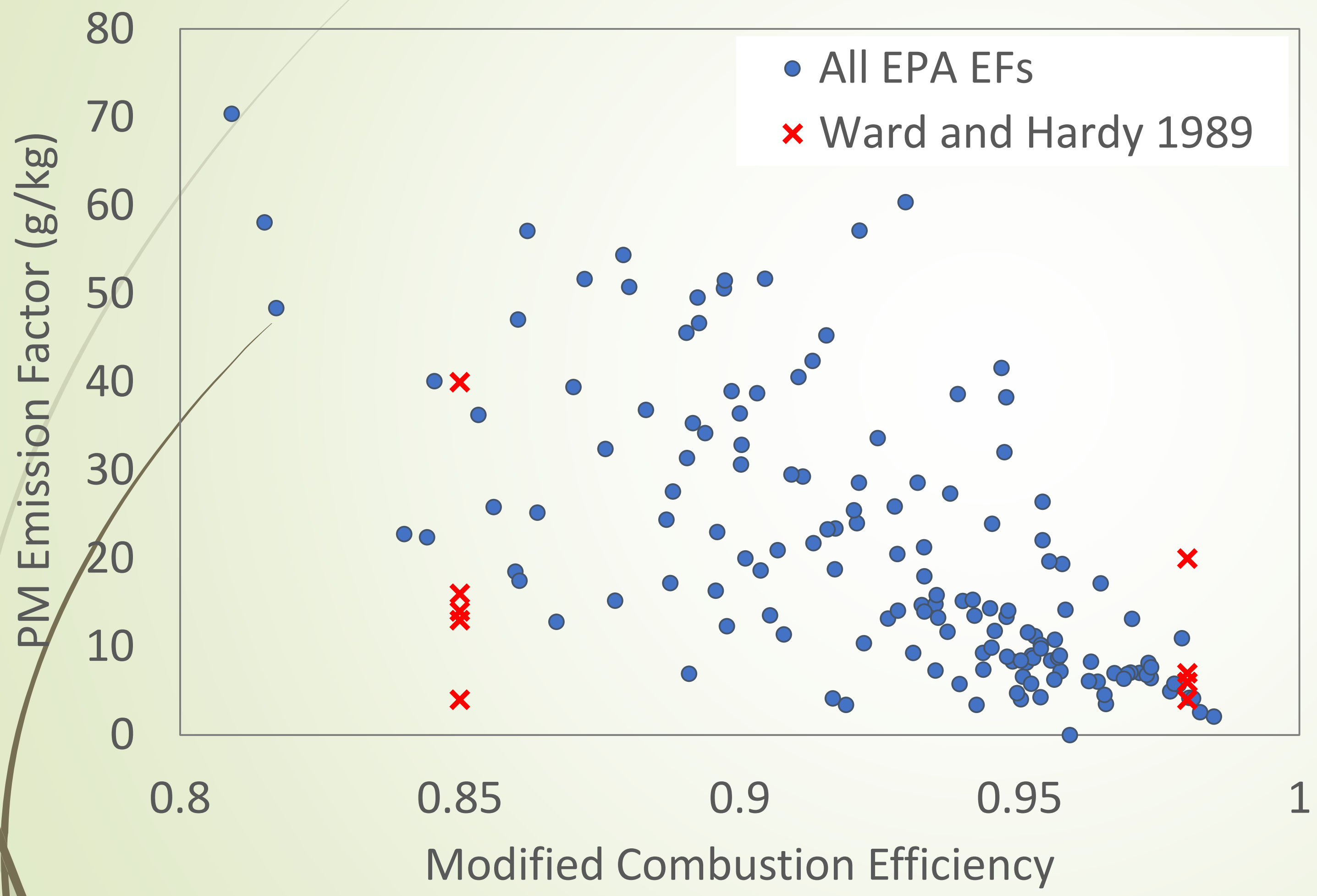
Results – PM emission factors show species specific trends

- Fine fuels, like grasses and pine needles, exhibited similar EF relationships with modified combustion efficiency
- EFs from burning forest fuels (litter, twigs, and branches) exhibited much large scatter, but no systematic difference between eastern and western US forests



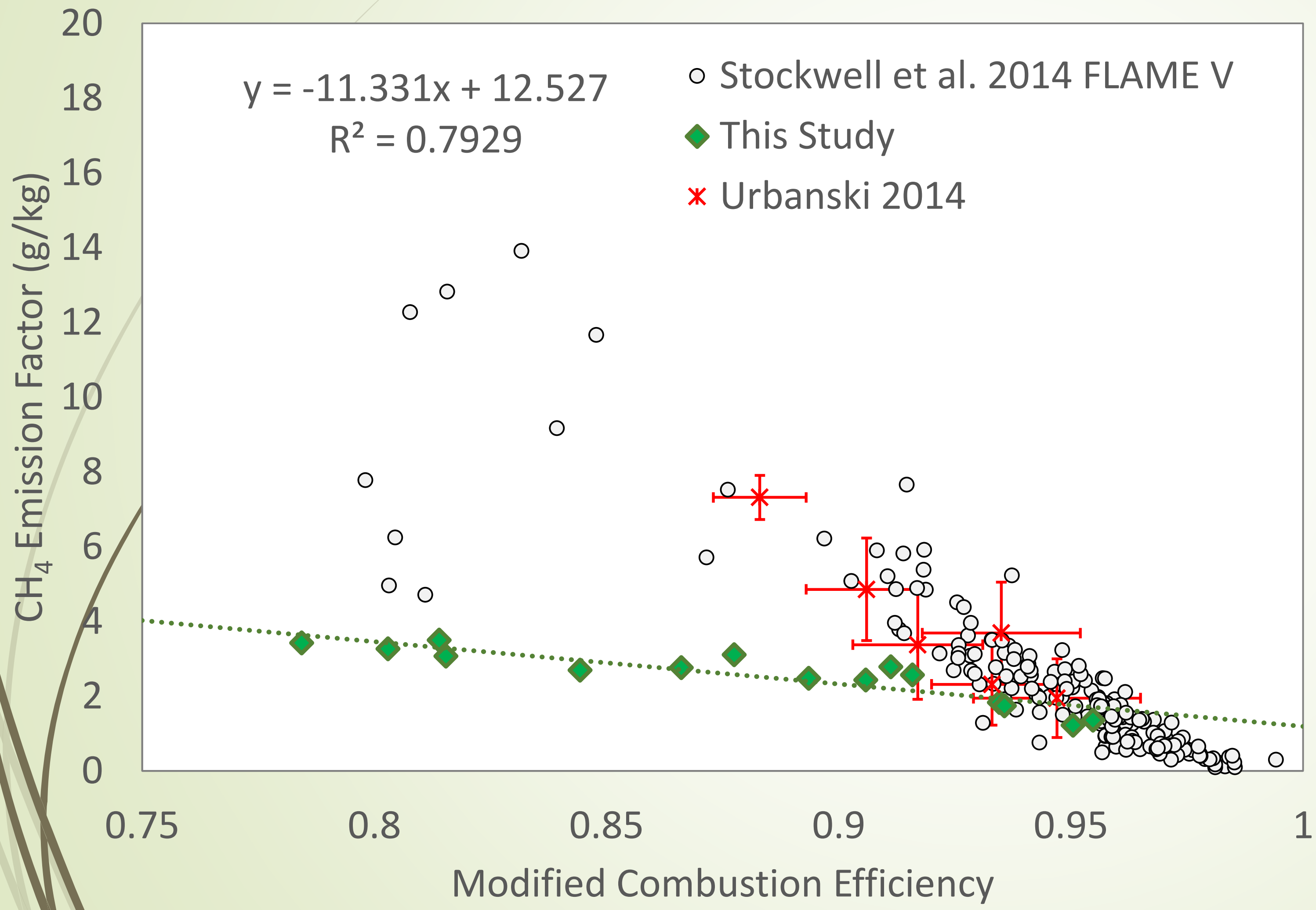


Results – Lab and Field data compared to model data used in Bluesky



Ward and Hardy EFs (which is currently used for NEI development) are substantially lower and have little variability compared to EPA's data across all fuel types

VOC Emission Factors by Combustion Phase



VOC emissions are strongly correlated to modified combustion efficiency, regardless of fuel type

Slope deviates from other laboratory study (Stockwell et al. 2014) and a compilation of field emission factors (Urbanski 2014)

Green triangles representing "This Study" were done on Ag crop residues

Our initial results are quite different from the literature PM profiles

Table 3
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Flaming

Compound	Current Study (%)		Balachandran et al. 2013 (%)
OC	56.5	≈	55
EC	3.0	≪	11
NO3	0.09	≪	1.45
SO4	0.36	≈	0.48
NH4+	0.20	≪	0.86

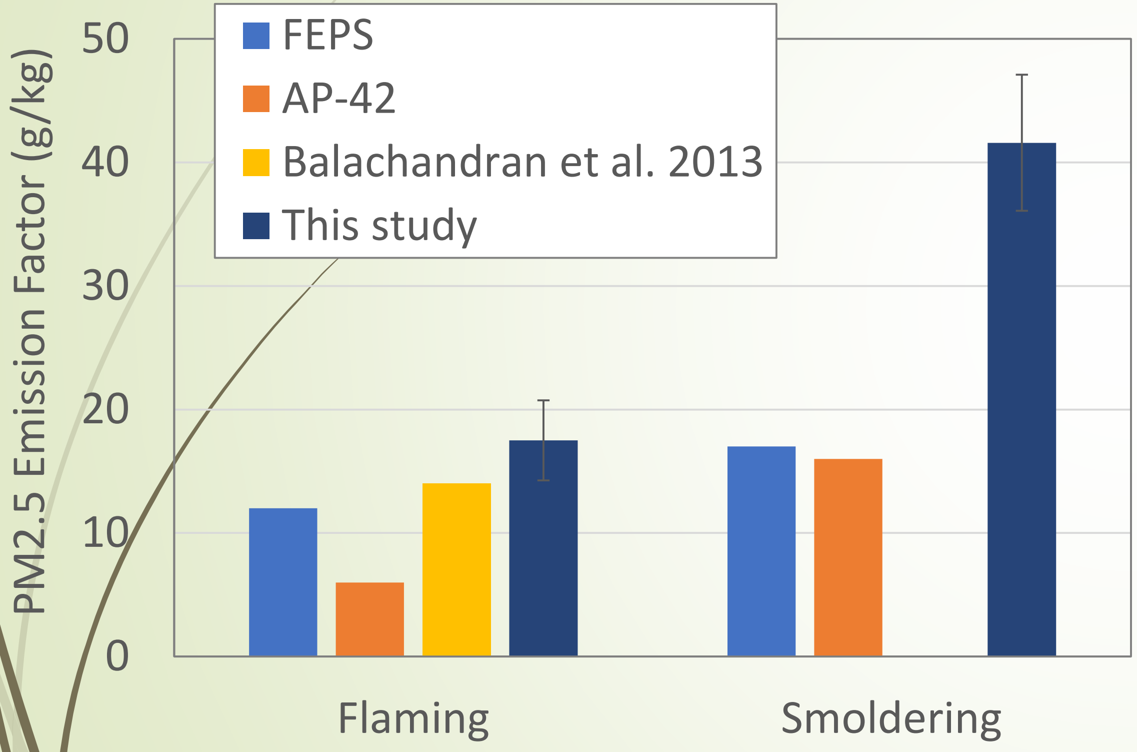
Smoldering

Compound	Current Study (%)		Balachandran et al. 2013 (%)
OC	58.4	≈	58
EC	0.4	≪	10
NO3	0.05	≪	1.55
SO4	0.10	≪	0.61
NH4+	0.07	≪	0.81

The balance of the PM mass is non-carbon organic material (e.g., O, N, S)

Case Study – SE United States: Emission Factors

Southeastern U.S.: Alabama, Georgia, Florida, North Carolina, South Carolina

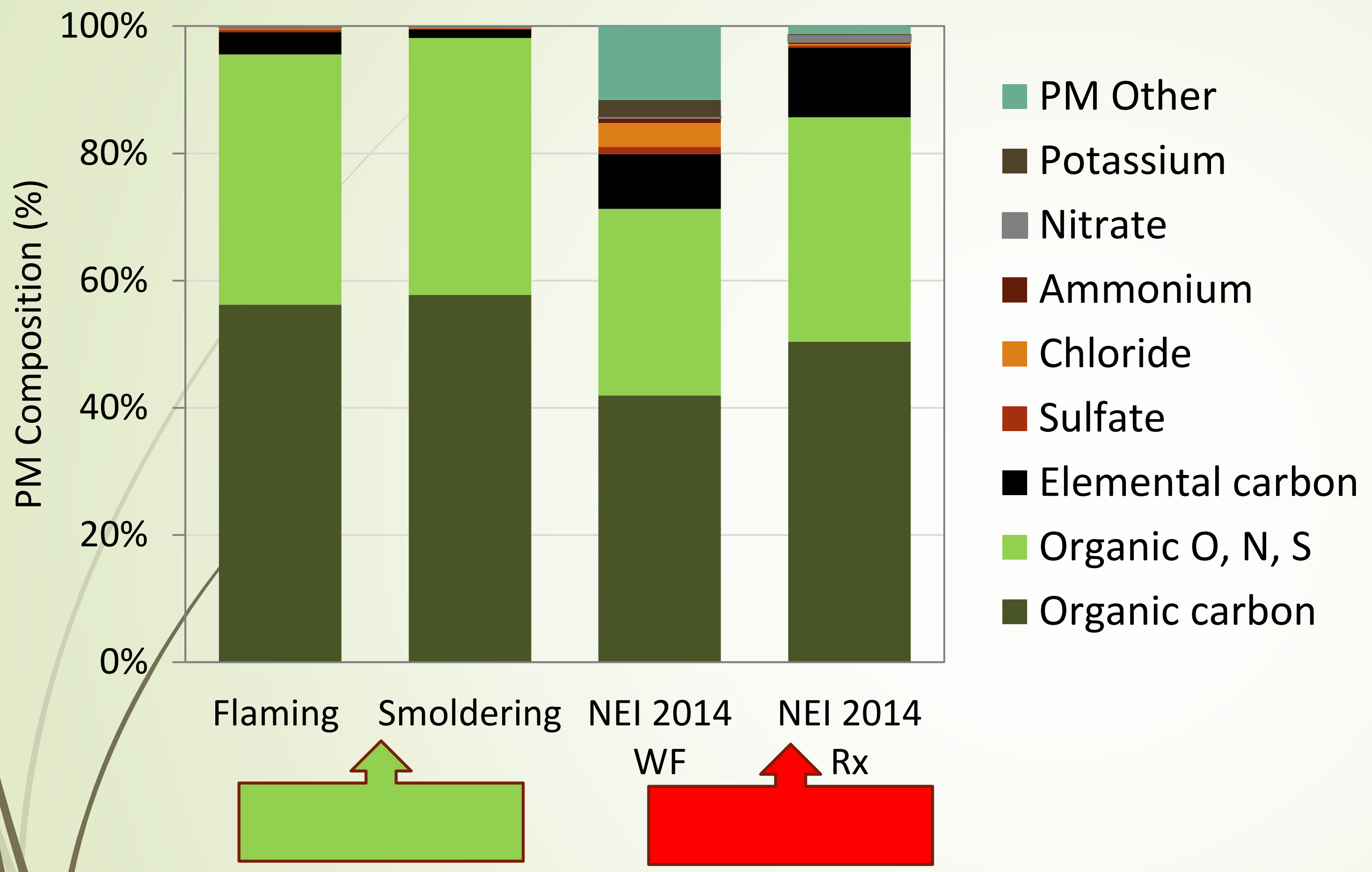


- NEI 2014 uses FEPS emission factors for flaming and smoldering
- Our lab flaming emission factor is 1.5 x FEPS
- Our lab smoldering emission factor is 2.4 x FEPS
- Previous measurements of Rx fires by Aurell et al. are comparable to our lab emission factors:

Fire Location	Emission Factor
FL	13.5 ± 0.7
NC	22.7 ± 11.2
SC	46.5 ± 18.0

Aurell et al. (2013) Emission factors from aerial and ground measurement of field and laboratory forest burns in the southeastern U.S.: PM2.5, black and brown carbon, VOC, and PCDD/PCDF. *ES&T*, 47, 8443-8452.

Case Study – SE United States: PM Composition



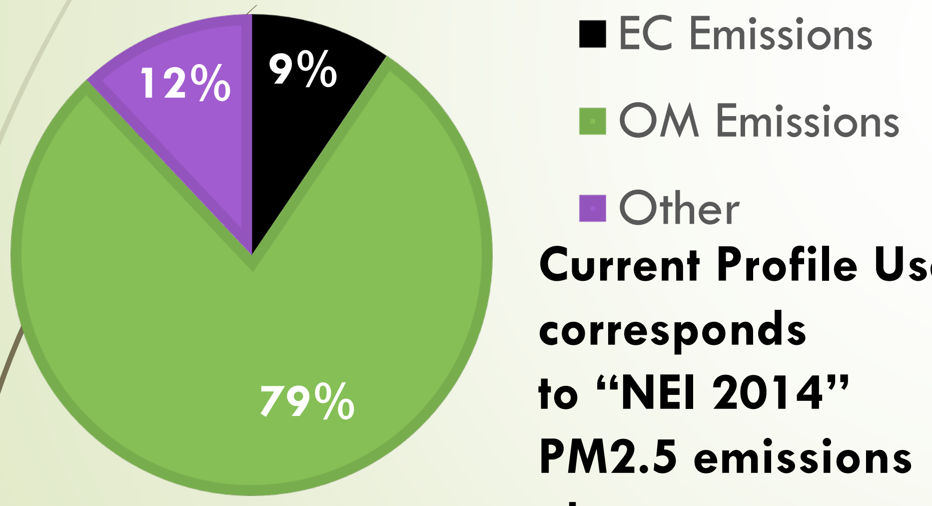
Based on our current research/testing results

What we currently use for the NEI and for modeling

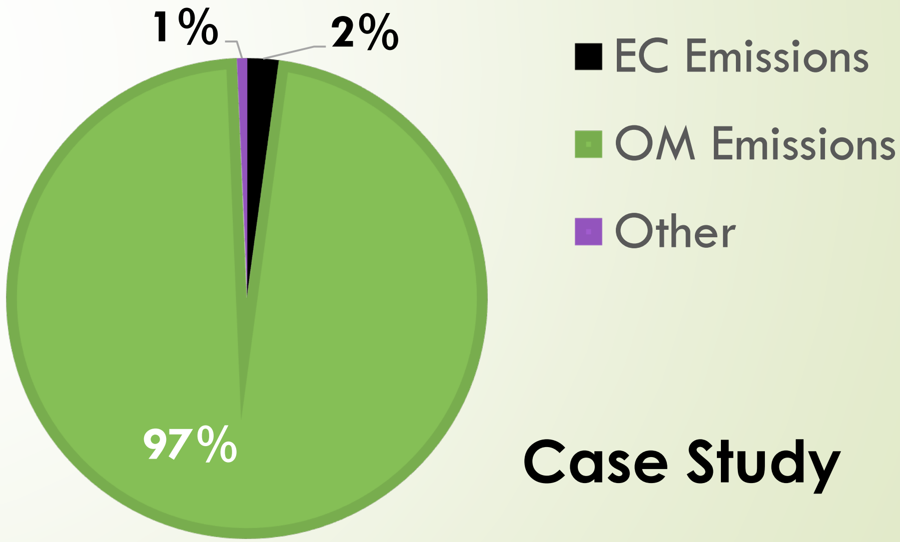
- Currently used Wildfire profile (WF) included some pile burns and fence posts, which may account for the higher elemental carbon and inorganic fractions.
- Working to add more profiles to cover other regions of the U.S.

Case Study – SE United States: Potential impact on inventory and input for modeling

Total SE U.S. PM2.5 Emissions (tons)		Wildfire PM2.5 Emissions (tons)		Prescribed Fire PM2.5 Emissions (tons)	
NEI 2014	Case Study	NEI 2014	Case Study	NEI 2014	Case Study
258,765	512,685	21,192	43,634	237,574	469,051



Current Profile Use, corresponds to "NEI 2014" PM2.5 emissions above



Case Study

Note: NEI 2014 uses FEPS BS emission factors and Reff et al. 2009 PM speciation. Potential impact data shown here is only a back of the envelope estimate of the potential impact of modifying the emission factors and speciation profile based on our research effort

Concluding remarks

- NEI development of WLF emission estimates
  - Need to better identify fire occurrences (smaller fires especially)
  - Need to consider using a modularized approach to estimating emissions: region and fuel-specific emission factors, consumption estimates, etc.
- Emission factors testing
  - Continue research to better understand VOC and PM composition as a function of combustion phase and other fire parameters
    - Our initial PM composition research shows EC fraction to be lower than what we are currently using (in the 2014 NEI), and also shows EC fraction to be higher for flaming compared to smoldering emissions
  - Research Lead (Pb)and Ammonia (NH3) emission factors
  - Coordinate work with USFS and other researchers to enhance available data for use in inventory development and air quality modeling
- Publish results; make data available to others for use in inventory development and air quality modeling

Thank You!!

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