Modeling Fire Plume Rise in AIRPACT5 - a preliminary study

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Idaho DEQ

2017 NW-Airquest Annual Meeting
6/14/2017 – 6/16/2017

*** Preliminary study, please do not cite ***

Difficulty in Fire Modeling

- Fire Emission
  - Fuel loading
  - Consume
- Fire plume rise
- Lack of Observation data

Atmos. Chem. Phys., 10, 1491–1510, 2010
www.atmos-chem-phys.net/10/1491/2010/

Atmospheric Chemistry and Physics

Smoke injection heights from fires in North America: analysis of 5 years of satellite observations

M. Val Martin[1], J. A. Logan[1], R. A. Kahn[2], F.-Y. Leung[3], D. L. Nelson[4], and D. J. Diner[5]

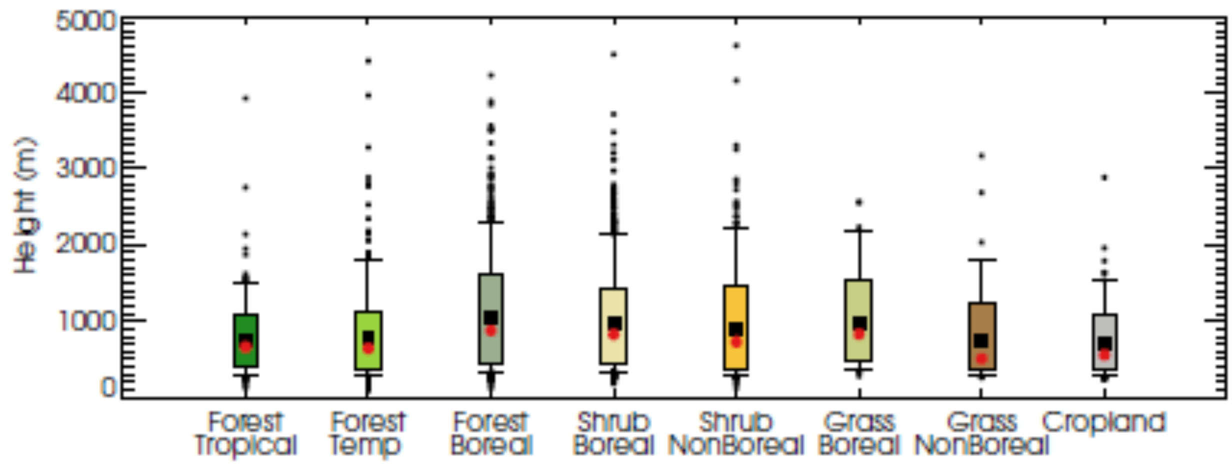
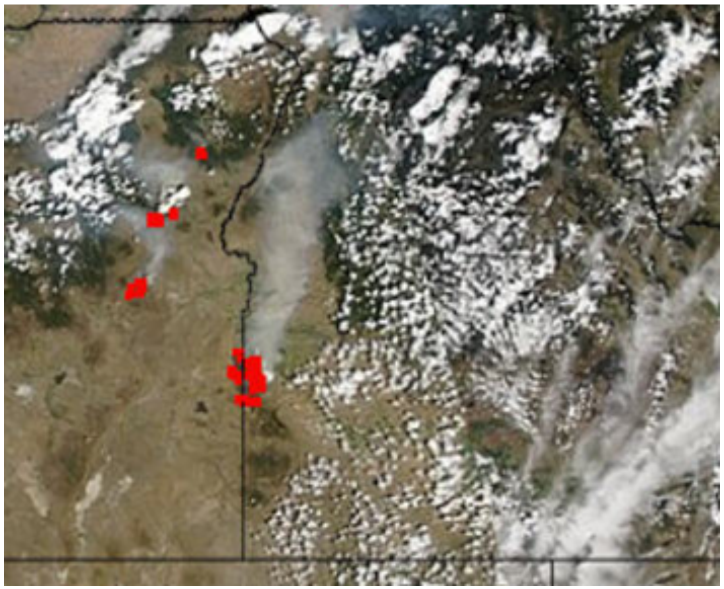
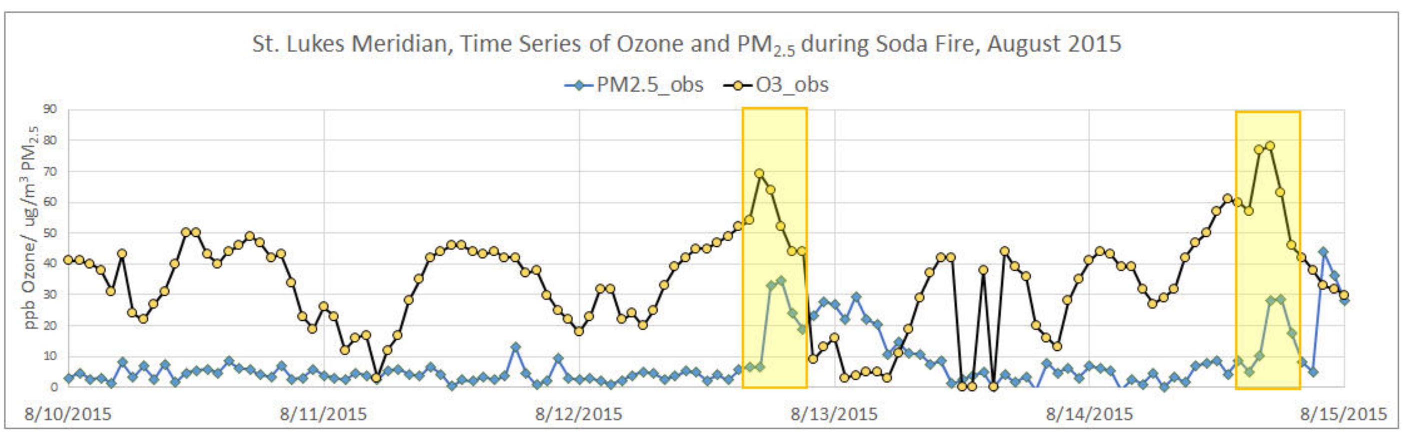


Fig. 6. Distribution of the median height above the terrain for smoke plumes in each biome (see Figure 3 for spatial distribution of the biomes). Bar plots indicate the distribution of the data. The medians (red circles) and the means (black squares) are shown along with the central 67% (color coded box) and the central 95% (thin black lines). Data that fall outside the bar plots are plotted with black circles.

Soda Fire

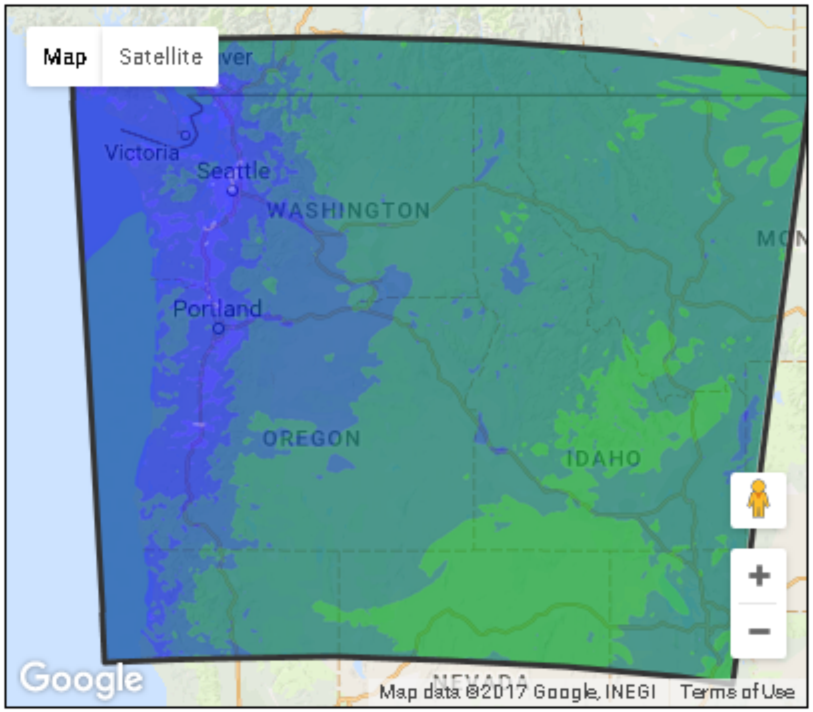


- 8/10/2015 – 8/15/2015
- $PM_{2.5}$ & Ozone data at St. Luke's (Meridian) and $PM_{2.5}$ data at Nampa
- No impact from other fires before 8/14/2015



Soda Fire, Aug. 12 Flyover

Modeling Setup

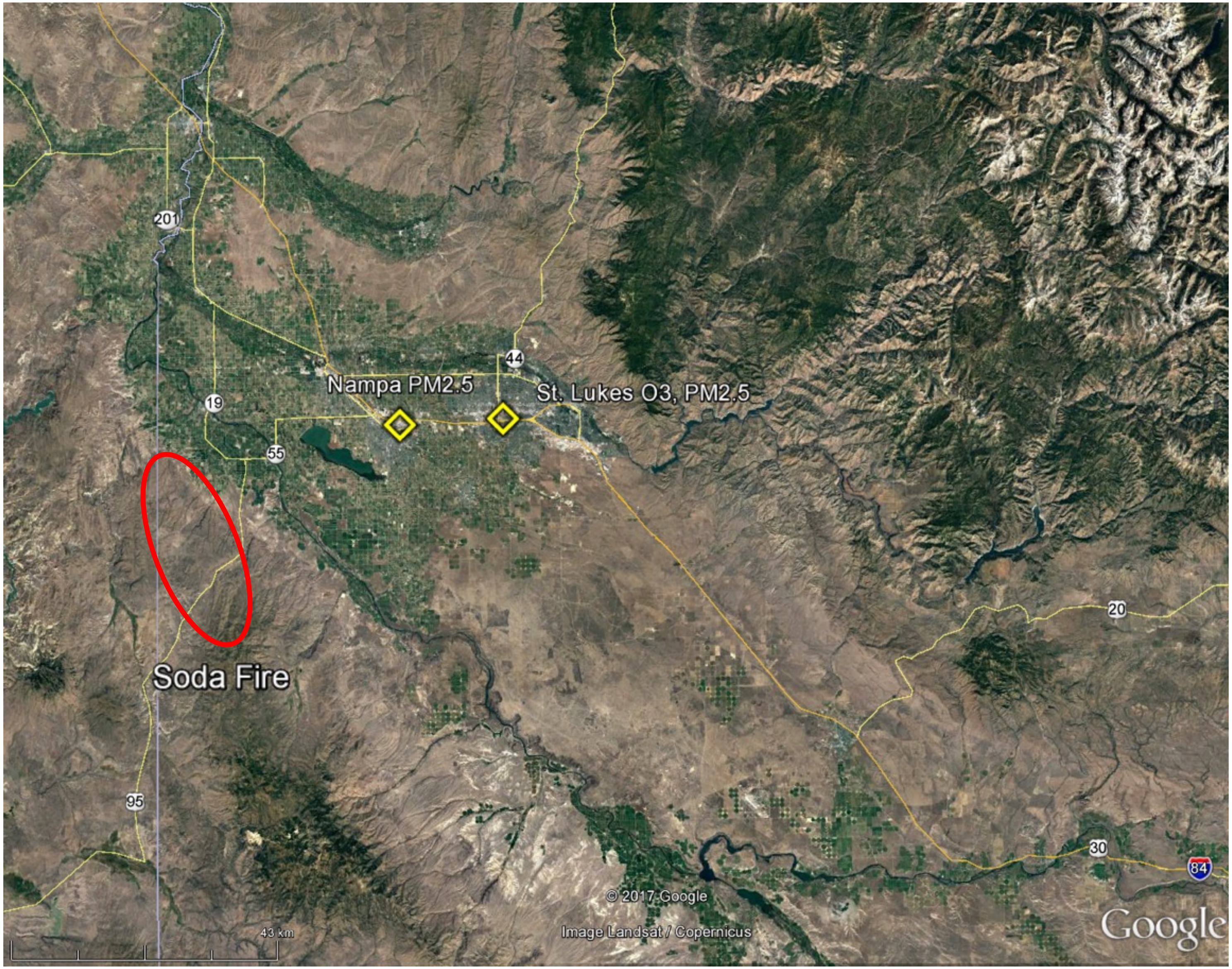


- The latest AIRPACT5 System (4km resolution)
- Updated onroad emission
- Soda fire emission generated from Bluesky Framework
- Plume rise determined in SMOKE

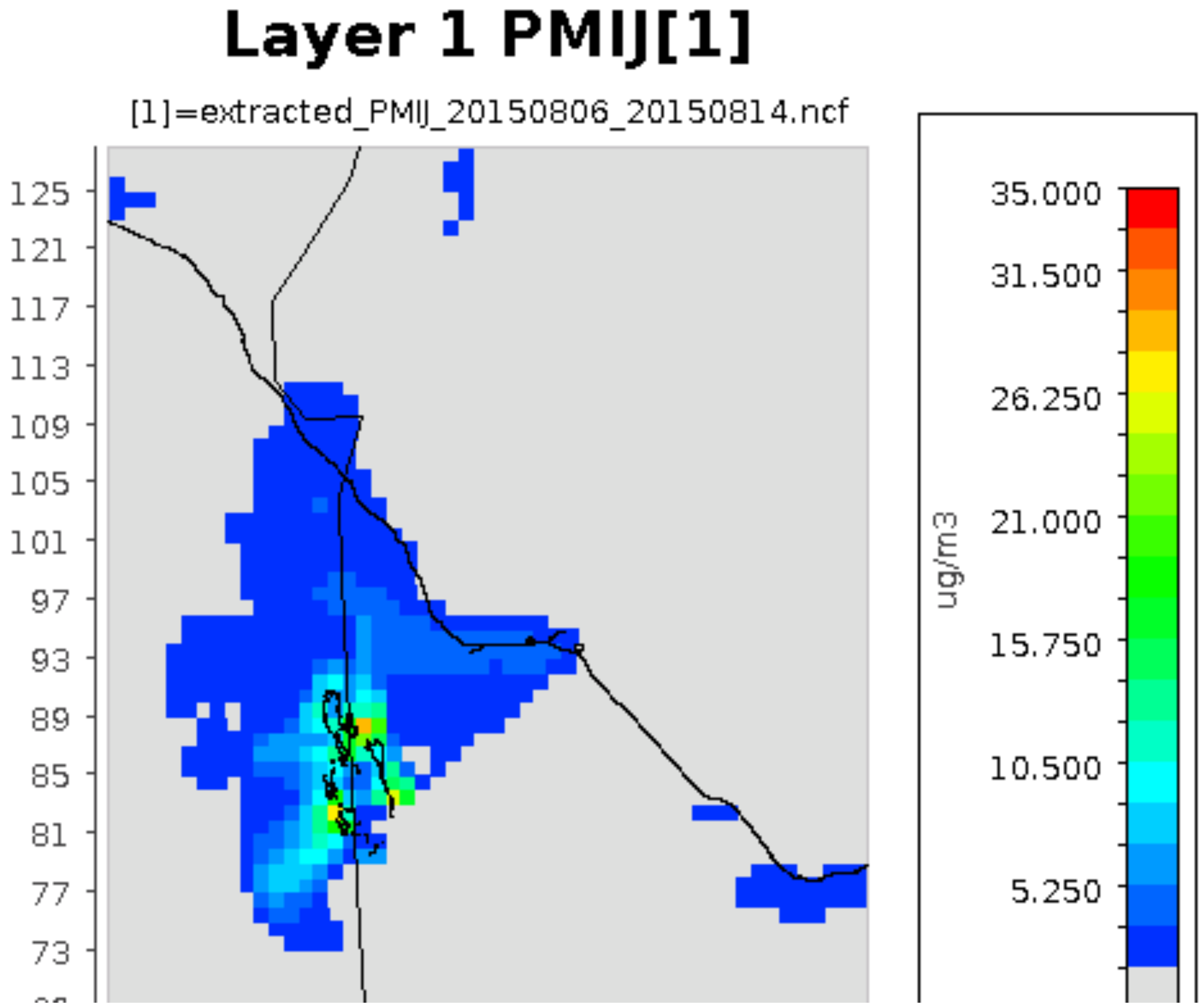
Vertical Structure at St Lukes

Layer	Middle Height (m)
1	21.25
2	63.83
3	110.40
4	165.20
5	225.10
6	290.90
7	367.90
8	458.20
9	564.60
10	689.40
11	835.40
12	1007.00
13	1207.00
14	1759.00
15	2913.00
16	4709.00
17	7273.00
18	10280.00
19	13200.00
20	15990.00
21	18720.00

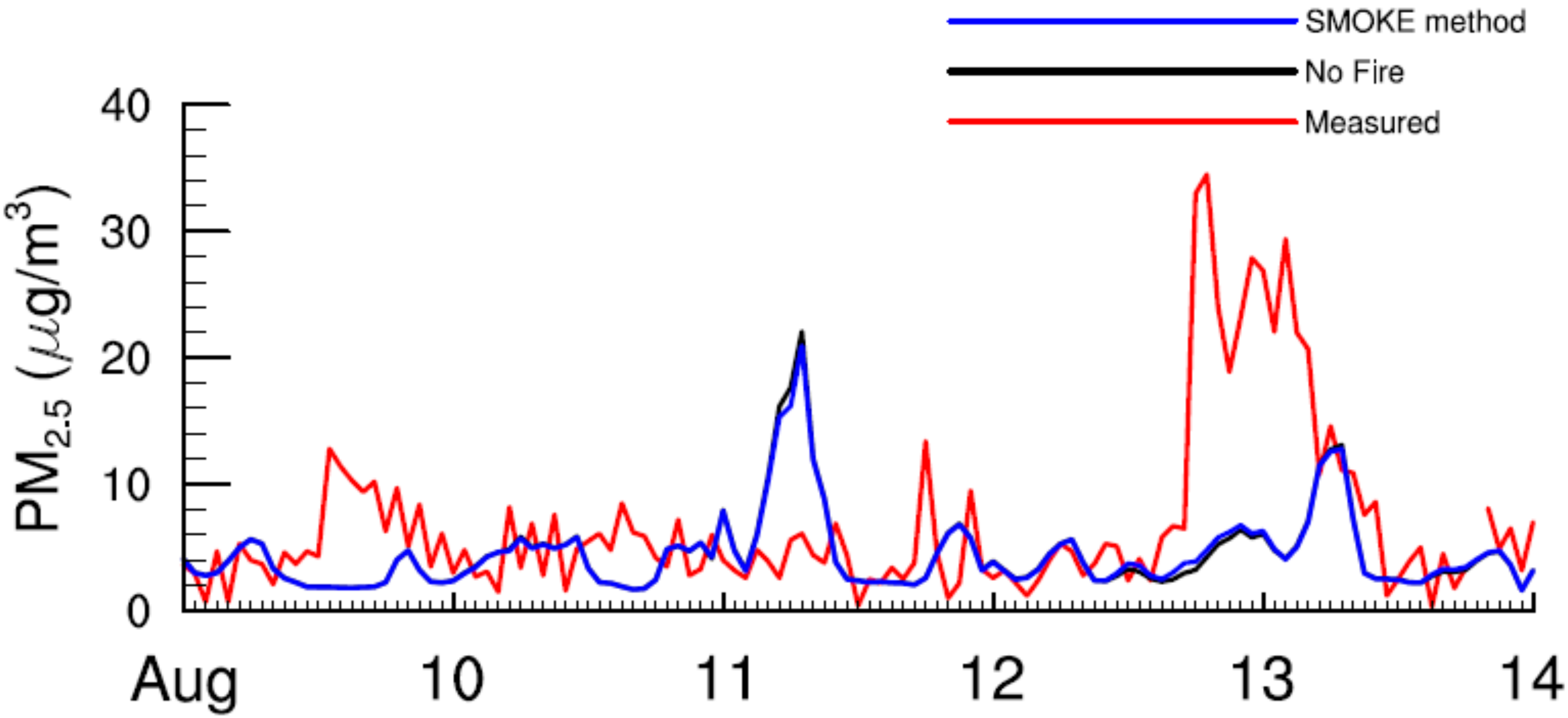
Locations of Monitoring Sites



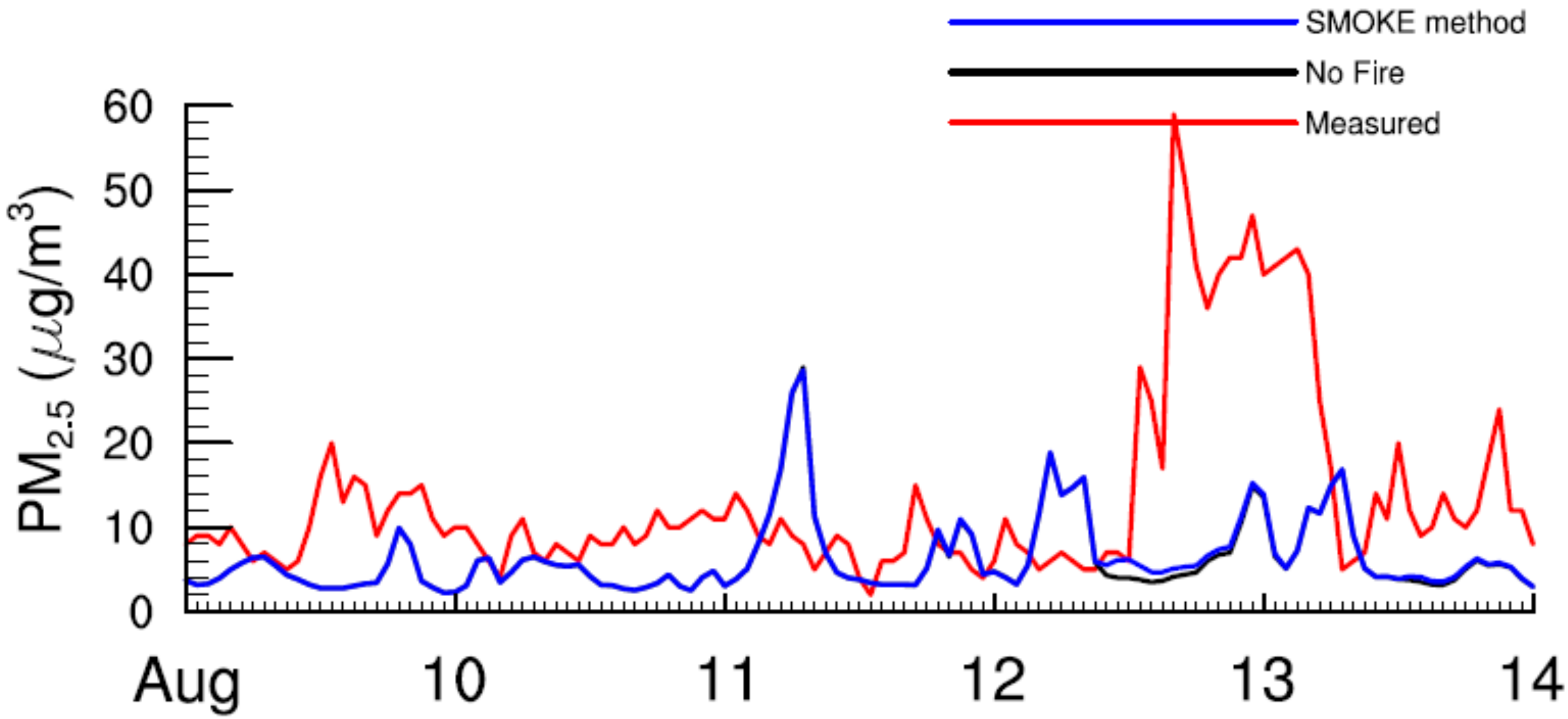
Initial Model Performance (1) Spatial



Initial Model Performance (2) Time Series at St lukes



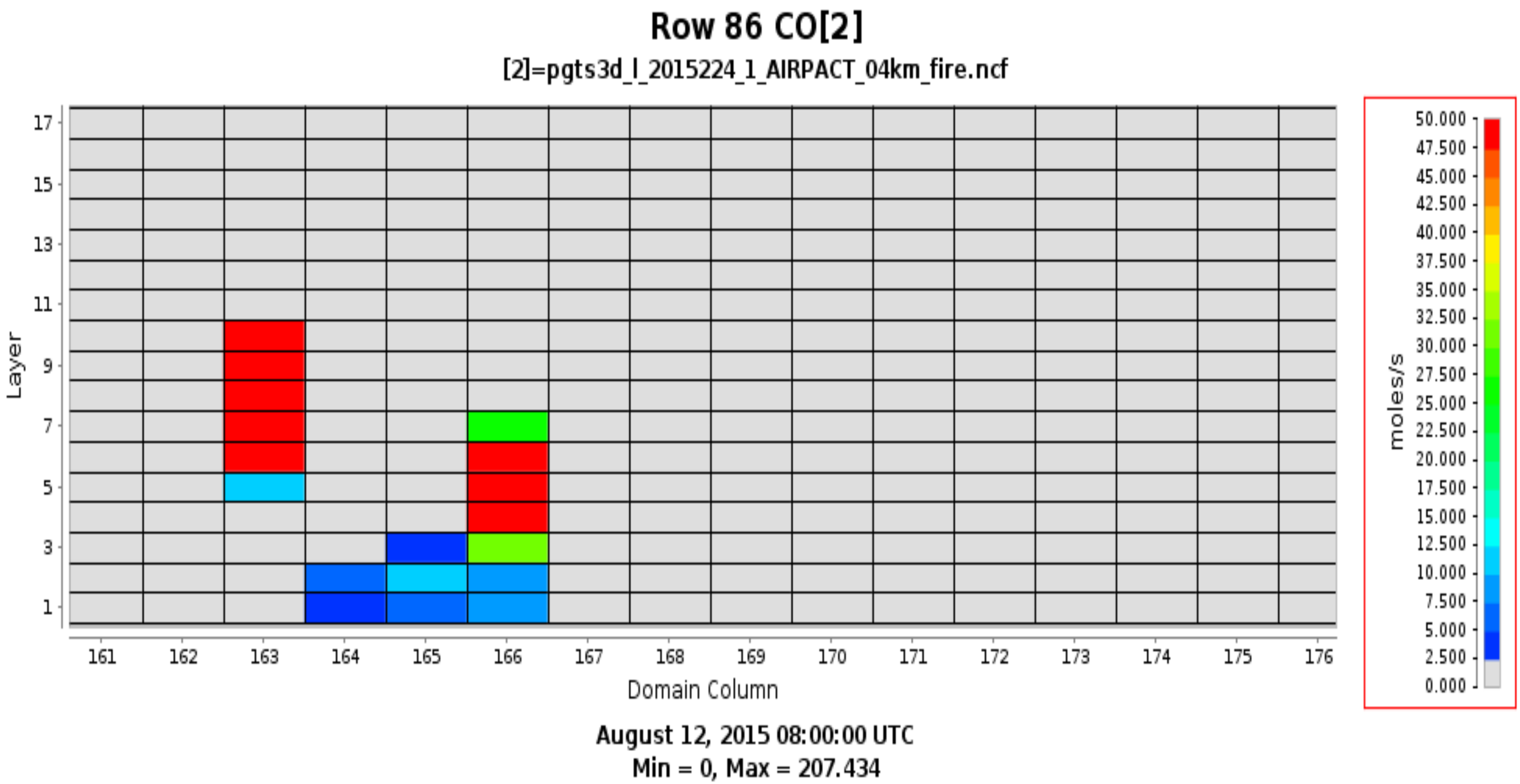
Initial Model Performance (3)
Time Series at Nampa



Why???

- Meteorology performance???
  - Evaluated the Meteorology performance
  - Checked neighboring grid cells to account wind direction uncertainty
- Emission???
  - STI data set under EPA contract
  - Best available
- Plume rise???

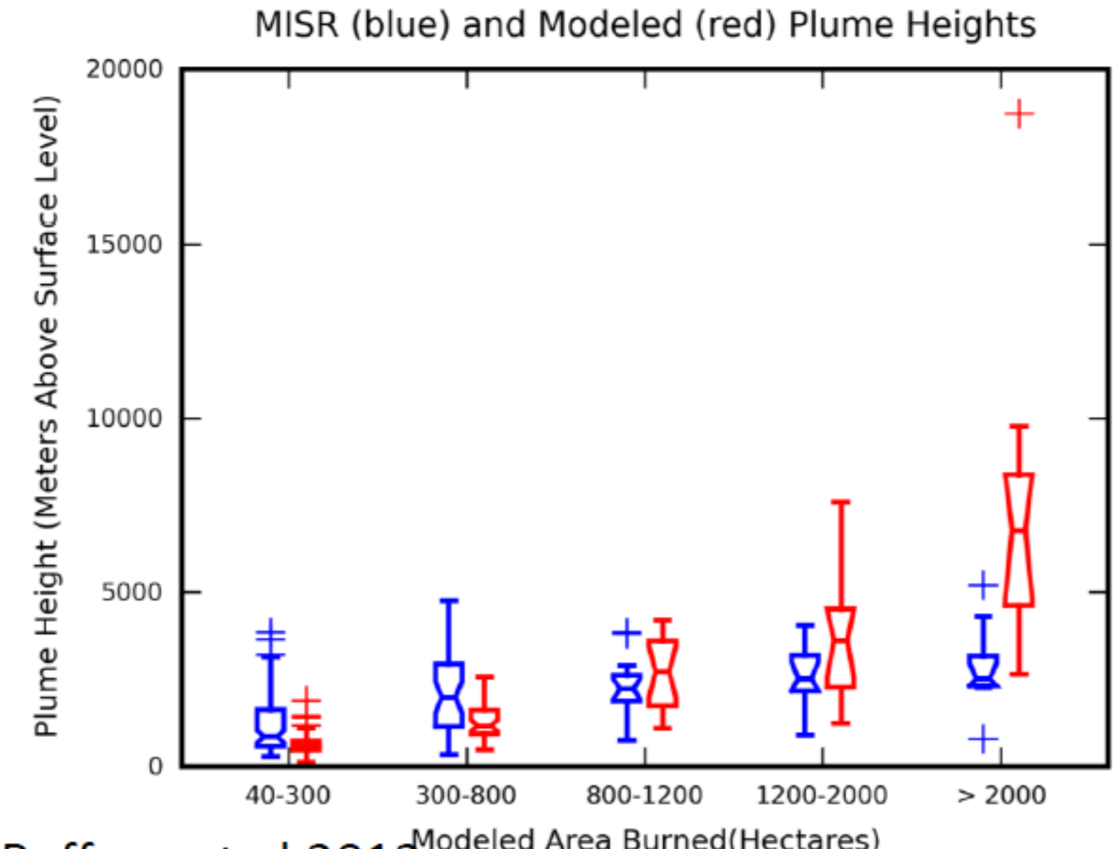
Initial Model
Emission Vertical Distribution



Problems

- Smoldering fraction is too low
- Plume rise is too high

Literature : Observation vs. Model



Raffuse et al 2012

Plume Rise in SMOKE

To be presented: 14th Internat. Emission Inventory Conf. "Transforming Emission Inventories Meeting Future Challenges Today" 4 /11 -4/14/05 Las Vegas

Wildfire Emission Modeling: Integrating BlueSky and SMOKE

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Plume Rise in SMOKE (1)

1. Calculate Plume bottom and Plume top
    - Briggs plume rise algorithm
2. Determine smoldering fraction
3. Inject smoldering portion of emission between ground level to plume bottom
4. Inject flame portion of emission between plume bottom and plume top

Plume Rise in SMOKE (2)

- Key inputs
  - Meteorology condition (wind speed, temperature, pressure, etc.)
  - Heat flux (BTU/hour)
    - [heat per acre] * [acreage burned]
  - Acreage burned (acres/hour)

- Heat flux and acreage burned used in different steps, no connection in the model

Plume Rise in SMOKE (3)

Calculate Plume bottom and Plume top

- Meteorology condition
- Buoyancy Flux

$$F = Q * 0.00000258 \quad (1)$$

where F = buoyancy flux (m^4/s^3)
Q = heat flux (BTU/hr)

No acreage burned in equation???

"1,000,000 British Thermal Units (BTUs) released over 100,000 acres is not equivalent, in terms of plume rise, to the same amount of heat released over 10,000 acres" (From DEASCO3 Report)

Plume Rise in SMOKE (4)

Determine smoldering fraction

$$BE_{size} = 0.0703 * \ln(acres) + 0.3 \tag{2}$$

where BE_{size} = buoyant efficiency
acres = fire size in acres

The smoldering fraction (S_{fract}) was calculated from the Bouyant efficiency as follows:

$$S_{fract} = 1 - BE_{size}.$$

DEASCO3

Objective

Quantify the contributions from fires to ambient levels of ozone using tools and procedures that are similar to those that will be used by state and local air agencies in State Implementation Plan (SIP) development.

Deterministic and Empirical Assessment of Smoke's Contribution to Ozone (DEASCO_3)

Final Report

Joint Fire Sciences Program Project # 11-1-6-6

Principal Investigator: Charles T. (Tom) Moore, Jr.

Western Governors' Association, Western Regional Air Partnership (WRAP)[1]

1600 Broadway, Suite 1700, Denver, CO 80202

WESTERN REGIONAL AIR PARTNERSHIP

Collaborators:

Air Sciences, Inc. – David Randall, Matthew Mavko, and colleagues

ENVIRON International Corp. – Ralph Morris, Bonyoung Koo, and colleagues

U.S. National Park Service – Mark Fitch, Michael George, Michael Barna, John Vimont

U.S. Forest Service – Bret Anderson, Ann Acheson

JOINT FIRE SCIENCE PROGRAM

FIRESCIENCE.GOV
Research Supporting Sound Decisions

1 - now with the Western States Air Resources Council (WESTAR), tmoore@westar.org

WRAP/DEASCO3 (1)

Fire Plume Classes

Equation 1. FPCI Calculation Used to Determine Plume Height Bins

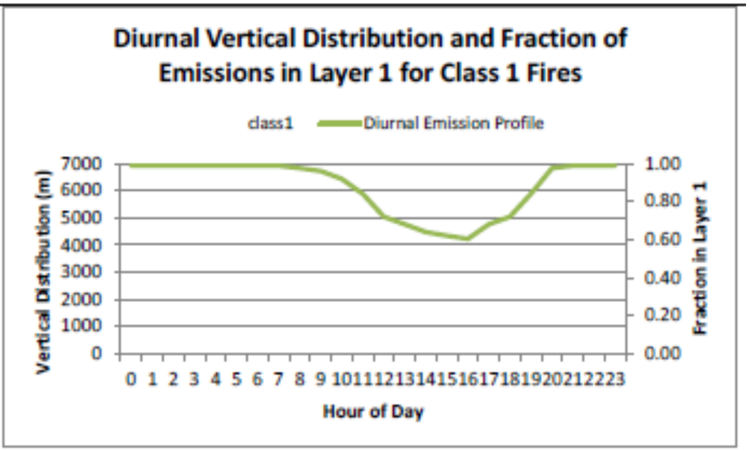
$$FPCI = \frac{Flaming\ Phase\ Consumption}{\sqrt{acres}}$$

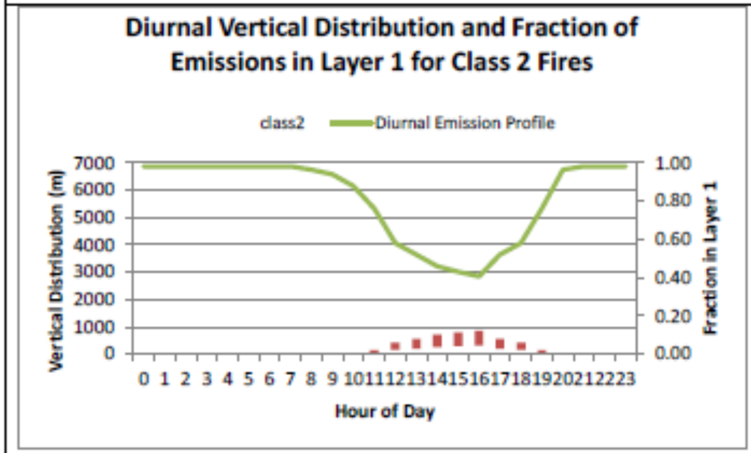
Table 1. Plume Height Bins Calculated Using FPCI and Fire Activity in the WRAP Region

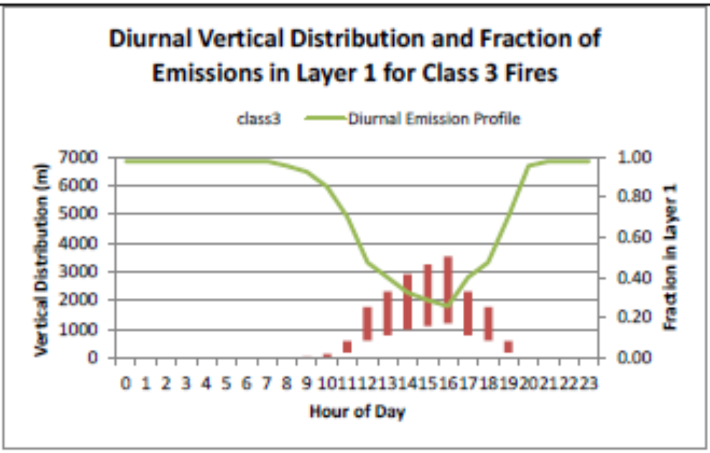
Plume Class ***FPCI***	**1** ***0-75***	**2** ***75-300***	**3** ***300-675***	**4** ***675-1,250***	**5** ***>1,250***	**Total**
Fire Days, DEASCO$_3$ 2008	48,725	9,912	1,167	366	96	60,266
Bin Frequency, DEASCO$_3$ 2008	81%	17%	1.9%	0.61%	0.16%	
Bin Frequency, WRAP 2002	62%	33%	4.5%	0.2%	0.02%	

WRAP/DEASCO3 (2)

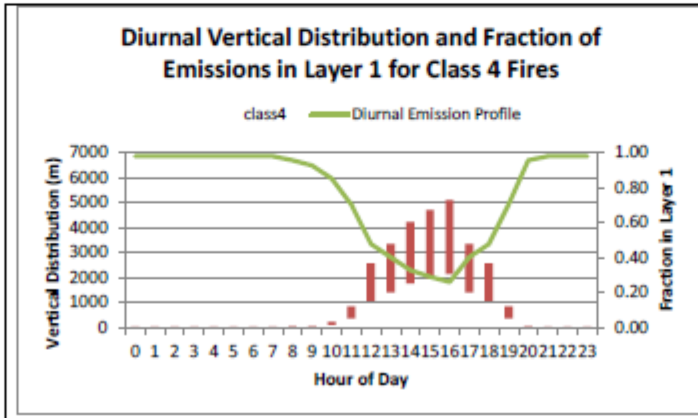
Class	Virtual Acreage
1	< 10
2	10 – 100
3	100 – 1000
4	1000 – 5000
5	>= 5000

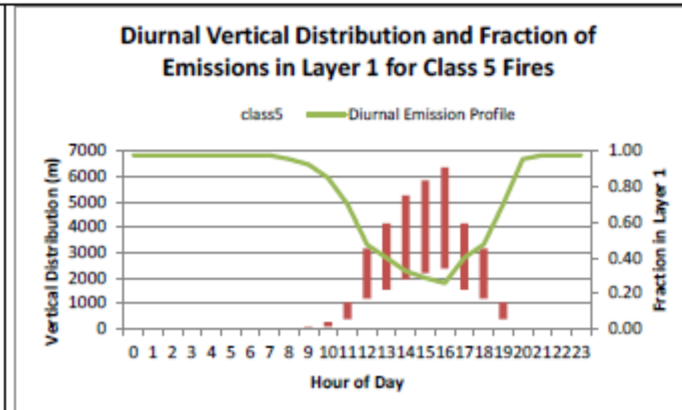






WRAP/DEASCO3 (3)





Preserving smoldering fraction in SMOKE Processing

- Pre-determine the smoldering fraction
  - Literature (WRAP/DEASCO3)
- Virtual area concept
  - [Virtual area] = EXP((1 - 0.3 - [S_fract])/0.0703)
  - Different from WRAP virtual area

Virtual Heat Approach (1)

- Inspired by DEASCO3 Flaming Phase Consumption Index
- Function of flaming phase heat and area burned
- Different fire (heat) density will have different plume rise
- Another way to think of it: multiple virtual flame fronts

Virtual Heat Approach (2)

Definition:

- **VH : Virtual Heat**
- **FPH : Flame Phase Heat (maximum heat)**
- **AR : Area burned**

If AR <= 1 acre :

$$VH = FPH$$

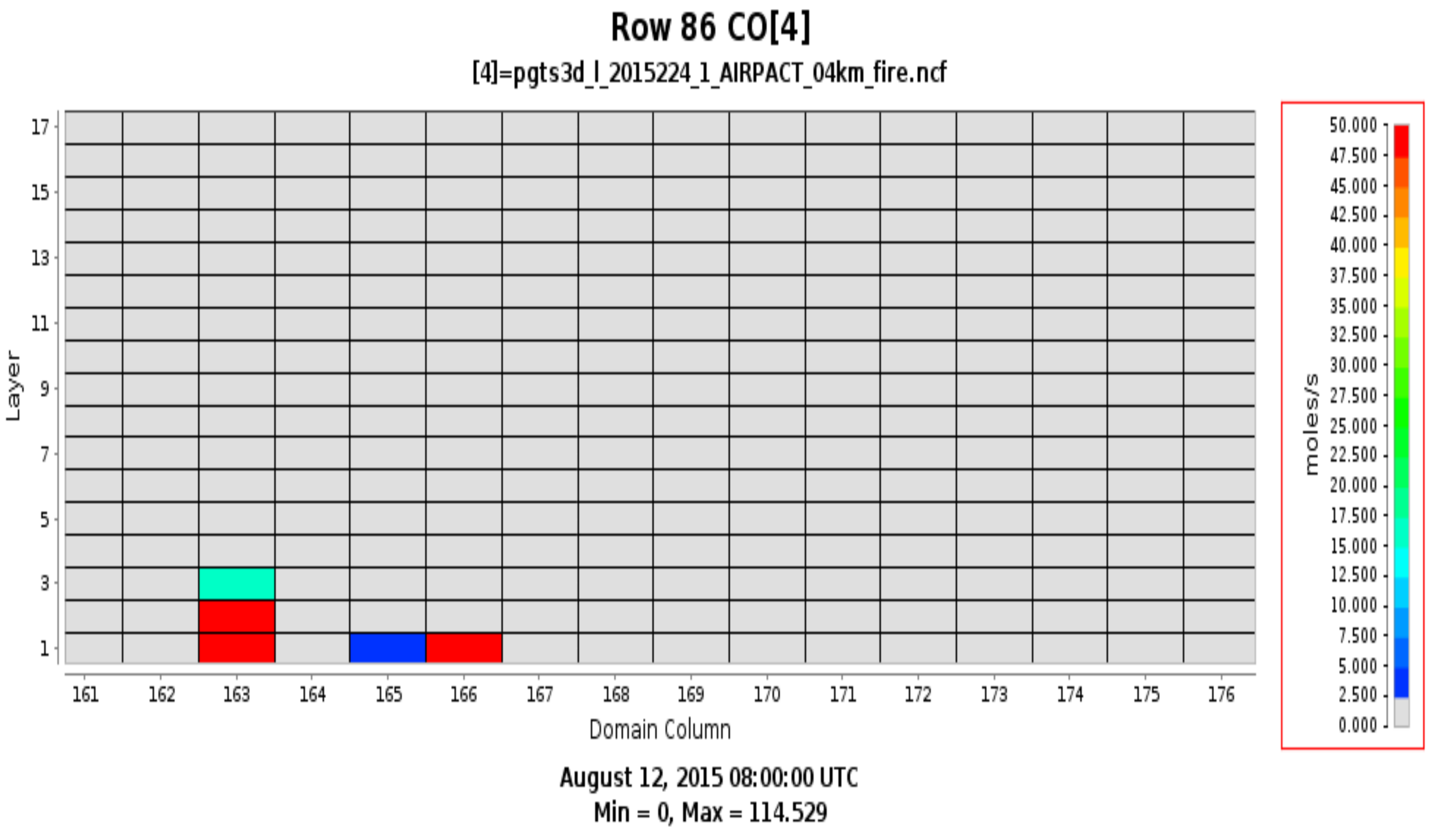
If AR > 1 and < 1001 acres :

$$VH = \frac{FPH}{\sqrt{AR}} + \left(FPH - \frac{FPH}{\sqrt{AR}}\right) * \left(\frac{1001-AR}{1000}\right)$$

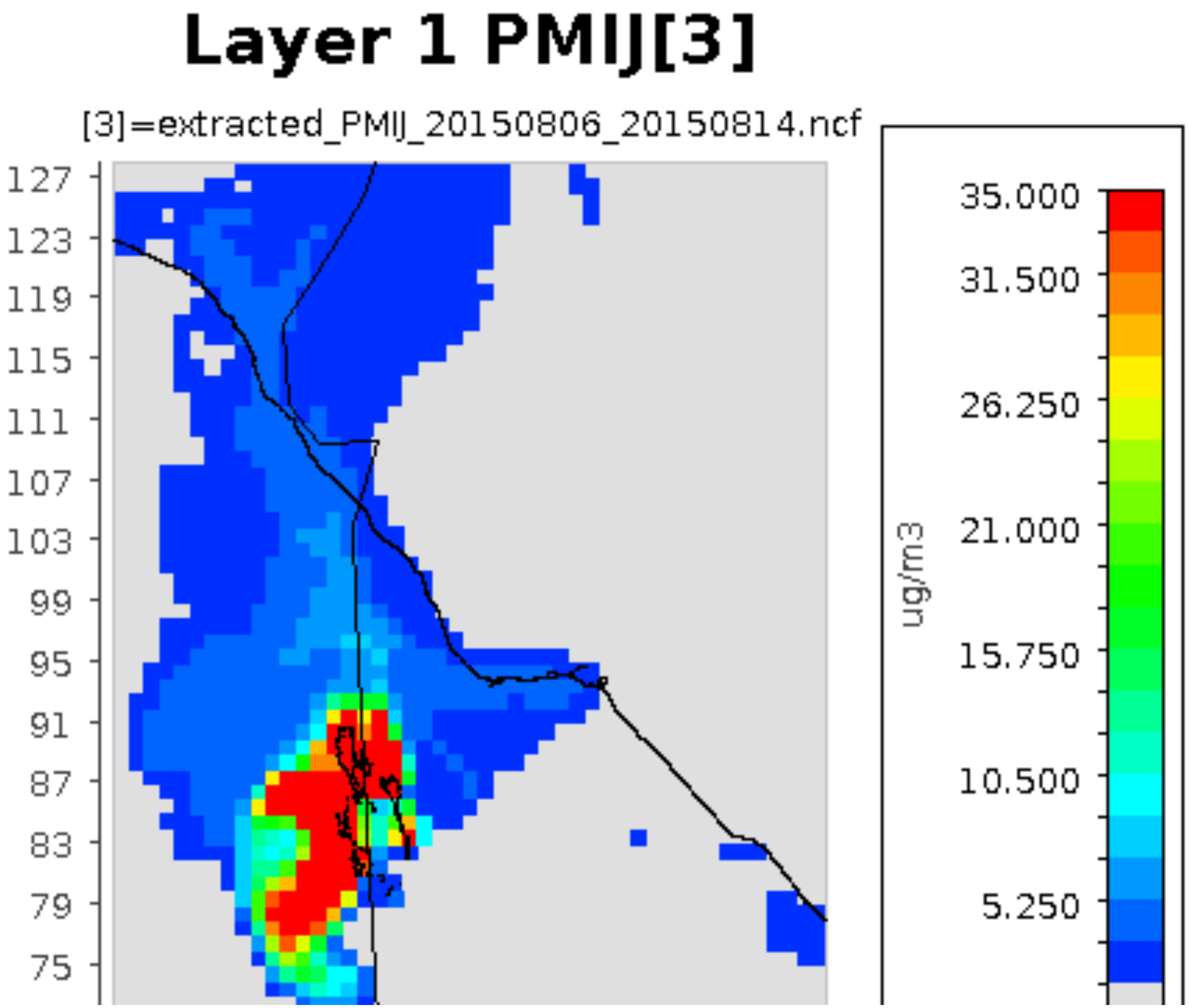
If AR >= 1001 acres :

$$VH = \frac{FPH}{\sqrt{AR}}$$

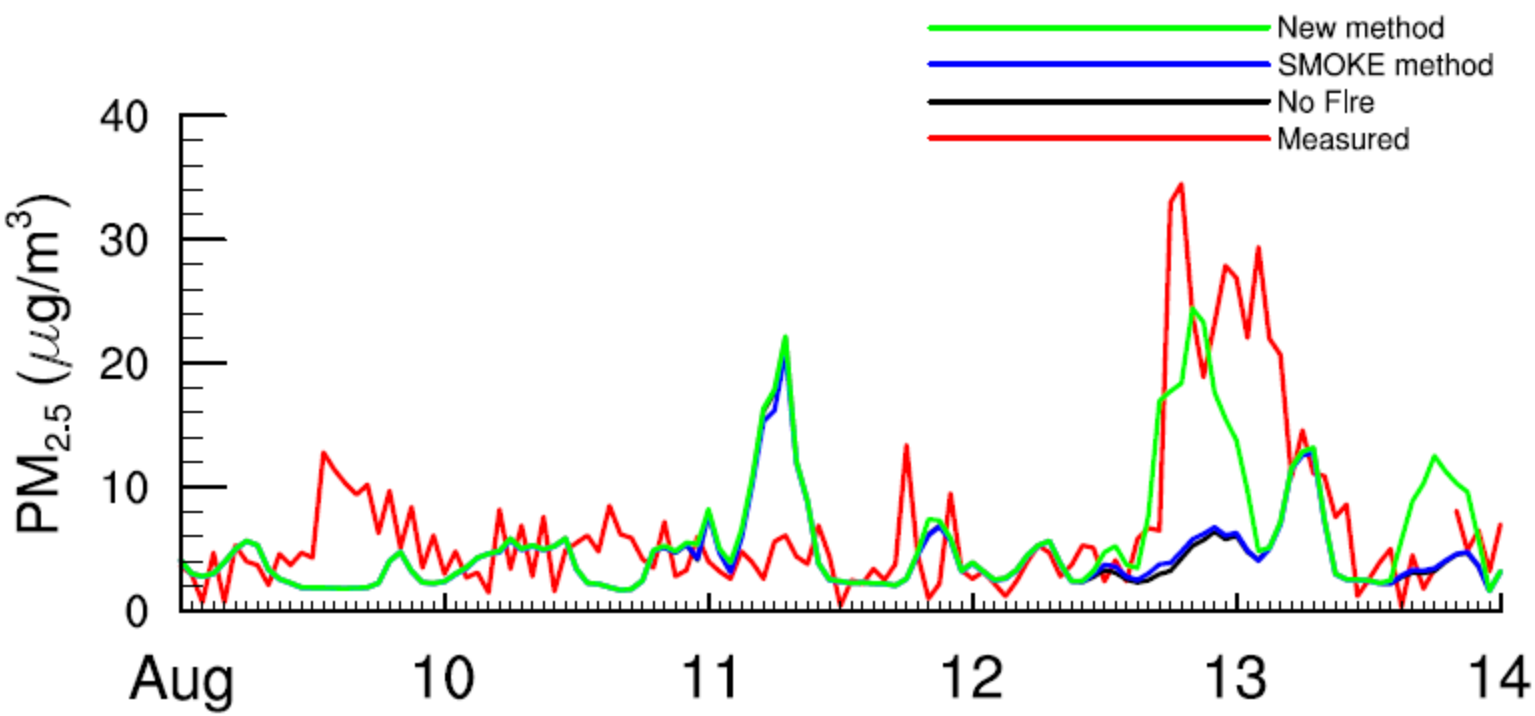
New Method Result (1) Emission Vertical Distribution



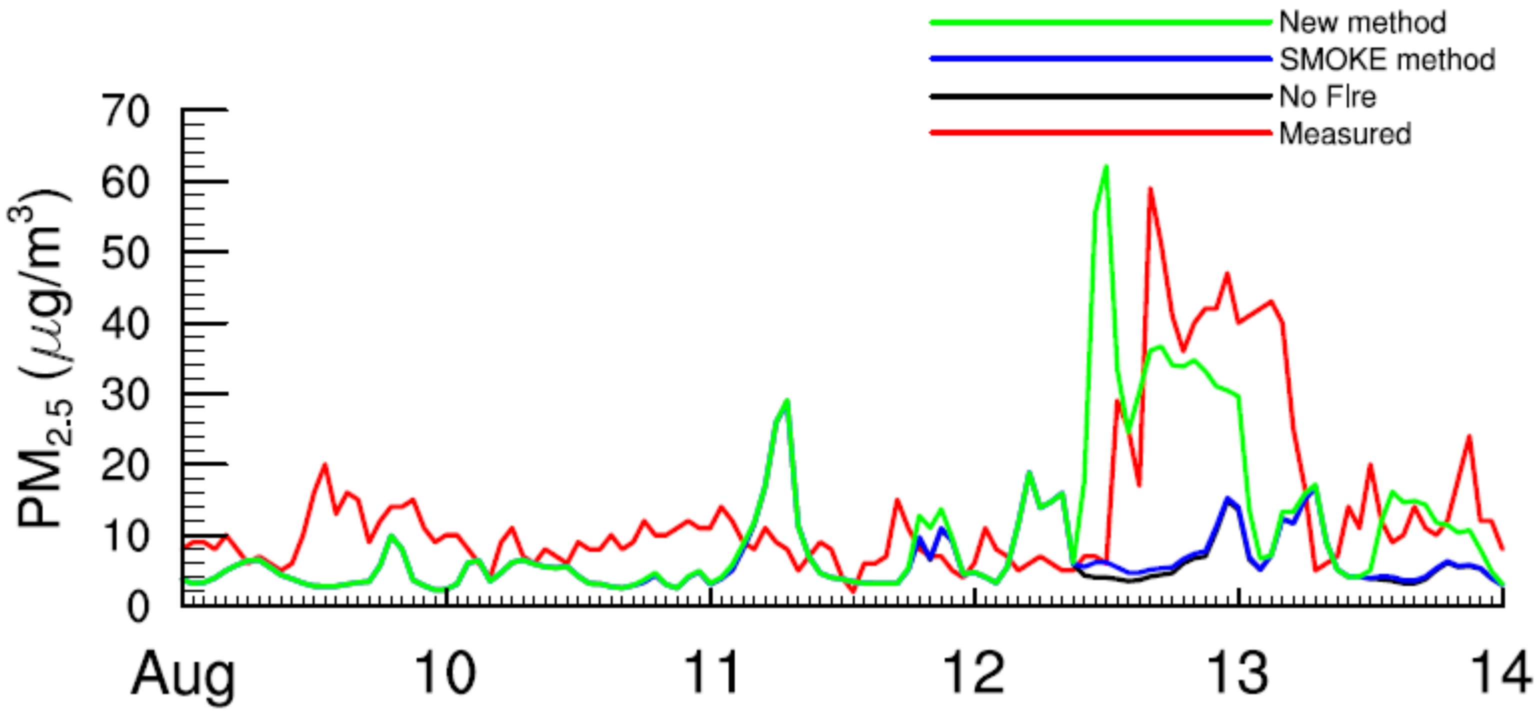
New Method Result (2)
Spatial



New Method Result (3)
Time series at St Lukes



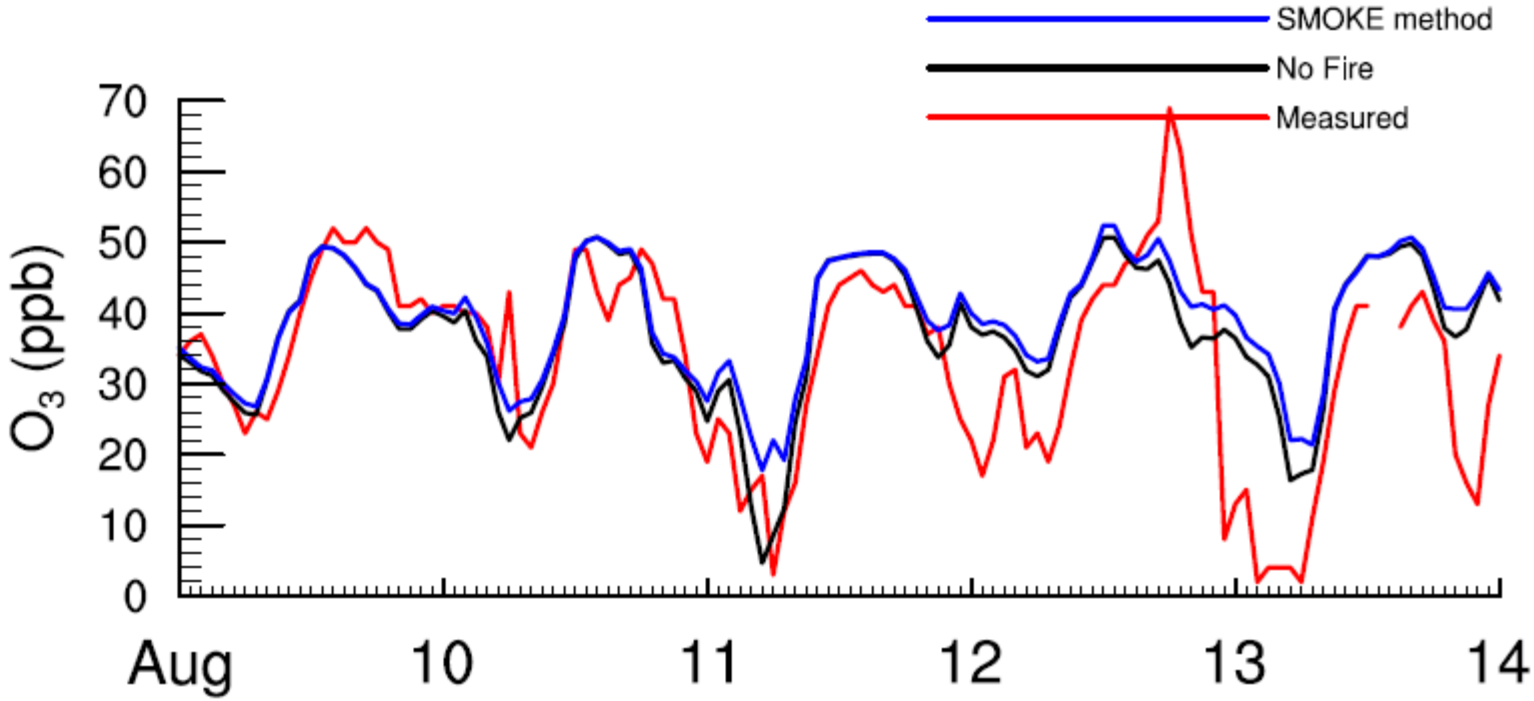
New Method Result (4)
Time series at Nampa



Questions???

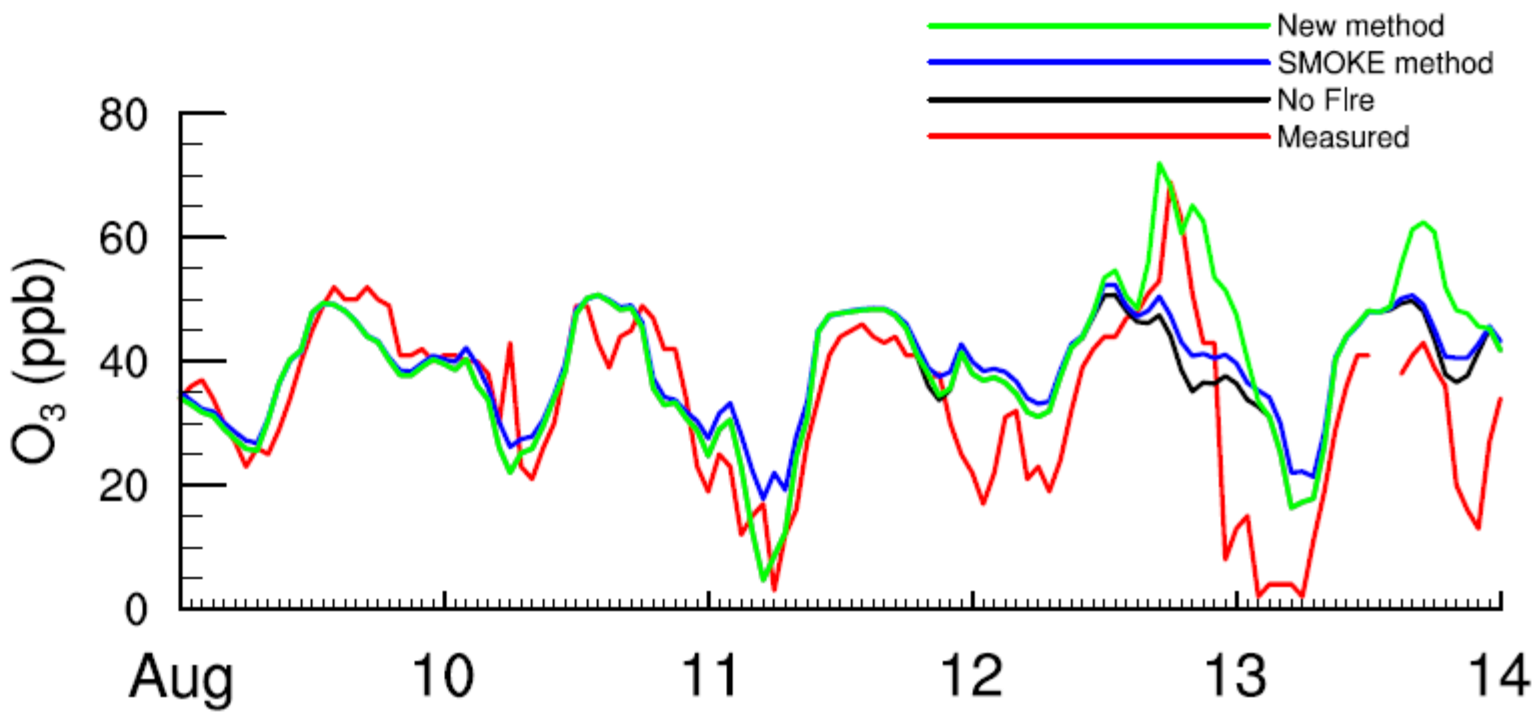
SUPPLEMENTARY SLIDES

St Lukes



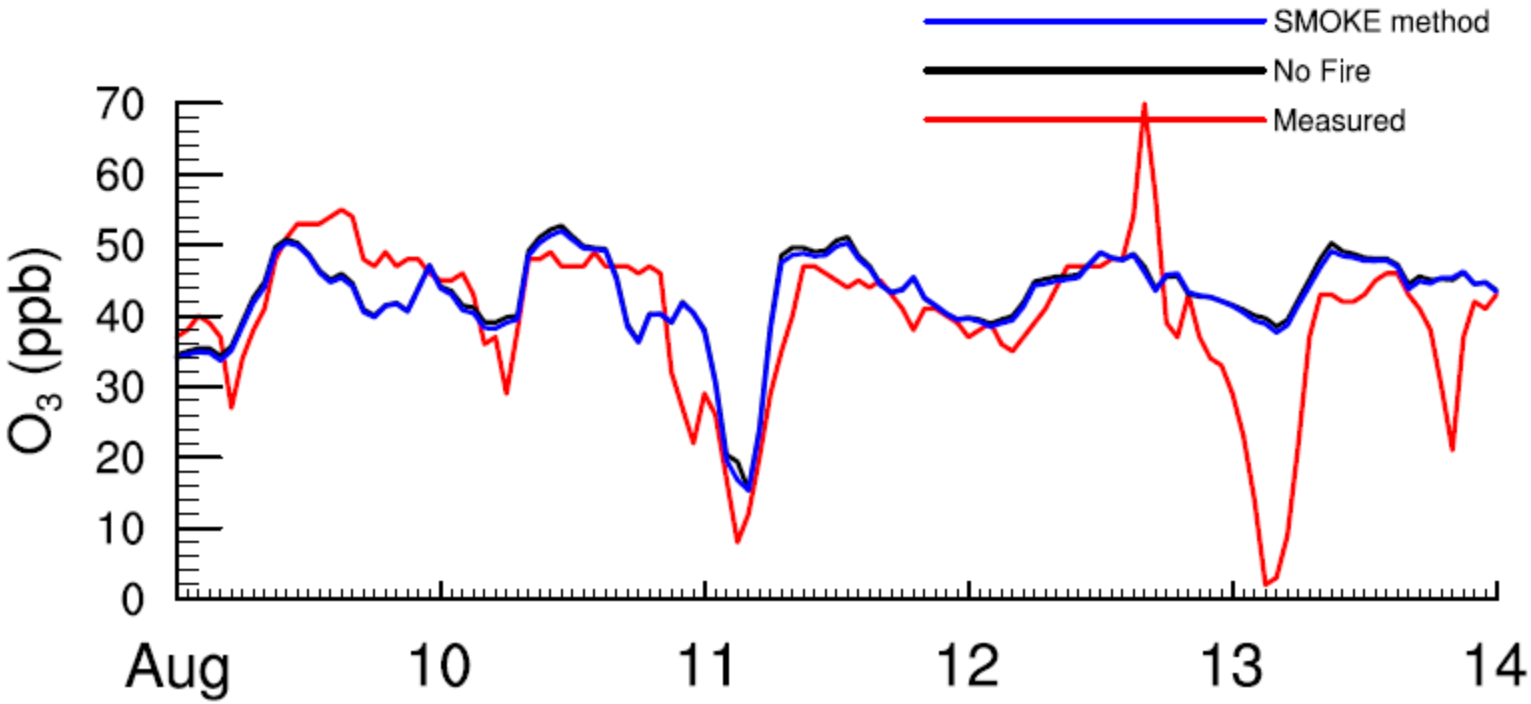
SMOKE method
No Fire
Measured
70
60
50
40
30
20
10
0
O_3 (ppb)
Aug
10
11
12
13
14

St Lukes



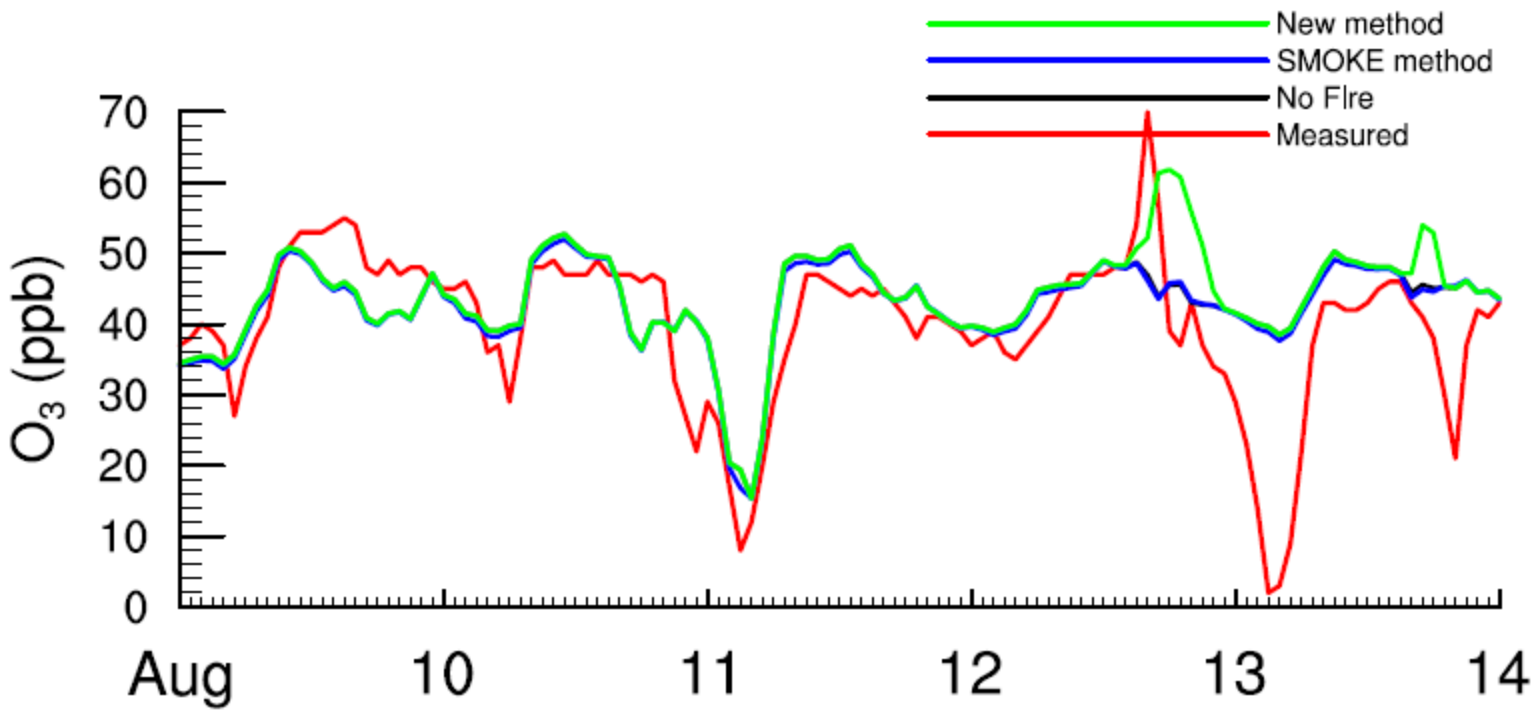
New method
SMOKE method
No Fire
Measured
80
60
40
20
0
O_3 (ppb)
Aug
10
11
12
13
14

White Pine



SMOKE method
No Fire
Measured
70
60
50
40
30
20
10
0
O3 (ppb)
Aug
10
11
12
13
14

White Pine



New method
SMOKE method
No Flre
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O_3 (ppb)
70
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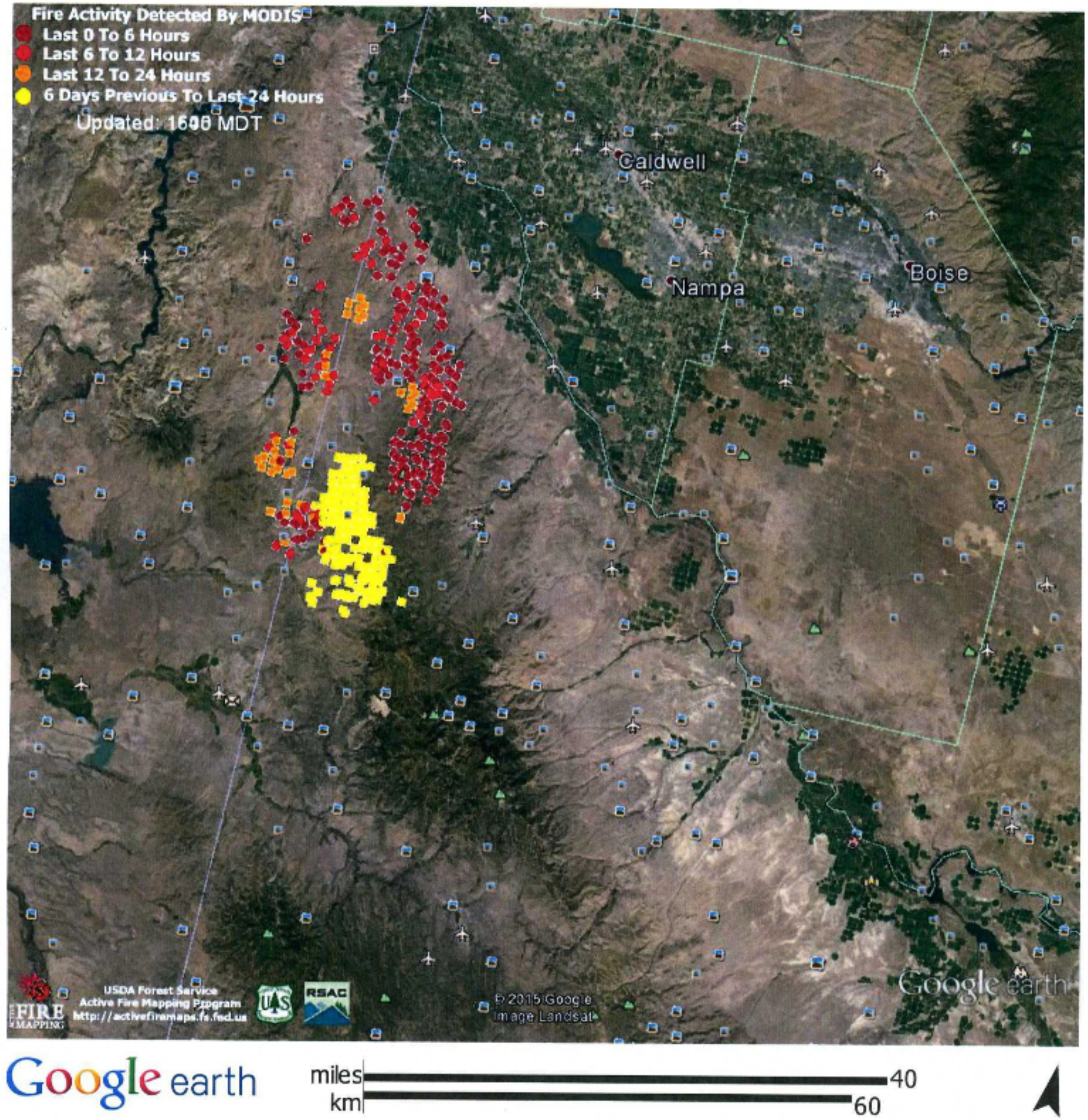
Fire Activity Detected By MODIS
Last 0 To 6 Hours
Last 6 To 12 Hours
Last 12 To 24 Hours
6 Days Previous To Last 24 Hours
Updated: 1600 MDT
Caldwell
Nampa
Boise
USDA Forest Service
Active Fire Mapping Program
http://activefiremaps.fs.fed.us
RSAC
© 2015 Google
Image Landsat
Google earth
Google earth
miles
40
km
60

Plume rise is dependent on intensity of the burn, not just total fuel consumption:

By using the actual flaming-phase fuel consumed, the Flaming Phase Consumption Index (FPCI) looks at the *actual* heat released instead of the *potential* heat released. In addition, dividing by the square root of the acres burned attempts to capture the intensity of the burn: 1,000,000 British Thermal Units (BTUs) released over 100,000 acres is not equivalent, in terms of plume rise, to the same amount of heat released over 10,000 acres.

Equation 1. FPCI Calculation Used to Determine Plume Height Bins

$$FPCI = {Flaming\ Phase\ Consumption}/{\sqrt{acres}}$$

Source: https://wraptools.org/pdf/DEASCO3_Plume_Rise_Memo_20131210.pdf

Lay1f Emissions Vertical Distribution

- Lay1f fire emissions = Surface to Max(Pbot, PBL)

Vertical Distribution of Elevated Pbot to Ptop Fire Emissions (1-Lay1f)

- 1-Lay1f fire emissions = Pbot to Max(Ptop, PBL)

Thus, in the case where the plume bottom is greater than the PBL height (Pbot > PBL), the Lay1f fire emissions are emitted from the surface to Pbot and the elevated (1-Lay1f) fire emissions are emitted in layers from Pbot to Ptop. In the case where the PBL height is between Pbot and Ptop, then both the Lay1f and the 1-Lay1f emissions are emitted in layers spanning Pbot and the PBL height, with the Lay1f emissions also emitted between the ground and Pbot. If the PBL height is above Ptop, then the Lay1f emissions are emitted from the ground to the PBL height and the 1-Lay1f emissions are emitted between Pbot to the PBL height.