Ozone Production from Wildfires in the Northwestern US

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975 µg/m³ !!

UNIVERSITY OF WASHINGTON
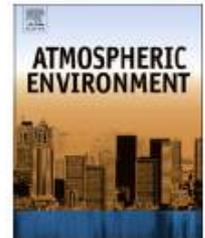
Review article of 132 studies

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Review

Ozone production from wildfires: A critical review

Daniel A. Jaffe [a,b,*], Nicole L. Wigder [a]

Normalized Enhancement Ratios allow an analysis of variability that is not influenced by fire size or dilution:

$$\Delta O_3/\Delta CO \text{ or } \Delta O_3/\Delta CO_2$$

Compilation of observational studies shows that $\Delta O_3/\Delta CO$ depends on biome and transport time

Boreal/ Temperate

Plume Age	Mean $\Delta O_3/\Delta CO$ (ppbv/ppbv) (# plumes)	Range of $\Delta O_3/\Delta CO$
$\leq$ 1-2 days	0.018 (n=55)	-0.032 - 0.34
2-5 days	0.15 (n=39)	-0.07 - 0.66
$\geq$ 5 days	0.22 (n=29)	-0.42 - 0.93

Tropics/ Subtropics

Plume Age	Mean $\Delta O_3/\Delta CO$ (ppbv/ppbv) (# plumes)	Range of $\Delta O_3/\Delta CO$
$\leq$ 1-2 days	0.14 (n=59)	-0.06 - 0.37
2-5 days	0.35 (n=13)	0.26 - 0.42
$\geq$ 5 days	0.63 (n=18)	0.19 - 0.87

Jaffe & Wigder (2012)

Mount Bachelor Observatory

- Research site in central Oregon since 2004

- 2763 meters a.s.l.

- Meteorological parameters, CO, PM_1, O_3, mercury

- 2012 fire season: added CO_2, NOx, NOy, EC/OC

- 2013 fire season: adding PAN to 2012 measurements

Ozone production in northwestern wildfires

Wigder et al. (2013)
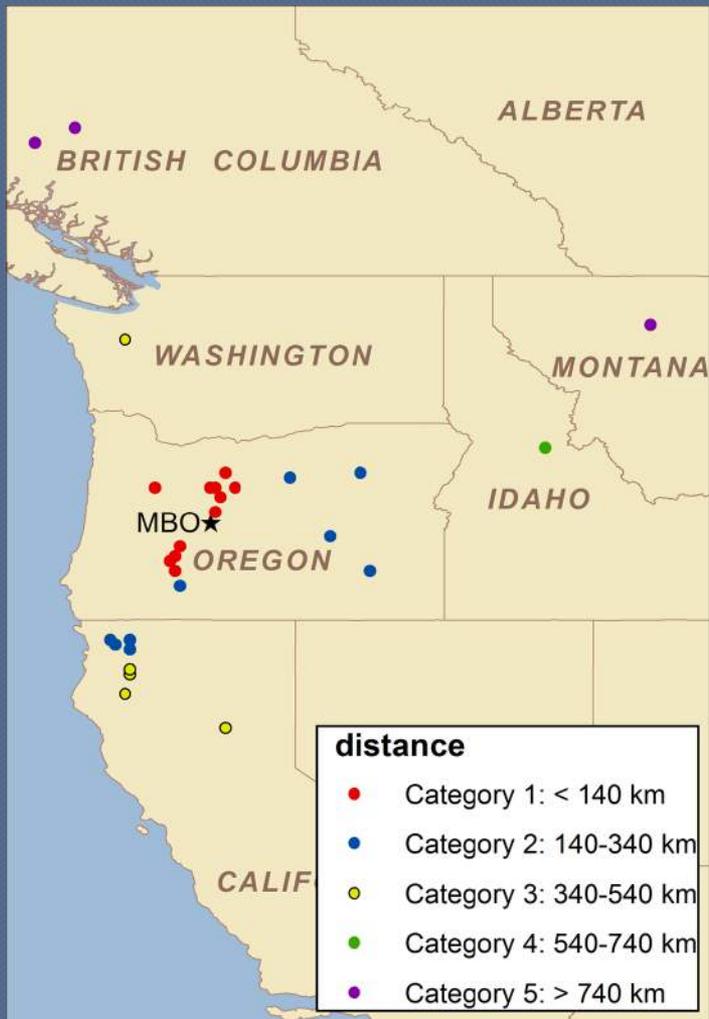
- 32 wildfires observed at Mt. Bachelor, 2004-2011

- 13 produced ozone

These 13 fires:

- $\Delta O_3/\Delta CO$ range: 0.01-0.51

- Large variation within a small geographic area

Mixed urban/fire plumes

- Ozone production in wildfire plumes is NOx-limited

- From our 2013 paper: plumes transported < 1 day:

$\Delta O_3/\Delta CO$ wildfire plumes	$\Delta O_3/\Delta CO$ wildfire/urban mixed plumes
0.04 (n=2)	0.28 (n=2)

- That's a factor of 7 increase in mixed plumes!

- Similar results for Californian plumes (Singh et al., 2012)

PAN and ozone production

NOx $\Rightarrow$ PAN: temperature dependent reservoir $\Rightarrow$ O_3

- Within hours:
  - ~40% of NOx → PAN (boreal; Alvarado et al., 2010)
  - ~22% of NOx → PAN (temperate; Akagi et al., 2012)

- One case study from Mt. Bachelor in 2008:

Plume	$\Delta O_3/\Delta CO$ (ppbv/ppbv)	$\Delta PAN/\Delta CO$ (pptv/ppbv)	$\Delta NOx/\Delta CO$ (pptv/ppbv)
1	0.01 ($R^2 = 0.54$)	0.15 ($R^2 = 0.40$)	4.83 ($R^2 = 0.68$)
2	no significant ozone production	1.14 ($R^2 = 0.96$)	0.33 ($R^2 = 0.83$)

- 2013 Mt. Bachelor field campaign will provide more data

Statistical modeling of ozone from wildfires

- e.g., $O_3 = A*temp + B*winds + C*DOY... + residual$

- Robust method for identifying "added" ozone from wildfires

- From discussion at WESTAR/EPA wildfire and ozone exceptional event meeting, March 5-6, 2013:
  - Used in approved CARB EE demonstration
  - More feasible for some state/local agencies than Eulerian models

Statistical vs. Eulerian models

EULERIAN

- Uses gridded emissions, meteorology, solar fluxes, known photochemistry and transport

- Wildfire challenges: emissions, plume rise, aerosols, photochemistry

- Modeled concentrations may differ significantly from observations, making quantitative attribution difficult

STATISTICAL

- Examines relationship between observed mixing ratios and known factors

- Possible factors to include are temp, wind speed, RH, solar flux, etc.

- Outliers (high residuals) represent an additional O_3 source and are candidates for further investigation

Locations modeled

Jaffe et al., submitted to Environmental Science & Technology
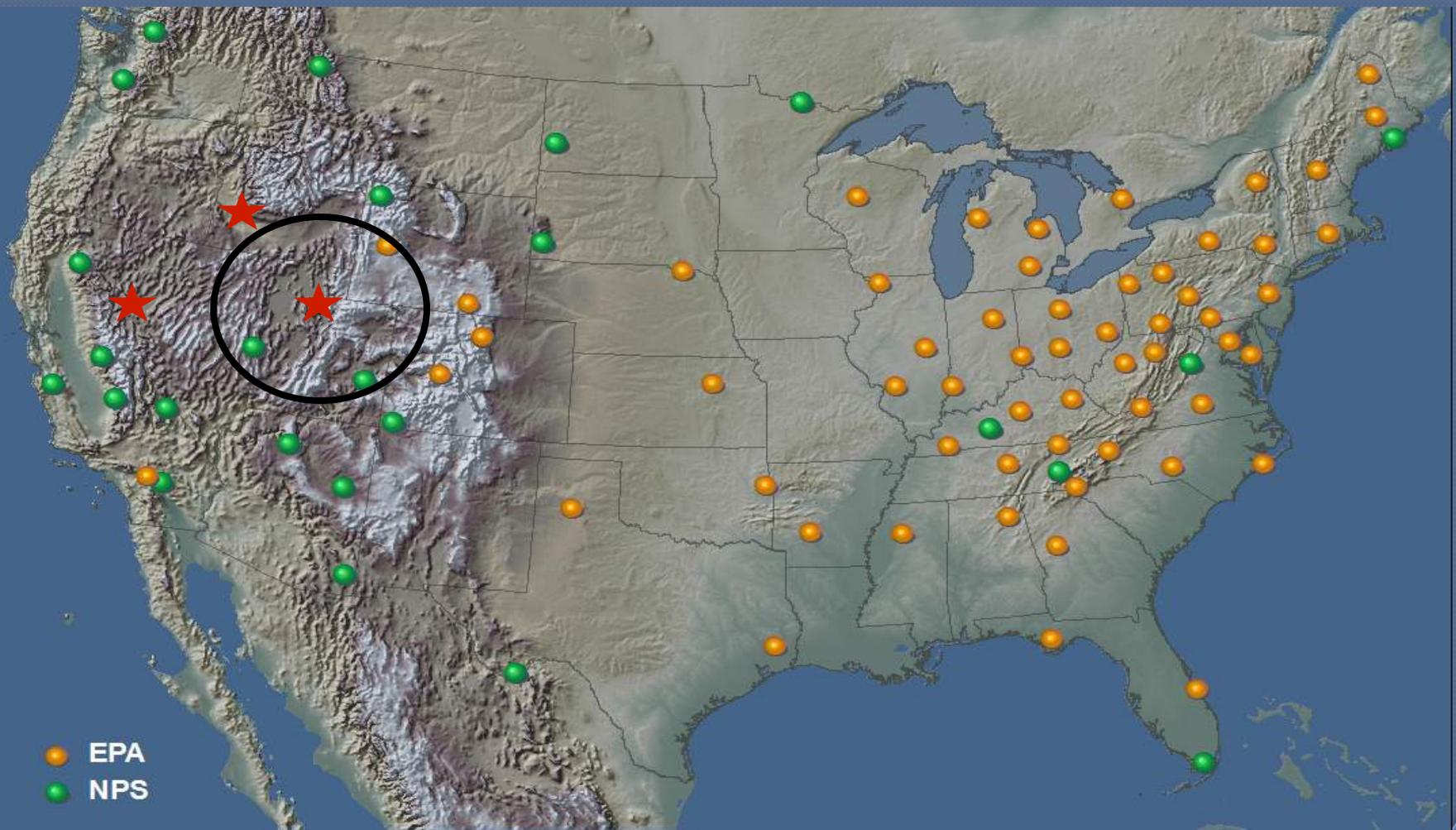
Data

- EPA AirData: MDA8 O_3, $PM_{2.5}$
- NCDC "Climate data online" for met data
- IMPROVE and CASTNET data
- Statistical models developed using SPSS software
- For Salt Lake City, used daily average of all AQS sites in Salt Lake and Davis counties
- Focus on June-Sept. 2000-2012

Example factor: max temperature for Salt Lake
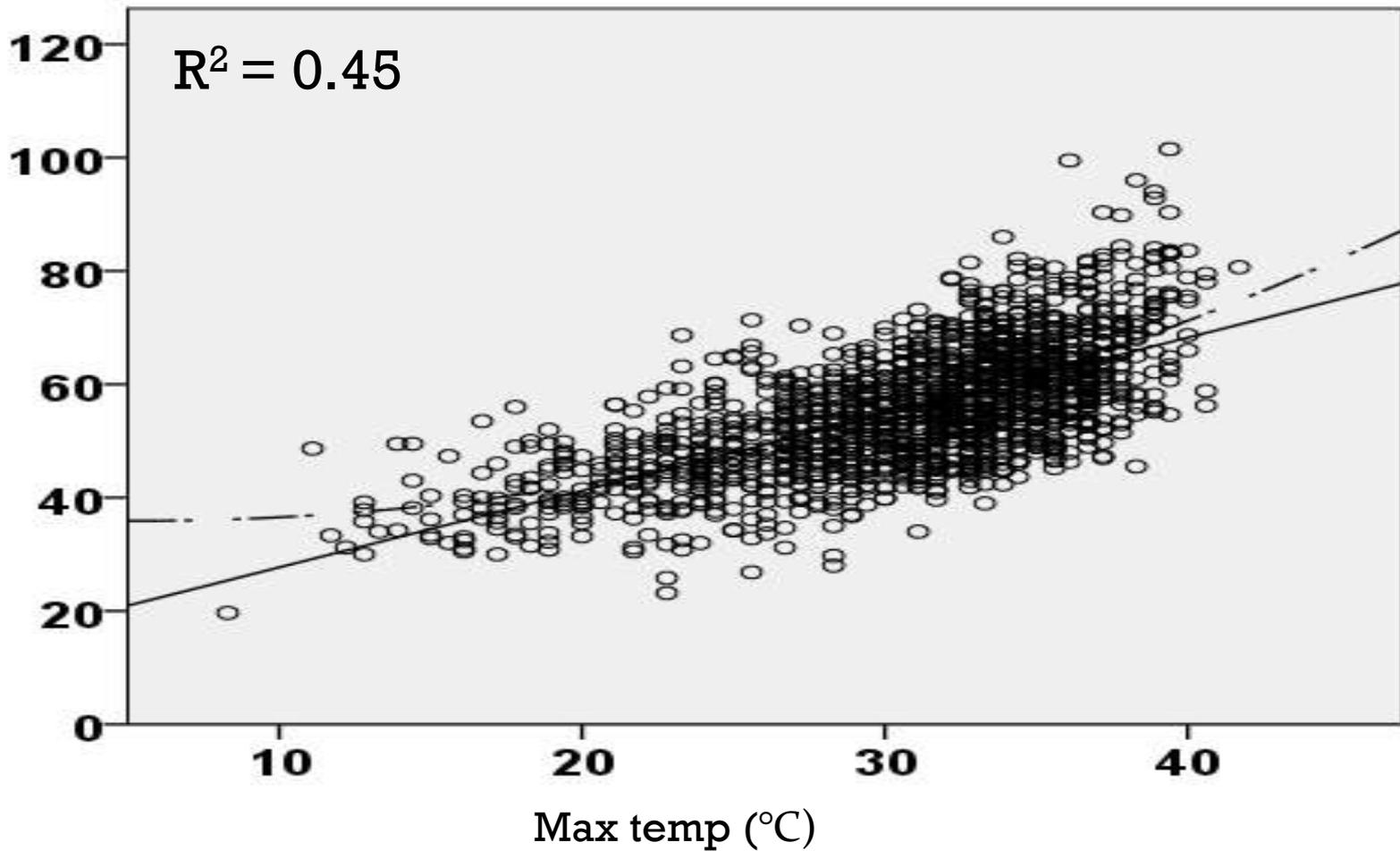
Statistical model for Salt Lake

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
Constant	814	95.8		8.50	.000
Daily max temp	1.29	.035	.634	36.7	.000
Daily avg. wind spd.	-.197	.014	-.237	-13.7	.000
Yr	-.388	.048	-.132	-8.14	.000
DOY²	-1.95E-4	1.24E-5	-.256	-15.6	.000
700 mb zonal wind	-.615	.076	-.140	-8.06	.000

- ⊙ Parameter inclusion requires:
  - Statistical significance
  - Reasonable physical interpretation

Interpreting residuals

O3 = A*temp + B*winds + C*DOY… + residual

- High residual could indicate:
  - Additional precursors from unusual sources within the region
  - Additional O_3 produced from precursors emitted by wildfires
  - Unusually large contribution of O_3 from the upper troposphere/lower stratosphere
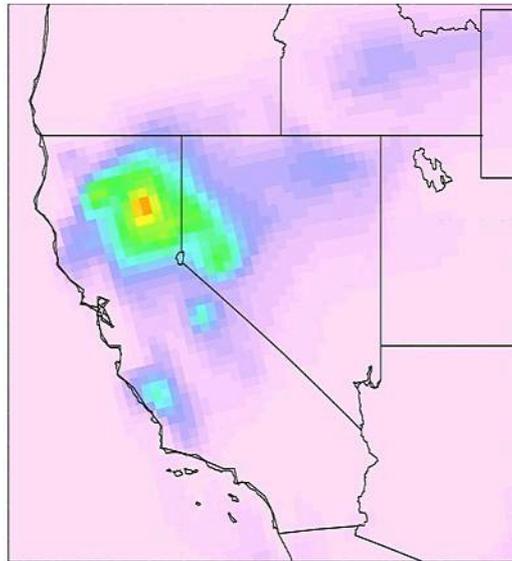 - Unusually large contribution from transport of O_3 and/or precursors from distant sources
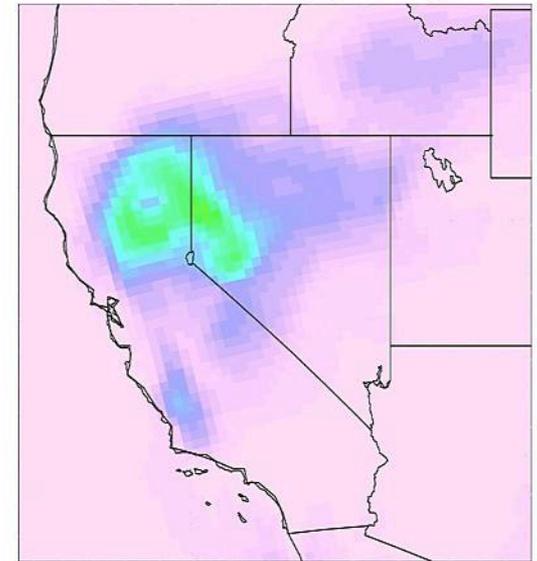
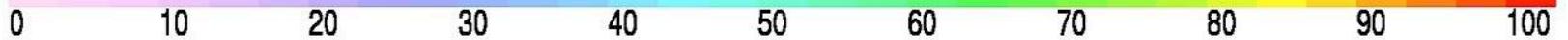# Model evaluation: 24 June 2008 CA wildfires

AQS and WRF-Chem
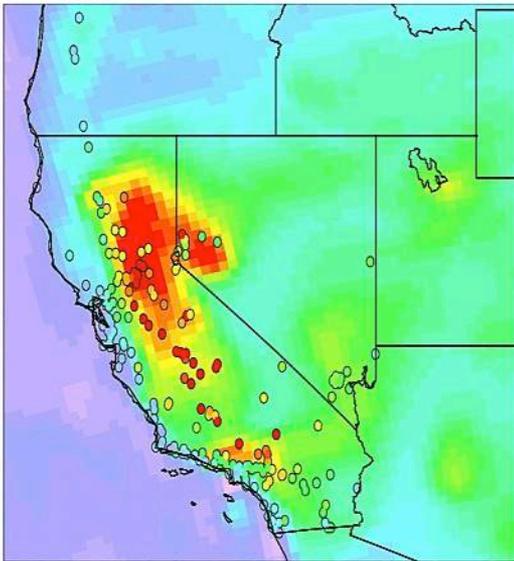
$O3^{FIRE}$

$(delta\_O3^{FIRE})/(O3^{FIRE})$

Surface O3 (ppbV)

| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |

Ratio (%)

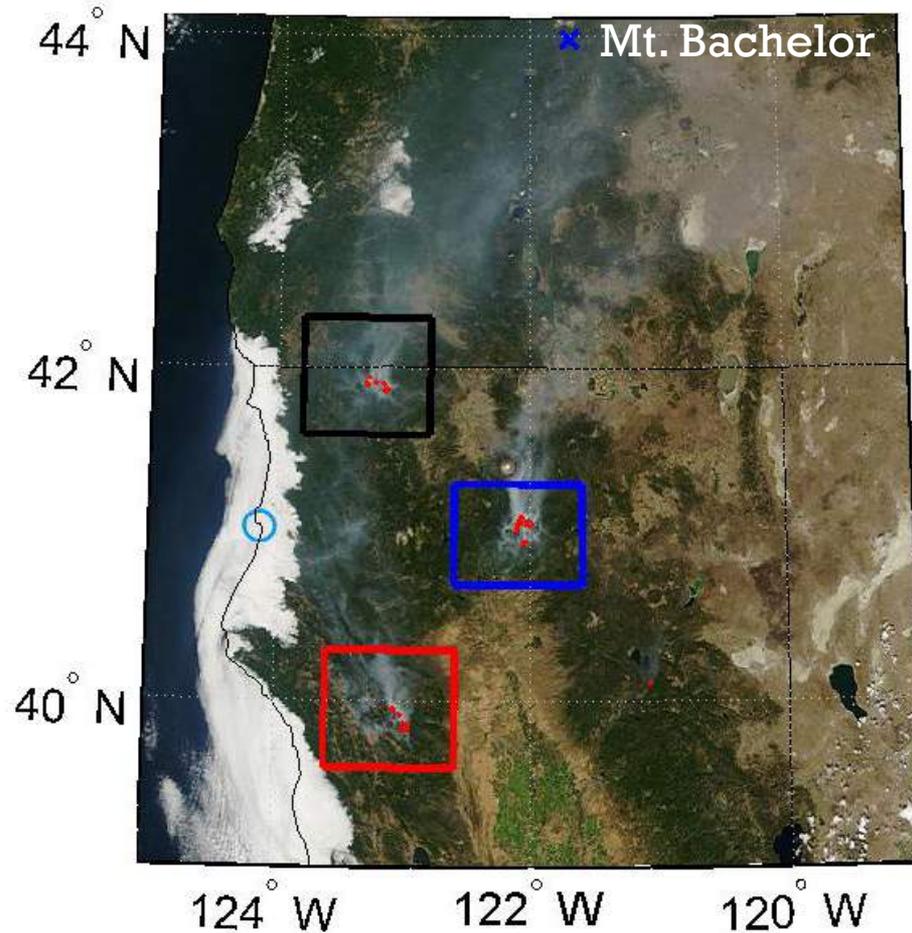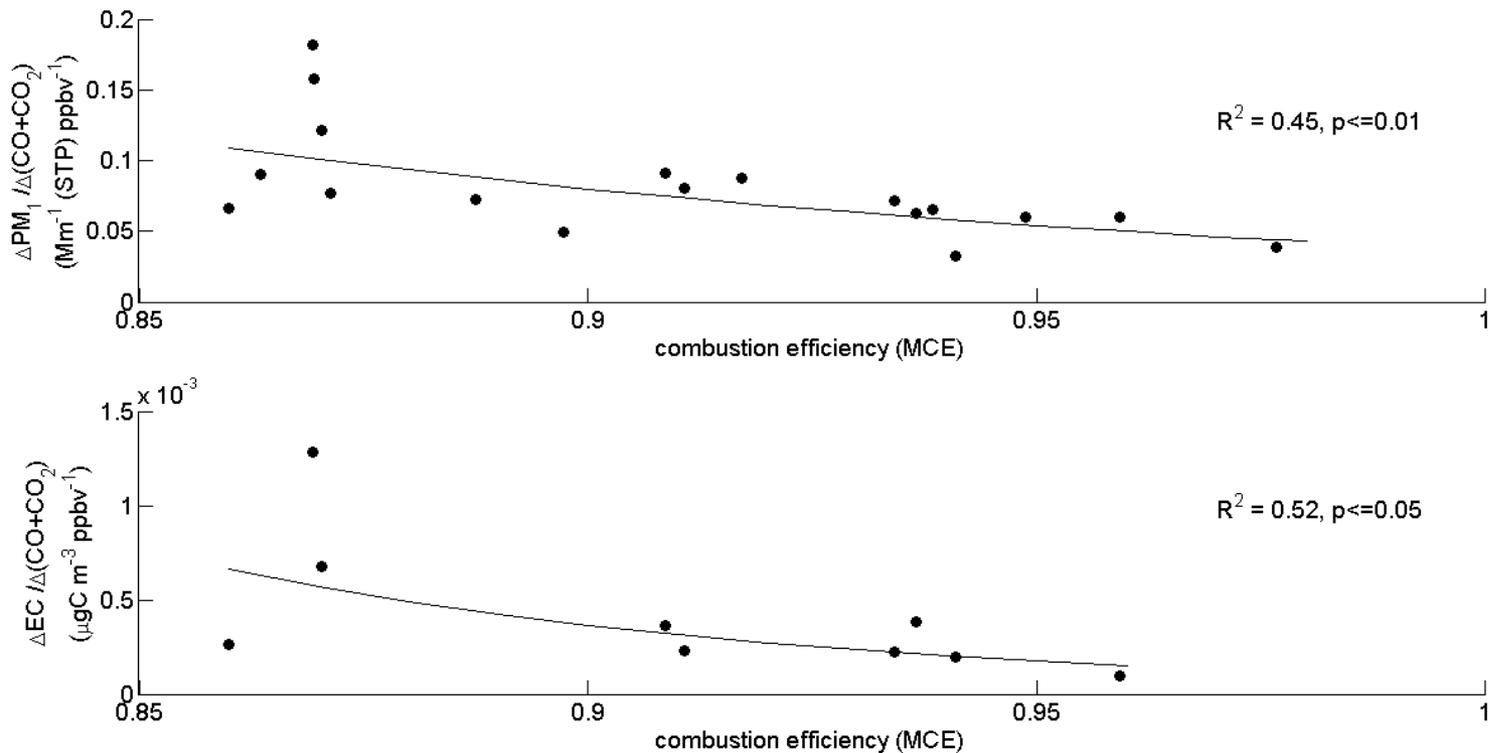| 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |

Model evaluation, cont.
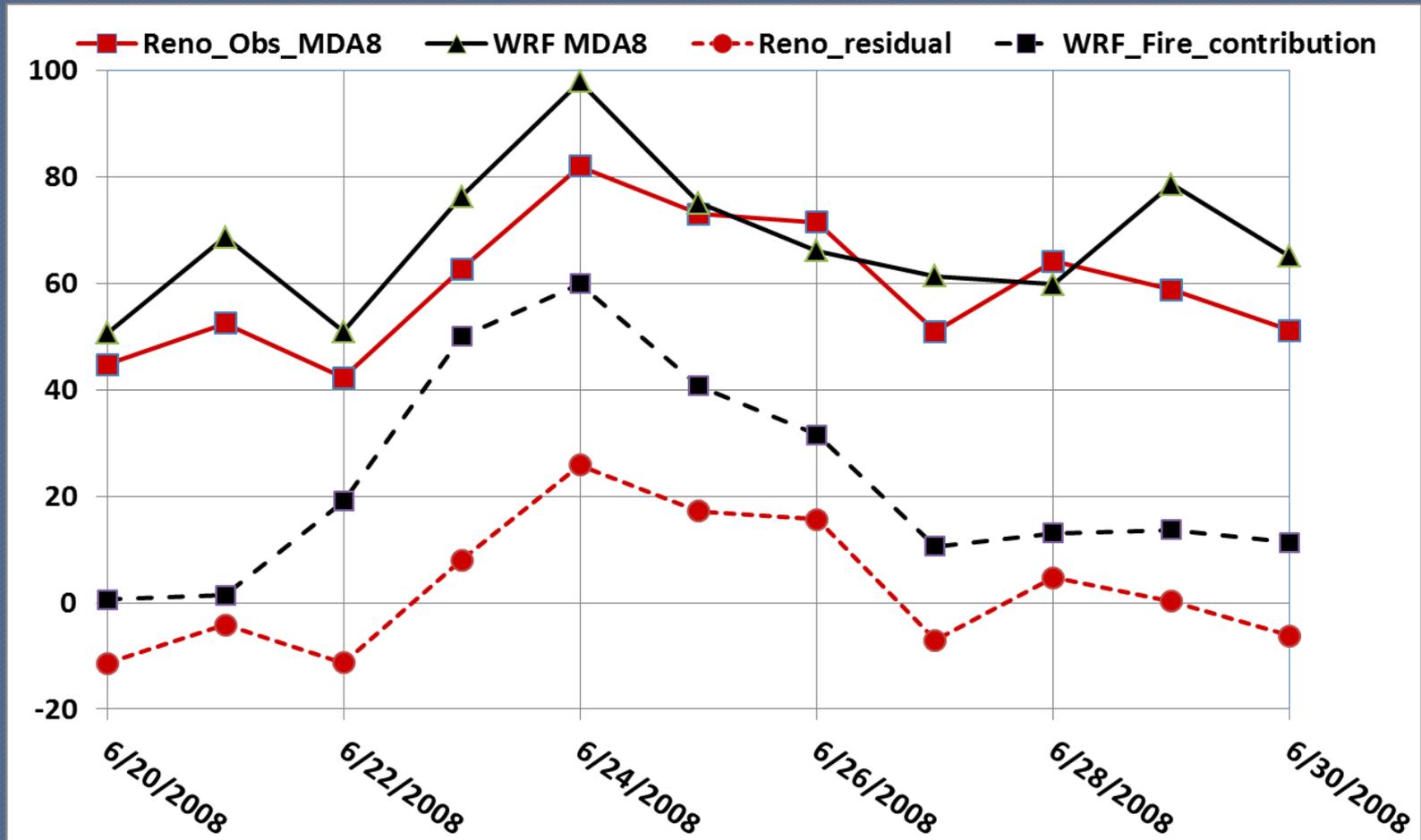
Connecting in situ and satellite measurements

Fire combustion efficiency and emission ratios

$R^2 = 0.45$, $p \leq 0.01$

$R^2 = 0.52$, $p \leq 0.05$

smoldering ← → flaming

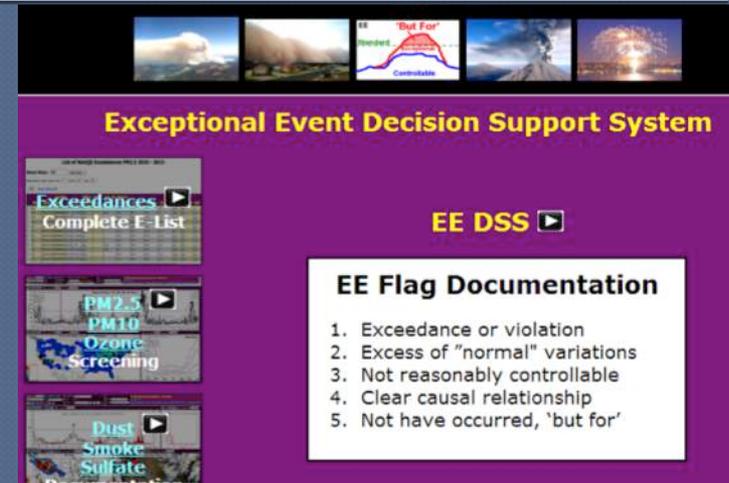Photo credits: NPS, USFS

Linking combustion efficiency to satellite Fire Radiative Power
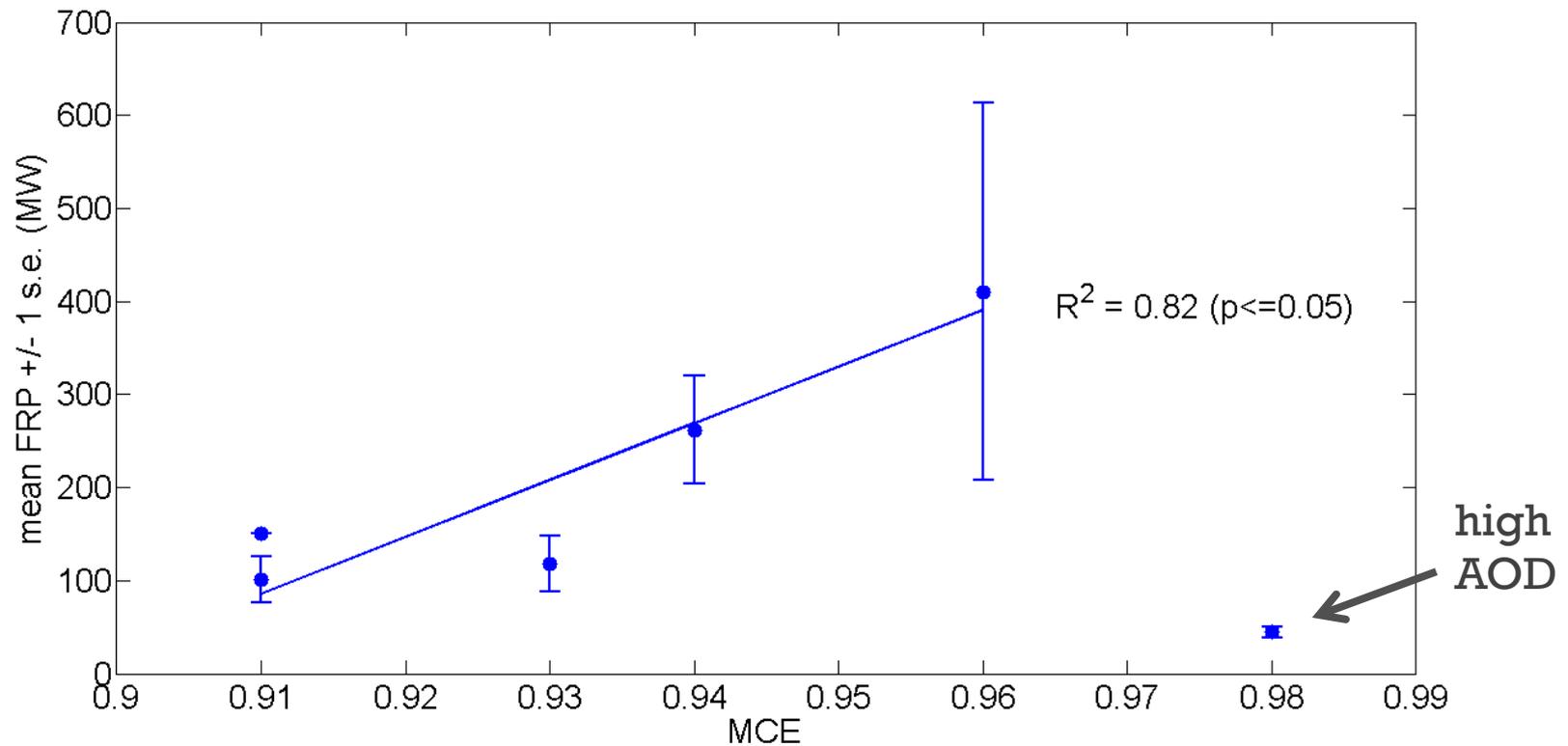
More data points expected from summer 2013 Mt. Bachelor field campaign

Other tools discussed at March WESTAR/EPA ozone exceptional events meeting

- Updated AIRNOW-Tech Navigator
- Updated Datafed (http://datafed.net/EE_DSS.htm)
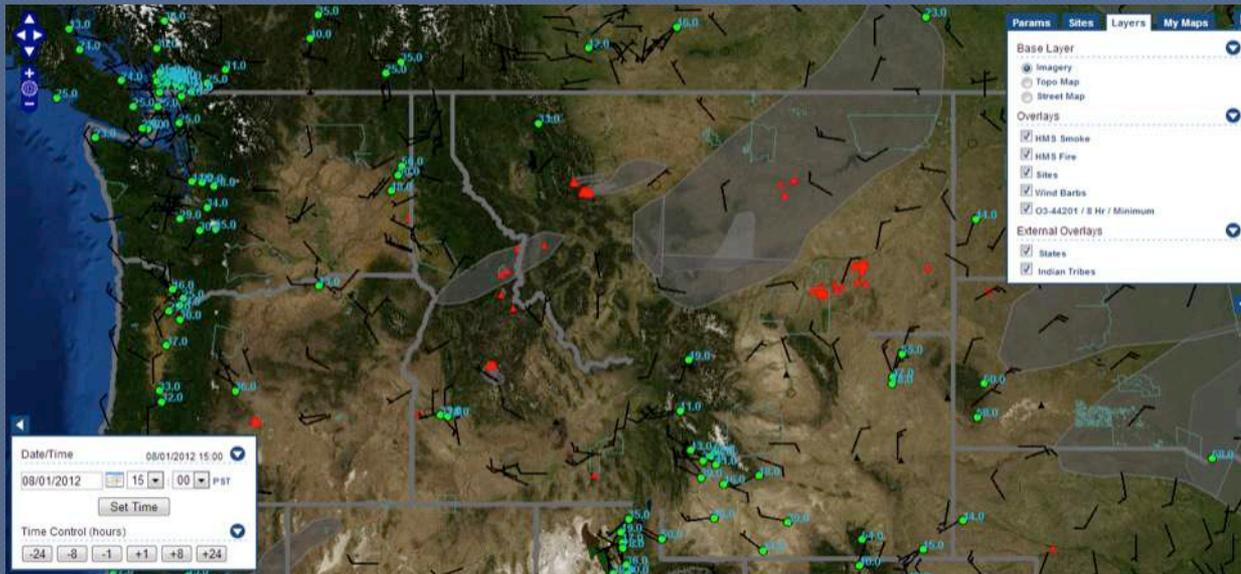- Bluesky playground

Summary

- Large variability in O_3 production, even within one biome
  - Transport distance is a key factor
  - PAN production likely another important factor

- Wildfire O_3 enhancements not necessarily coincidental with PM enhancements

- Statistical models provide a robust method of calculating the O_3 "added" by wildfires
  - Must be combined with data sources that clearly identify the source of the high O_3 (e.g., models, satellite data)

- Satellite FRP data may be useful for understanding fire emission ratios