Identification of Ozone Sources in the Western US

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National Science Foundation
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The Challenge:
New O_3 Standard in Light of Increasing Background

- **Most urban areas in the West have made substantial progress in reducing peak O_3 mixing ratios.**
- **But the new O_3 standard presents our greatest challenge yet.**
- **Springtime background O_3 is increasing;**
- **Wildfires are increasing.**

➢ **Need to improve our understanding of O_3 sources.**

➢ **Need to improve our methods to document which O_3 is controllable, and which is not, on a day-to-day basis.**

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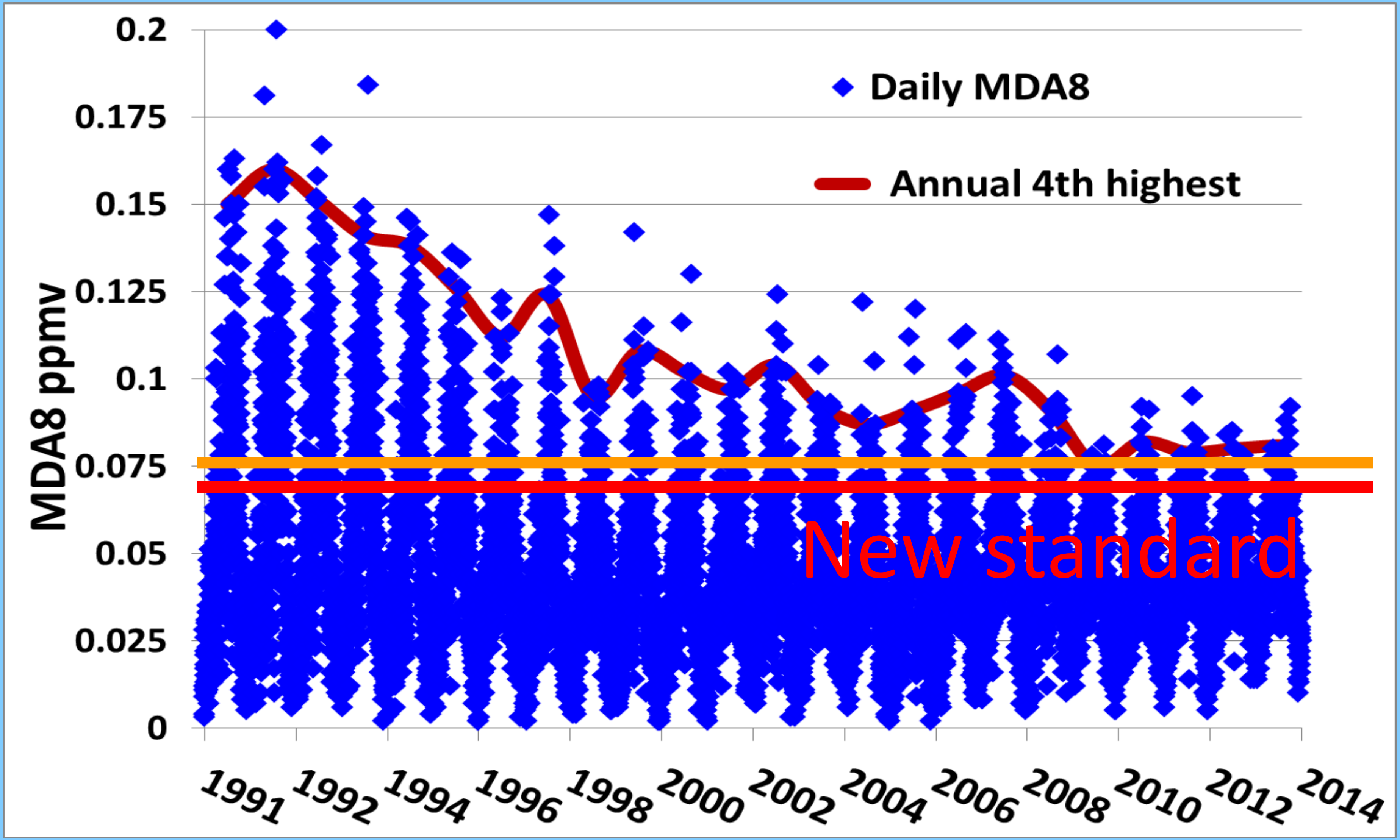
Los Angeles, Max Daily 8-hour Average O_3



AQS site # 06-037-0002

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Sources of O_3 in the Western US

O_3 Source	Meteorological Characteristics	Chemical characteristics	Controll-able
Local photochemical buildup	Stagnation, high temps.	CO/NOx/VOCs/PM consistent with local sources	Y
Regional transport (domestic sources)	Regional transport from major source regions (eg Calif) *Currently not well characterized	CO/NOy/VOCs consistent with upwind sources+chemistry	Y
Upper trop/Lower strat intrusions (UTLS)	Post-cold front Broad spatial distribution (high O_3 in non-urban areas)	Very dry air.	N
Very long-range transport (VLRT)	Important at higher elevation. Subsidence and mixing into the boundary layer can enhance local concentrations.	Dry. Can be hard to distinguish from UTLS without good chemical data.	N
Wildfire smoke	Warm. Can be stagnant or not. Can be regional or large distant fires.	Chemistry complex and diff from typical urban. O_3 enhancements not always seen. O_3-PM often poorly correlated. PM/CO/NOy always well correlated and ratios very diff from typ urban.	N

How to id sources of O_3 ?

- **Observations:**
  - Spatial relationships;
  - Tracer ratios;
  - Meteorology/trajectories;
  - Satellite observations.
- **Modeling:**
  - Regional Eulerien modeling;
  - Source apportionment modeling (e.g. WRAP-DEASCO3;
  - Statistical modeling.

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Mt. Bachelor, Oregon, (MBO) 2.8 km asl

- **The only high elevation/free trop research site on west coast of U.S.**
- **Continuous observations of CO, O_3, aerosols and Hg since 2004;**
- **Frequent detection of Asian pollution and biomass burning plumes;**
- **More than 2 dozen papers since 2004 on O_3, PM. Hg, LRT, wildfires, etc.**
- **Key goal: Identify importance of global sources on US air quality.**

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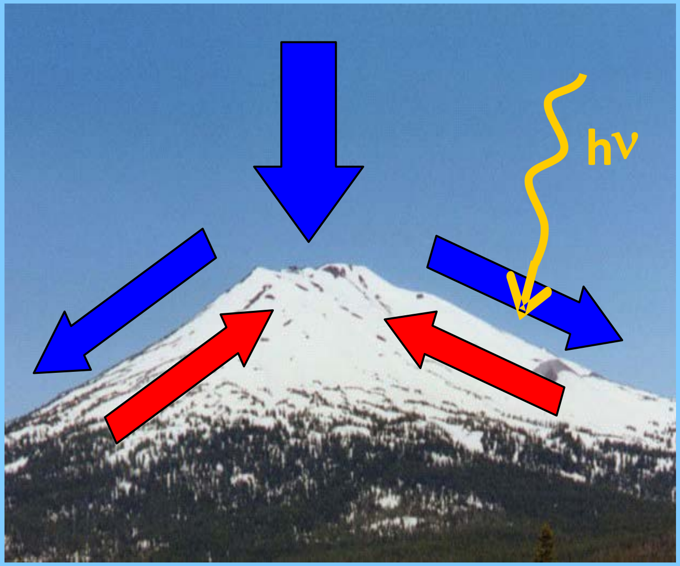
Diurnal circulation pattern at Mt. Bachelor



Day: upslope flow brings modified BL air to summit. This air is wet and usually low in O_3.

Night: downslope flows brings Free Tropospheric (FT) air to the summit. This air is dry and usually high in O_3.

ID of Free Tropospheric Air

- **Time of day.**
- **Water vapor mixing ratio**
- **Chairlift soundings, observations of NOx (Weiss 2006, 2007; Fischer 2009; 2010; Reidmiller 2011)**

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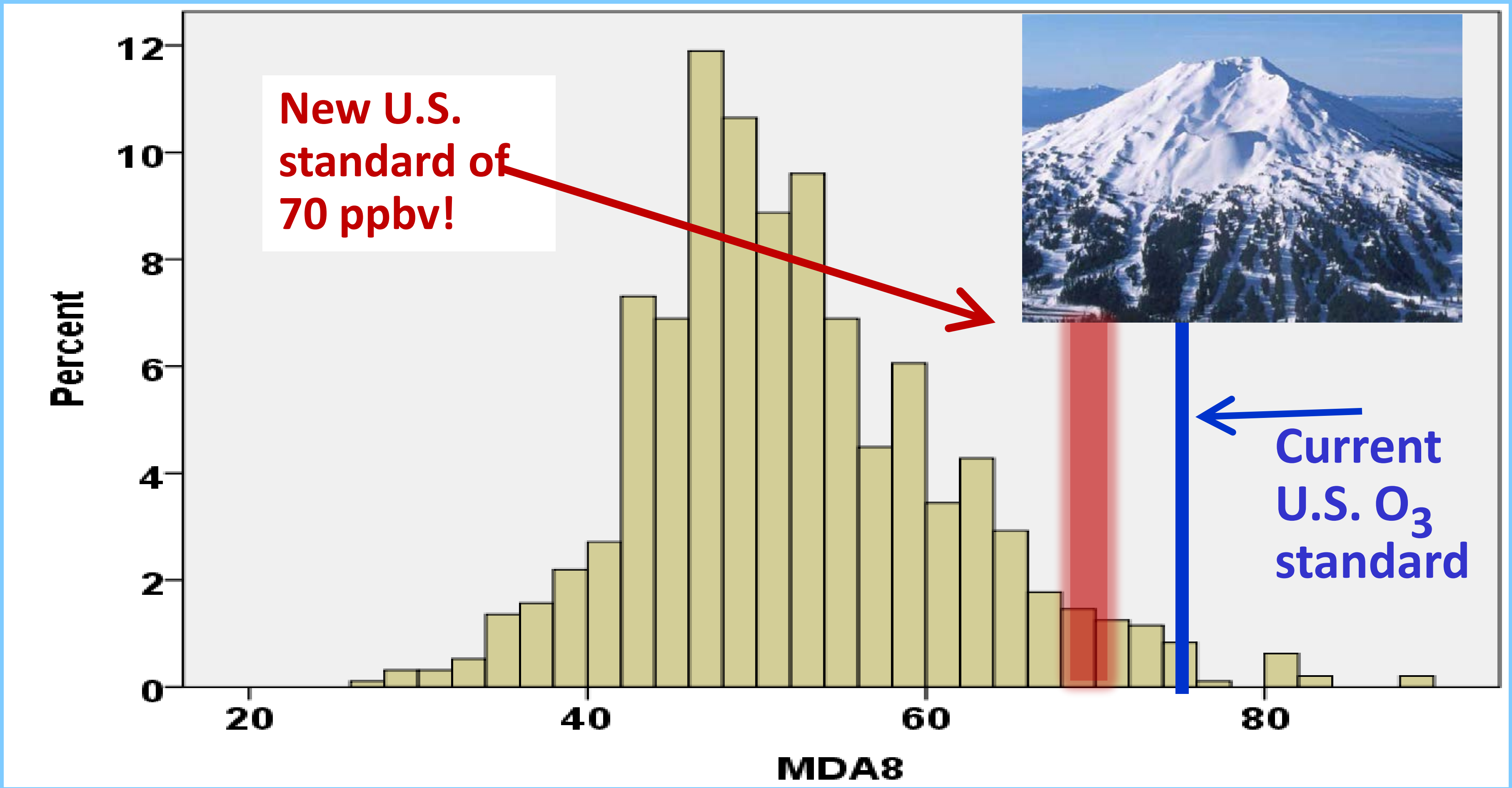
MDA8 O_3 at MBO



Max daily 8 hour avg O_3 at Mt. Bachelor for 2012-2014
Latest 3-year design value =79 ppbv

What are causes of high O_3 at MBO and how does this influence surface AQ?

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Causes of high O_3 days at MBO: Strat intrustions, Asian pollution and wildfires

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ATMOSPHERIC ENVIRONMENT

Causes of high O_3 in the lower free troposphere over the Pacific Northwest as observed at the Mt. Bachelor Observatory

J.L. Ambrose [a,*], D.R. Reidmiller [b,1], D.A. Jaffe [a,b]

Ambrose et al 2011

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ATMOSPHERIC ENVIRONMENT

Ozone enhancement in western US wildfire plumes at the Mt. Bachelor Observatory: The role of NO_x

P. Baylon [a,*], D.A. Jaffe [a,b], N.L. Wigder [a], H. Gao [b], J. Hee [b]

Baylon et al 2014

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Role of background O_3 on urban air quality
Wigder et al 2013

JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES, VOL. 118, 3343–3354, doi:10.1029/2012JD018738, 2013

Influence of daily variations in baseline ozone on urban air quality in the United States Pacific Northwest

Nicole L. Wigder,[1] Daniel A. Jaffe,[1,2] Farren L. Herron-Thorpe,[3] and Joseph K. Vaughan[3]

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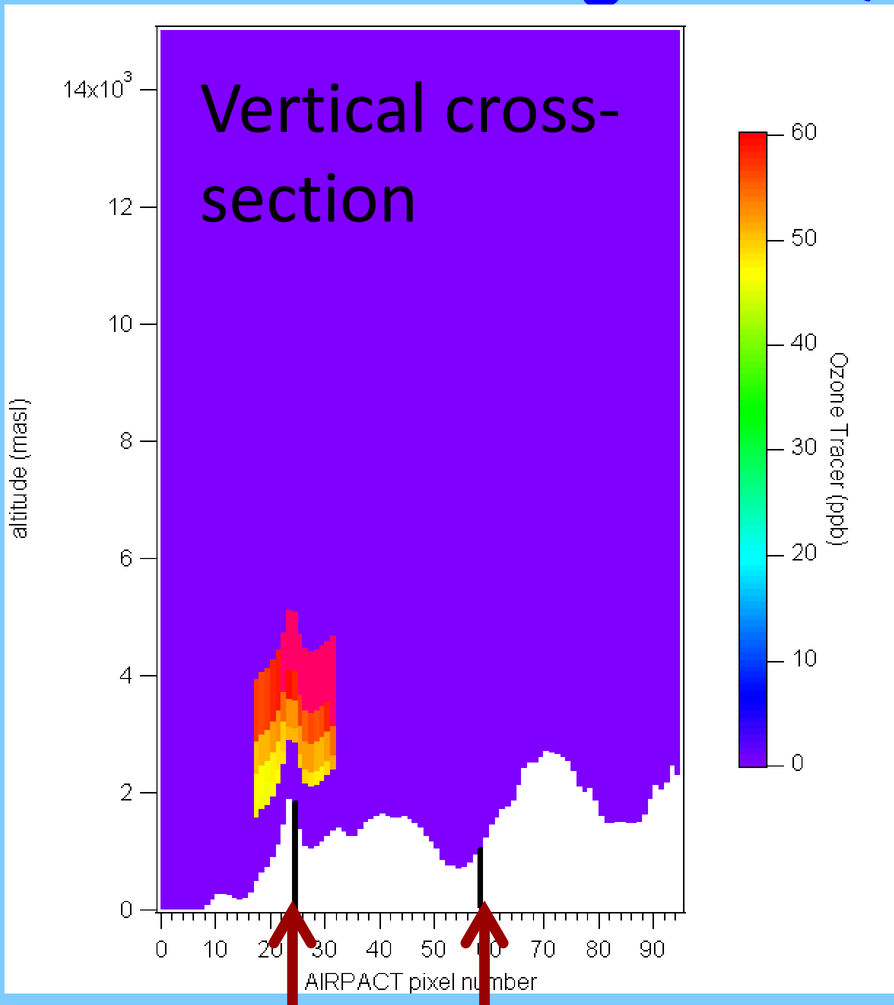
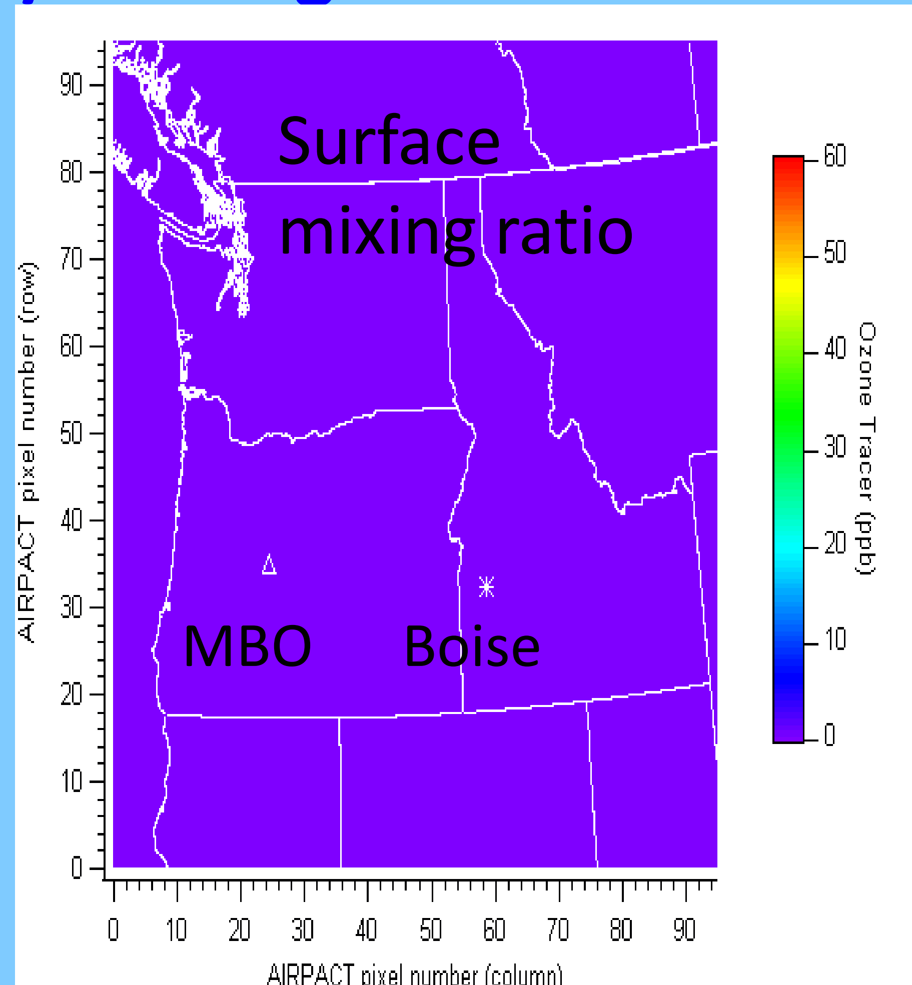
Modeled FT O_3 tracer for 4/6/2010 (high O_3 day) using CMAQ w/12 km grid





MBO Boise

Wigder et al 2013

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Springtime O_3 trend at MBO: Gratz et al, 2014

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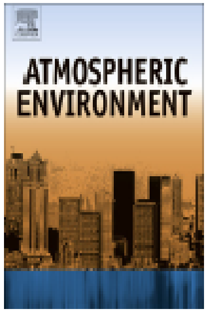
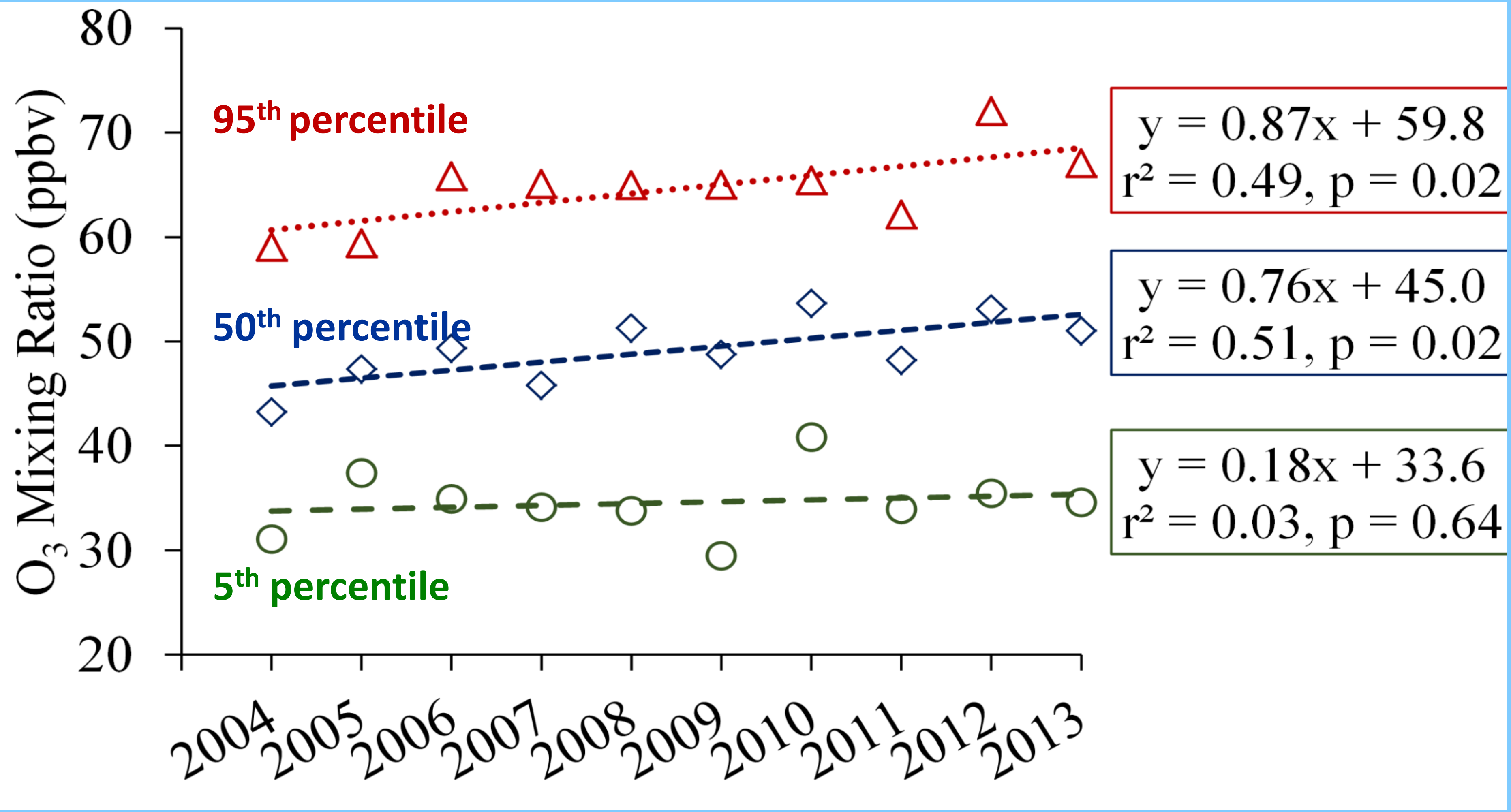


Causes of increasing ozone and decreasing carbon monoxide in springtime at the Mt. Bachelor Observatory from 2004 to 2013

L.E. Gratz [a,*], D.A. Jaffe [a,b], J.R. Hee [a]

Changes in Spring O_3 at MBO



This is likely due to the build up of Asian emissions (Gratz et al 2014).

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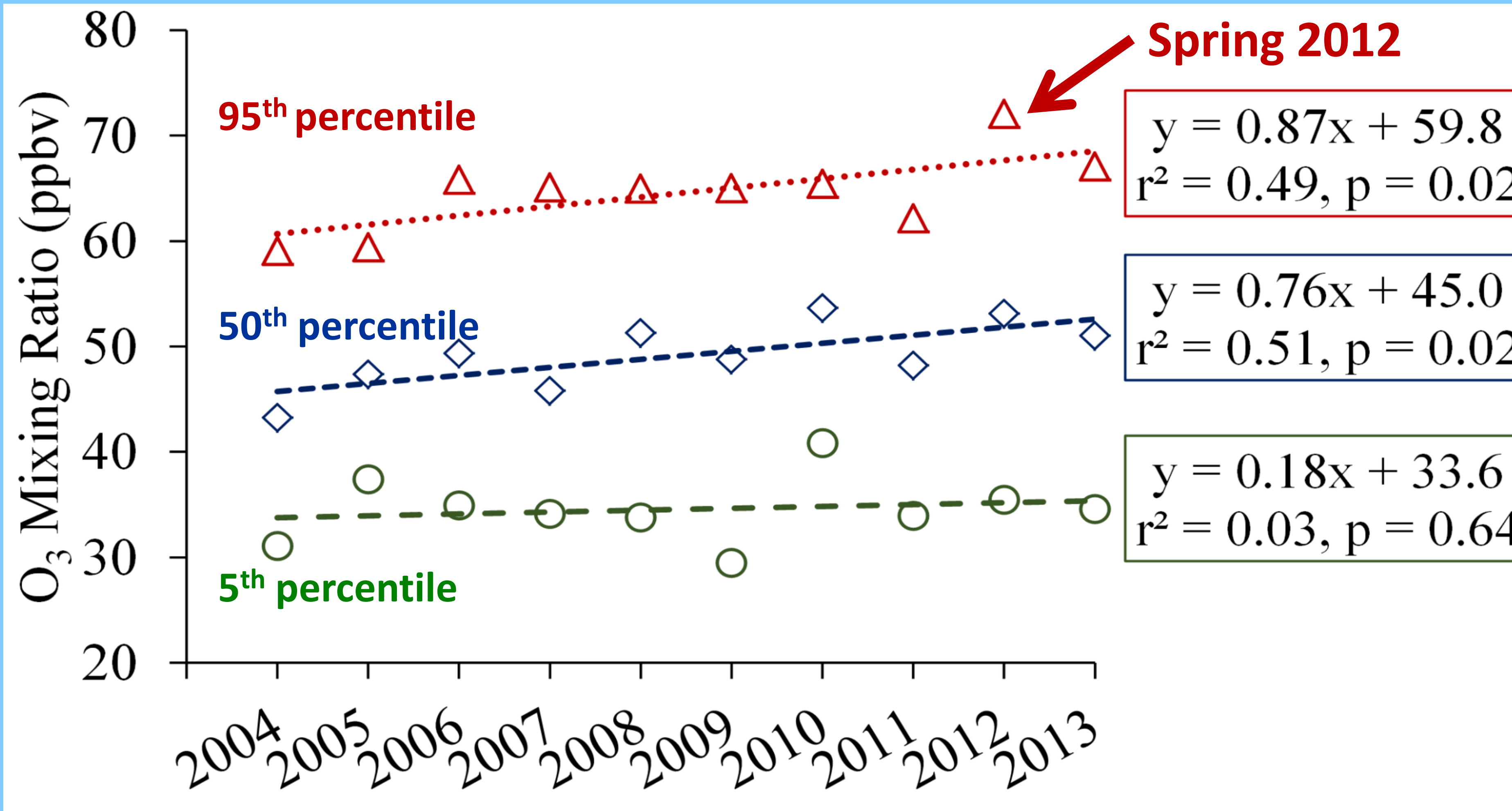
Changes in Spring O_3 at MBO



This is likely due to the build up of Asian emissions (Gratz et al 2014).

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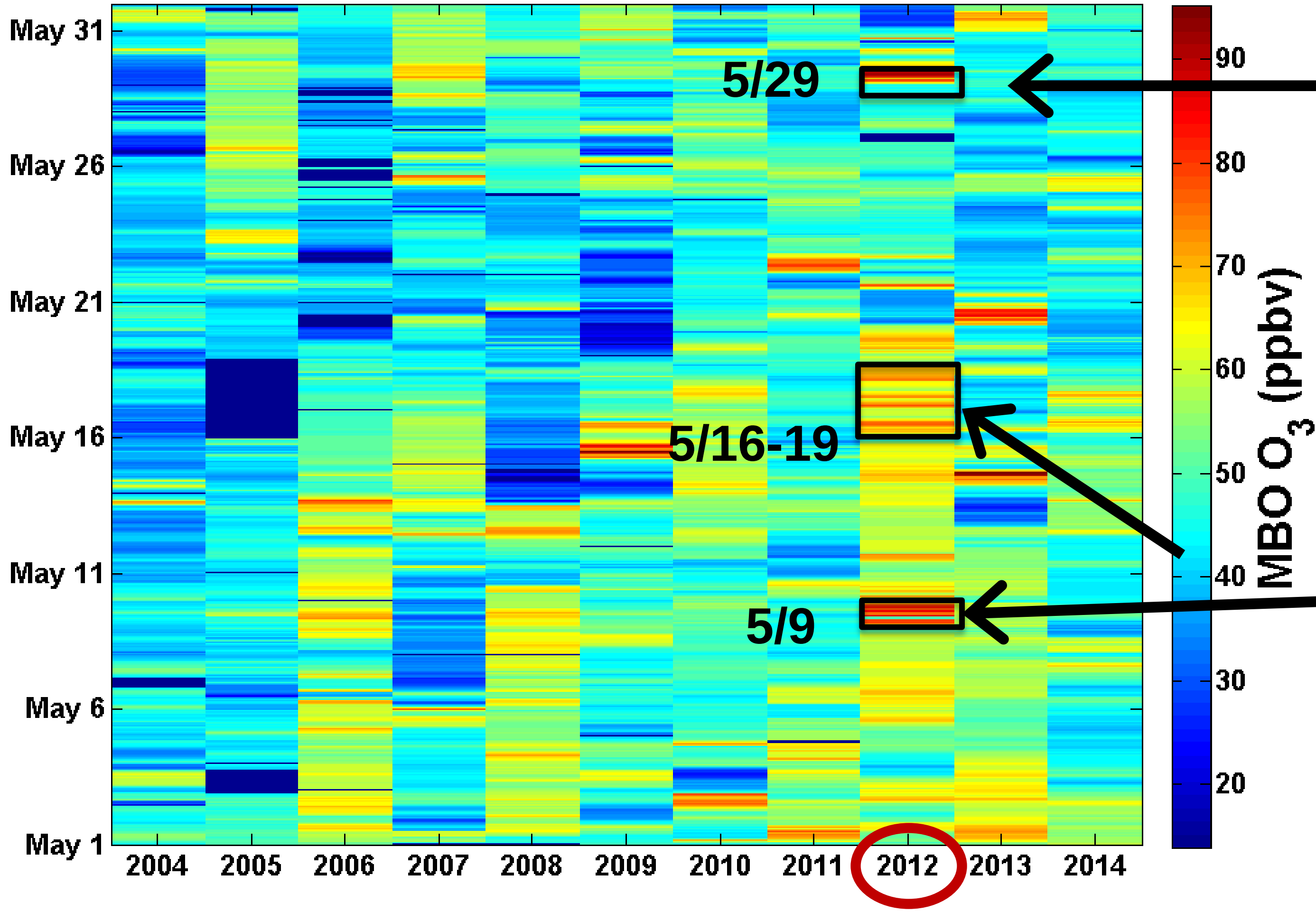
MBO MDA8s May 2004-2013 O_3



Asian LRT (High $CO+O_3$)

UTLS (High O_3 low CO and RH)

Was high O_3 seen in 2012 at surface monitoring sites?

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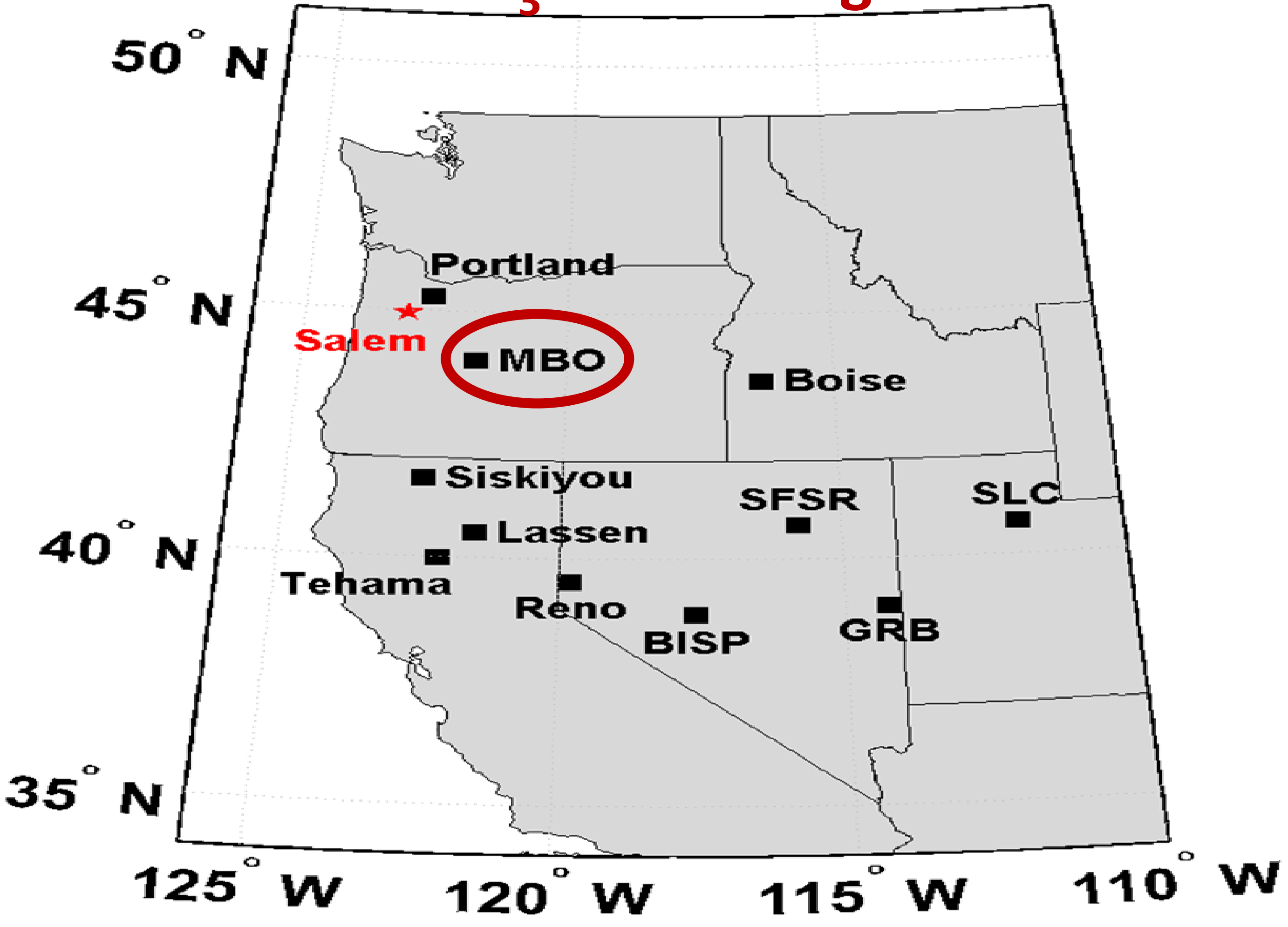
Importance of spatial correlation in Western US

Selected O_3 monitoring sites



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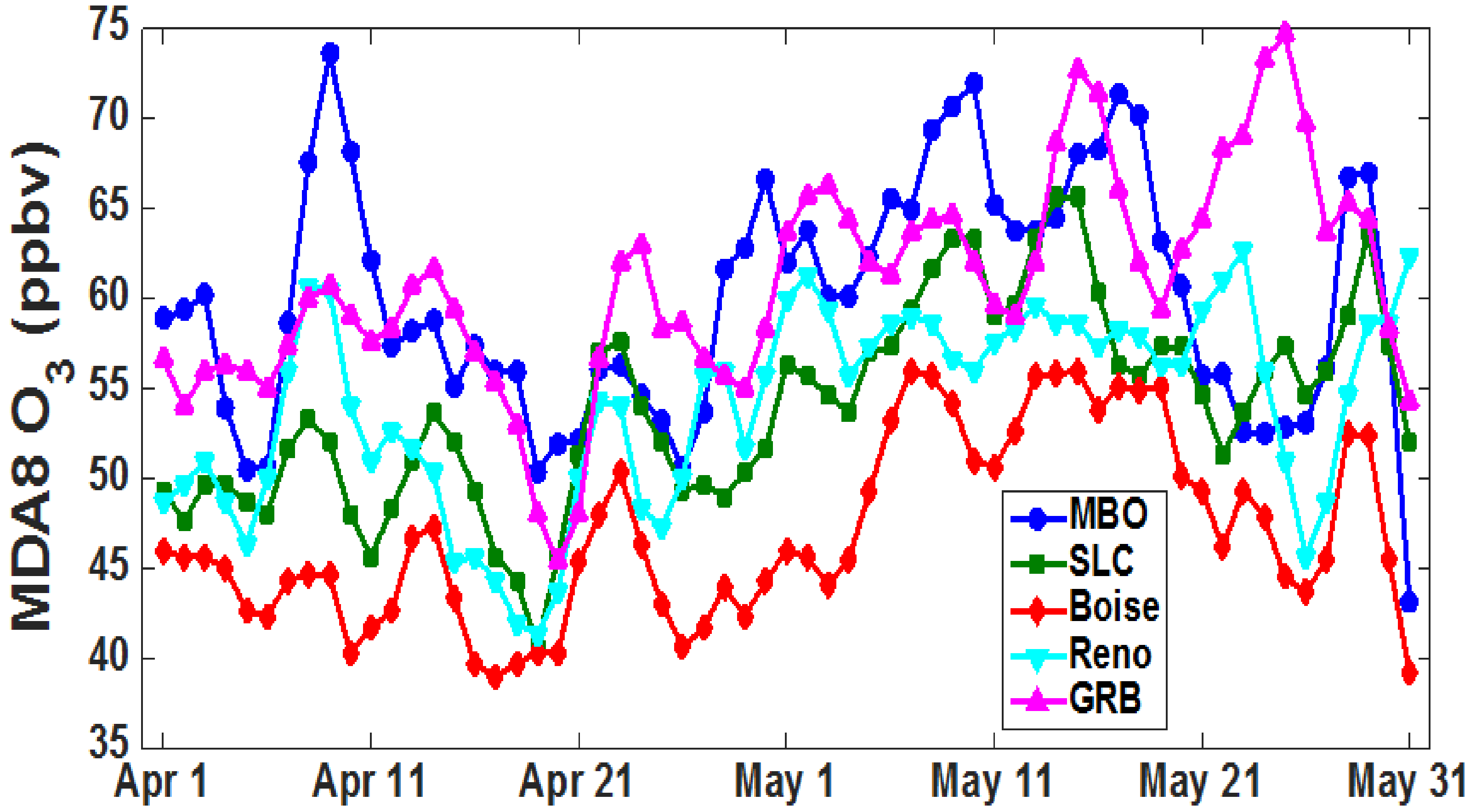
Location	May 2012 Relative to May 2010-2014 (MDA8, ppbv)
Great Basin NV (2.1 km)	+ 6.1
Mt Bachelor OR (2.8 km)	+ 5.4
Boise ID MSA (0.8 km)	+ 4.0
Reno-Sparks, NV (1.5 km)	+ 4.1
Salt Lake City, UT (1.4 km)	+7.0
Tehama Cty CA (0.6 km)	+ 3.1
Portland OR MSA (0.2 km)	+ 2.3
Lassen N.P. CA (1.8 km)	+ 2.1
Siskiyou Cty CA (0.8 km)	+ 2.2
San Joaquin Cty (0.1 km)	+ 5.2

Higher elevation sites shows greater enhancement.

Spatial correlation between sites in W. US, Spring 2012

Plotted with 3 day smoothing of MDA8 values



This spatial-temporal correlation tells us that on these dates, high O_3 was not locally generated.

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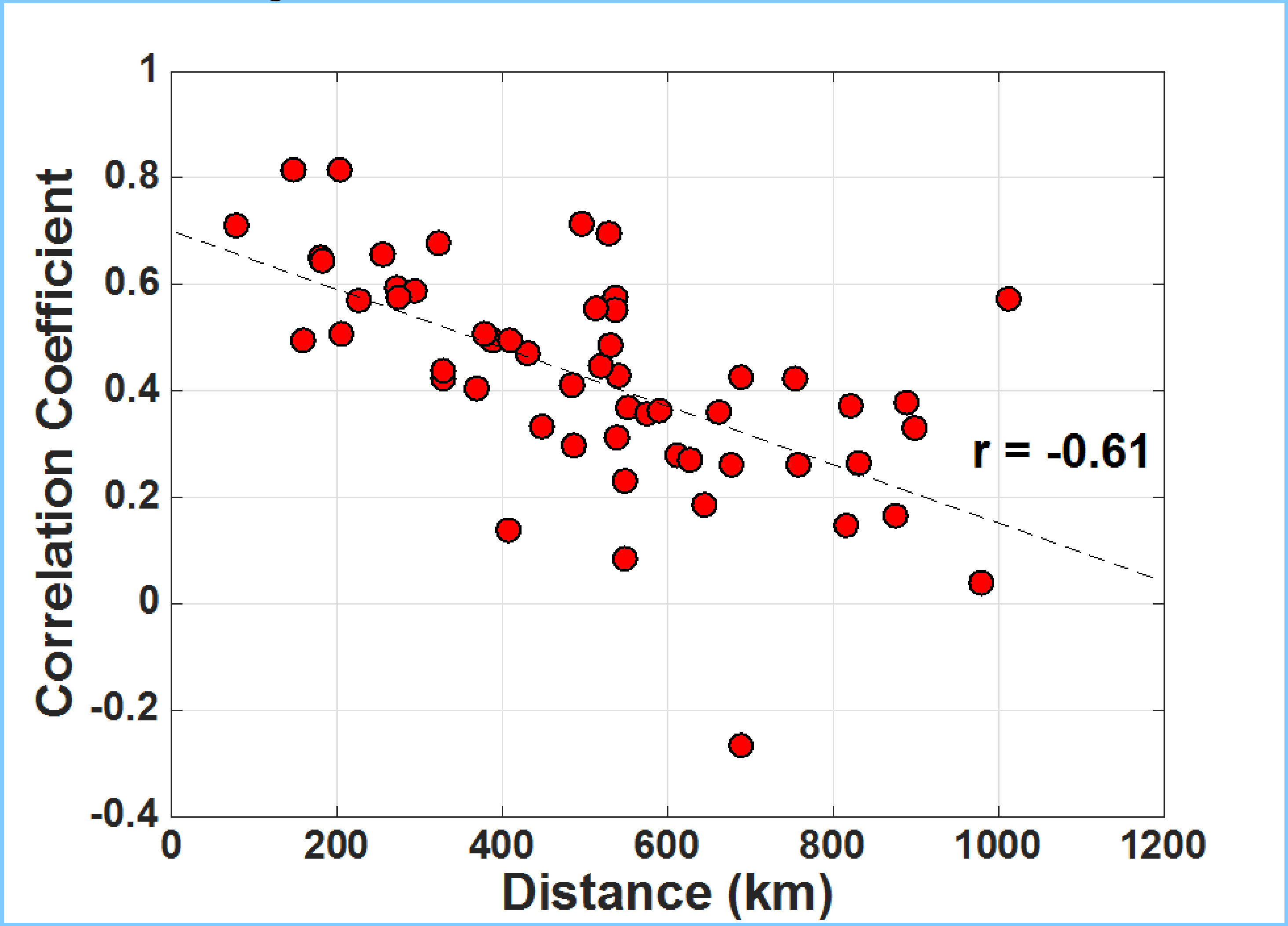
Spatial correlation between Ozone sites in W. US,

MDA8 O_3 for Spring 2012 with 3-day Smoothing



Baylon et al 2015

Wildfires

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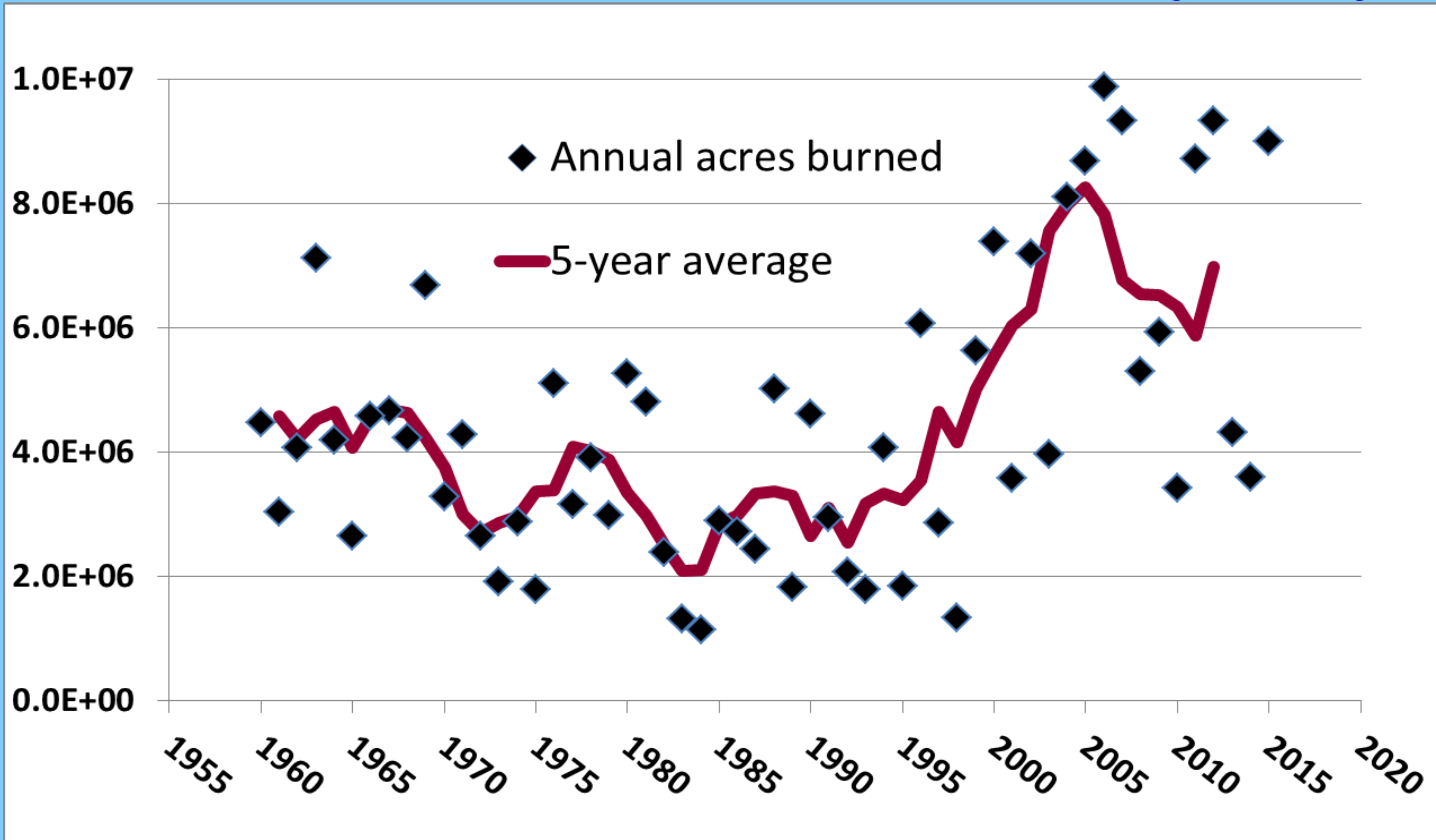
Area Burned for US Wildfires (NIFC)



The last decade has seen a significant increase in the area burned. Approx 70% of these fires are in the Western US

Summary of $\Delta O_3/\Delta CO$ from >100 published studies

Boreal/ Temperate:

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

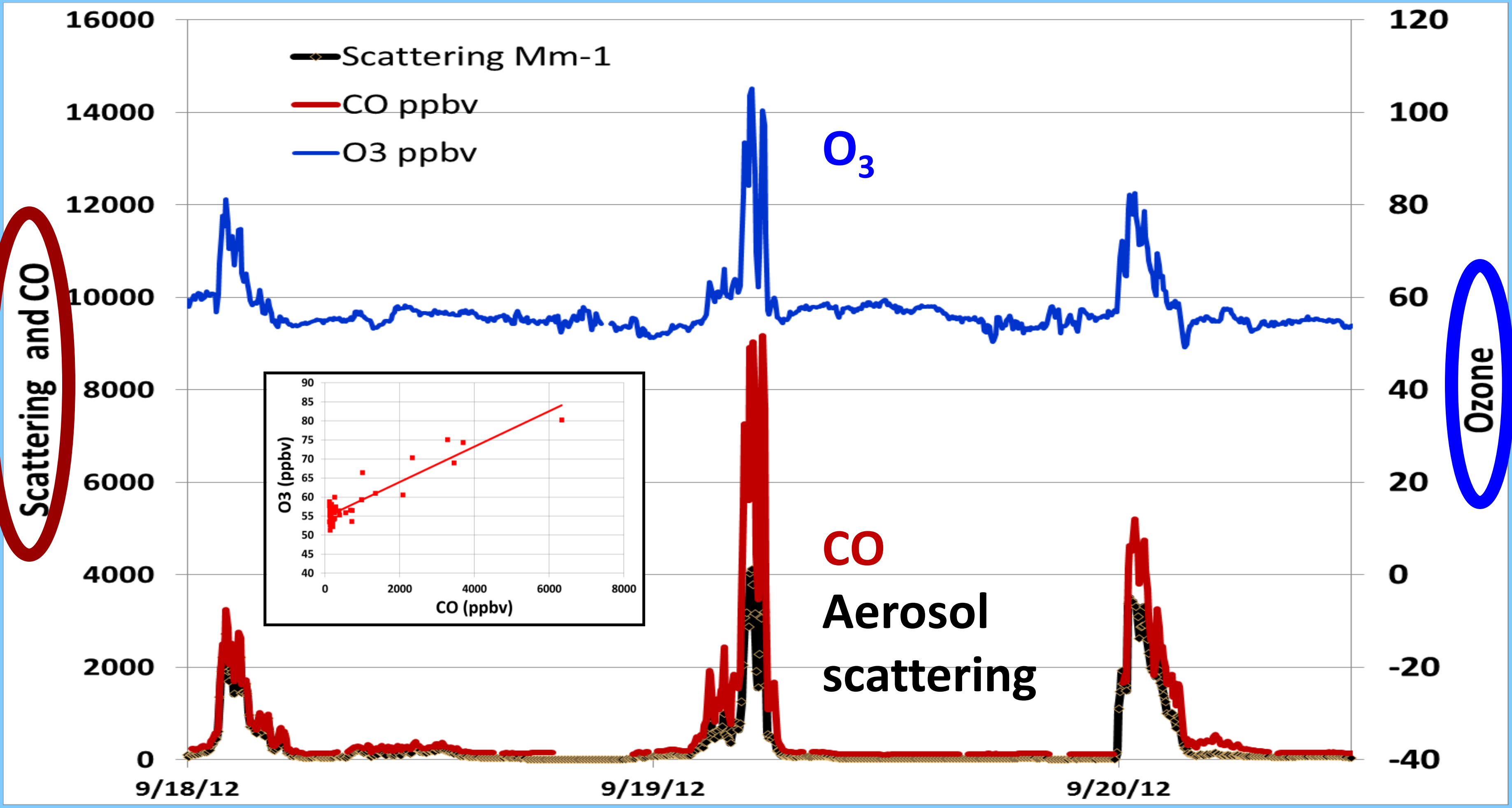
Tropics/ Subtropics:

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

Jaffe, D.A. and Wigder, N.L., Ozone production from wildfires: A critical review. Atmos. Envir., doi:10.1016/j.atmosenv.2011.11.063, 2012.

Jaffe & Wigder (2012)

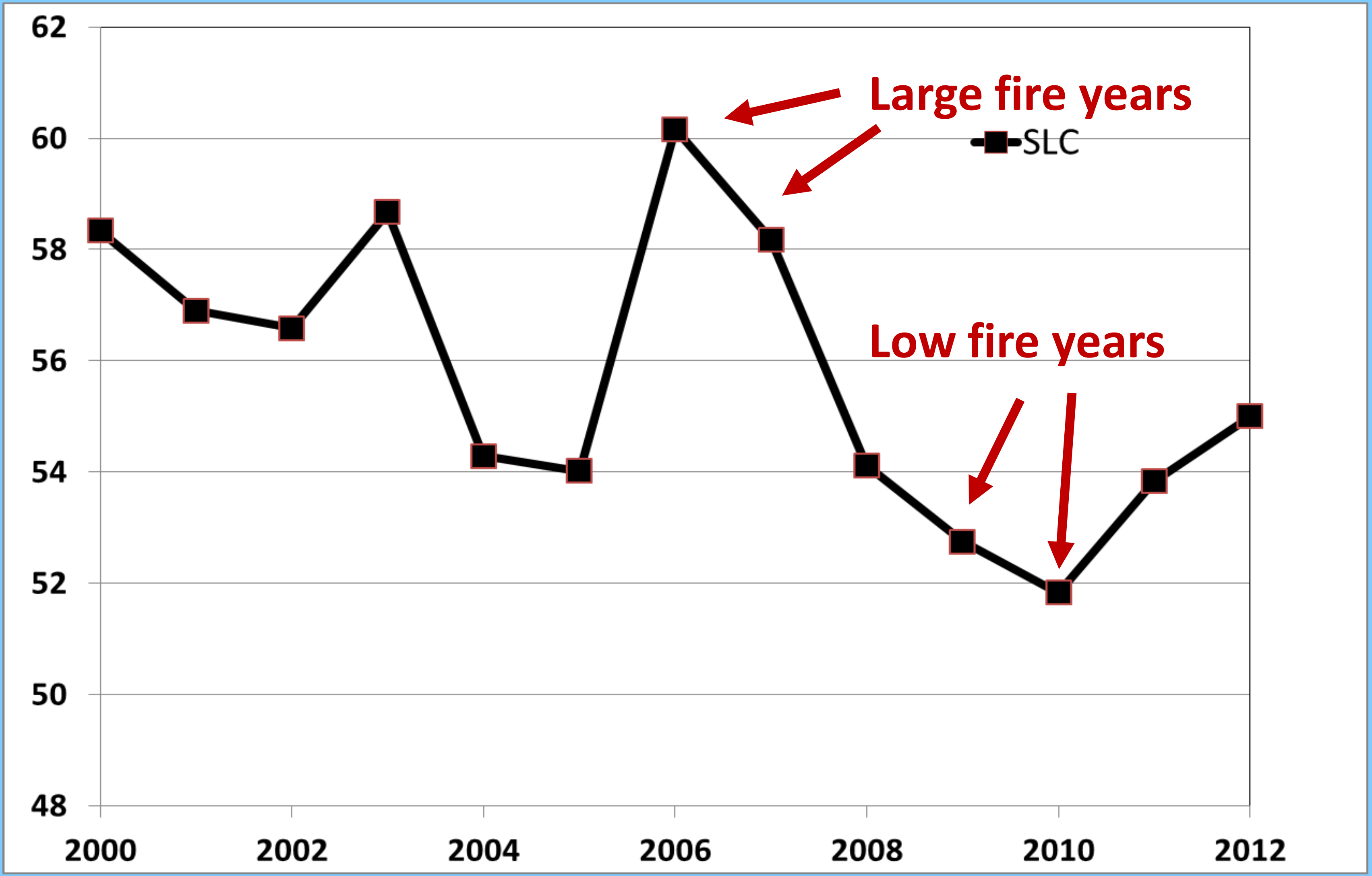
Wildfires can make O_3 very quickly



Mt. Bachelor observations of the Pole Creek Fire on three successive days. O_3 production of 20-50 ppbv in 6 hours.

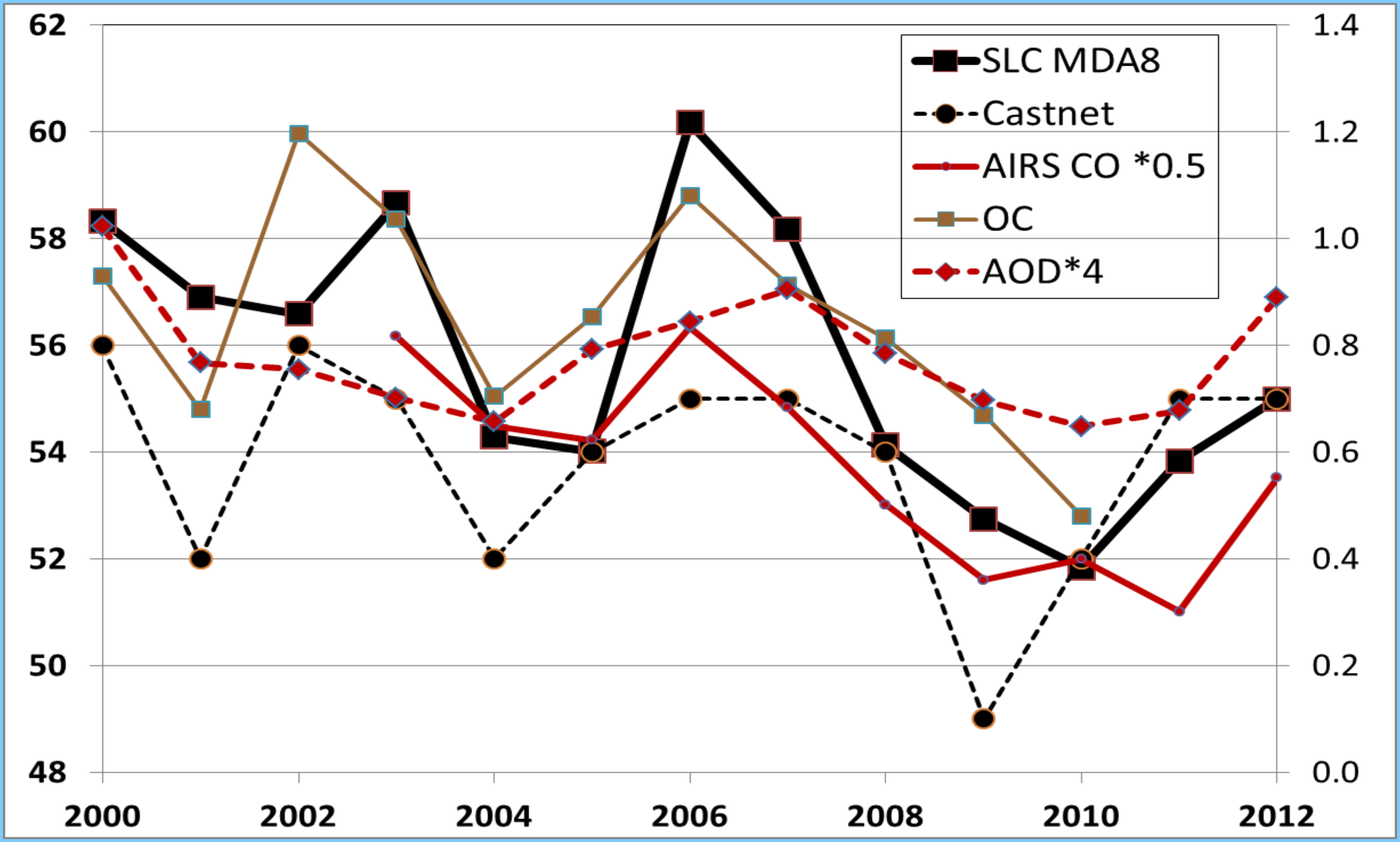
Many other examples of fast O_3 production in lit.

Median O_3 summer MDA8 in Salt Lake City, Utah



Wildfires are responsible for year to year variation in frequency of high O_3 days.

Median MDA8 in SLC, CASTNET, OC, AIRS CO and AOD



R values between 0.58 and 0.86 for these. Wildfires are partly responsible for year to year variation in frequency of high O_3 days (Jaffe et al 2013).

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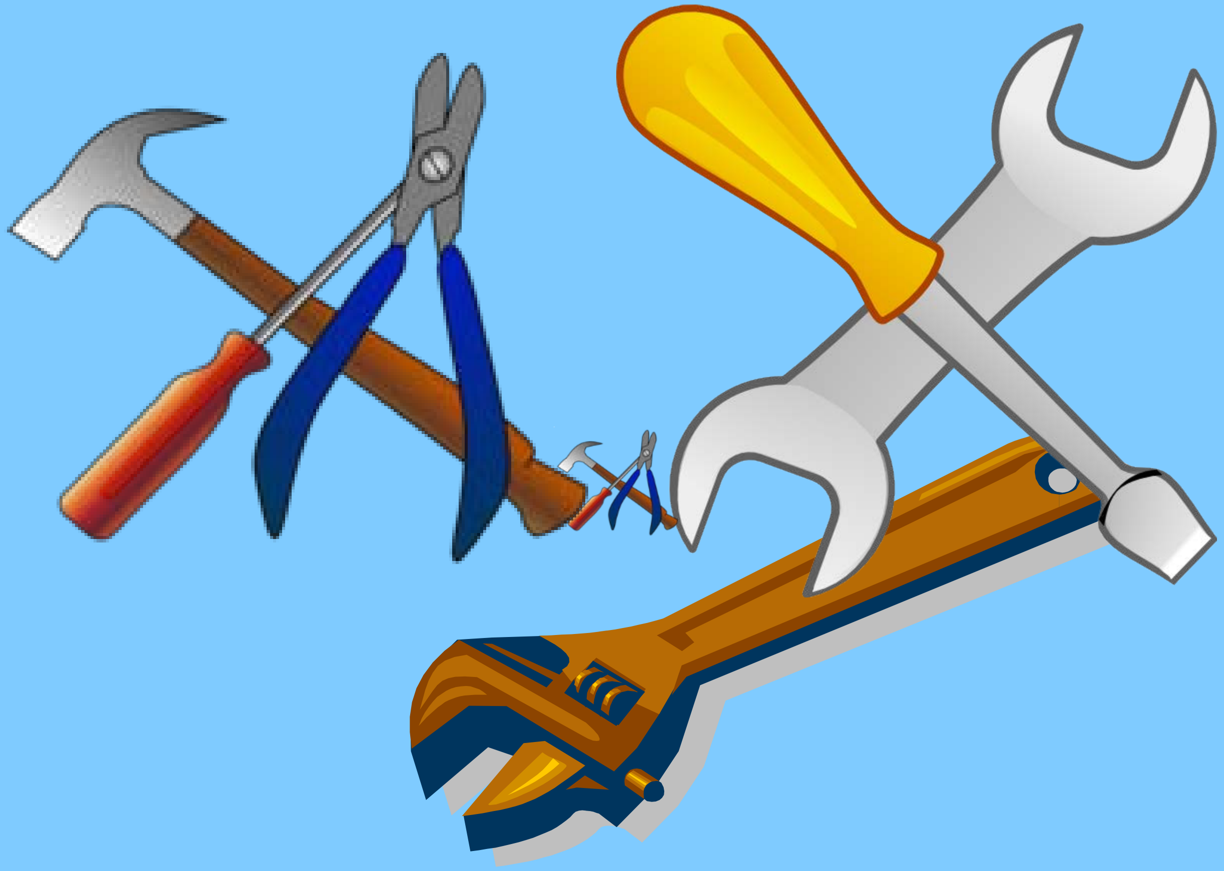
More tools



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Observations

- **Observations of <u>key tracers and meteorology</u> are critical to understand causes for high O_3 days;**
- **<u>Tracer ratios</u> provide more information than one pollutant alone;**
- **Most agencies follow EPA specs for O_3 and $PM_{2.5}$ and these are done reasonably well;**
- **Not all regulatory sites have meteorology (!);**
- **At minimum, need good quality measurements of CO and NOx.**
- **VOCs and speciated PM are also highly desirable.**
- **A specific tracer of fires (such as CH_3CN) is also very useful.**

- **Shameless self promotion… my group is working on a simple, transportable "suitcase" method to measure CH_3CN.**

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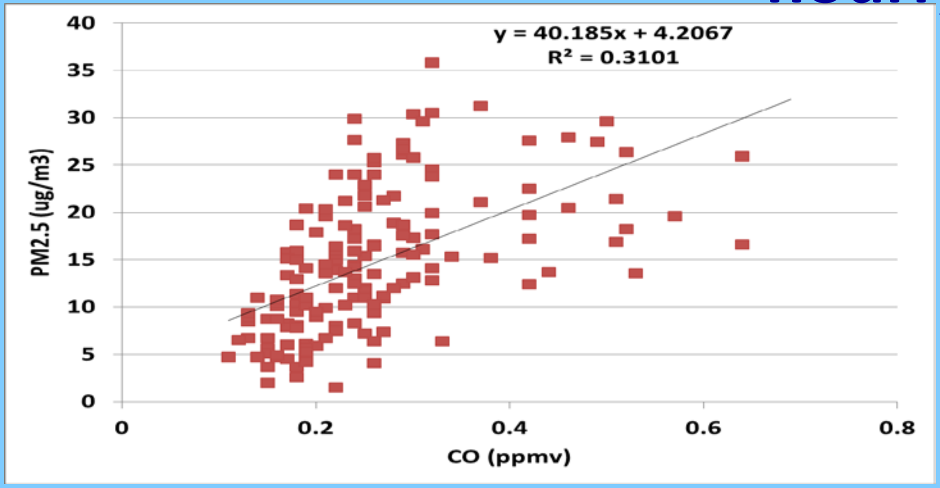
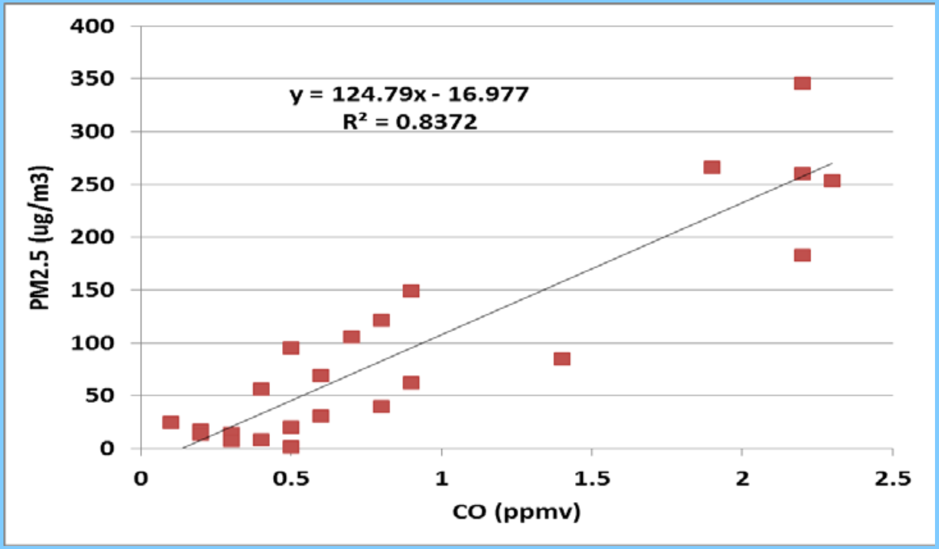
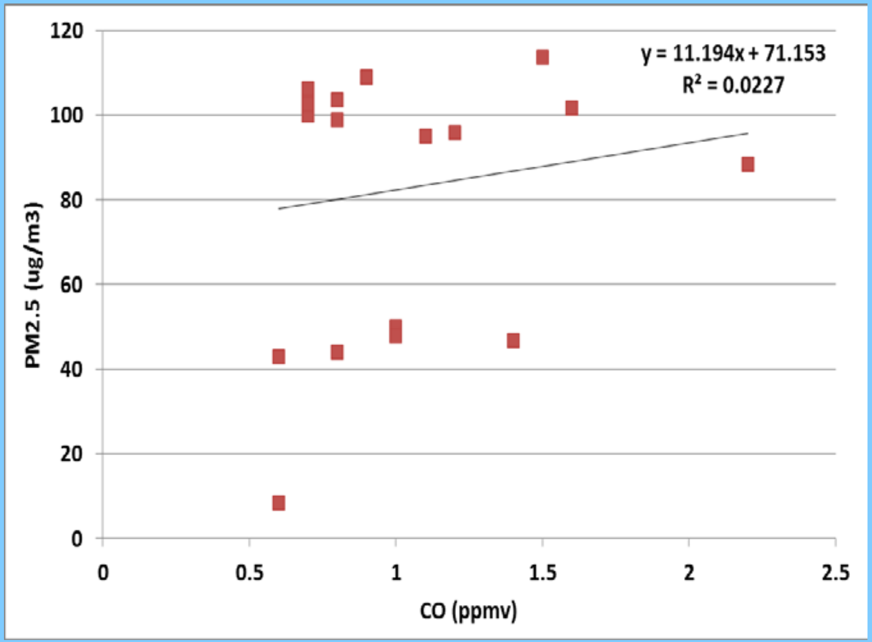
PM2.5-CO relationship in smoke at some NCORE sites, hourly data



SLC, Utah NCORE site, Aug 7-14, 2012. Smoke confirmed using multiple models (Jaffe 2013).



Spokane, WA site Aug 21, 2015. Smoke confirmed.



Spokane, WA site Aug 26, 2015 Smoke confirmed.

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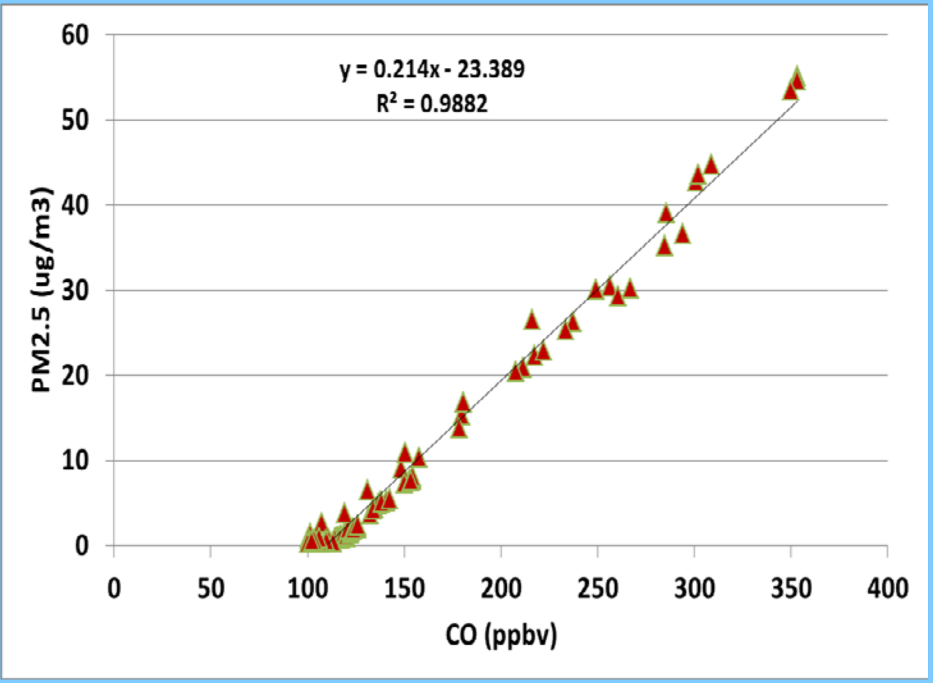
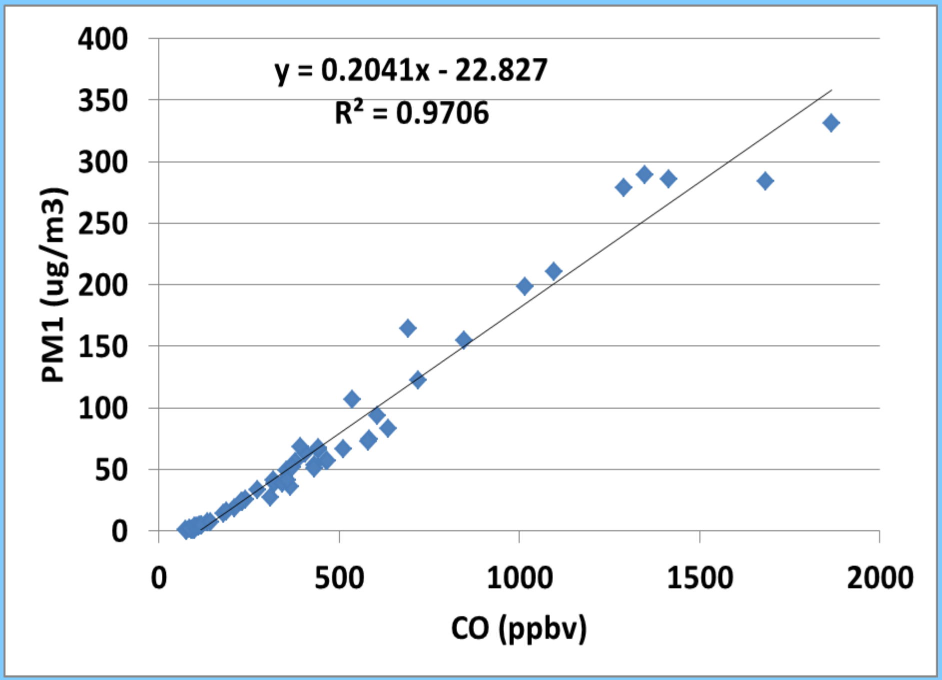
Examples of PM2.5-CO relationship at Mt. Bachelor Observatory-hourly obs



Smoke plume observations at the Mt. Bachelor Observatory, Sept 9, 2014 using Picarro G2302



Smoke plume observations at the Mt. Bachelor Observatory, Sept 25, 2009 using Thermo 48C TLE.

Our observations show that fire plumes have ΔPM/ΔCO ratios of 0.1-0.4 μg/m^3 per ppb.

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Fires vs typical urban emissions

	NOy/CO molar	PM2.5/CO µg/m^3 per ppb
Typical urban obs		
EPA emission inventory	0.123	0.06
Fire emission inventory (Akagi 2011)	0.026 to .009	0.12-0.16
Fire plume observations	0.01 to 0.005	0.1-0.4

Observations of CO, PM2.5 and NOy can distinguish source of pollutants on high O_3 days.

Eularian modeling vs Statistical modeling

Eularian modeling:

- Gridded emissions, meteorology, solar fluxes (J values).
- Use known photochemistry and transport to model mixing ratios.
- For wildfires significant challenges with emissions, plume rise, aerosols and the chemistry, which can be very different from typical urban photochemistry.
- Modeled concentrations may differ significantly from observations making quantitative attribution difficult.

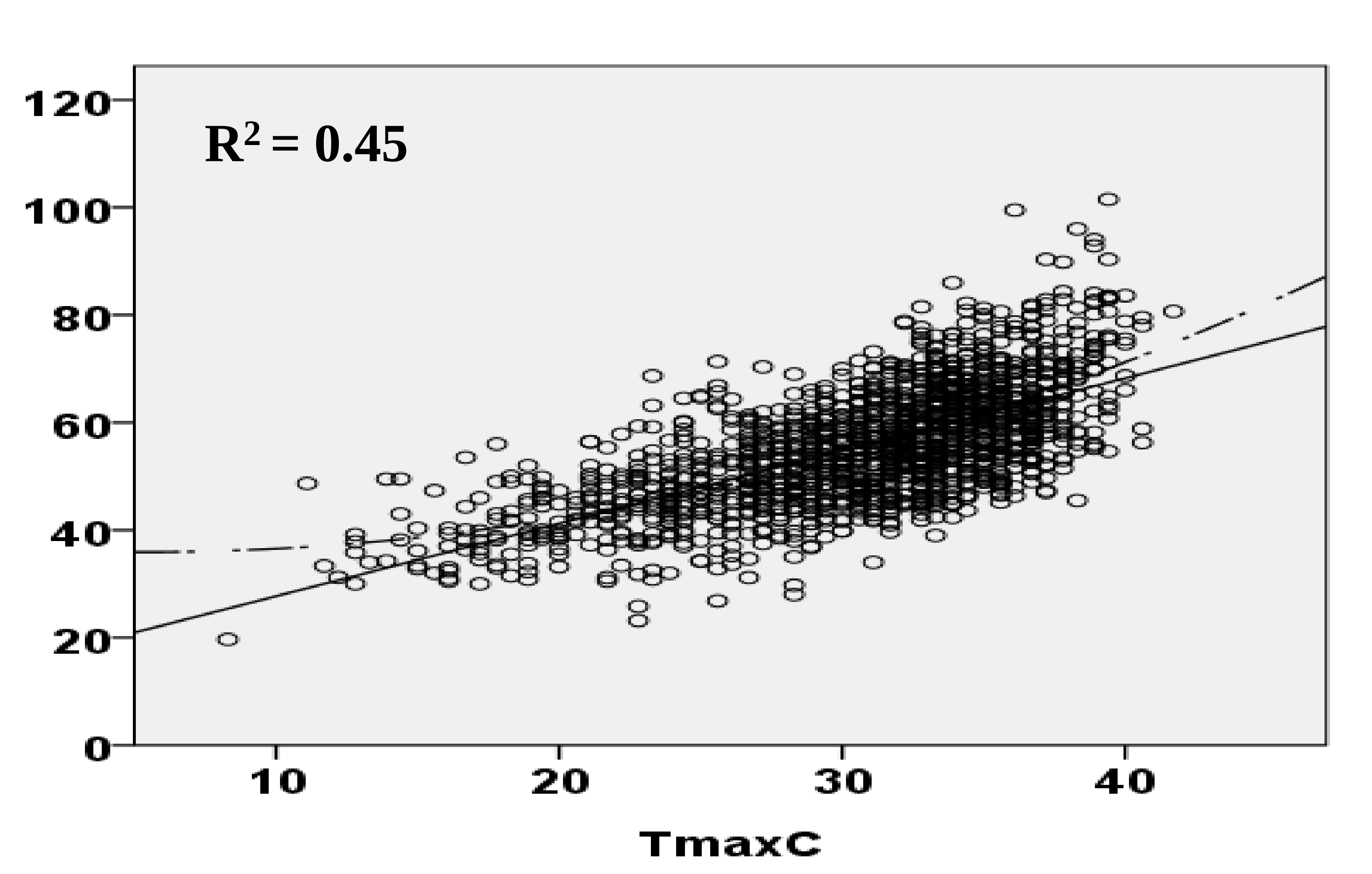
Statistical modeling:

- Examines the relationship between the observed mixing ratios and other 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.

O_3 = A*temp + B*winds + C*DOY… + residual

(Jaffe et al 2004; 2013; Camalier et al 2007; CARB 2011; EPA 2015)

SLC MDA8 vs Daily max T (SLC airport)



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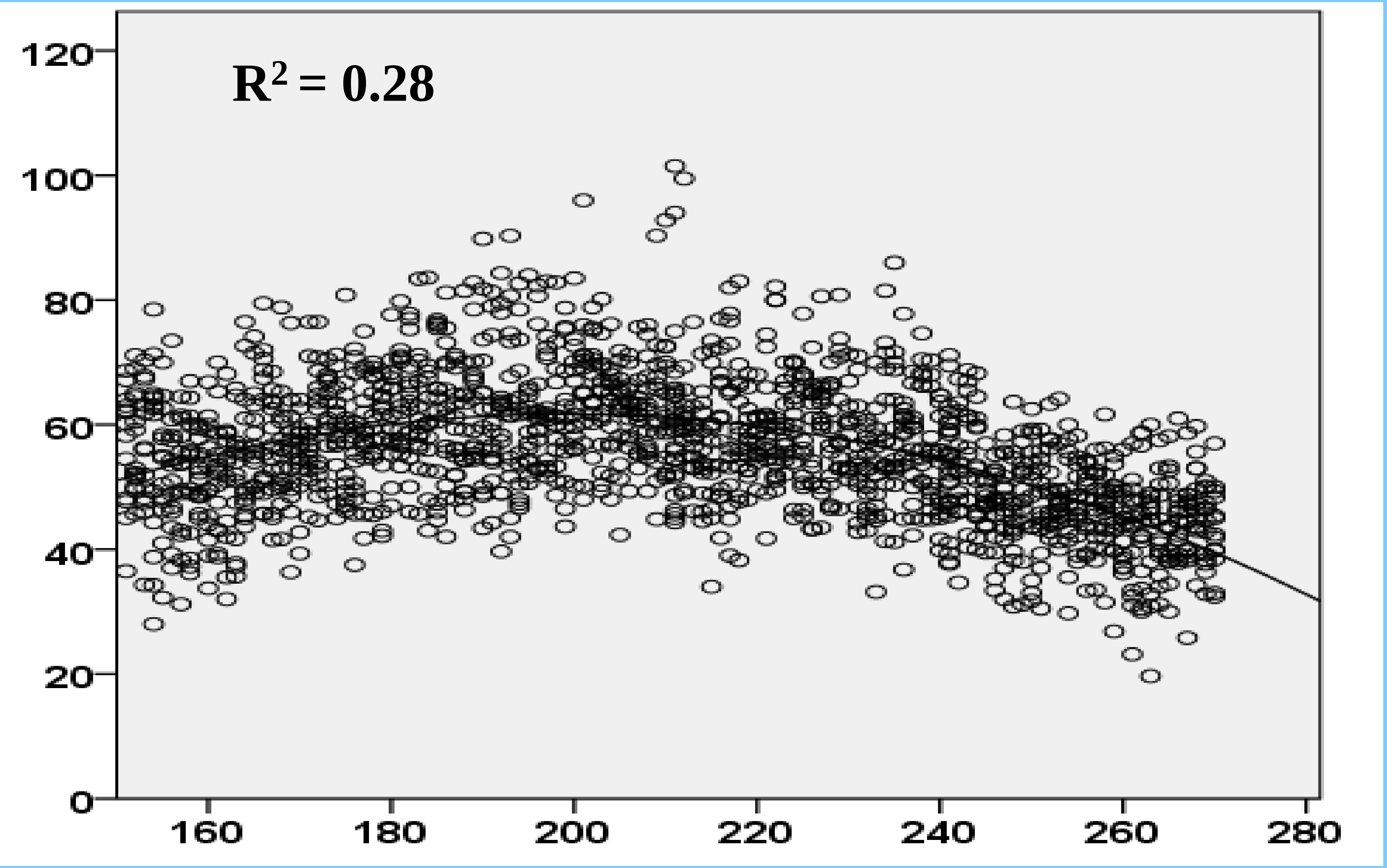
SLC MDA8 vs DOY



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Statistical model for SLC: R^{2}= 0.60

SLC Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
	Constant	829.8	96.62		8.59	.000
	T-max2	.0243	.0006	.683	40.7	.000
	Daily Avg Wnd Spd	-2.38	.138	-.286	-17.2	.000
	Yr	-.389	.048	-.132	-8.08	.000
	DOY^2	-.000177	.000	-.233	-14.1	.000

Parameter inclusion requires:

1. **Statistical significance**
2. **Reasonable physical interpretation**

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Why use Statistical Models?

1. Give important information on meteorology impacts on AQ in your area;
2. Give information on usual relationship between met variables and AQ;
3. Provides quantitative information on unusual conditions; e.g. exceptional events.

In Jaffe et al 2013 (EST) we compared statistical model with two Eulerien models for wildfire O_3 impacts in SLC, Reno and Boise.

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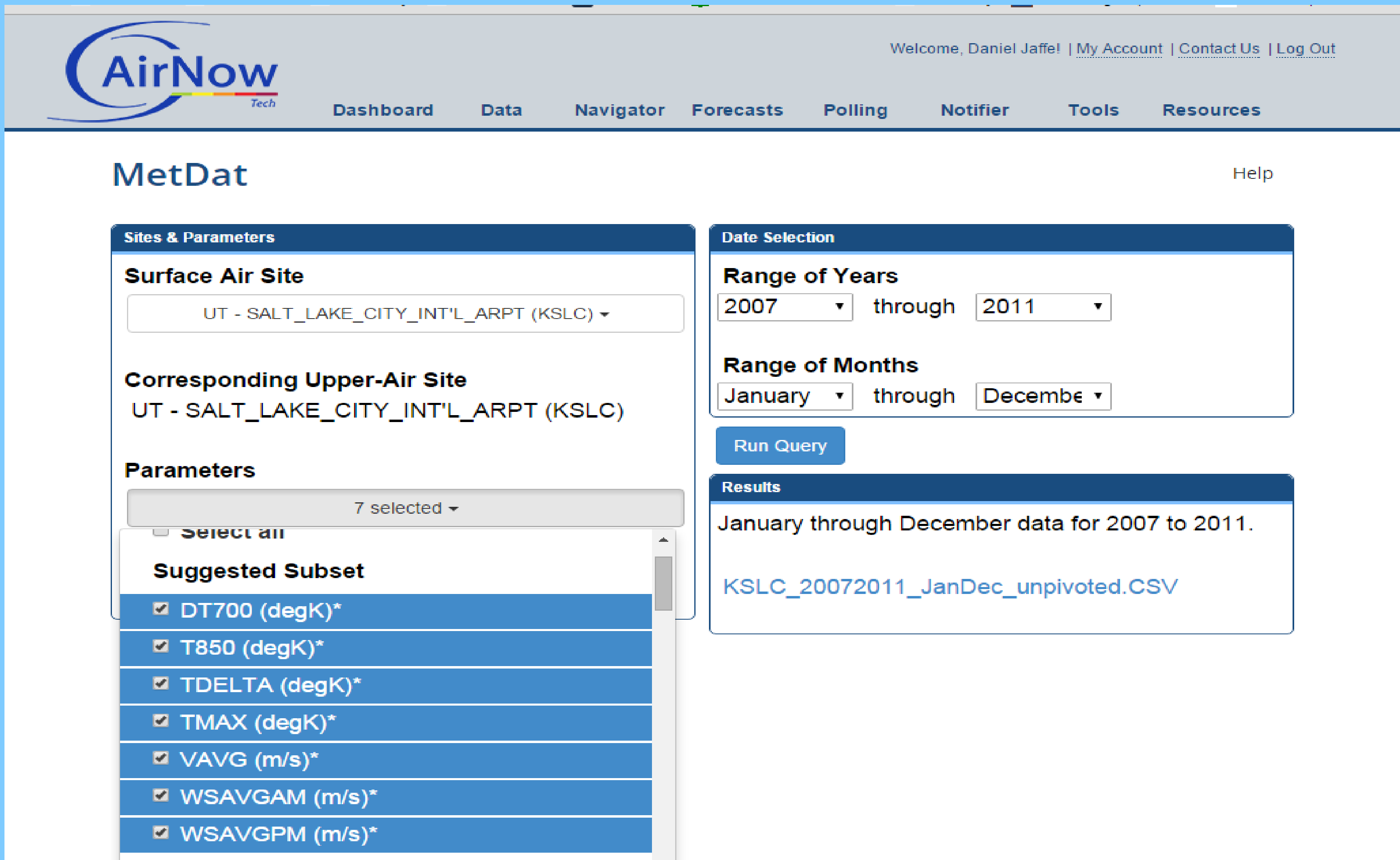
EPA 2015:

Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations

Miller D., DeWinter J., and Reid S. Documentation of data portal and case study to support analysis of fire impacts on ground-level ozone concentrations. Technical memorandum prepared for the U.S. Environmental Protection Agency, Research Triangle Park, NC by Sonoma Technology, Inc., Petaluma, CA, STI-910507-6062, Sept. 2014: Documentation of Data Portal and Case Study to Support Analysis of Fire Impacts on Ground-Level Ozone Concentrations

AirNow MetData



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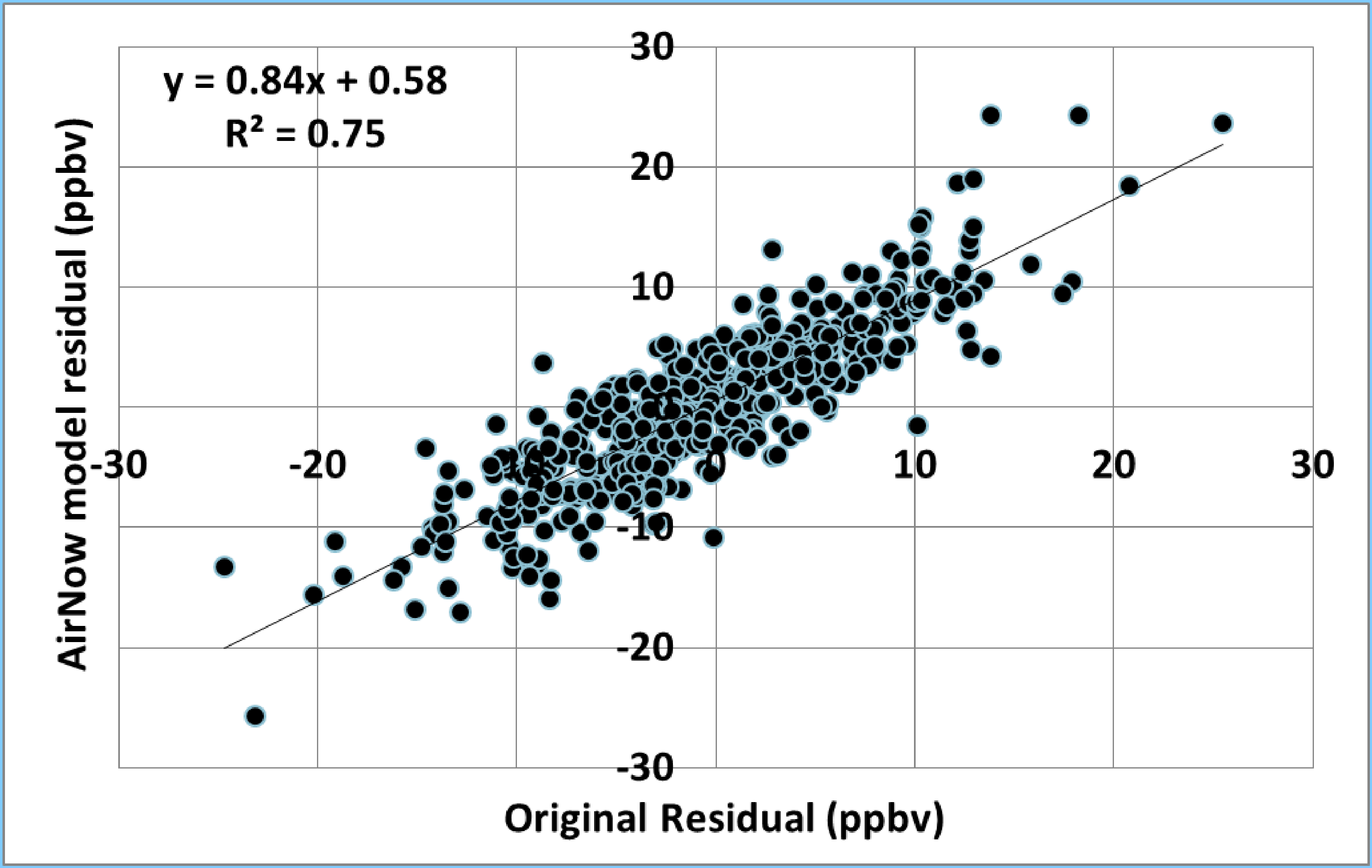
Comparison of my original statistical model with AirNow statistical model

	My model (Jaffe et al 2014-EST)	AirNow model
Location	Salt Lake City, UT	Salt Lake City, UT
Time period	2000-2012	2008-2011
% variance explained	0.60 (60%	0.59 (59%)
Key met variables	Maxtemp, WS, DOY, 700 mb zonal wind, etc.	Maxtemp, WS, 850 mb temp, etc.
How long to construct	~ 1 month	~ 1 hour

Comparison of residuals in my original statistical model with AirNow statistical model



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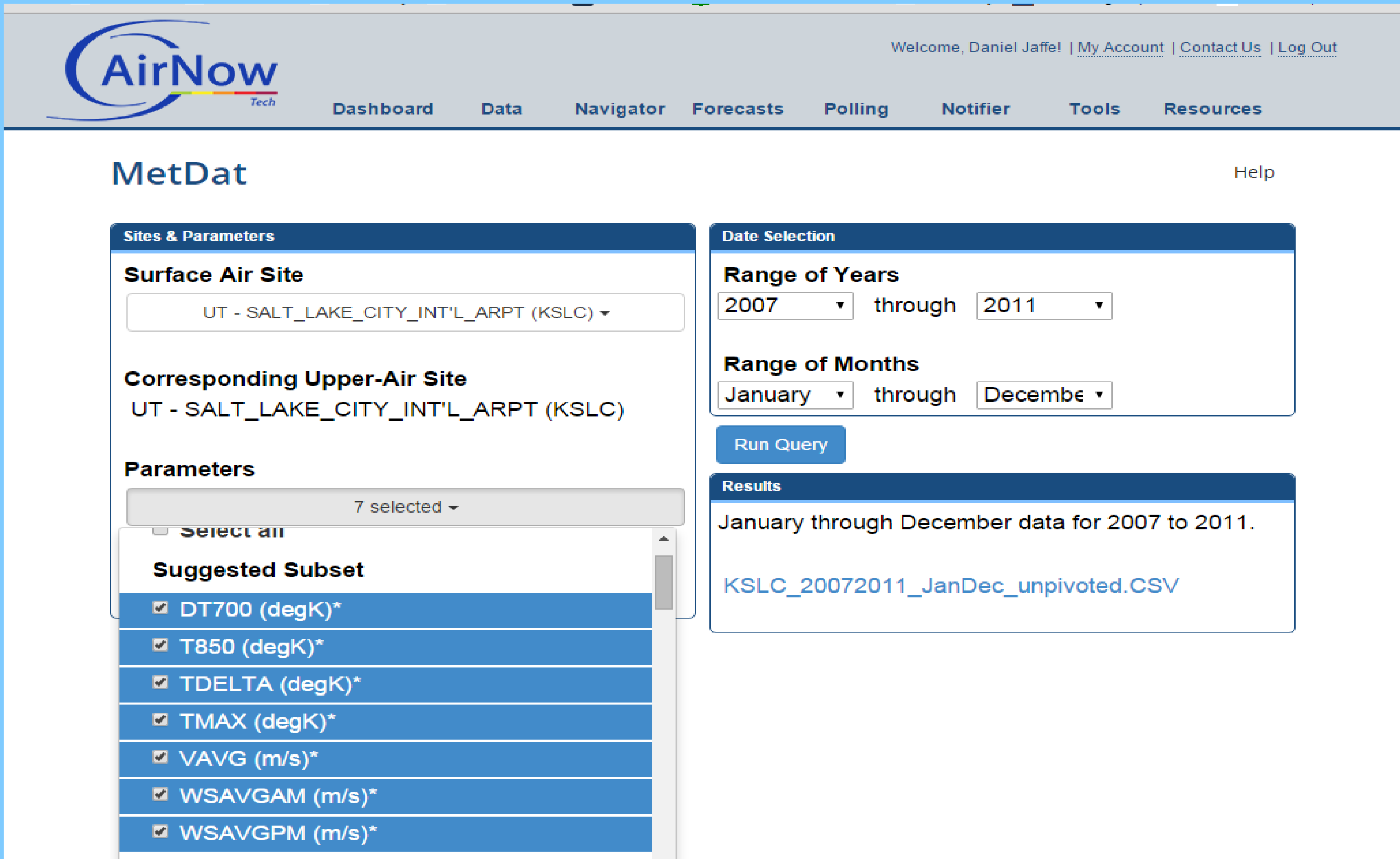
AirNow MetData



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Anna Wood (EPA-AQPD) and Chet Wayland (EPA-AQAD)

Westar Fall 2015 meeting

- **Final area designations due Fall 2017 - based on 2014-2016 final DVs (120-day letters by June 2017)**
- **Early-certified 2017 data may also be relevant to final designations.**
- **We expect state designation recommendations to be based on 2013-2015 and preliminary 2016 data, including any exceptional event considerations.**
- **Exceptional event demonstration submission deadlines: October 1, 2016 for 2014-2015 events**
- **May 31, 2017 for 2016 events**

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Anna Wood (EPA-AQPD) and Chet Wayland (EPA-AQAD)

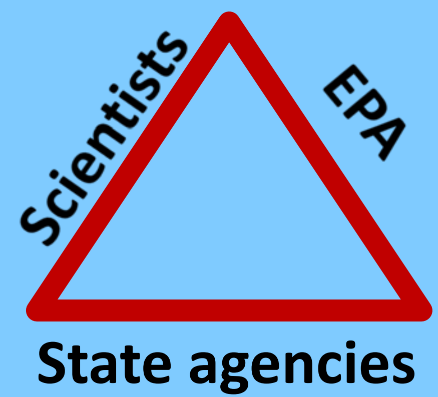
Westar Fall 2015 meeting

Preliminary stakeholder discussion questions:

- **From the stakeholder perspective, what additional data elements and/or model improvements are needed to better characterize background O3 levels across the U.S.?**
- **From the stakeholder perspective, has EPA properly characterized the various CAA provisions under consideration for areas influenced by background O3?**
- **Are there sufficient technical tools and data available to make the demonstrations necessary to invoke relevant CAA provisions?**

More on process and timeline-tentative

- **EPA plans to convene state agency/stakeholders meeting in Phoenix in late Feb (last week?) to discuss implementation;**
- **AWMA will convene a second webinar on O_3 implementation in spring (April or May?)**
- **Exceptional event designations for 2014-2015 due Oct 1, 2016.**
- **Need a continuous dialogue.**



Summary

1. **The new O_3 standard will be a major challenge for the western US. While O_3 is improving in many urban areas the standards are now approaching background concentrations;**
2. **Stratospheric intrusions (UTLS) and very long-range transport can be identified from tracer ratios, met and spatial correlations;**
3. **Wildfires are becoming increasingly important. While the PM and health effects are obvious, there are many uncertainties around secondary aerosol and O_3 production;**
4. **Need to develop and use all the tools available to us. This includes better observations, tracer ratios, spatial-temporal correlations and statistical modeling;**
5. **Need to push EPA to improve these tools.**

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