

A Decade of Observations at the Mt. Bachelor Observatory

Dan Jaffe, University of Washington



National Science Foundation
WHERE DISCOVERIES BEGIN



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The Team



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June 2015: O₃ in the political hot seat...

UNITED STATES SENATE
COMMITTEE CHANNEL

Hearing entitled, "Challenges and Implications of EPA's Proposed National Ambient Air Quality Standard for Ground-Level Ozone and Legislative Hearing on S. 638, S. 751, and S. 640."
Coverage begins at 9:30 am.

COMMITTEE ON ENVIRONMENT & PUBLIC WORKS



ENERGY & COMMERCE COMMITTEE
UNITED STATES HOUSE OF REPRESENTATIVES
CHAIRMAN FRED UPTON

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EPA's Proposed Ozone Rule



Friday, June 12, 2015 - 10:30am

[Energy and Power](#)

2123 Rayburn

Background Documents and Information:

[Hearing Notice](#)

[Background Memo](#)

To read a related press release, click [here](#).



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Outline

- Trends and variability of O_3 in the free troposphere (FT);
- Relationship of FT O_3 to surface O_3 and AQ;
- O_3 and PM in wildfire smoke

Mt. Bachelor, Oregon, 2.8 km above sea level



- ❖ The only high elevation/free trop research site on west coast of U.S.
- ❖ Continuous observations of CO, O₃, aerosols and Hg since 2004;
- ❖ Frequent detection of Asian pollution and biomass burning plumes;
- ❖ Key goal: Identify importance of global sources on US air quality.

Chemical measurements at MBO

Continuous since 2004:

- CO and CO₂ Cavity Ring Down Spectroscopy
- O₃: UV spectroscopy
- Aerosol scattering (continuous PM₁, PM_{2.5})
- Aerosol absorption (climate relevance)

Campaigns:

- NO_x: Chemiluminescence spectroscopy w/UV photolysis
- NO_y: Chemiluminescence spectroscopy
- Peroxyacetyl nitrate (PAN): Gas chromatography-ecd
- Mercury (Hg): Cold vapor atomic fluorescence (CVAFS)
- Hydrocarbons: Gas chromatography/mass spec.
- Acids (H₂SO₄, HNO₃): Ion chromatography
- Aerosol chemistry: X-ray fluorescence, AMS (Zhang UCD)

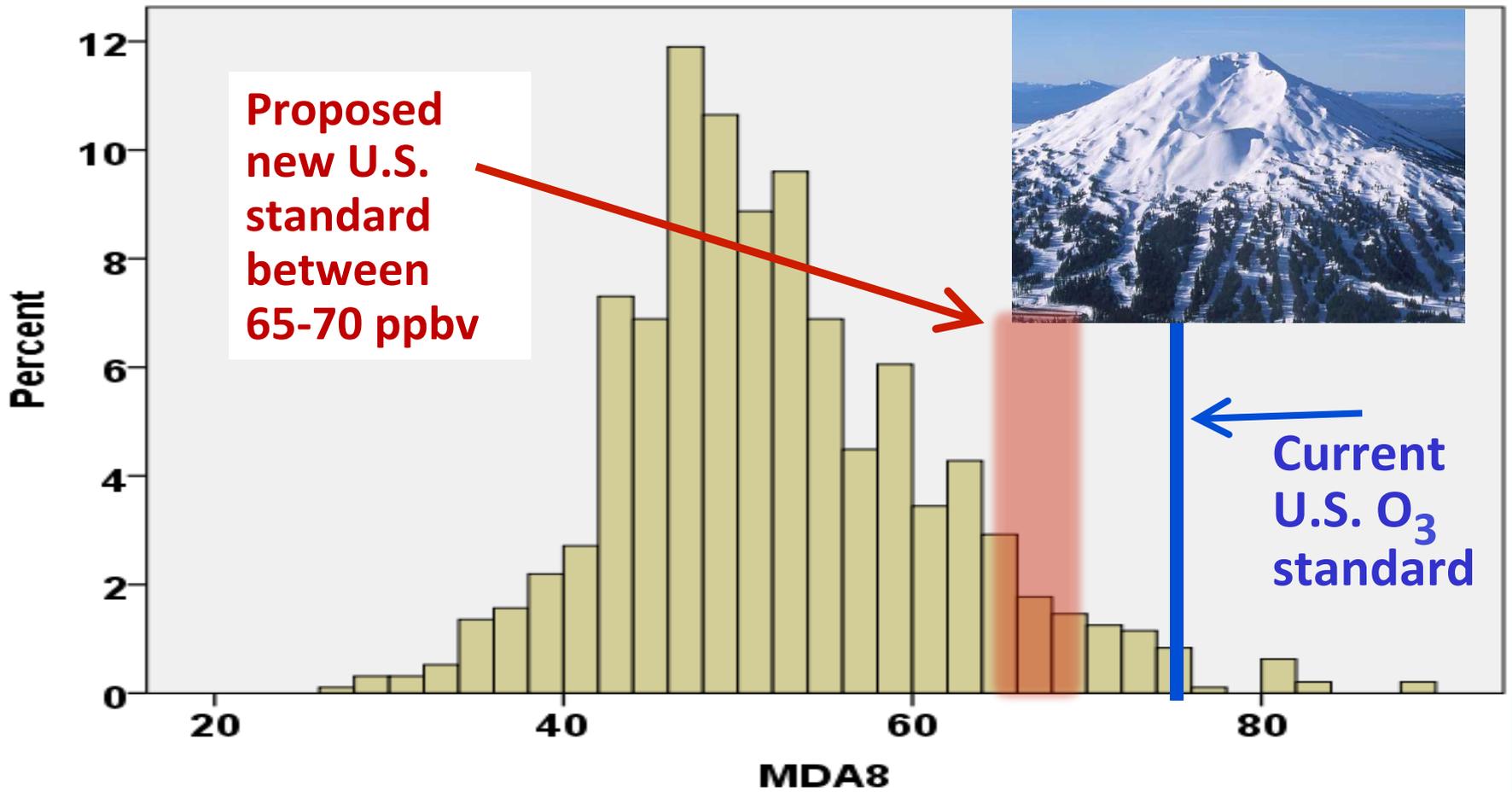


Multiple measurements are essential to understand the sources and chemical processing!

What are boundary conditions?

- The time varying concentration of O_3 along all boundaries of the domain under consideration.
- Similar to “background”;
- Similar to “policy relevant background”
- Similar to “baseline concentrations”.
- At present, we have very limited tools to get the BC for O_3 along the west coast of the US.

MDA8 O₃ at Mt. Bachelor



Max daily 8 hour avg O₃ at Mt. Bachelor for 2012-2014
Latest 3-year design value = 79 ppbv

What are causes of high O₃ at MBO and how does this influence surface AQ?



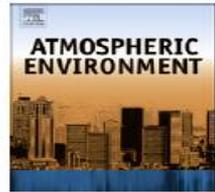
Causes of high O₃ days at MBO: UTLS, Asian pollution and wildfires



Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv



Causes of high O₃ 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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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

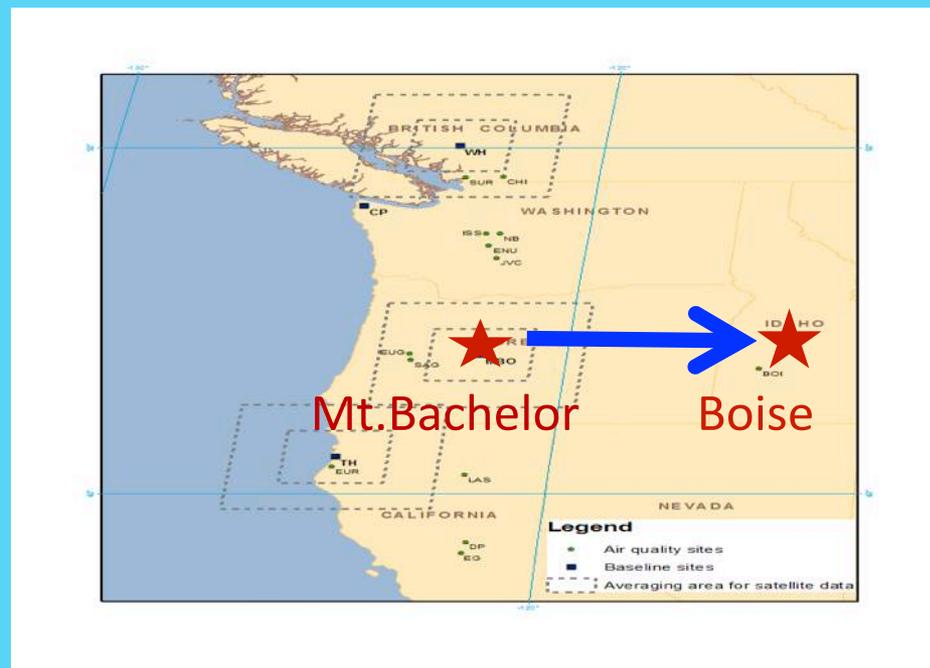


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Transport of Free Trop O_3 to surface sites: Wigder et al; J.Geophys Res., 2013

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. Vaughan³



Springtime O₃ trend at MBO: Gratz et al, 2015



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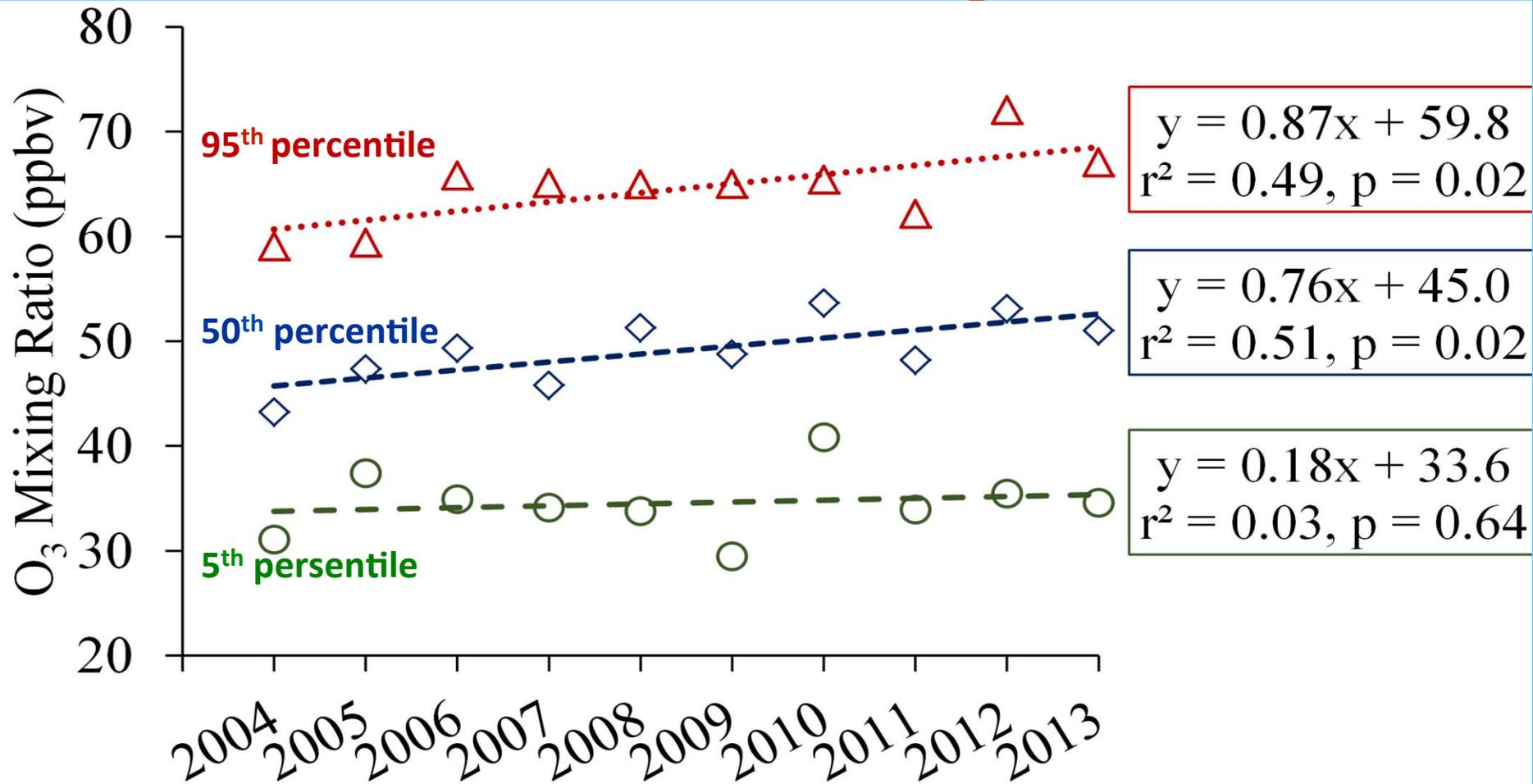
Causes of increasing ozone and decreasing carbon monoxide in springtime at the Mt. Bachelor Observatory from 2004 to 2013

L.E. Gratz^{a,*}, D.A. Jaffe^{a,b}, J.R. Hee^a



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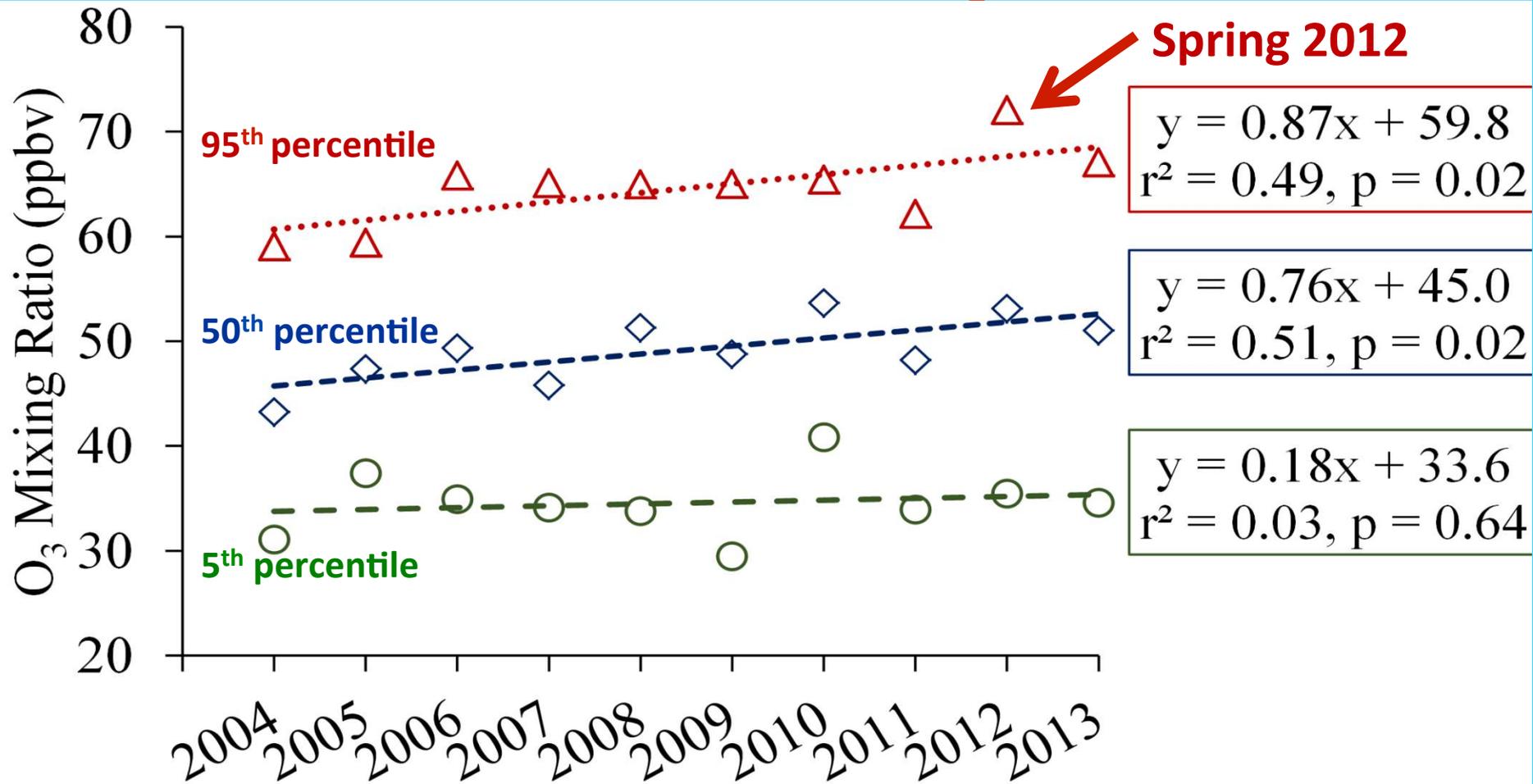
Changes in Spring O₃ at MBO



This is likely due to increasing Asian emissions (Gratz et al 2015).



Changes in Spring O₃ at MBO

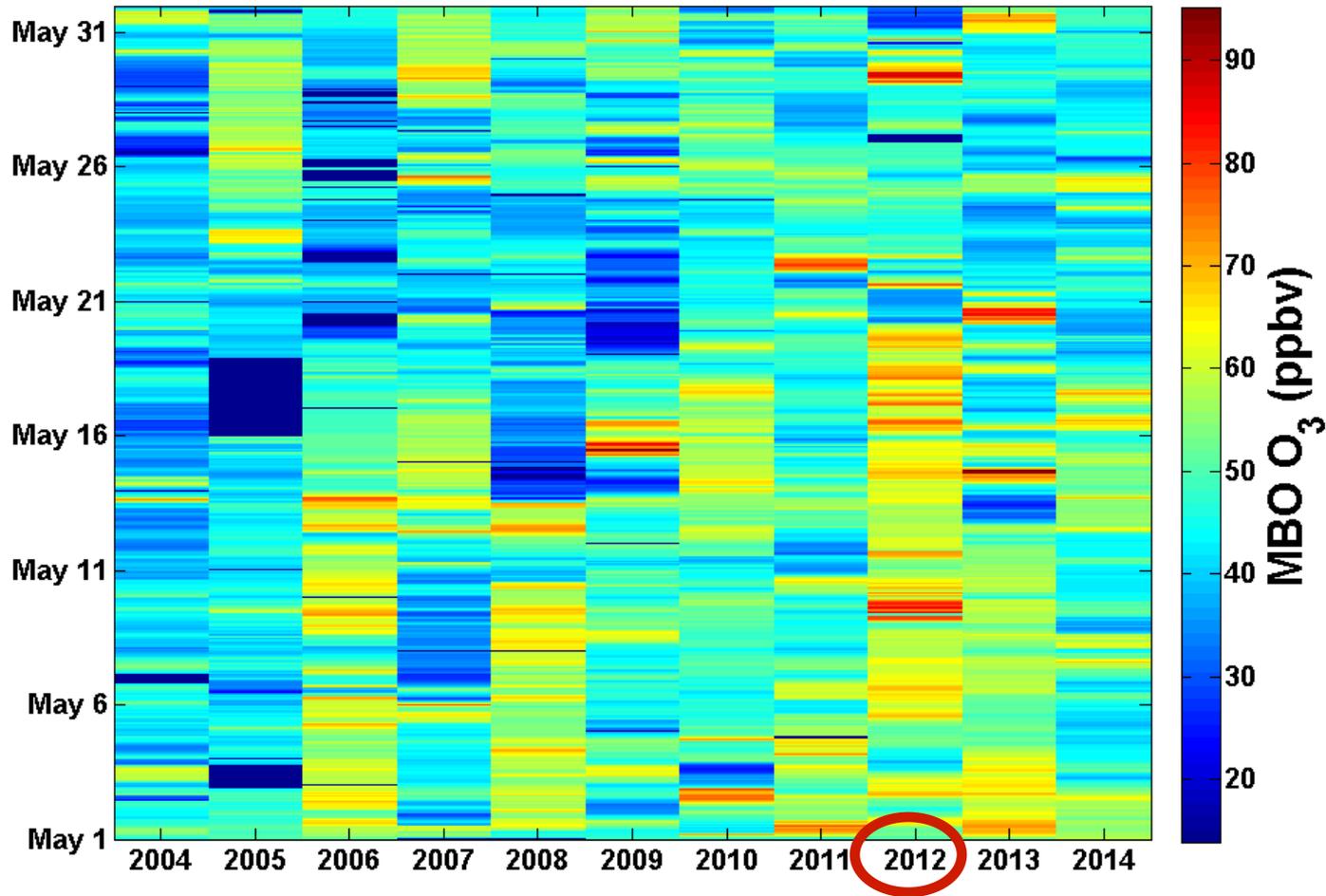


What is cause for high O₃ in Spring 2012?

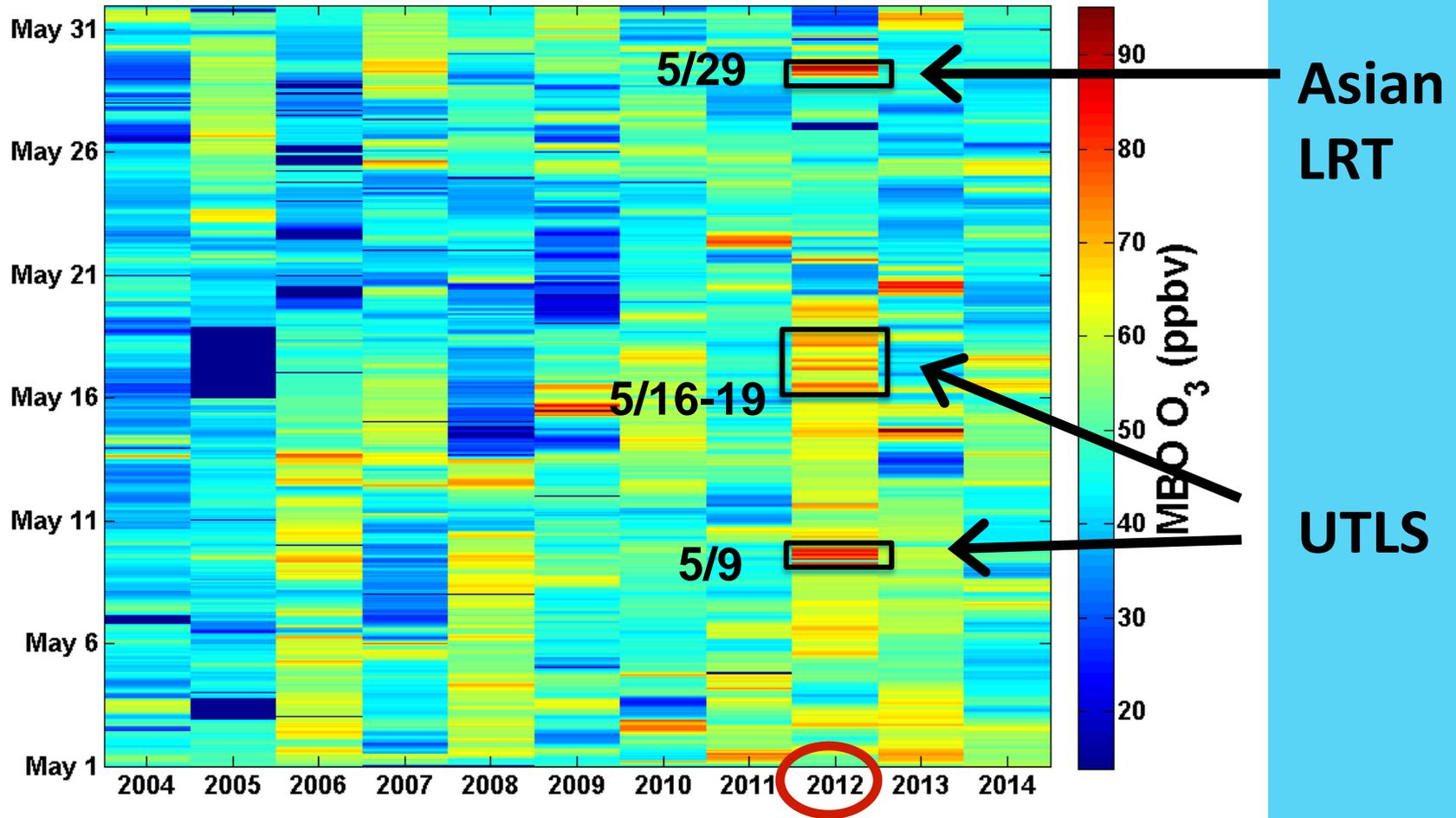
Is it important to surface AQ?



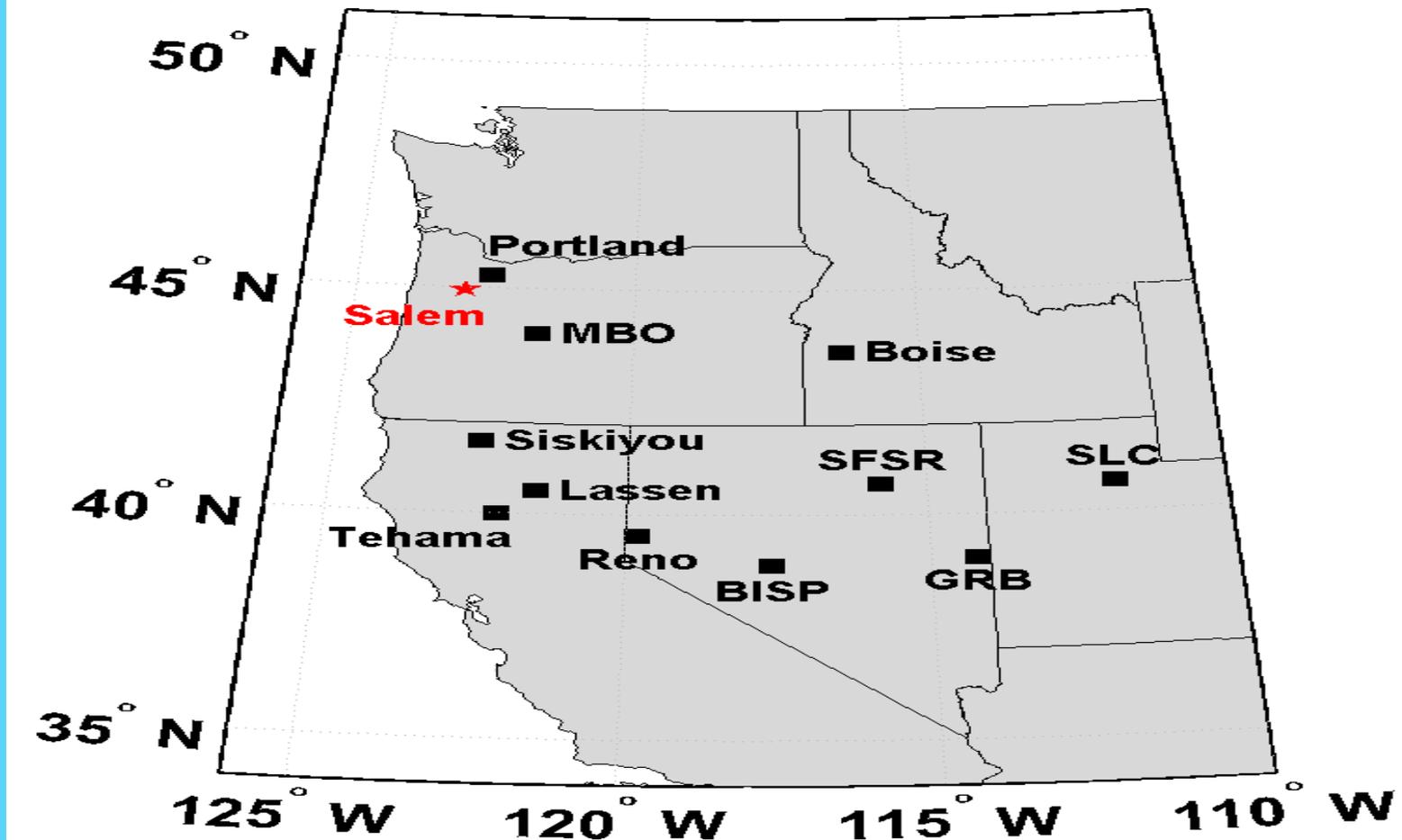
MBO Hourly O₃ May 2004-2013



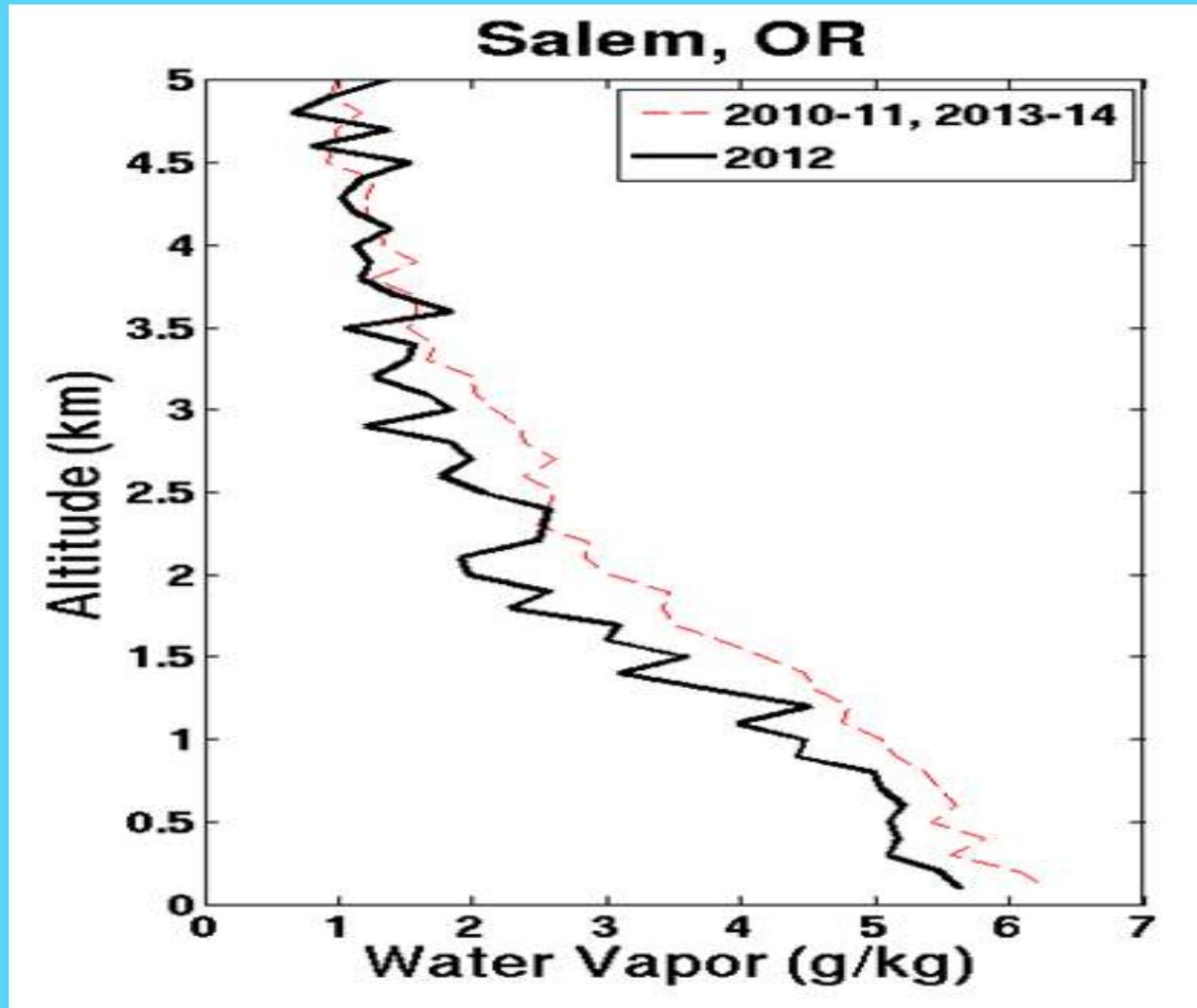
MBO Hourly O₃ May 2004-2013



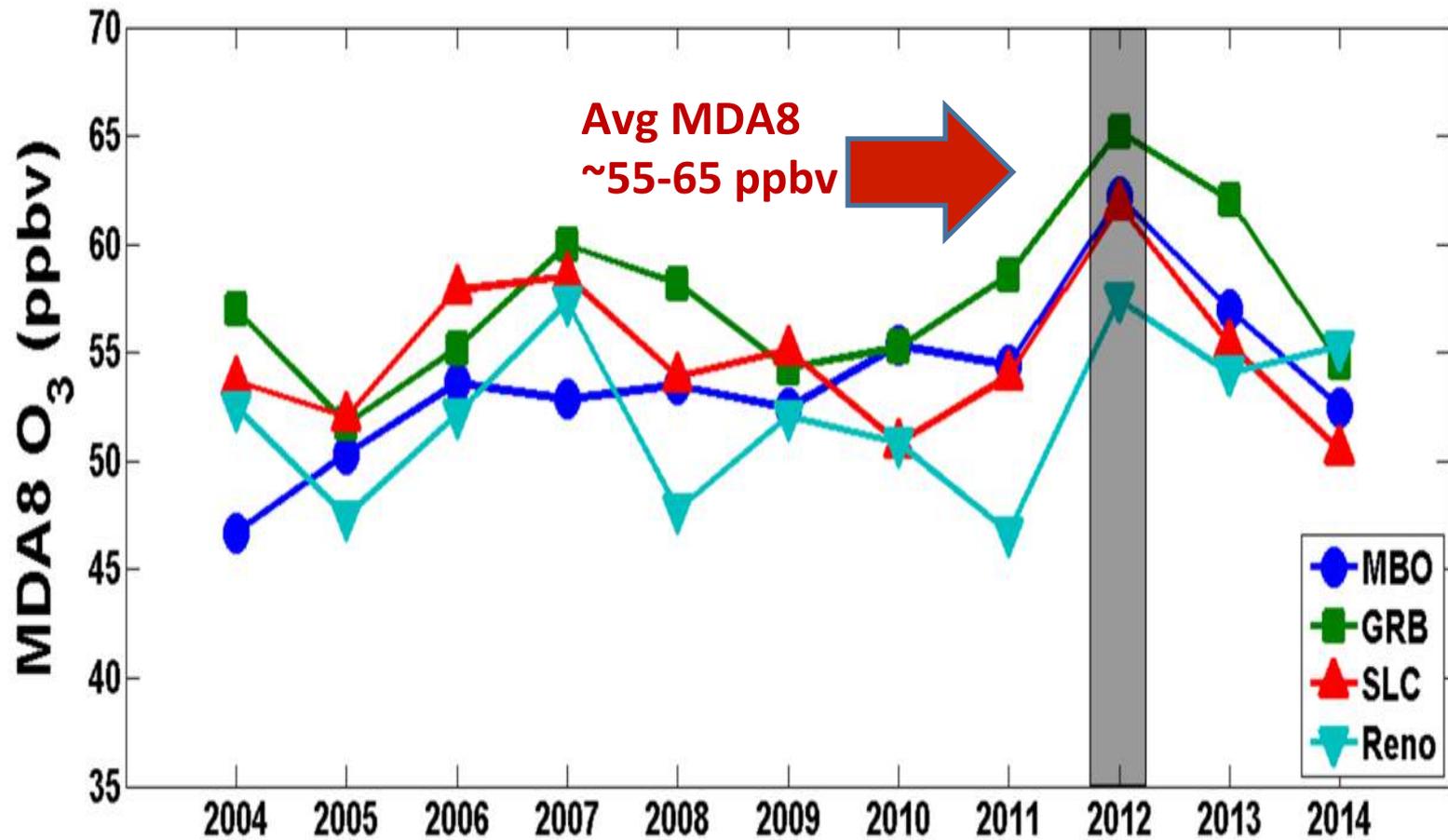
Western US Ozone sites



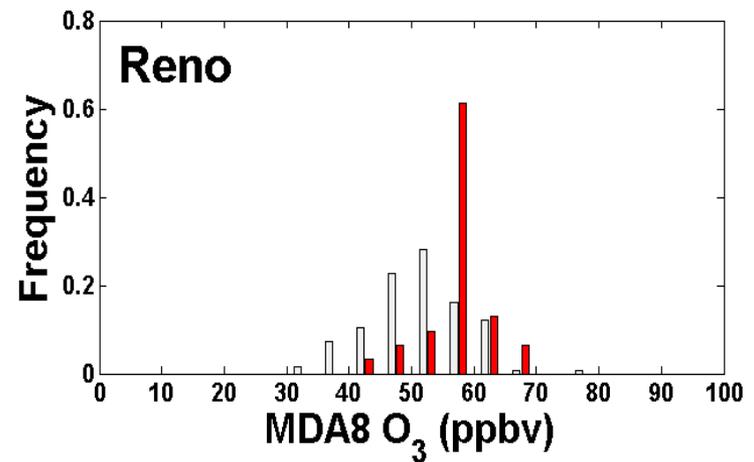
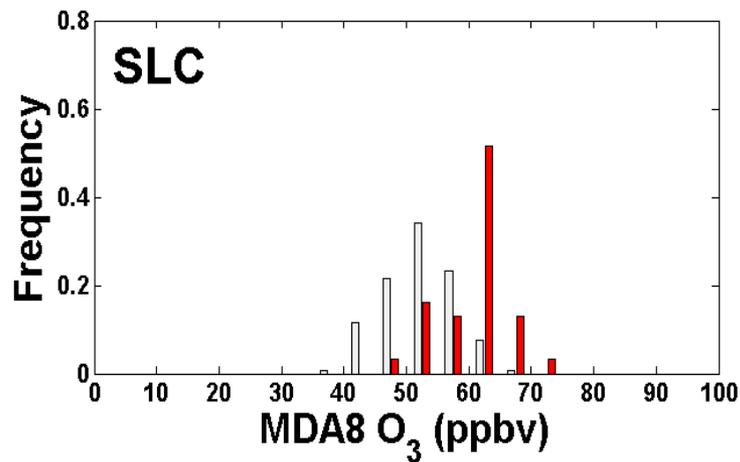
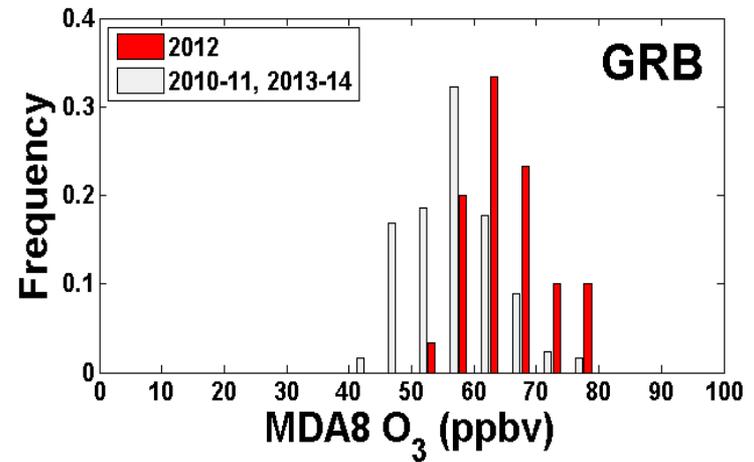
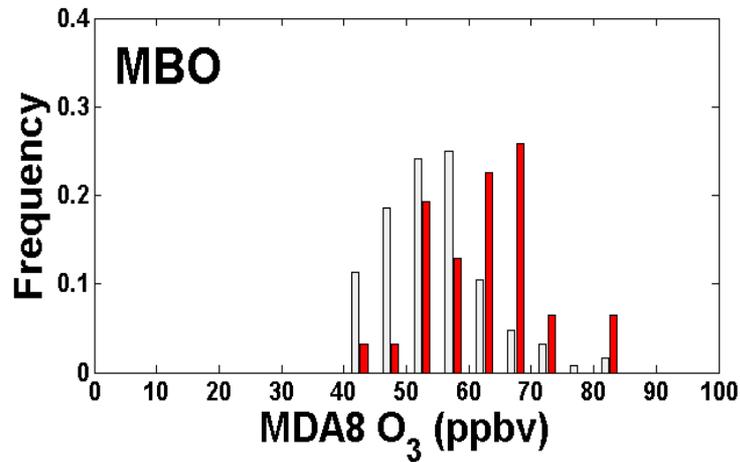
Salem Radiosonde data



Inter-Annual in MDA8 for May



May 2012: Shift in Distribution to higher MDA8s

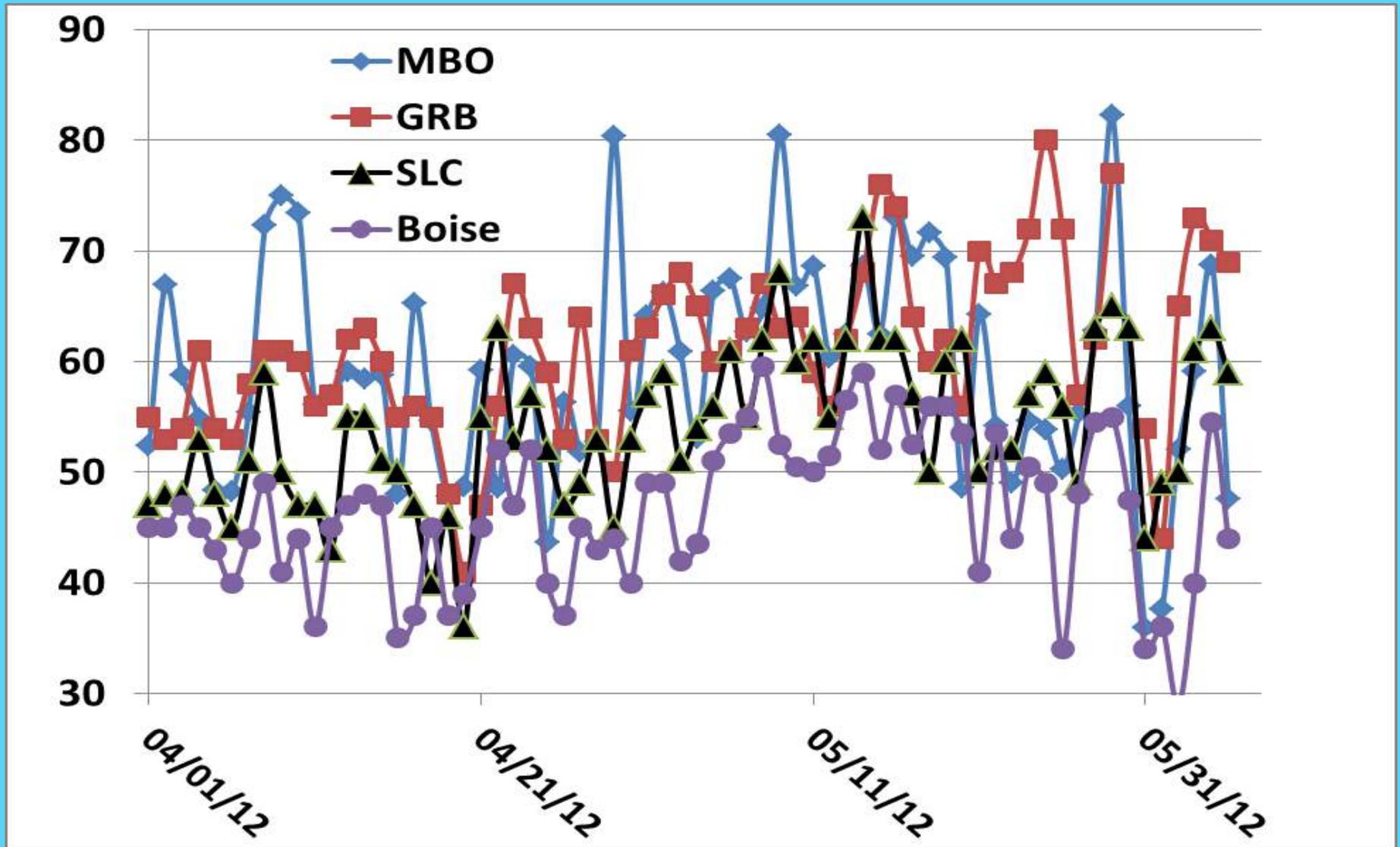


Location	May 2012 Relative to May 2010-2014 (MDA8, ppbv)
Great Basin NV (2.1 km)	+ 6.1
Mt Bachelor OR (2.8 km)	+ 5.4
Boise ID MSA (0.8 km)	+ 4.0
Reno-Sparks, NV (1.5 km)	+ 4.1
Salt Lake City, UT (1.4 km)	+7.0
Tehama Cty CA (0.6 km)	+ 3.1
Lassen N.P. CA (1.8 km)	+ 2.1
Siskiyou Cty CA (0.8 km)	+ 2.2
San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

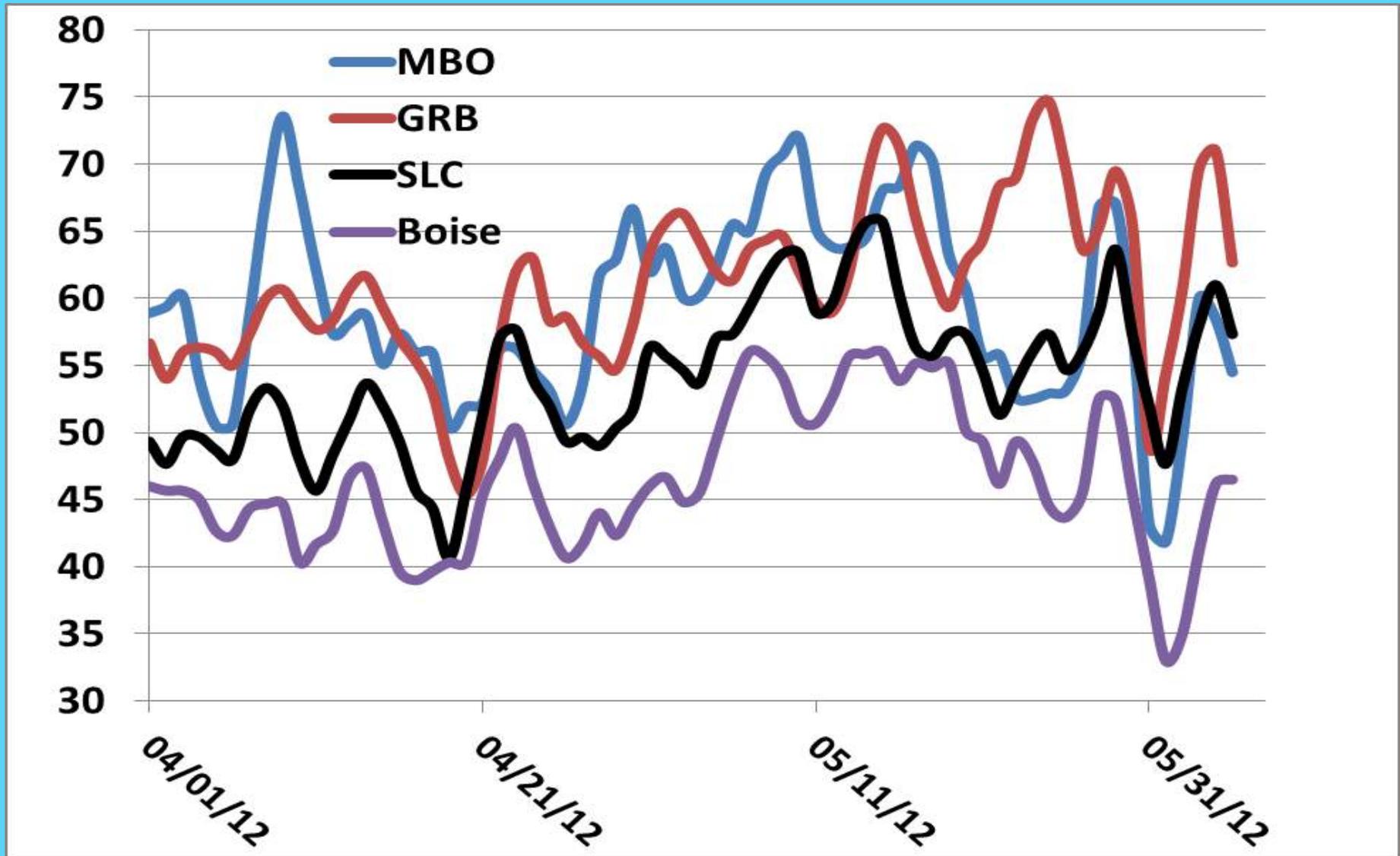
Higher elevation sites generally show greater enhancement.



Daily MDA8 at Four High Elevation Sites in WUS in Spring 2012



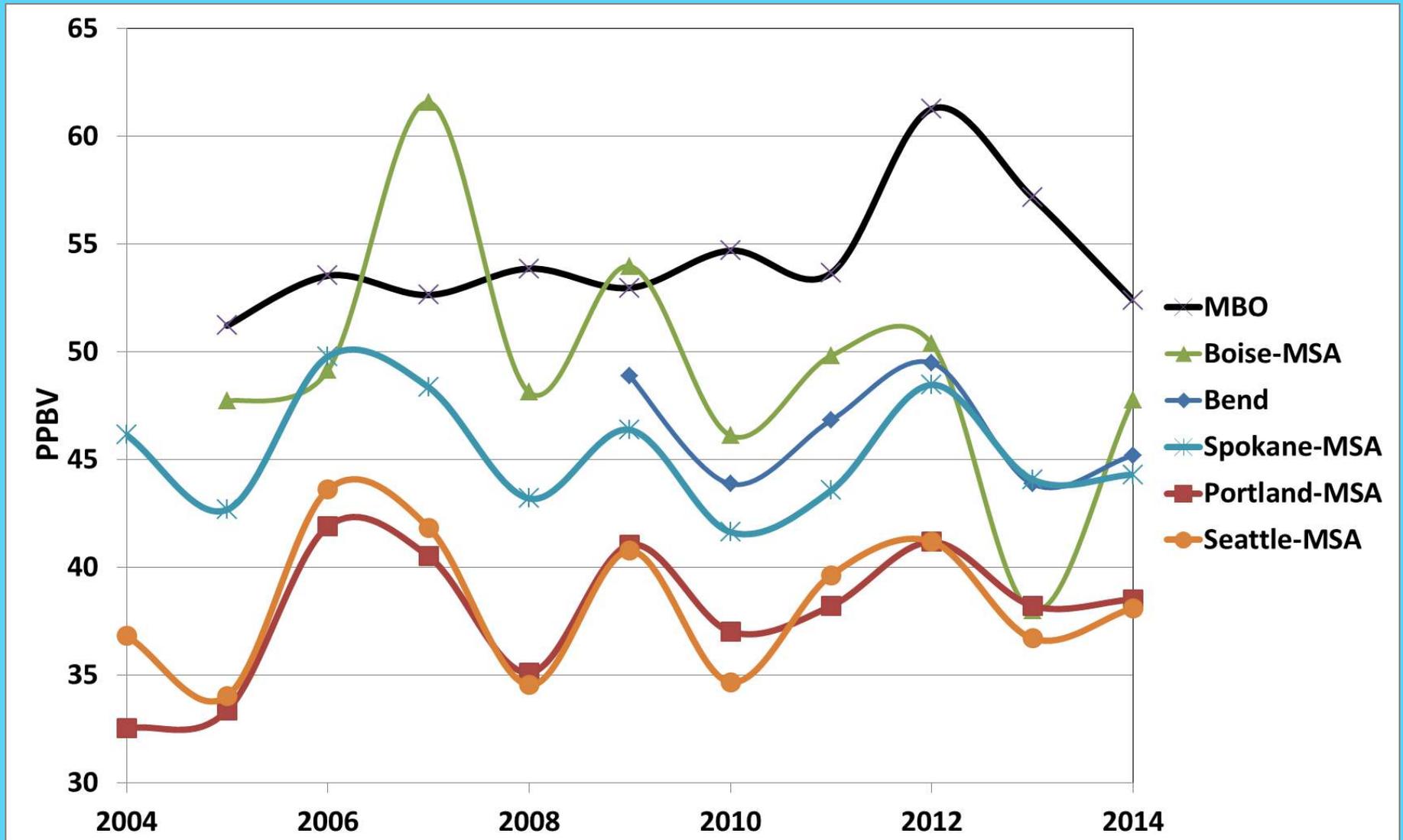
MDA8 at Four High Elevation Sites in WUS in Spring 2012



1. Large scale coherence across WUS
2. Boundary Conditions matter!



Monthly mean MDA8 for May



Boundary Conditions Matter!

1. How do we evaluate daily and inter-annual variations in BC? (Mountain top observations ?
O₃ Lidar? satellites ?
2. How sensitive is urban air to BC? How does this vary at lower NAAQS?
3. How well can we model variability in BCs? How do we evaluate the models BCs?

Studies on O₃ and PM in wildfire plumes at Mt Bachelor



View from Mt. Bachelor of the Pole Creek fire on 9/19/ 2012. Up to 9 ppmv and 1000 $\mu\text{g}/\text{m}^3$ PM₁ seen at MBO.

- MBO is an ideal location to study wildfire plumes due to frequent fires in the PNW and N. Calif.
- To date 9 publications with MBO data on the relationships between PM, O₃ and a variety of wildfire tracers;

Focus on uncertainties in:

- Primary and secondary aerosol production;
- O₃ production;
- Radiative impacts of smoke plumes.

Fire plumes are very different from urban plumes



Pole Creek fire on 9/19/ 2012

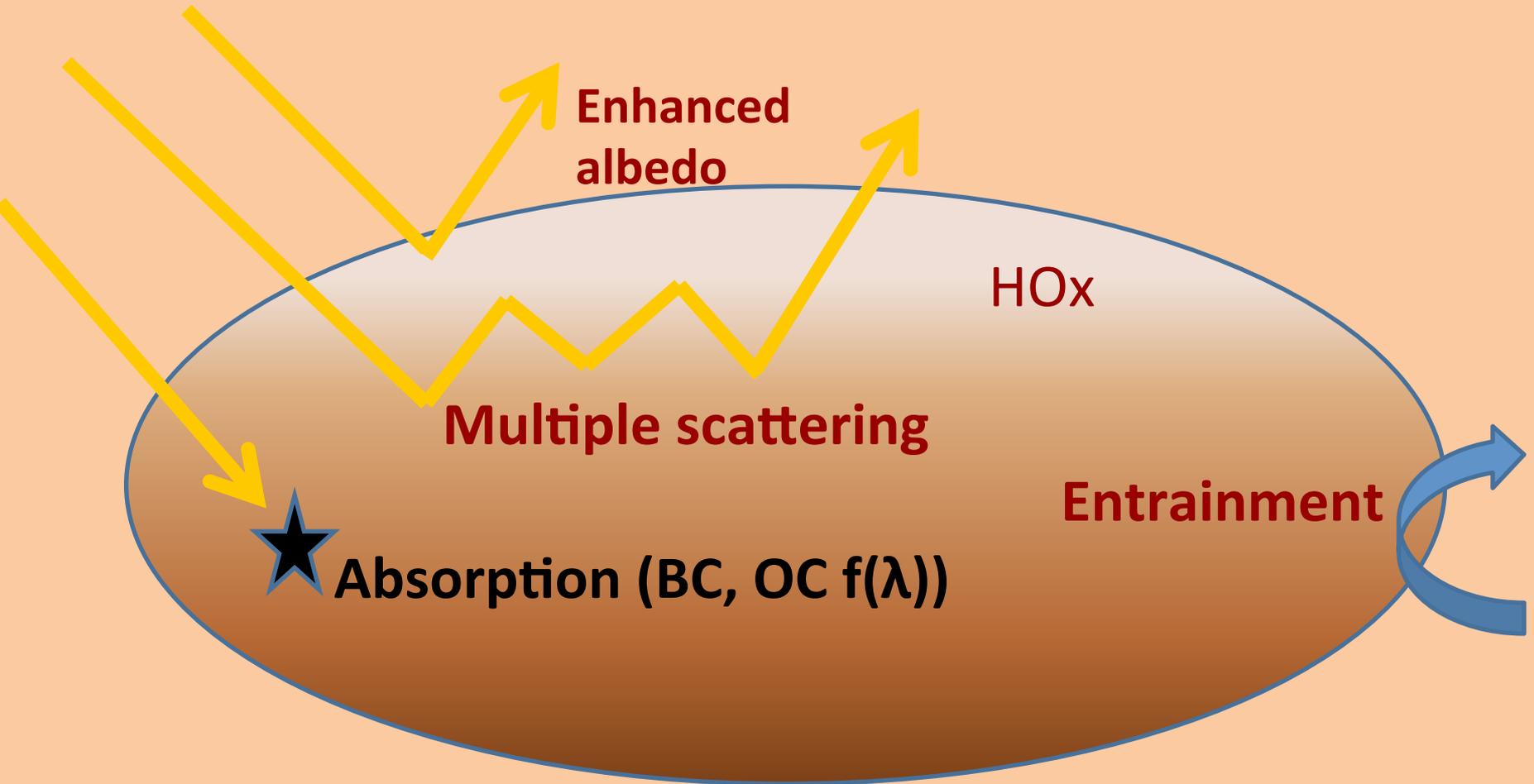
CO > 9000 ppbv

PM₁ > 1000 µg/m³

- **Huge PM levels, which impacts chemistry and photolysis.**
- **Emissions vary dramatically with time, combustion efficiency, etc.**
- **Very different chemistry: Oxy-VOCs, PAN, HONO, etc.**

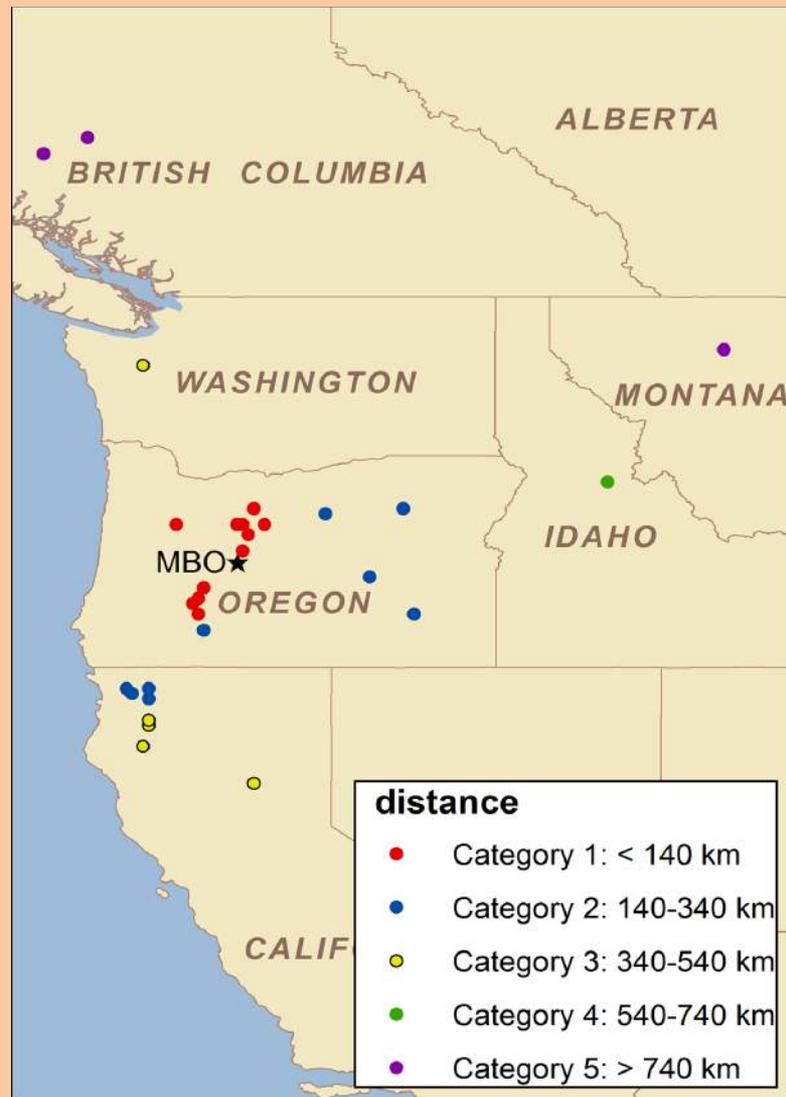
At MBO we found PAN to be 48% of NO_y in 6 plumes (Wigder et al 2014) compared to 10-15% for urban plumes (Roberts 2008). This likely contributes to significant O₃ production far downwind (Jaffe and Wigder 2013).

Plume cross-section



Need AOD and single scattering albedo ($\sigma_s/\sigma_s+\sigma_a$) as a function of λ

Ozone and PM in wildfires seen at MBO



- 32 fire plumes observed in 2004-2011;
- $\Delta\text{PM}_{10}/\Delta\text{CO}$ ratio varied from 0.06-0.42 $\mu\text{g}/\text{m}^3$ per ppbv
- 13 plumes had enhanced ozone with $\Delta\text{O}_3/\Delta\text{CO}$ range of 0.01-0.51 (Wigder et al 2013)
- Due to controversy over whether wildfires make O_3 we completed a review of >125 papers on wildfires obs. We found that the majority reported significant O_3 production but with large variability (Jaffe and Wigder 2012; *Atm. Env.*)

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 $\Delta O_3 / \Delta CO$
$\leq 1-2$ 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

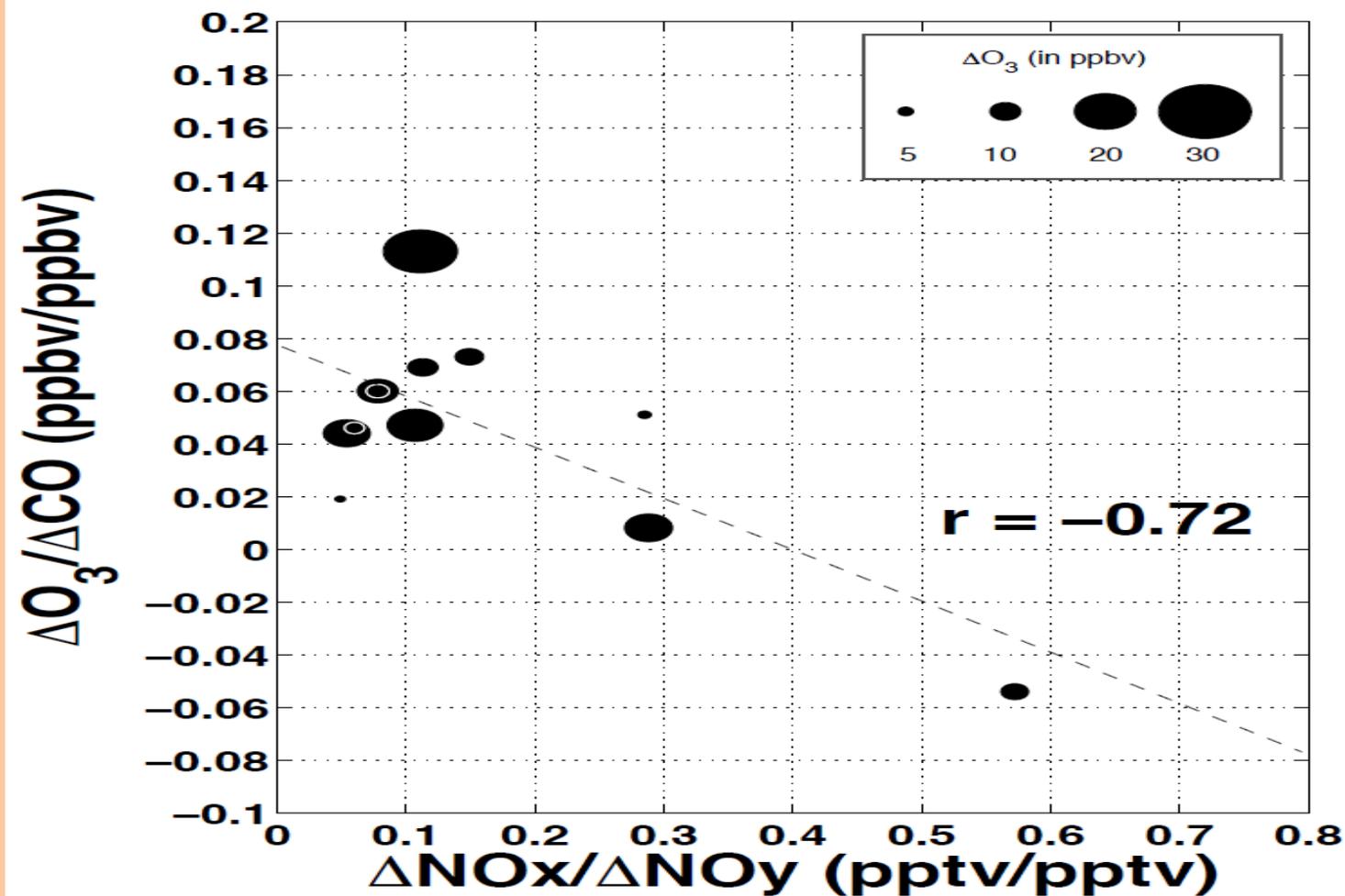
Tropics/ Subtropics:

Plume Age	Mean $\Delta O_3 / \Delta CO$ (ppbv/ppbv) (# plumes)	Range of $\Delta O_3 / \Delta CO$
$\leq 1-2$ 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.



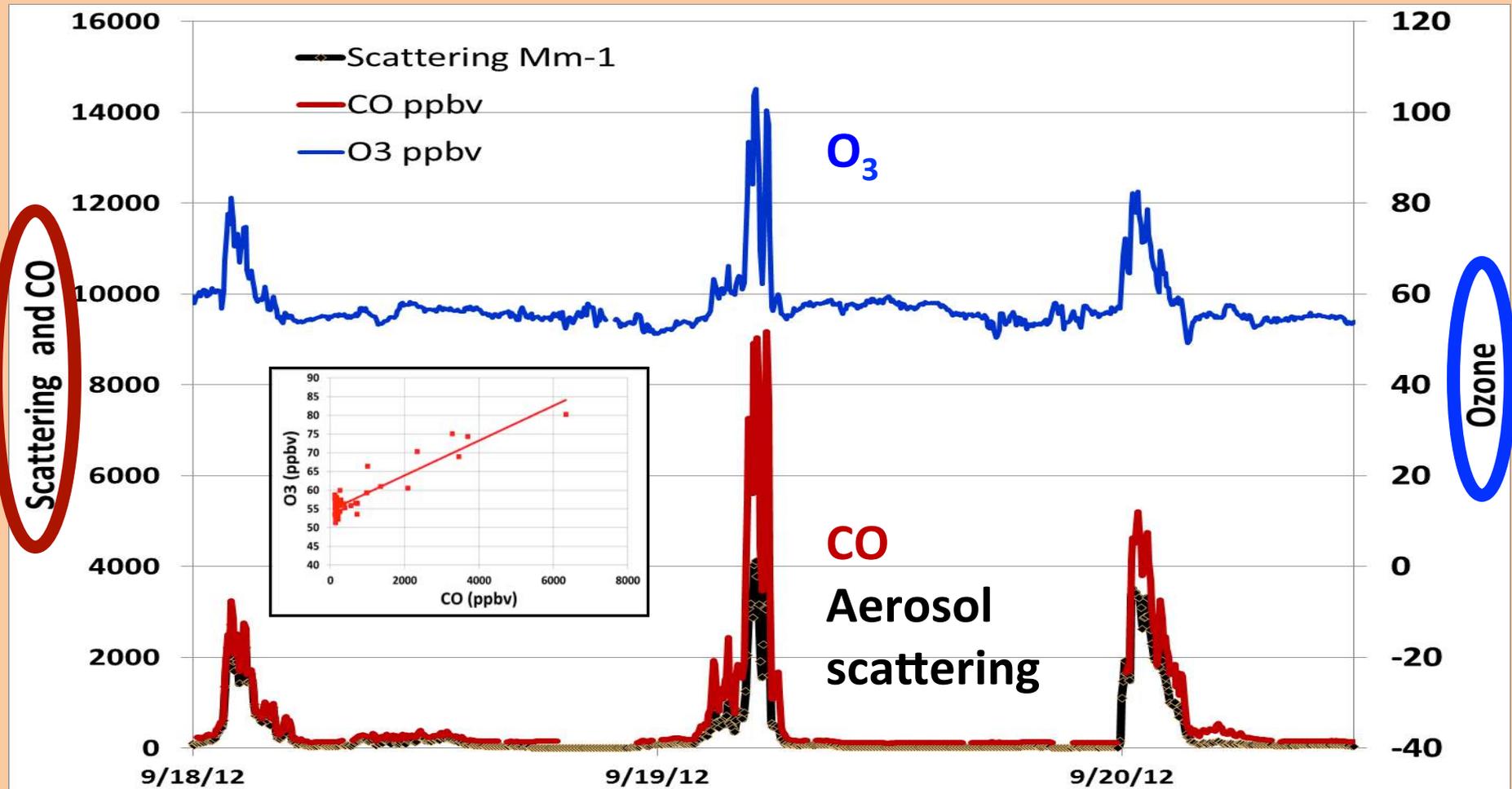
Ozone production depends on where we sample the plume



Baylon et al 2014

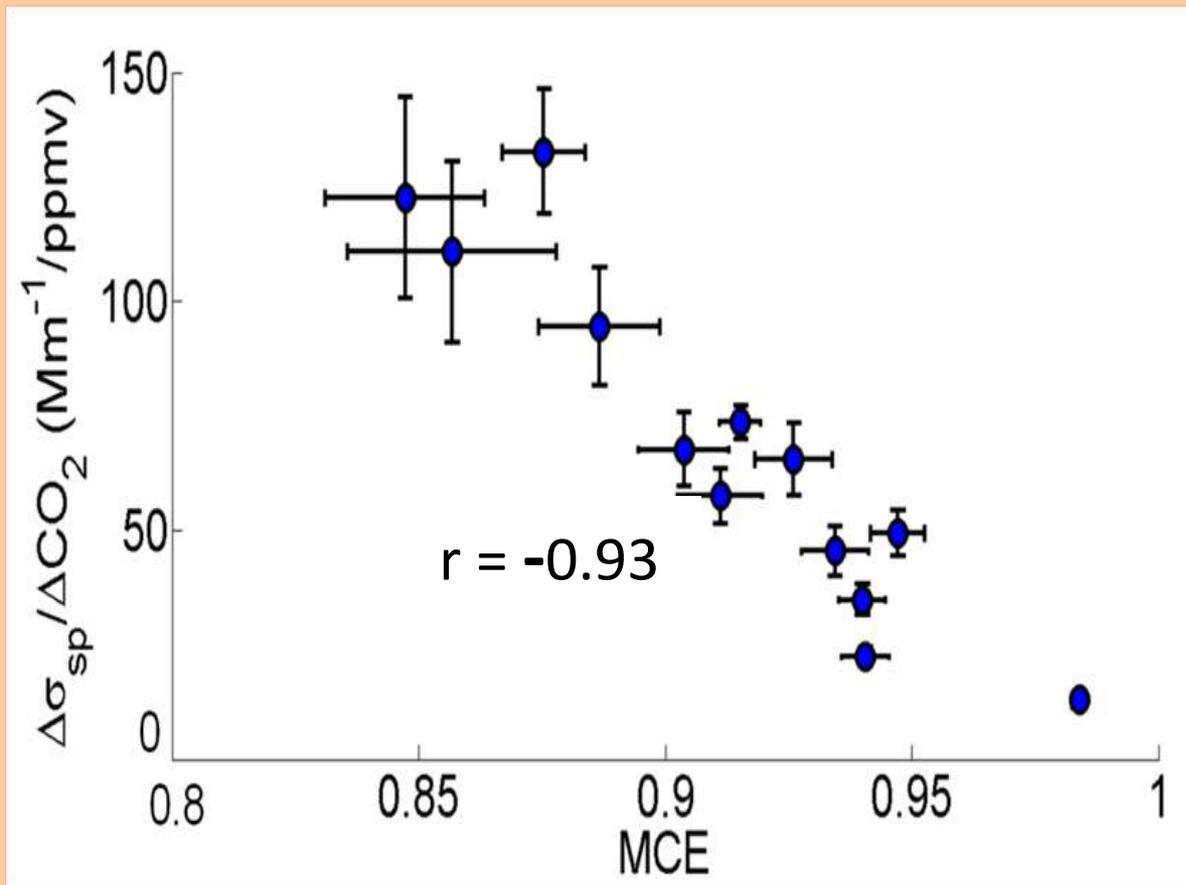


Wildfires can make O₃ very quickly



Mt. Bachelor observations of the Pole Creek Fire on three successive days. O₃ production of 20-50 ppbv in 6 hours. (Baylon et al 2014)

Influence of Modified Combustion Efficiency on Pollutant Enhancements in Fire Plumes



Aged fire plumes (1-2 days) at MBO from 2012-2013 shows negative correlation between aerosol scattering enhancement ratio ($\Delta\sigma_{sp}/\Delta\text{CO}_2$) and Modified Combustion Efficiency (MCE) due to:

- 1) Greater primary emissions of aerosols at low MCE
- 2) Greater SOA formation at low MCE due to greater emissions of oxygenated VOCs
- 3) Wigder et al 2015

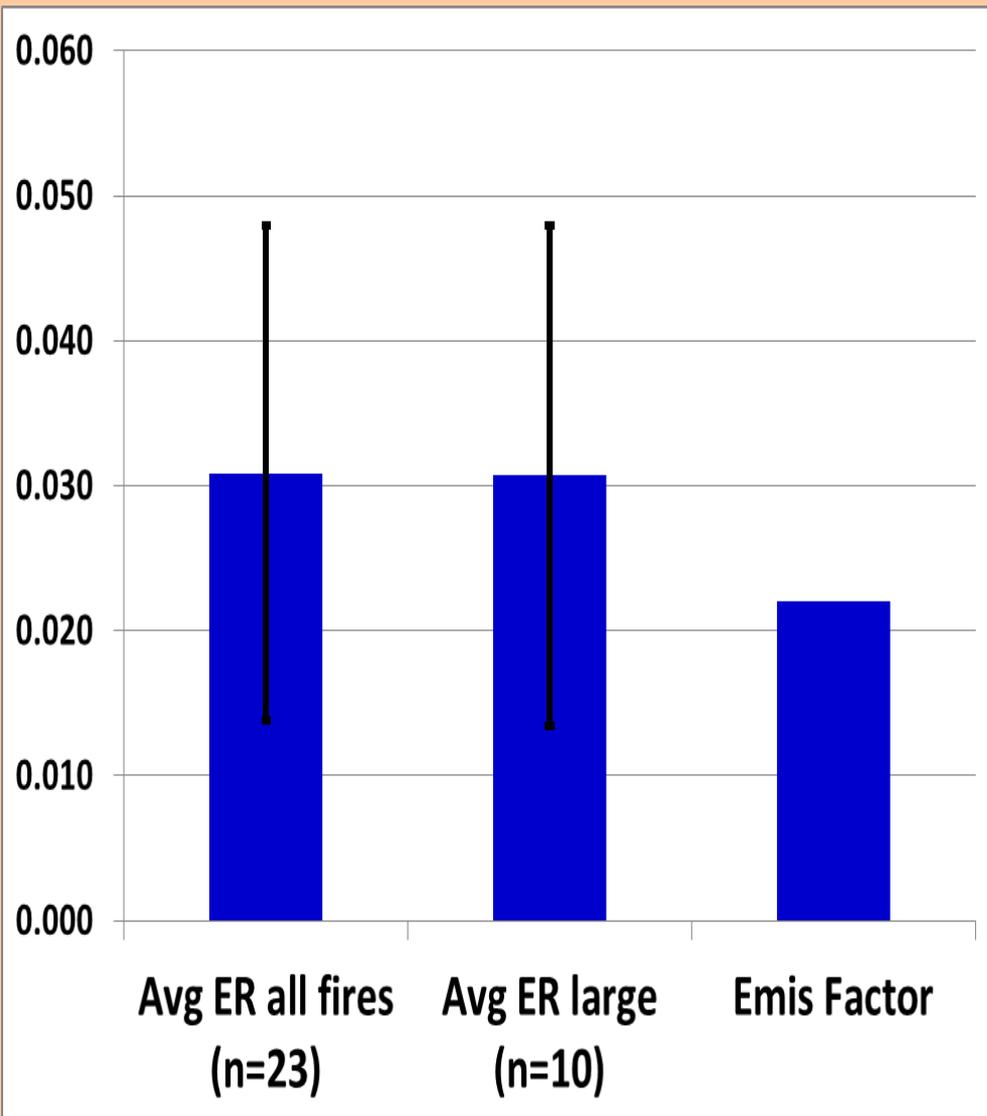
Low MCE: more smoldering combustion



High MCE: more flaming combustion



Emission Ratios vs Emission Factors for OC/CO₂ (gmC/gmC)



- Error bars show variability (1 σ) in observed ERs at MBO
- Average ER is about 50% greater than average EF suggesting SOA production during transport.
- Uncertainty is dominated by uncertainty in CO₂ bg.
- Focus on large plumes (n=10) reduces the uncertainty and strengthens evidence for SOA production.

High Resolution TOF Aerosol Mass Spectrometer at MBO in summer 2013-Qi Zhang's group at UCD

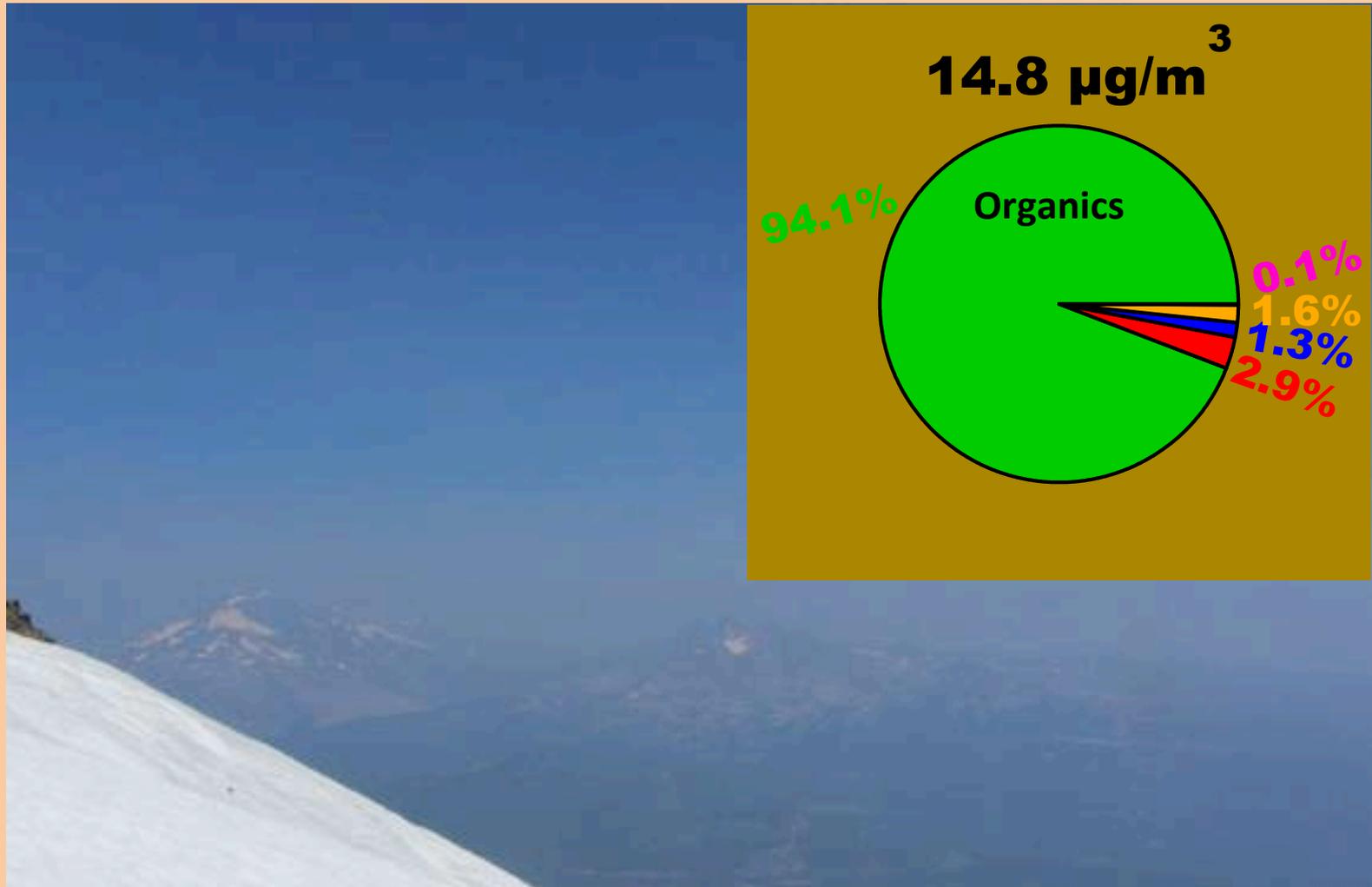


**AMS
on a ski
lift at
MBO.**



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Average chemical composition of PM in smoke by AMS

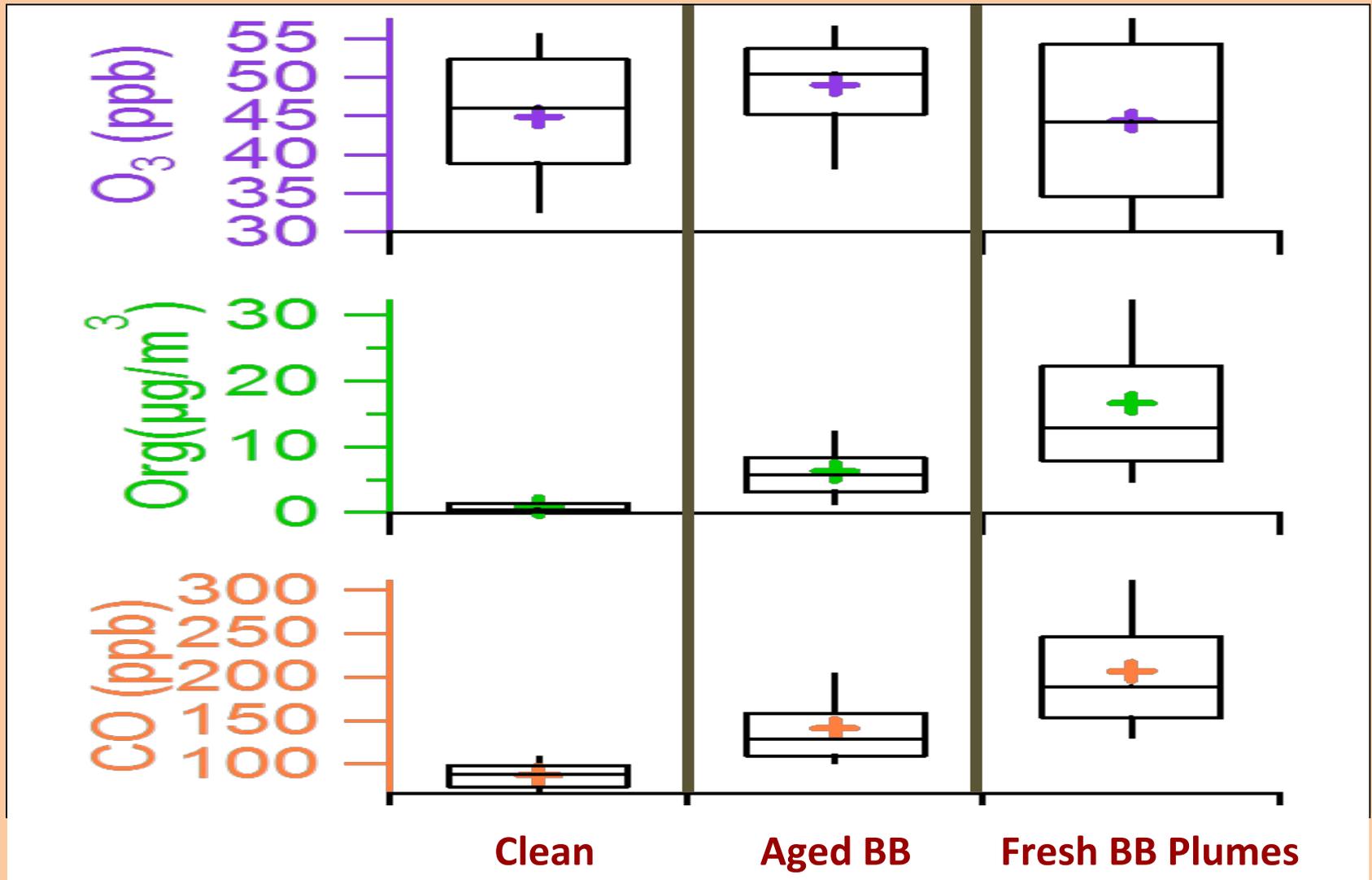


Data from Sonya Collier, Shan Zhou and Qi Zhang University of California-Davis



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Segregation of AMS data based on f60 (fraction of $C_2H_4O_2^+$ $m/z = 60$)



Our past work has demonstrated large variability
in emissions and chemistry from fire to fire.

Why? What are the controlling factors?



W

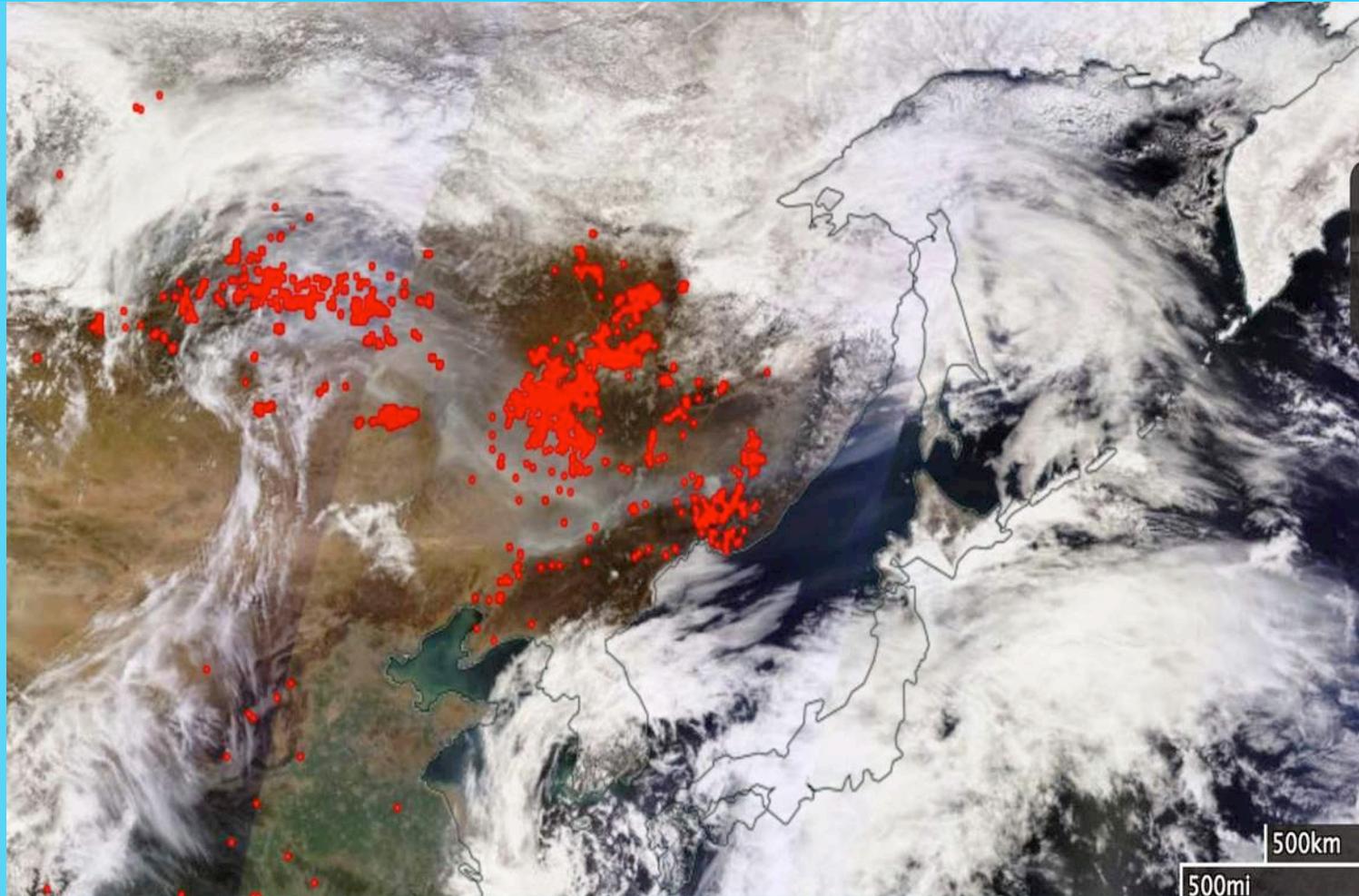


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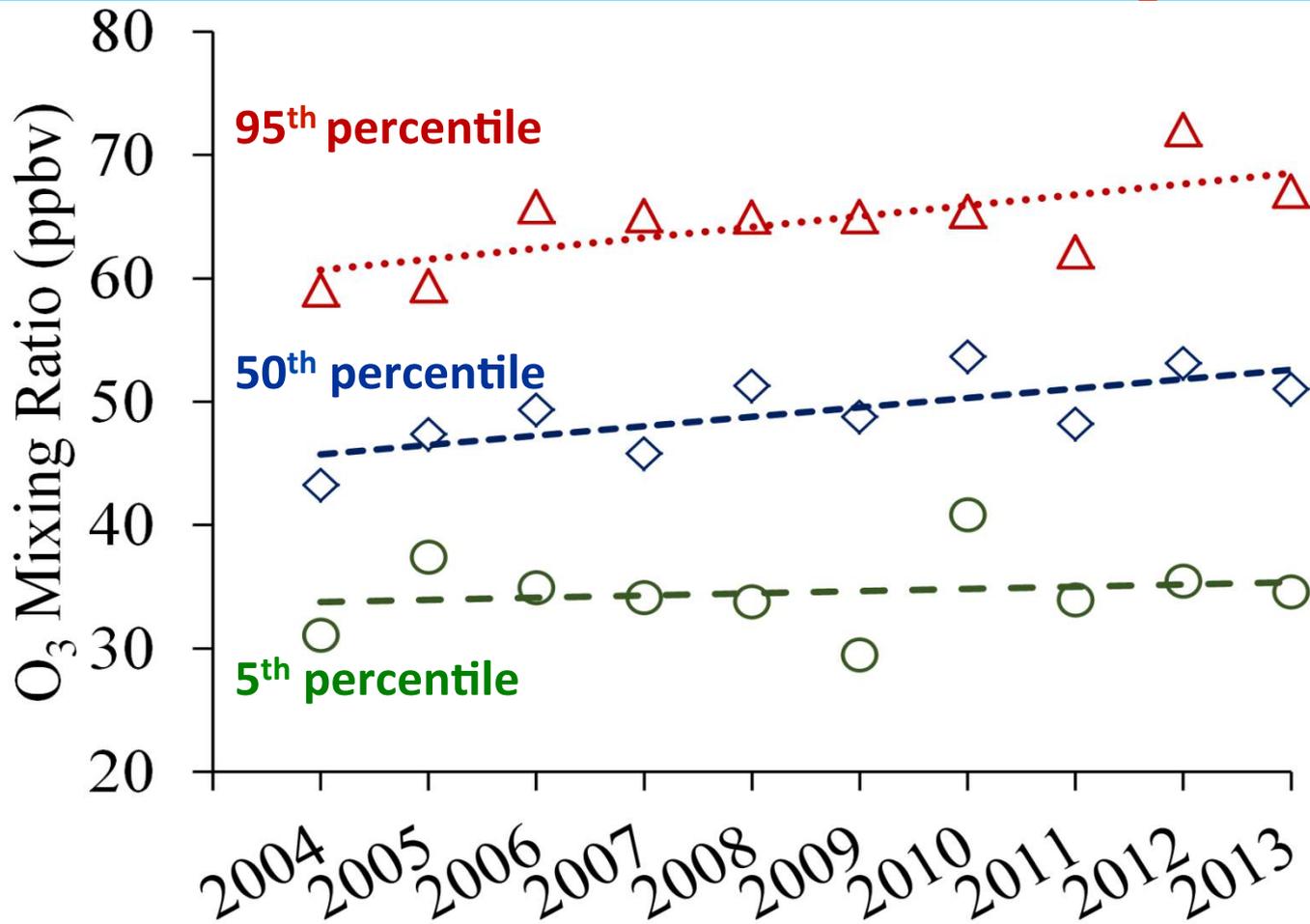
Summary

- MBO observations show that high MDA8 days can occur due to UTLs, Asian pollution or wildfires.
- We see a pos trend in spring O_3 at MBO for 2004-2013.
- Modest variations in BC (3-6 ppbv) can have substantial impact on the number of exceedance days, especially if NAAQS is lowered.
- May 2012 was highest May in last decade at MBO (+5 ppbv) and this enhanced O_3 by a similar amount at many urban sites in the W. US.
- Many fires show clear evidence for significant O_3 and SOA production, but large variability from fire to fire. Need to integrate gas, aerosol and radiative measurements to understand photochemistry in fire plumes.

Siberian Fires, Mid-April 2015



Changes in Spring O₃ at MBO



2015

I predict many more days with elevated O₃ across the WUS in spring 2015.



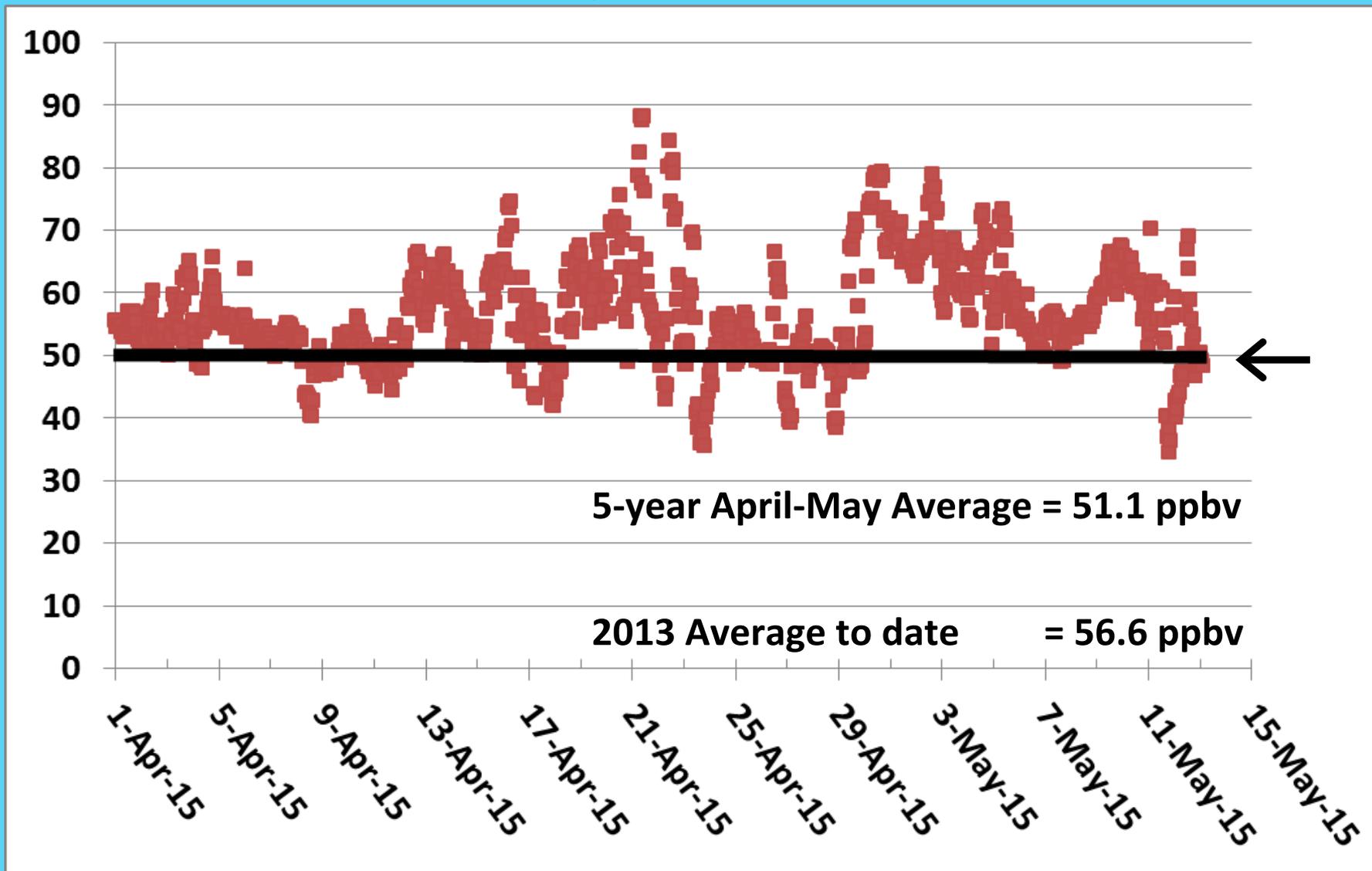
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SPARES

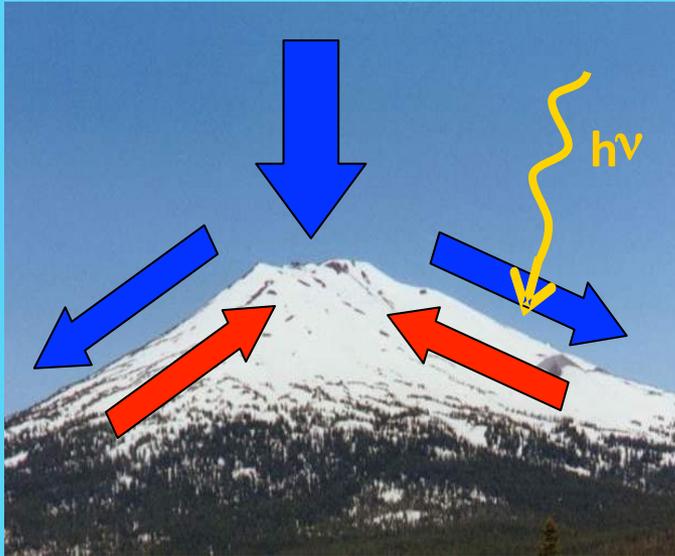


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Spring 2015 O₃ data at Mt. Bachelor



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 .

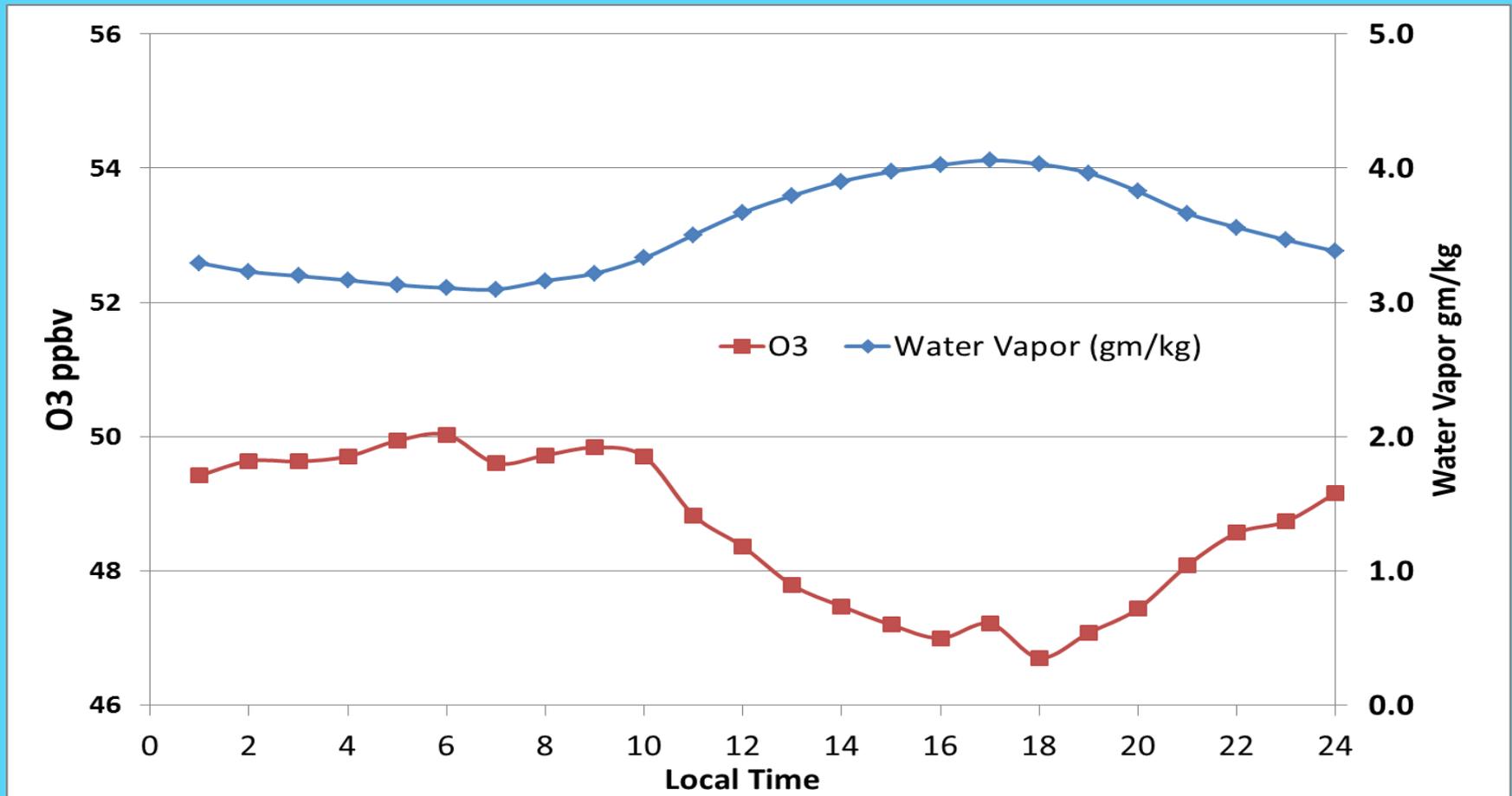
Night: downslope flows brings Free Tropospheric (FT) air to the summit. This air is dry and usually high in O_3 .

ID of FT Air

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



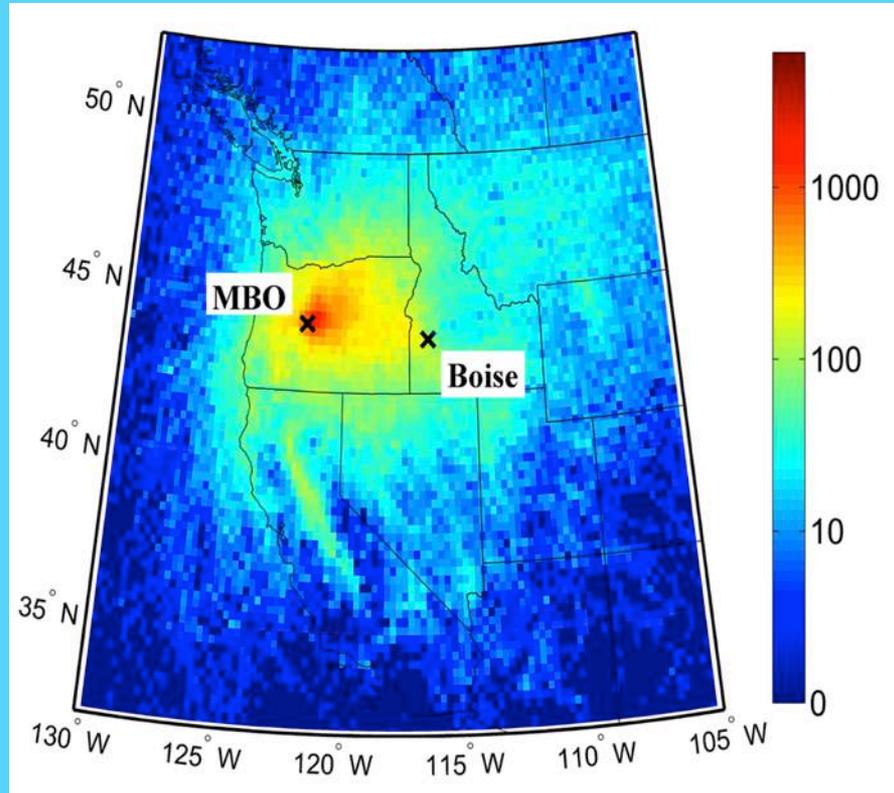
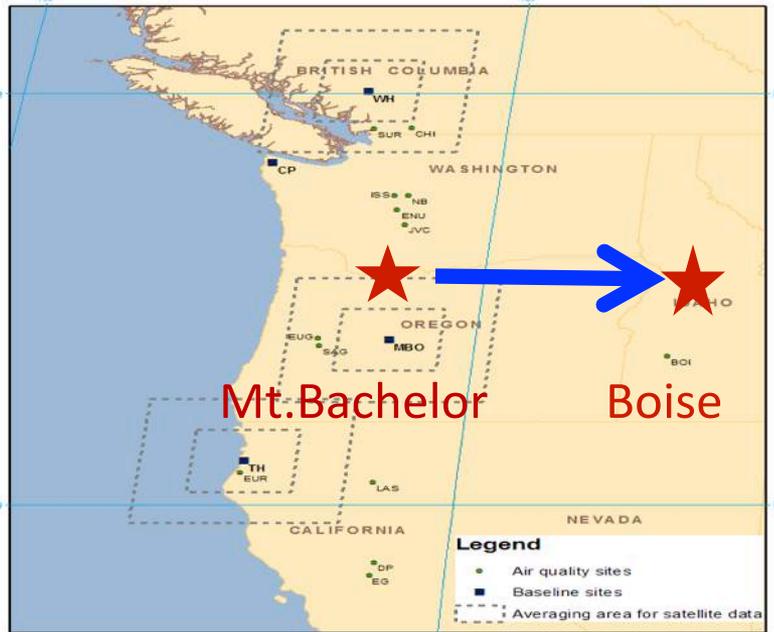
Diurnal cycle of Water vapor and O₃ in spring at MBO



- At night average WV is similar to free trop data from balloons.
- In daytime, WV levels indicate a mix of FT and BL air.
- Use WV to help identify FT air



We know that MBO can experience high O₃ days.... How does FT O₃ influence surface/urban AQ?



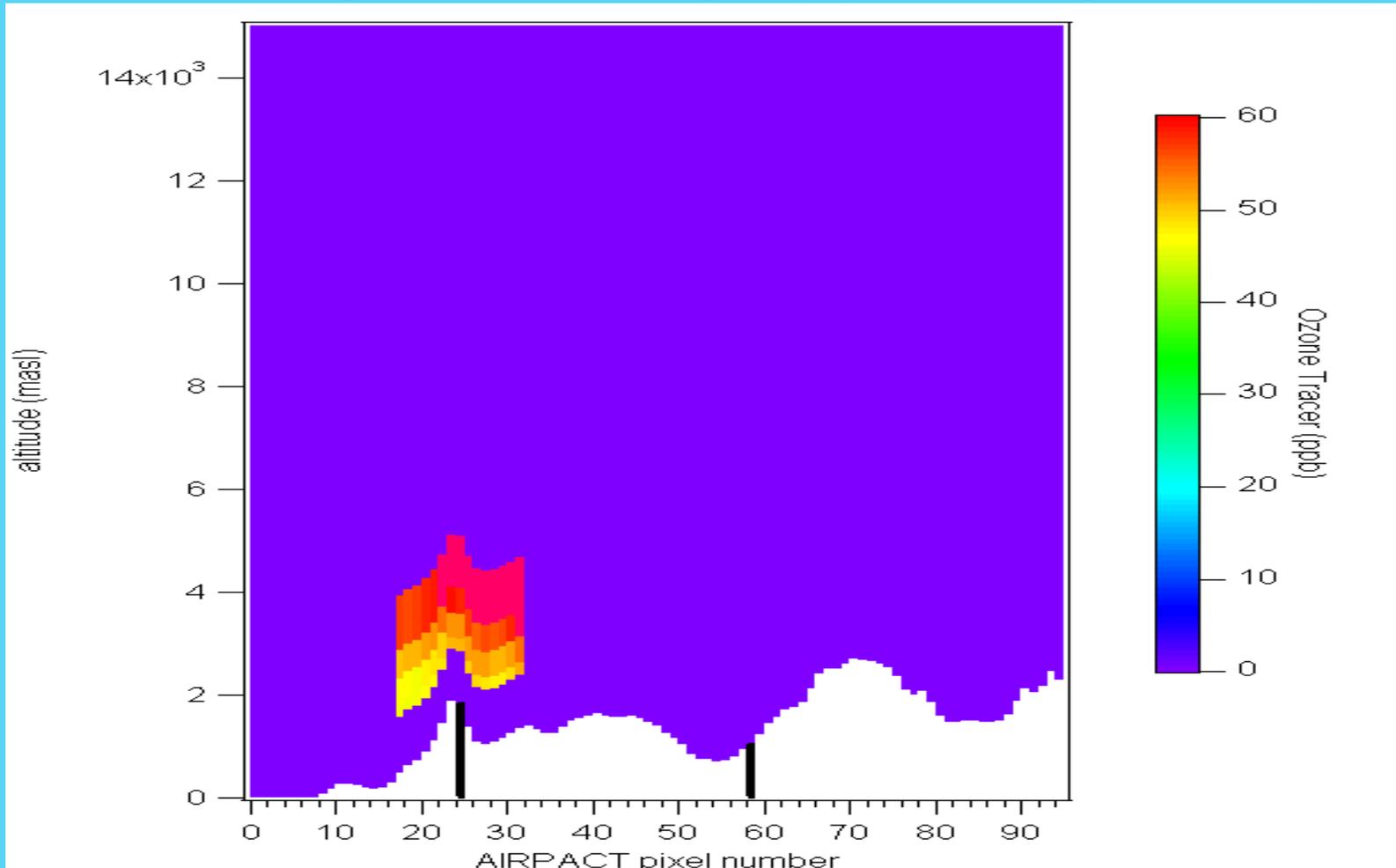
48-hour forward air trajectories starting from Mt. Bachelor

Wigder et al 2013



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Use of CMAQ to model FT-BL exchange for 4/6/2010 using WSU-AIRPACT group (Lamb, Vaughan, Thorpe)



↑
MBO

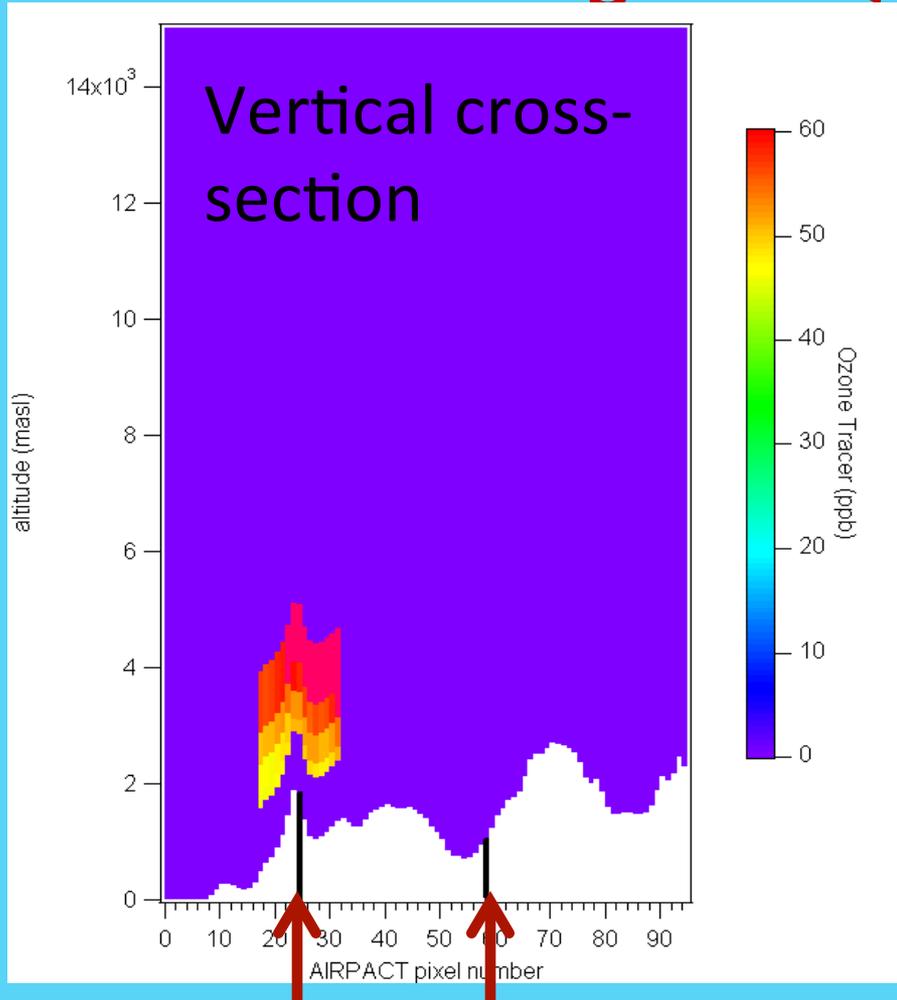
↑
Boise

Wigder et al 2013

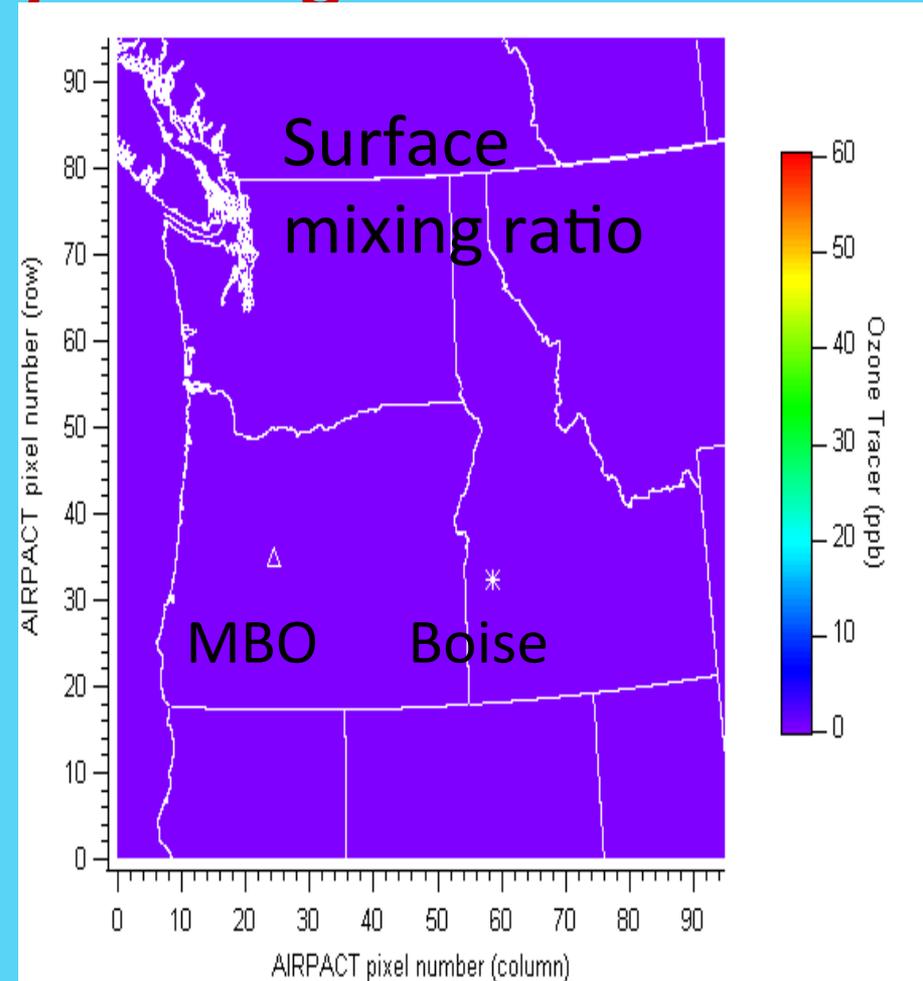


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Modeled FT O₃ tracer for 4/6/2010 (high O₃ day) using CMAQ w/12 km grid



MBO **Boise**

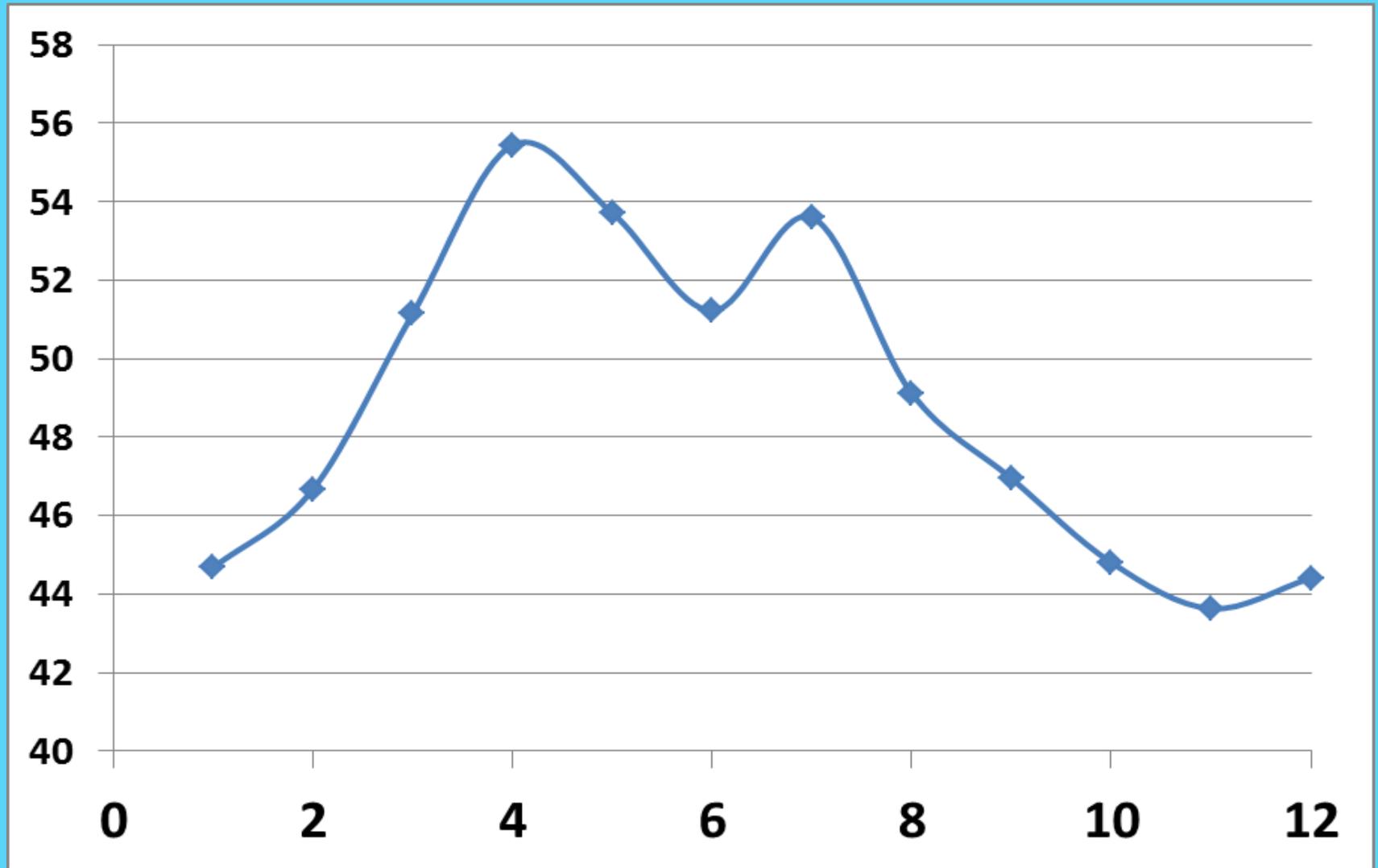


Wigder et al 2013



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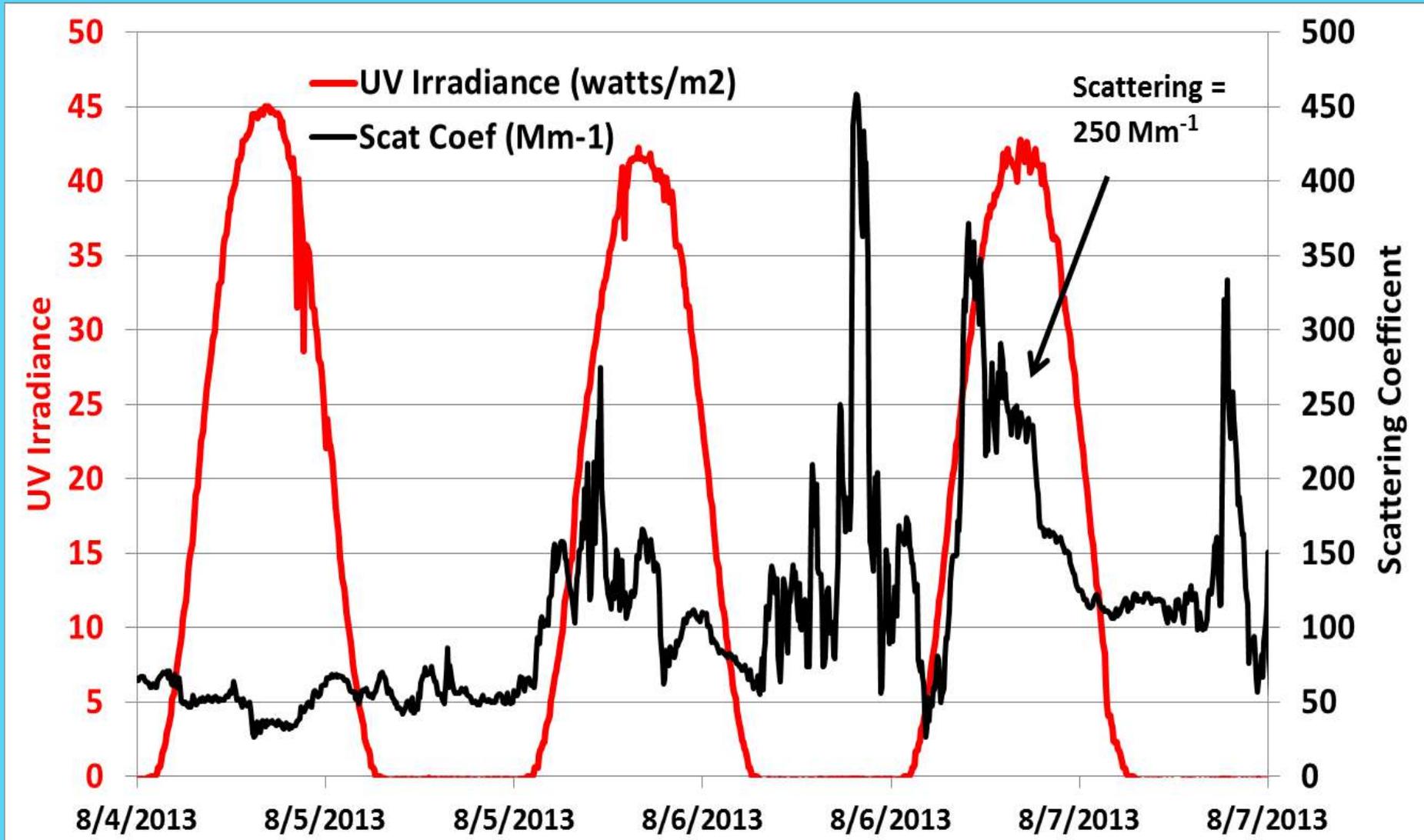
MBO Avg MDA8 vs Month



Key points

1. Fire plume chemistry is very different from urban plumes (e.g. radiation, oxidants, OVOCs, PAN, etc).
2. O_3 production is highly variable from plume-to-plume and depends on where in the plume we sample.
3. O_3 production can occur rapidly (locally) or slowly (regionally) via PAN transport.
4. CO and PM are always correlated in a fire plume, but these may or may not correlate with O_3 .
5. Need to integrate our understanding across gases, aerosols and radiation fields to understand O_3 and SOA production in wildfire plumes.

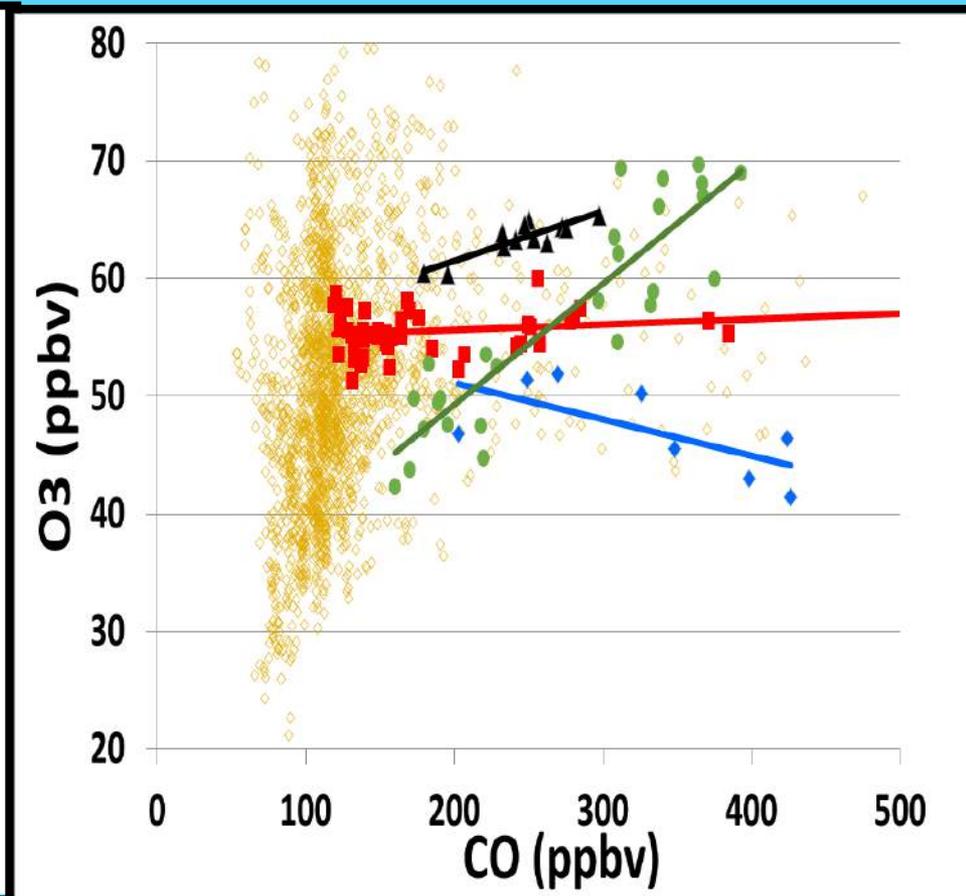
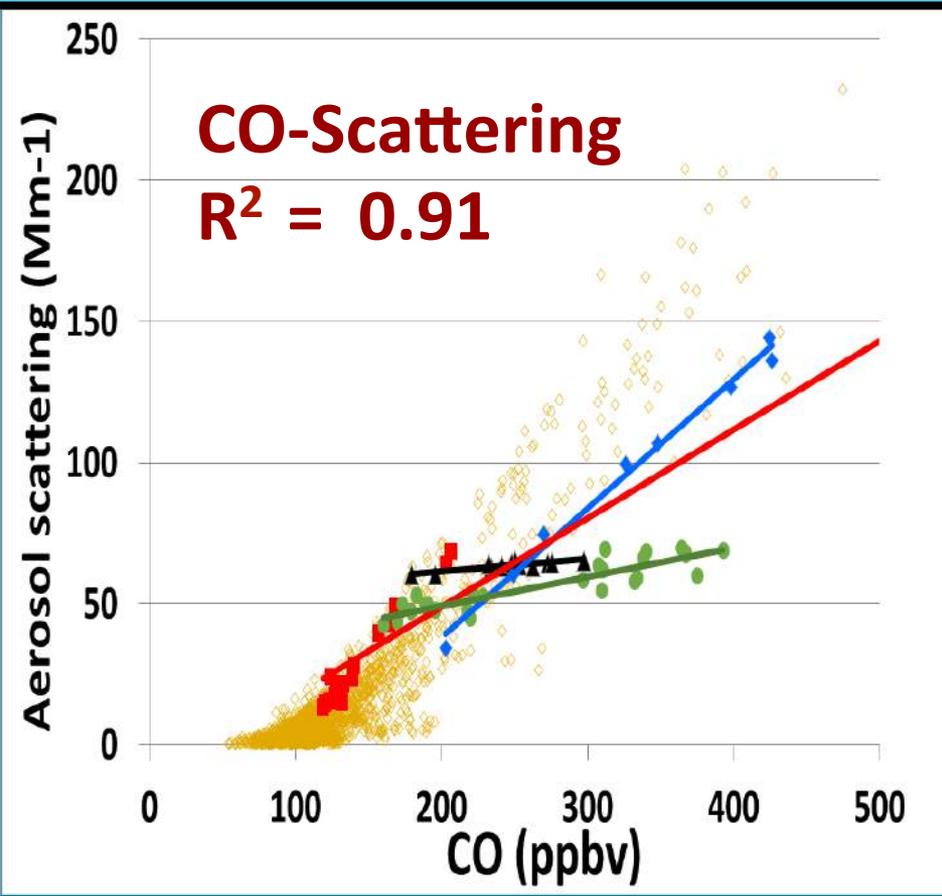
UV irradiance (295–385 nm) and scattering in a fire plume



In this case, only a 6% reduction in irradiance.
(Also note Sam Hall's poster on J's on Friday).



MBO Summer 2012 data (fire plumes highlighted)



CO and aerosols are very well correlated at MBO in summer, but not with O₃.