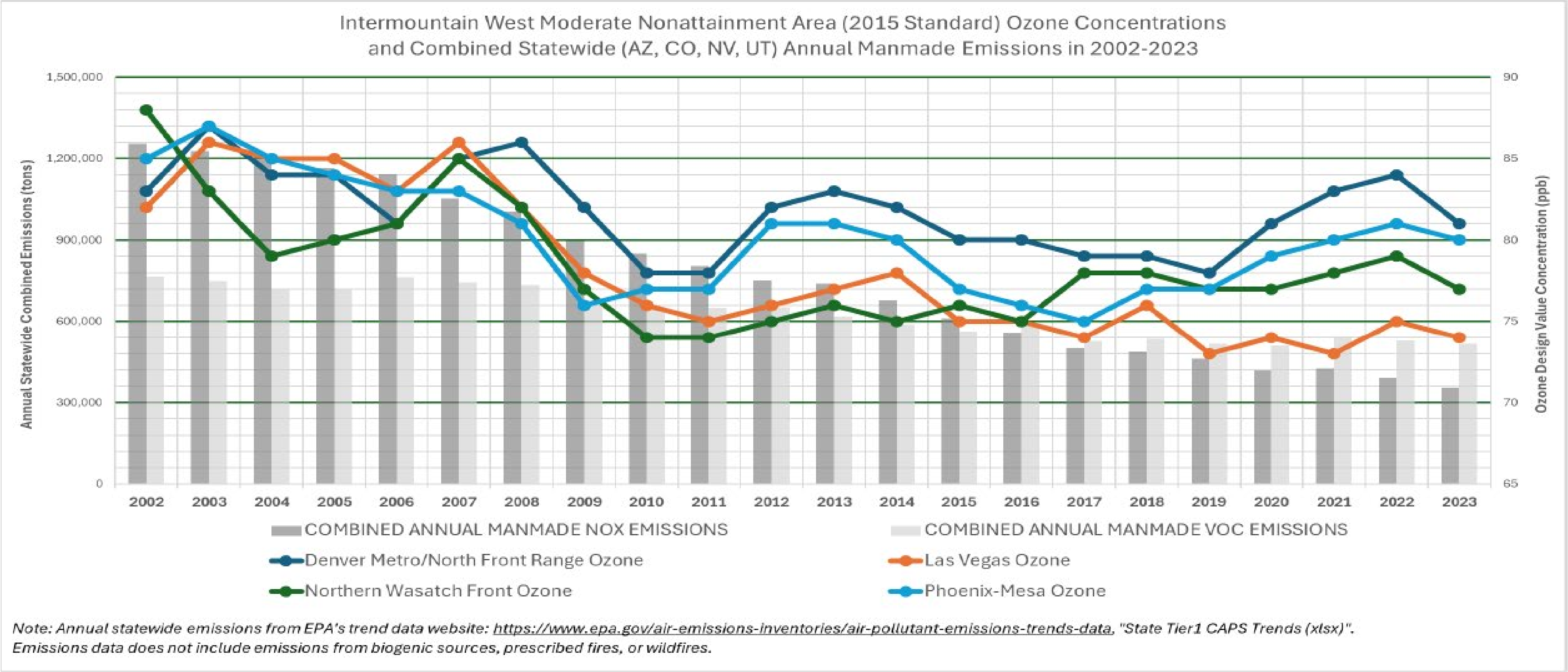
Ground Level Ozone Research (GLOR) Field Campaign Summer 2025

Armin Sorooshian (U-Arizona), Matt Fraser (ASU)

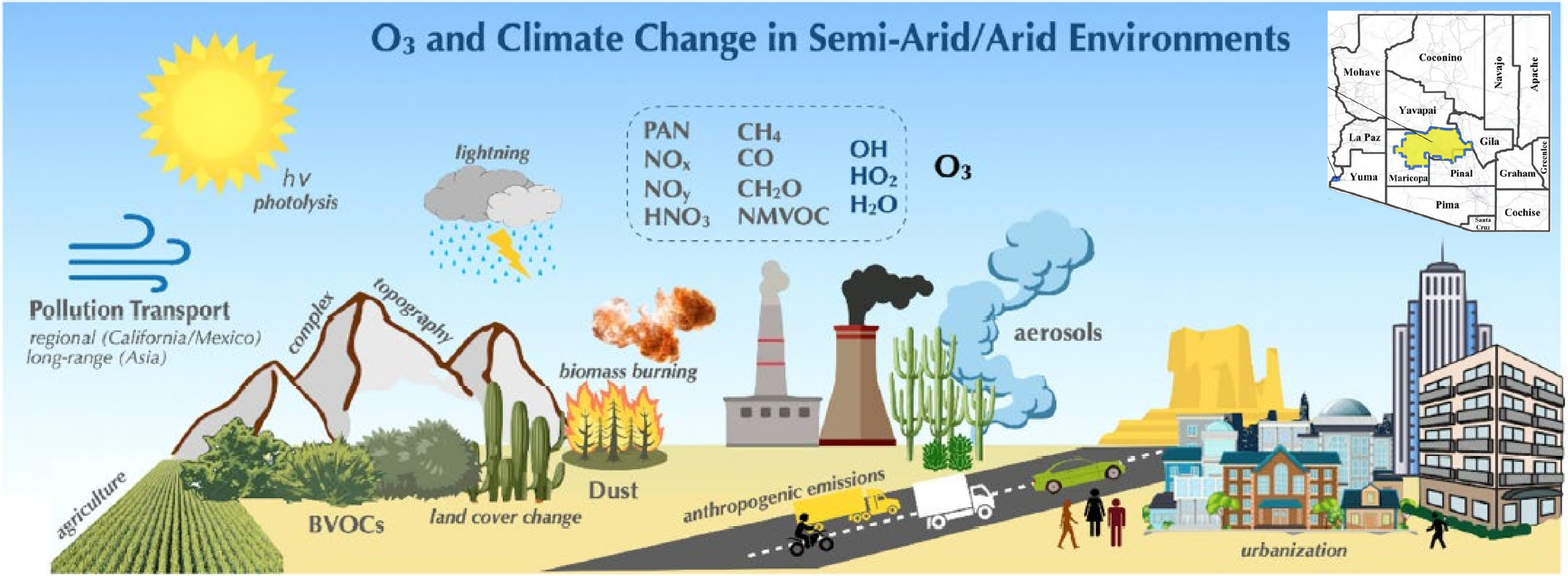
Association of Air Pollution Control Agencies (AAPCA) Spring Meeting, 1 May 2025

The Intermountain West Faces Similar Challenges



GLOR focuses on ozone transport and formation for the 2025 ozone season: May-October

What makes Maricopa County a challenge?



- Environment/climate
- Extreme heat
- Complex terrain
- Urbanization
- Wildfires
- Transport

Sorooshian et al., (2024) EST-Air

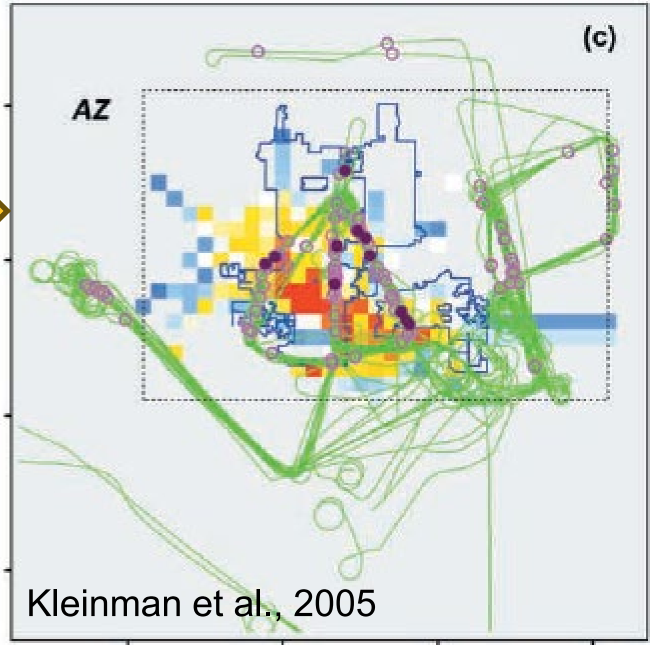
Historical Context

Table 1. Chronology of Peer-Reviewed Literature Discussing Ozone Pollution in Arizona Categorized by Location (Phoenix, Tucson, Other)[a]

period of analysis	study topic	analysis type	ref
Phoenix			
Summer 1998	transport mechanism across Phoenix	O	7
Summer 1998	climate factors leading to high O_3 in Phoenix	O	16
Summer 1998	factors affecting O_3 in Phoenix	M/O	17
Summer 1998	mechanistic understanding of O_3 formation in Phoenix	O	18
1995–1997	associations between mortality outcomes for elderly people and air pollutants (including O_3)	O	19
Summer 1998	O_3 production characteristics in Phoenix	O	20
Summer 1998	mechanistic understanding of O_3 formation in Phoenix	M/O	21
1997–1999	relationship between O_3 and secondary aerosol in urban air	O	22
June 2001	examine role of vertical mixing on O_3 chemistry of the boundary layer	O	23
June 2001	transport of O_3 around Phoenix	O	24
May to June 1998	factors affecting O_3 in Phoenix	O	25
June to July 2001	using beryllium-7 to study stratospheric intrusions of O_3	O	26
Summer 1998	comparing O_3 production between major U.S. cities	O	27
June 2001	structure of Phoenix's lower atmosphere associated with premature vertical mixing	O	28
May to September 2001–2003	weekend effect of O_3 in Phoenix	O	29
June 2001	vertical profiles of CO, NO_x, and O_3	O	30
1996–2004	weekly periodicity of meteorology, pollution, and human activity variables	O	31
1998	mesoscale meteorological modeling of low-level atmospheric flow	M/O	32
June 2001	vertical profiles of NO_x and O_3 in Phoenix's nocturnal boundary layer	O	33
1999–2000	analyzing factors that contribute to disparities in asthma hospitalizations	O	34
June to July 2002	simulating Phoenix O_3 concentration distribution	M/O	35
N/A	environmental impacts of urban development in Phoenix	M	36
1998–2003	weekend effect of O_3 in Phoenix and other U.S. cities	O	37
June to September 2000–2005	characterization of heat-related deaths	O	38
May to September 1999–2002	association between mean apparent temperature and total mortality	O	39
2005–2007	simulating southwest U.S. O_3 levels	M/O	40
July 1996	photochemical plume modeling around Phoenix	M/O	41
14 May 2012 and 9 June 2011	modeling of urbanization effects on O_3 in Phoenix	M/O	42
2005–2009	assessment of air quality monitoring network for Maricopa County	M/O	43
2008–2010	sensitivity of O_3 analysis to spatial scale of analysis	M/O	44
14 May 2012 and 19 July 2005	regional transport of O_3 from southern California to Phoenix	M/O	45
2007–2012	relationship between O_3 and asthma hospital visits	O	46
2008–2010	environmental justice analysis related to O_3 in Phoenix	O	47
2006–2016	atmospheric patterns in relation to observed O_3	O	48
2006–2017	analysis as a forecasting tool for O_3 in Phoenix	O	49
2015–2019	barrier posed by urban heat on adopting alternative transportation to reduce O_3	O	50
2016 and 2028	O_3 source apportionment over U.S.	M	51
2010–2019	factors governing heat-associated mortalities	M/O	52
2019–2020	low-cost sensors: CO, NO_2, and O_3 measurements	O	53
Tucson			
April to September 1995–1998	weekend/weekday effect in O_3	O	54
N/A	development of high-resolution (30 m) BVOC emissions inventory	O	55
1995–1998	emissions inventory for NO_x and VOCs in Tucson	O	56
April to September 1995–1998	factors affecting O_3 in Tucson	O	57
1972–1986	O_3-induced foliar injury to ponderosa pine trees	O	58
1995–1998	new method for spatially mapping O_3 around Tucson	O	59
1990–2003	Kolmogorov–Zurbenko (KZ) filter for O_3 trend analysis	O	60
1990–2001	sensitivity of O_3 to meteorological factors in Tucson	M/O	61
2010–2012	O_3 column abundance over Tucson	O	62
Other			
1990–2003	meteorologically adjusted urban air quality trends (Arizona)	O	63
1997–1999	nationwide examination of weekend/weekday effect in ozone	O	64
1963–1994	relationships between synoptic conditions and ground-level O_3 (U.S.–Mexico border)	O	65
1995–2009	relationship between surface and free tropospheric O_3 in western U.S.	O	66
Summer 2008	transported background pollutants over western U.S.	M/O	67
2006–2018	transport influences on O_3 in Yuma	M/O	68
May 2010	O_3 transport to Arizona from southern California	M/O	69
March to September 2010	modeling O_3 concentrations across North America	M	5
February to July 2020	impact of COVID-19 on environmental pollutants in Arizona	O	70
1988–2018	weather relationships with air pollution in Arizona over a 30 y period (1988–2018)	O	71
2001–2010	wildfire contributions to O_3 (Chiricahua)	O	72
1996–2000	cause for spring-time ground-level O_3 peak (Grand Canyon National Park)	O	73
April to September 2017	VOC and O_3 measurements (Grand Canyon National Park)	O	74

[a]Analysis type: O = observational; M = modeling. Please see Table S1 for key information on modeling studies.

- ~65 publications on ozone research in Arizona
- First published 1996
- Majority based on ground sampling
- One major airborne campaign
- Speciated VOC data are lacking
- Limited remote sensing data



Kleinman et al., 2005

<u>Phoenix Sunrise Experiment</u>

May-June 2001 (ADEQ/DOE)

Sorooshian et al., (2024) EST-Air

Building on Recent Regional Work

FAST-LVOS
Fires, Asian, and Stratospheric Transport
Las Vegas Ozone Study

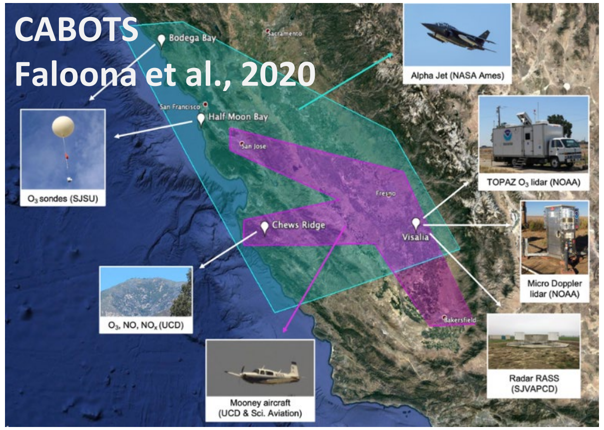
Front Range Air Pollution & Photochemistry Experiment

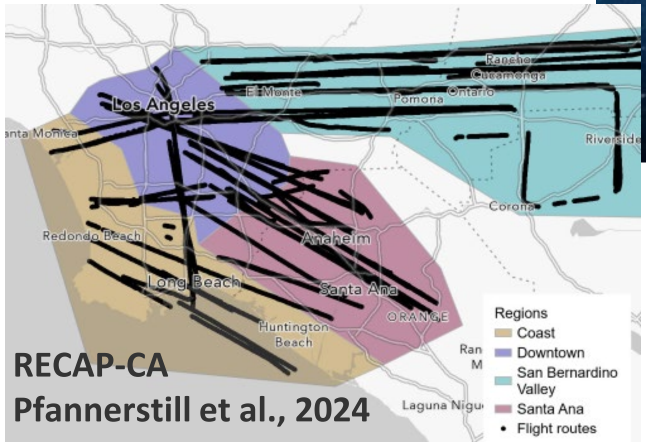
NOAA • NASA • CDPHE
AMMBEC 2024

LVOS
Las Vegas Ozone Study

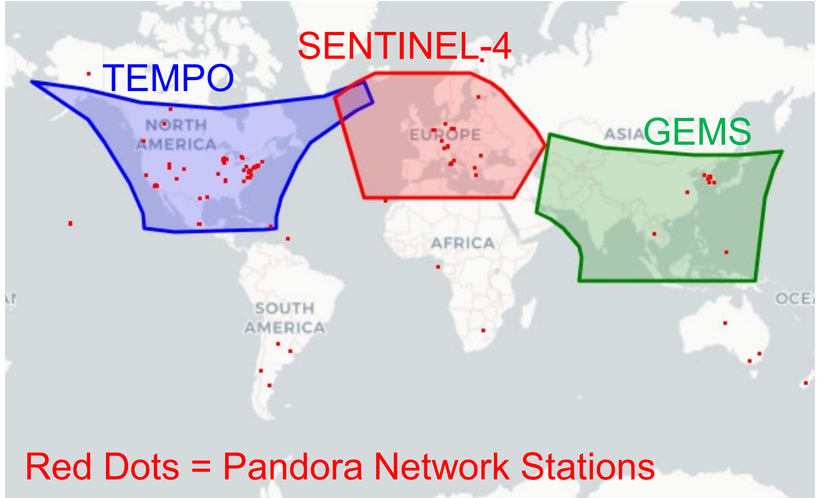
UTAH SUMMER OZONE STUDY
USOS 2024
SCIENCE ELEVATED

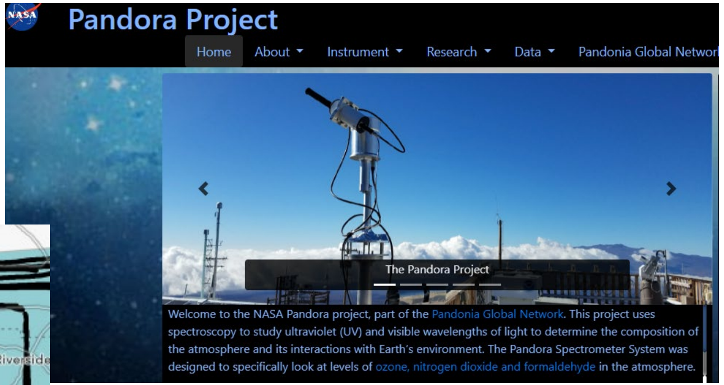
Figure 3. AiRMAPS airborne survey schedule for 2024-2026. The base map shows nitrogen dioxide columns as measured from the TROPOMI satellite instrument for summer 2023. The shaded areas and dashed circles show O&G basins and urban areas for AIRMAPS surveys by





Arizona Needs To Catch Up





Tropospheric Ozone Lidar Network
TOLNet

Timeline of Events

Ground Level Ozone Research (GLOR)

6/2024
- Task Force Assembled
- White paper drafting begins
- Immediate inquiry into airborne research possibilities
- 6/18 = first GLOR meeting

~Biweekly/weekly meetings hereafter

7/2024
- Inquiries into NASA surface-based remote sensors (TOLNet and Pandora)

Development of the GLOR Research Plan

Field Logistics

Fundraising

Team Assembly

Engaging Regional Experts

5/2025
GLOR data collection tentatively begins; aggressive data analysis

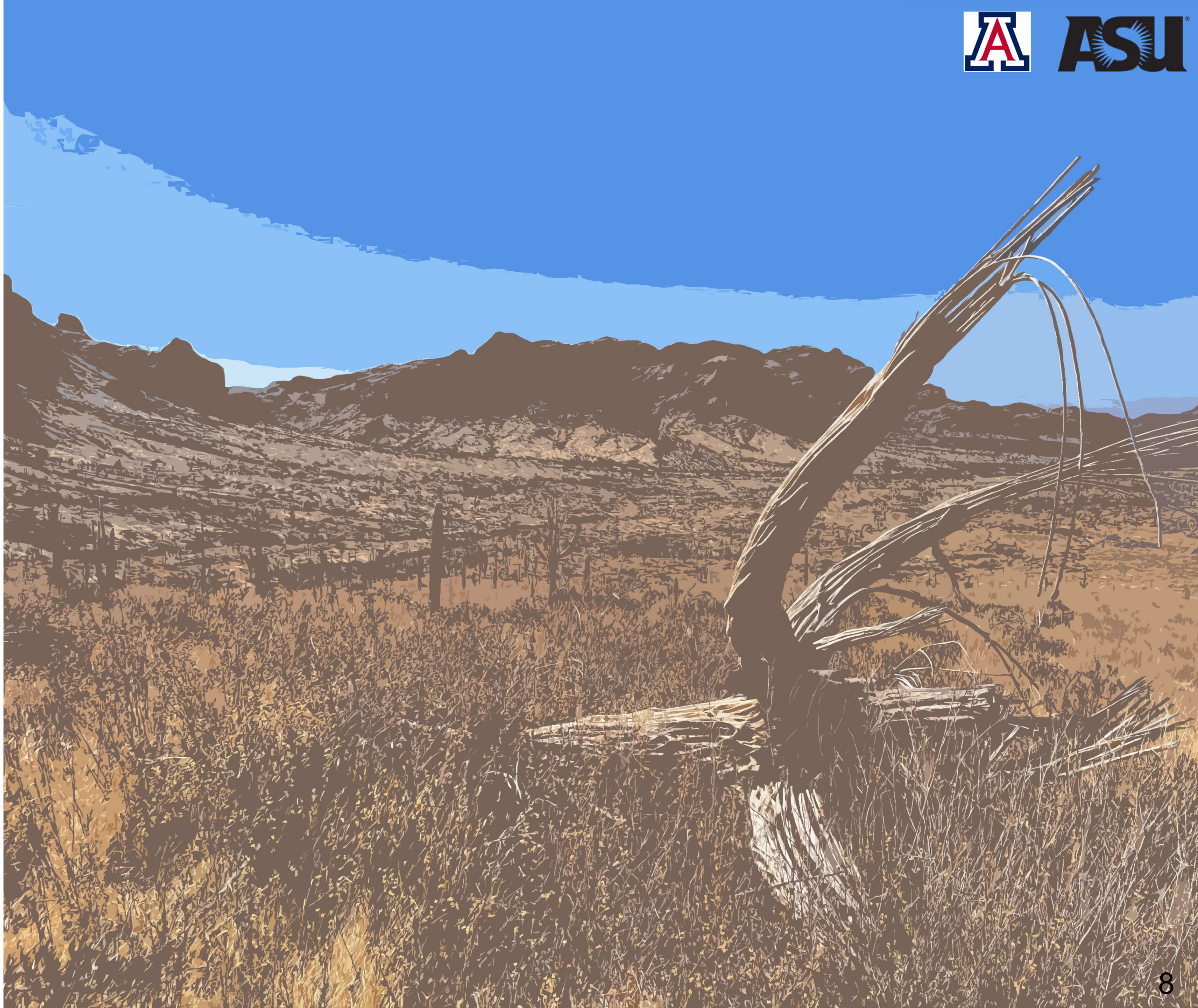
10/2025
GLOR sampling tentatively ends; continued data analysis

Hypotheses Related to Phoenix Ozone Levels

- Hypothesis 1: Increased wildfire activity throughout western continental North America has significantly and consistently raised background ozone concentrations, higher exceedance day ozone concentrations, and more frequent ozone exceedance days in Intermountain West nonattainment areas.
- Hypothesis 2: Anthropogenic NO_x and VOC emissions locally and nationally may not be decreasing as quickly as expected by existing emission projections
- Hypothesis 3: Biogenic sources of NO_x and VOC may be counteracting reductions from anthropogenic sources such that ambient NO_x and VOC concentrations may not be decreasing at the expected rate.
- Hypothesis 4: Changes in atmospheric ozone chemistry are impairing the impacts of reductions in manmade precursor emissions on expected reductions in policy-relevant ozone concentrations in Intermountain West nonattainment areas.
- Hypothesis 5: Increases in transported ozone from outside Intermountain West nonattainment areas have contributed significantly to background ozone concentrations, higher exceedance day ozone concentrations, and more frequent ozone exceedance days.
- Hypothesis 6: Meteorological and climatological factors play a significant role in impairing the impacts of reductions in manmade precursor emissions on expected reductions in policy-relevant ozone concentrations in Intermountain West nonattainment areas.
- Hypothesis 7: Ozone concentrations above the 2015 EPA NAAQS (70 ppb) in the Intermountain West nonattainment areas (Phoenix, Salt Lake, Las Vegas, Denver) are primarily the result of a combination of regional factors (wildfires, transport, rising background, etc.) as opposed to local precursor emissions.

To explore these hypothesis, we have a robust research plan.

- Augmented monitoring at 7 sites
- Faculty and staff at two universities focused on analysis and interpretation
- AZDEQ, MCAQD, MAG, NASA JPL and EPA partners
- Focused assessment of 2025 ozone season



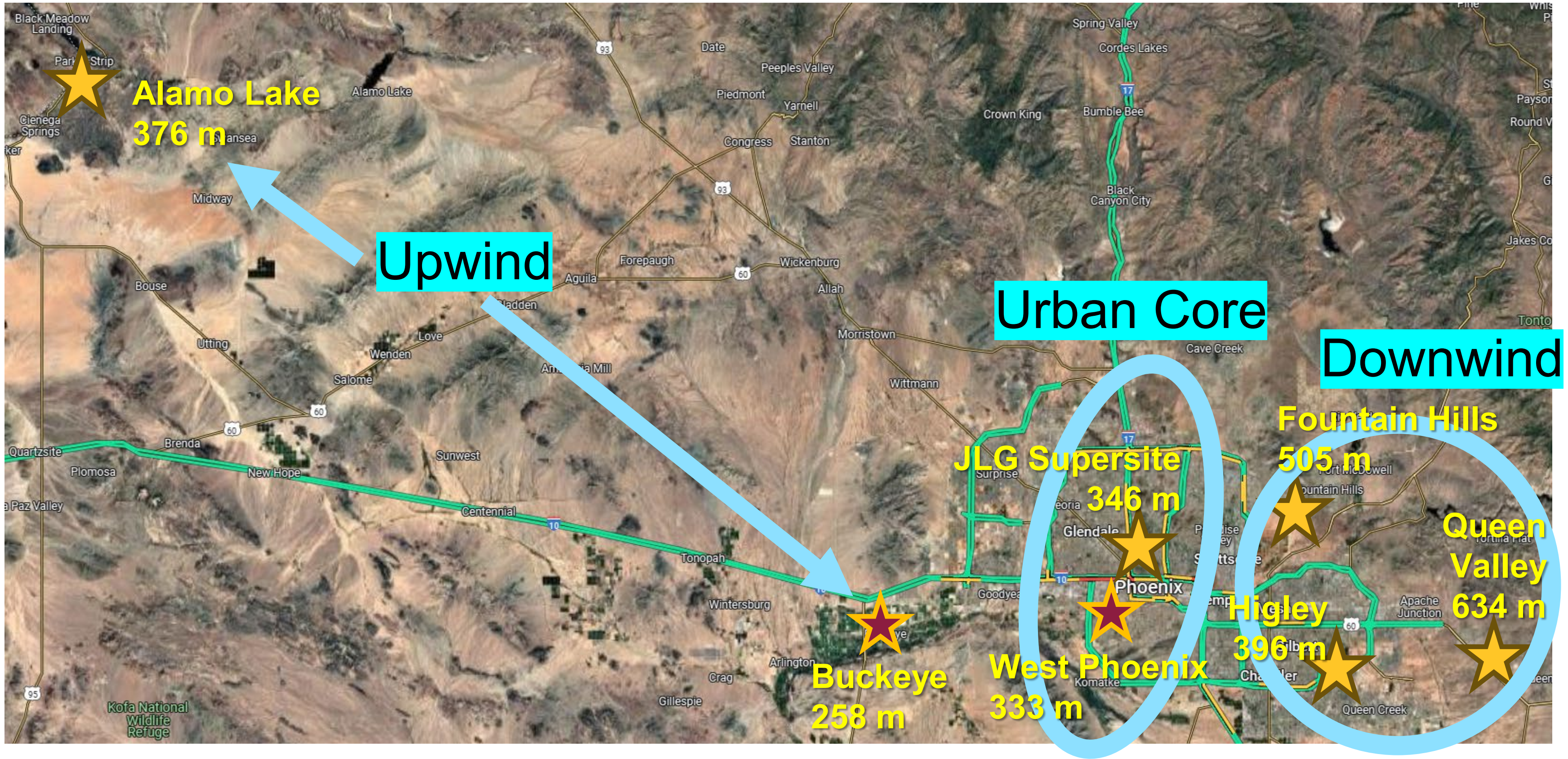
Research uses Ground Monitoring

Logistically, ground monitoring was the only option to deploy quickly to capture the summer 2025 ozone season

Augmented monitoring of VOCs by auto-GC, NO_x and NO_y at seven sites (2 upwind, 2 urban core, 3 downwind) – Sonoma Tech

Two Small Mobile Ozone LIDARs (SMOLs) to monitor transport aloft of ozone – NASA; possibly inclusion of Pandora units

Targeting May to October deployment



Auto-GC, NO_x and NO_y

Auto-GC, NO_x, NO_y and ozone LIDAR

How can ASU and UA best support the MAG SIP development process?

Flow of data from the deployed ground sites – ground level concentrations, VOC/NO_x chemistry limitations, NO_y formation rates, aloft ozone transport – to support MAG Ozone SIP Weight of Evidence analysis.

- Identification of woodsmoke episodes

- Ozone chemistry analysis

- Studying common exceedance days across intermountain west

- WRF-Chem modeling to compliment/corroborate regulatory modeling

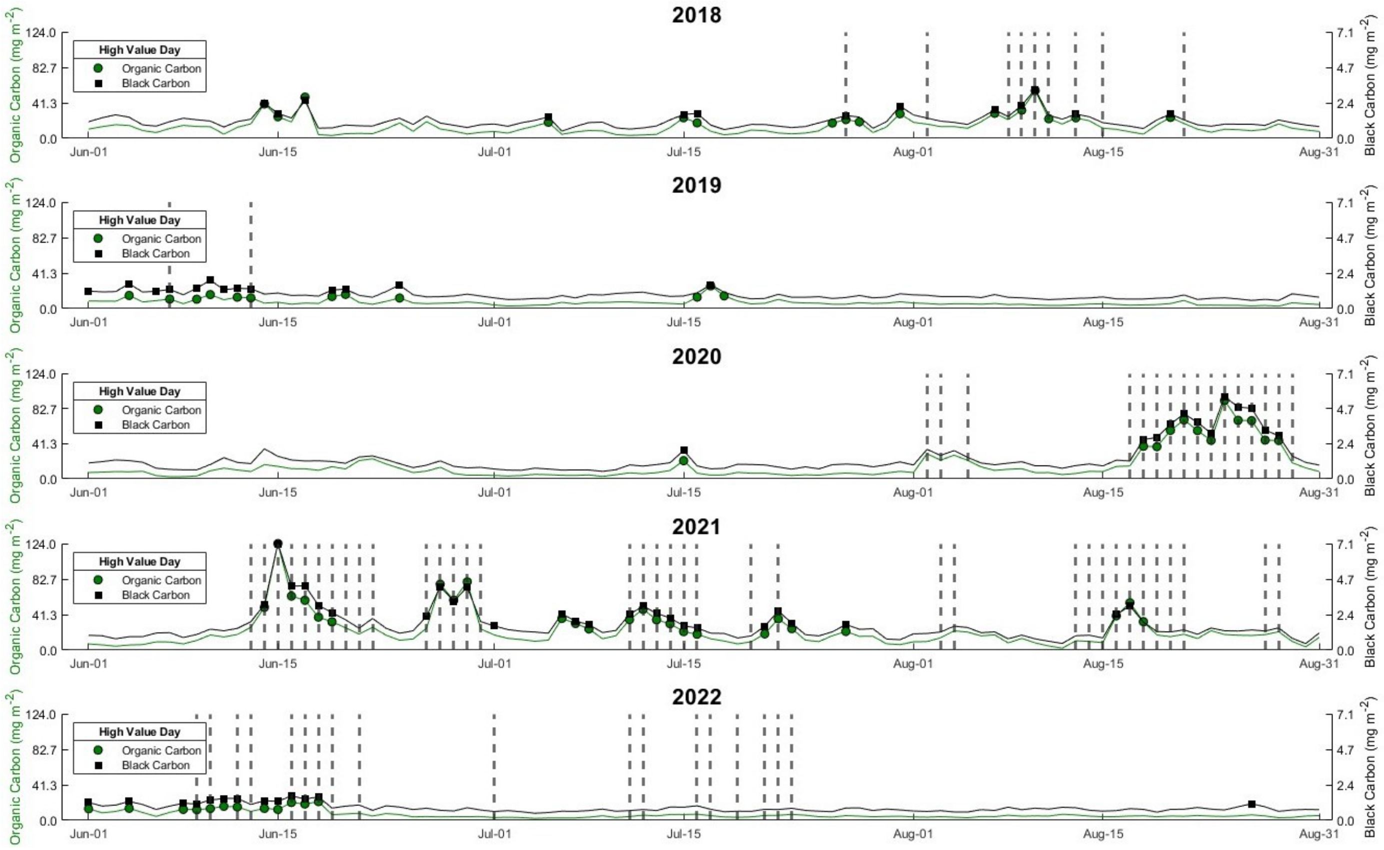
- Biogenic flux measurements and comparison to MEGAN

Identification of Woodsmoke Episodes

Analysis of woodsmoke episodes for exceptional events starts with ozone exceedance days. We* have focused on analysis of all days to separate the contribution of woodsmoke transport on ozone formation.

Using NOAA-HMS and NASA MERRA-2, we identify days clearly impacted by woodsmoke and days not impacted by woodsmoke as approaches used in other locations (spikes in $PM_{2.5}$ or ozone measurements) do not work here

We tried other approaches (HYSPLIT/NCAR-FINN) but had the most success with these two approaches



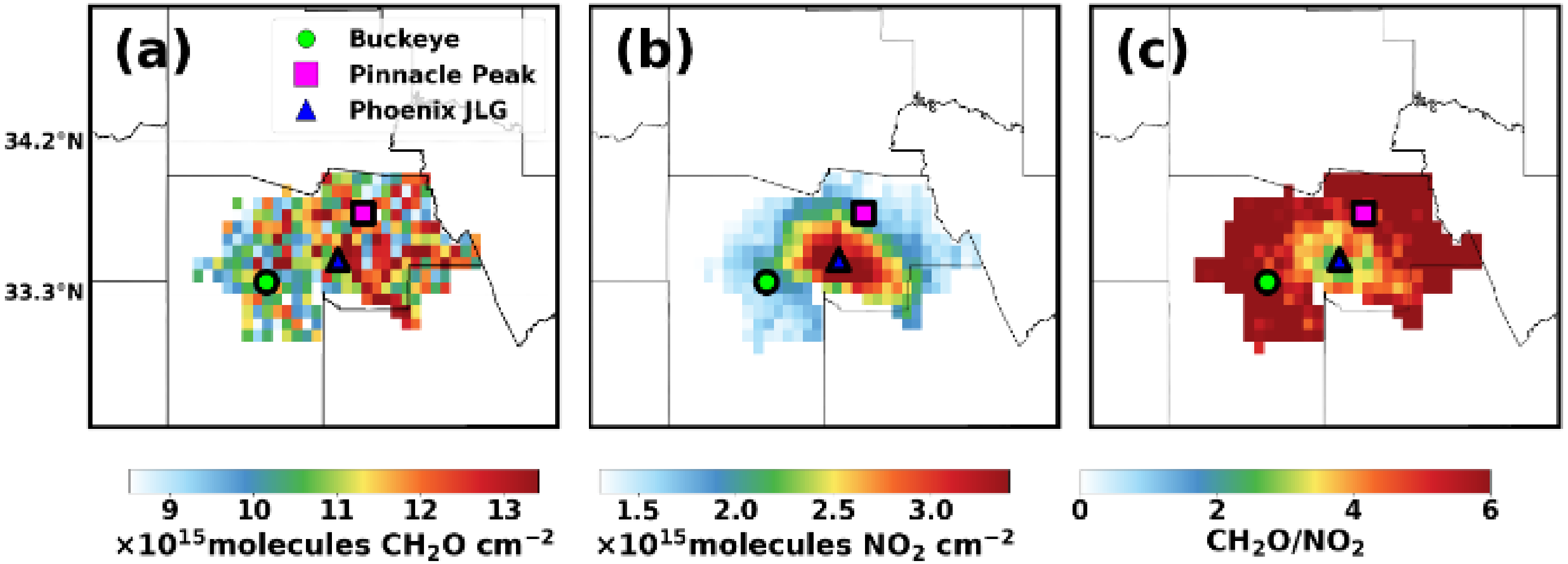
* Braun and Fraser (2025) submitted for publication in *Atmos. Environ.*

Ozone Chemistry Analysis - Satellite Data

With ABOR funding, ASU and UA investigated existing datasets to better understand ozone chemistry in Phoenix.

Specifically, we looked at ground-level monitoring data, satellite data and airshed modeling to investigate VOC vs NO_x limitations on ozone formation

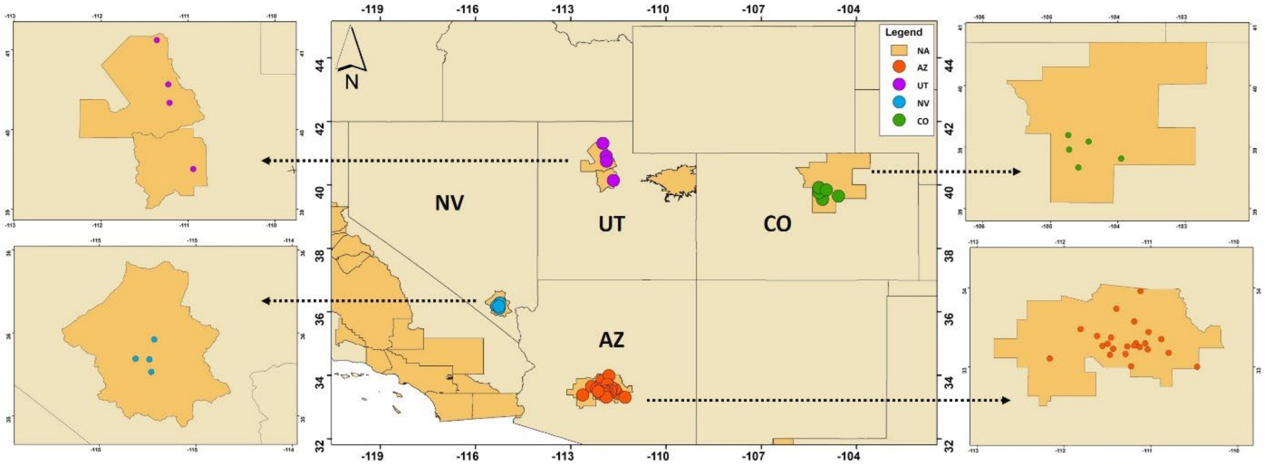
TROPOMI satellite retrievals suggest the chemistry in central Phoenix is more VOC limited than surrounding areas based on column data



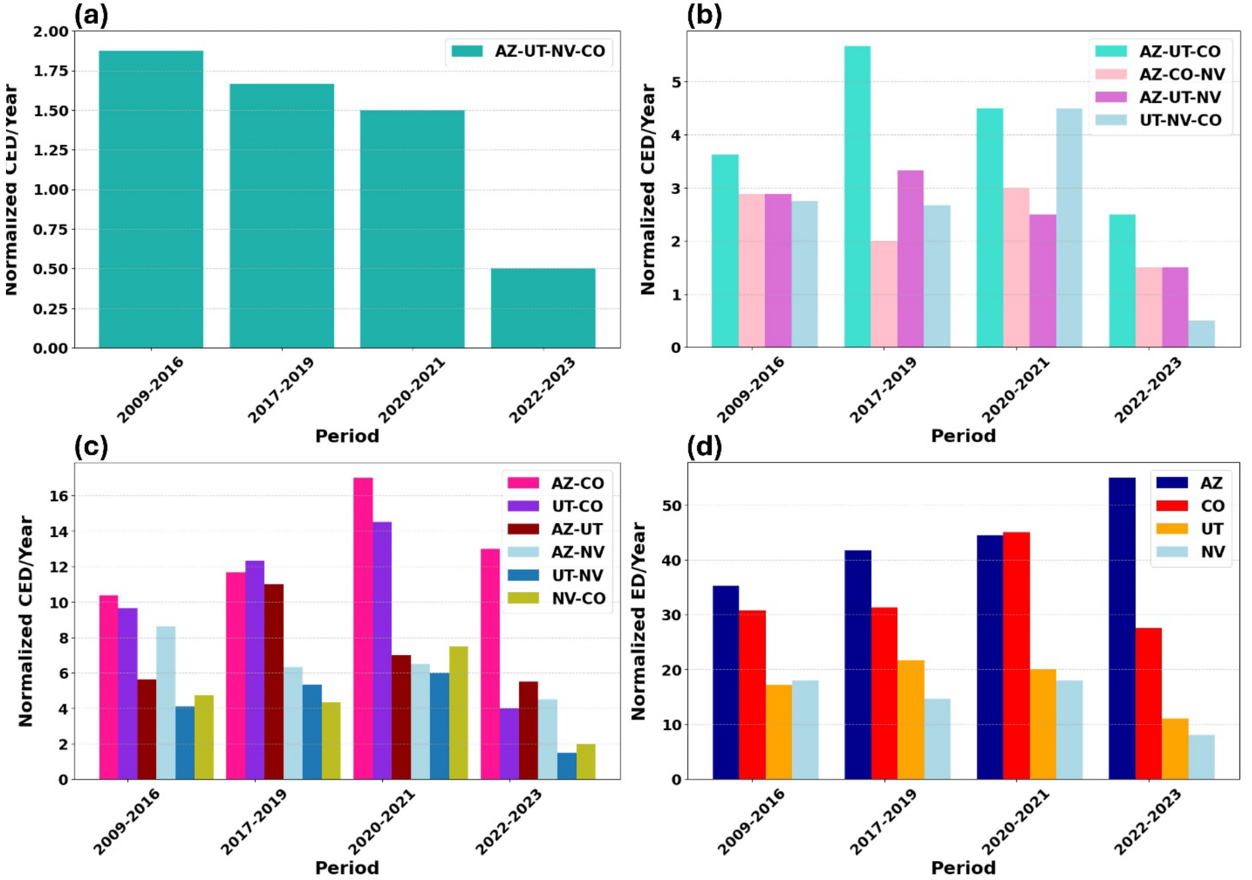
Averaged HCHO (**a**) and NO_2 (**b**) satellite column densities, HCHO/NO_2 ratio(**c**) over the Phoenix metro area for all available dates summer 2021

* **Miech, Herckes, Fraser, Arellano, Mirrezaei and Guo (2024)** ***Atmosphere*** **15**(5) 555

Common Exceedance Days Across Intermountain West



Maricopa County and Denver are most common among the 4 areas



Investigating common O_3 exceedance days across 4 major areas looking at 4-, 3-, and 2-state combinations:

- 2009-2016 (post-great recession, exceedances still responding to emission decreases)
- 2017-2019 (pre-COVID pandemic, exceedances not responding to emission decreases)
- 2020-2021 (COVID pandemic period, exceedances not responding to emission decreases)
- 2022-2024 (post-COVID, exceedances not responding to emission decreases).

GLOR is engaging in outreach efforts with our neighboring states to share our work and learn about theirs

*** Naghmeh Soltani (Postdoc – U-Arizona) Unpublished Results**

BVOC Emissions Sensitivity and Ground Truthing

Using MEGAN 3.2, ASU has been investigating the sensitivity of emission estimates to environmental parameters.

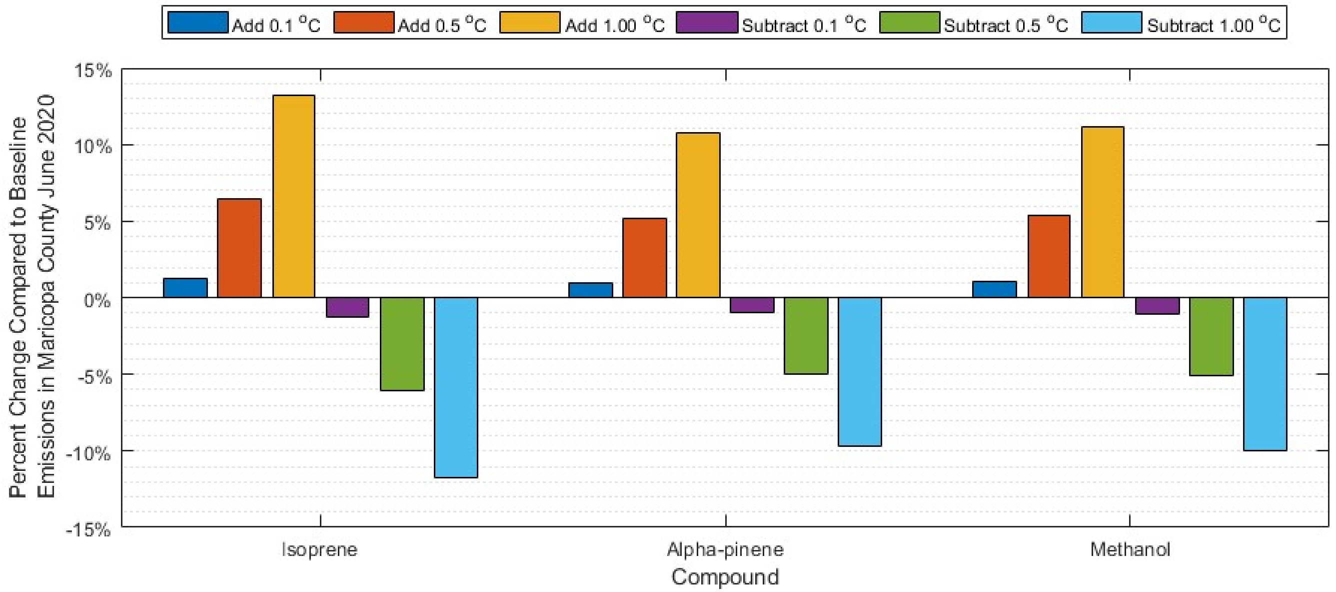
The take away from this analysis is that temperature is the key environmental driver to BVOC emissions

Elevated temperatures over the summer result in MEGAN predicting very high BVOC emissions which feeds into SIP modeling efforts

Changes in Isoprene Emissions in Maricopa County in June 2020

Meteorological Variables	Multiply meteorological input values by:			
	0.99	**0.999**	**1.001**	**1.01**
Photosynthetically Active Radiation	-0.4%	*	*	0.4%
Pressure	-0.2%	*	*	0.2%
Water Vapor Mixing Ratio	-0.2%	*	*	0.2%
24 hr Rain Accumulation	*	*	*	*
Soil Moisture	*	*	*	*
Soil Temperature	*	*	*	*
2 m Air Temperature	-32.0%	-3.8%	3.9%	46.2%
Wind Speed	-0.1%	*	*	0.1%

Notes:
- ** denotes approximately 0.0% change*
- *Temperature values are in K, so 1% would equate to approximately ~3K or ~3^{o}C*



*** Rachel Braun (Asst Research Professor) Unpublished Results**

Conclusions

GLOR is designed to better understand:

- The region's O_3 chemistry - periphery vs core; daytime (when ozone is formed) vs nighttime
- Transport and other regional factors such as wildfire smoke
- Role of vertical mixing - with extreme high temperatures and very high mixing depths and no aloft data (due to timing/logistics) the small mobile ozone lidars are key (i.e., smoke plumes can reside aloft and be missed by ground sampling)

Acknowledgement

GLOR was a significant team effort thanks in part to many individuals: Kelly Barr[1], Gary Dirks[1], Matt Fraser[1], Rynda Kay[2], Rene Nsanzineza[3], Matt Pace[4], Ron Pope[5], Matt Poppen[6], Jake Swanson[1], Luke Valin[2], among others

[1]Arizona State University, [2]EPA Region 9, [3]ADEQ, [4]USDA Forest Service, [5]MCAQD, [6]MAG

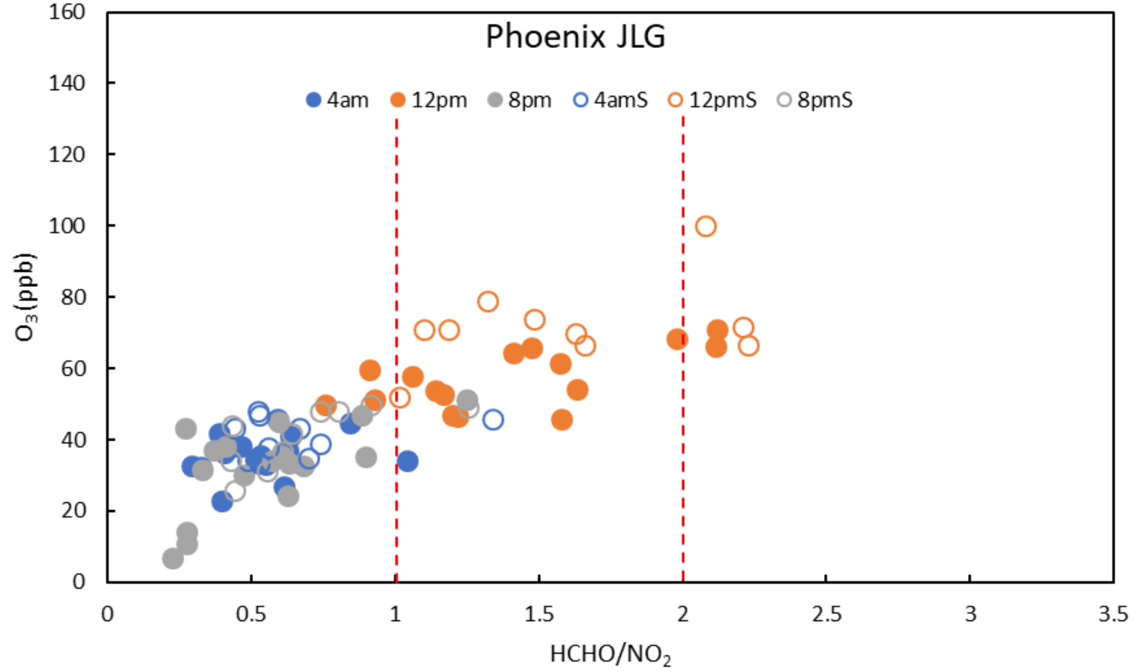
Back-up slides

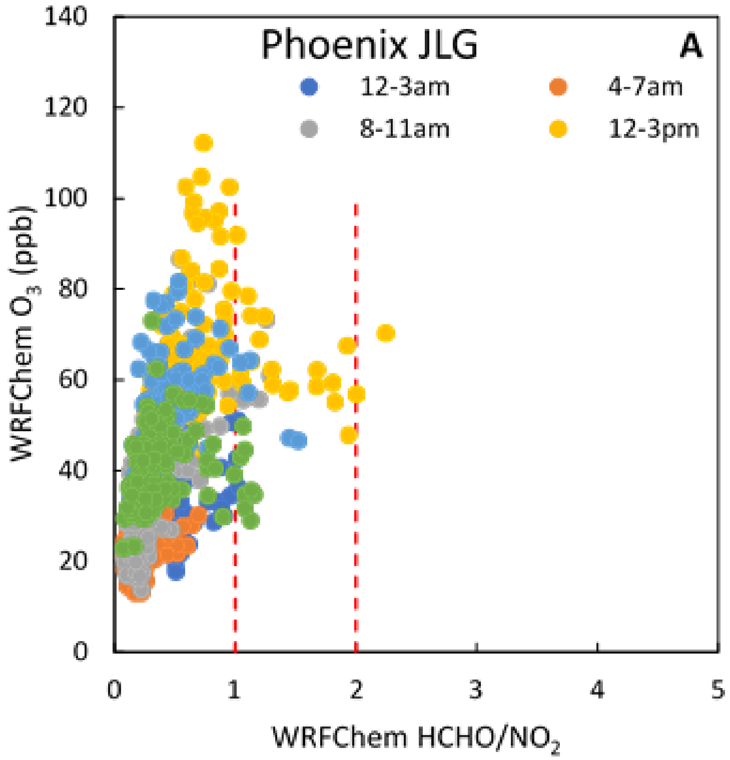
Ozone Chemistry Analysis - Ground Data and Modeling

When you look at ground-level data at JLG, there is a clear time of day impact

Nighttime data absolutely looks VOC limited (HCHO/NO2<1)

Daytime data does not appear VOC limited showing the need for time resolved data



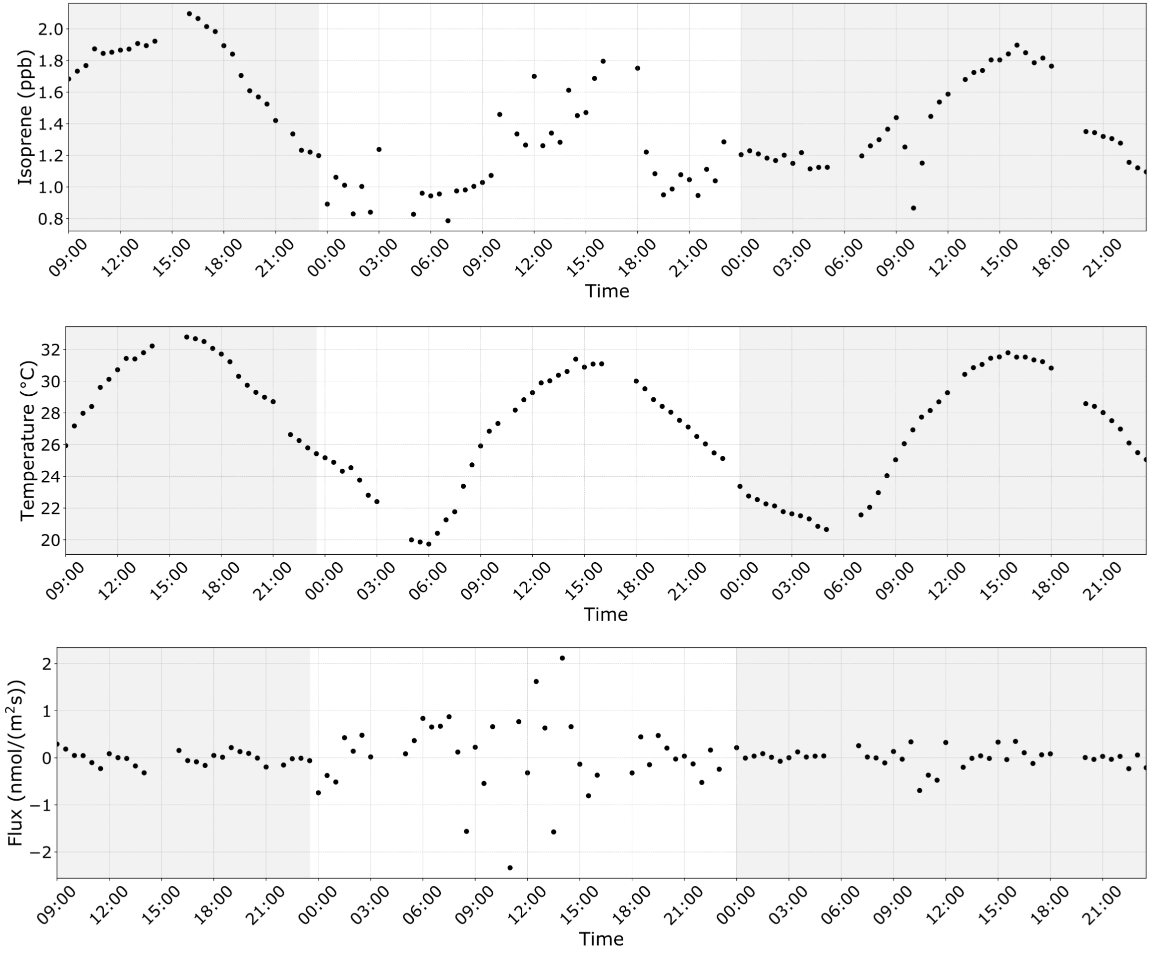


Left: ground-level HCHO/NO2 ratios from JLG based on time of day and isolating smoke (open circles) and non-smoke (closed circle) days. Right: WRFChem model runs of summer 2021 showing same ratio

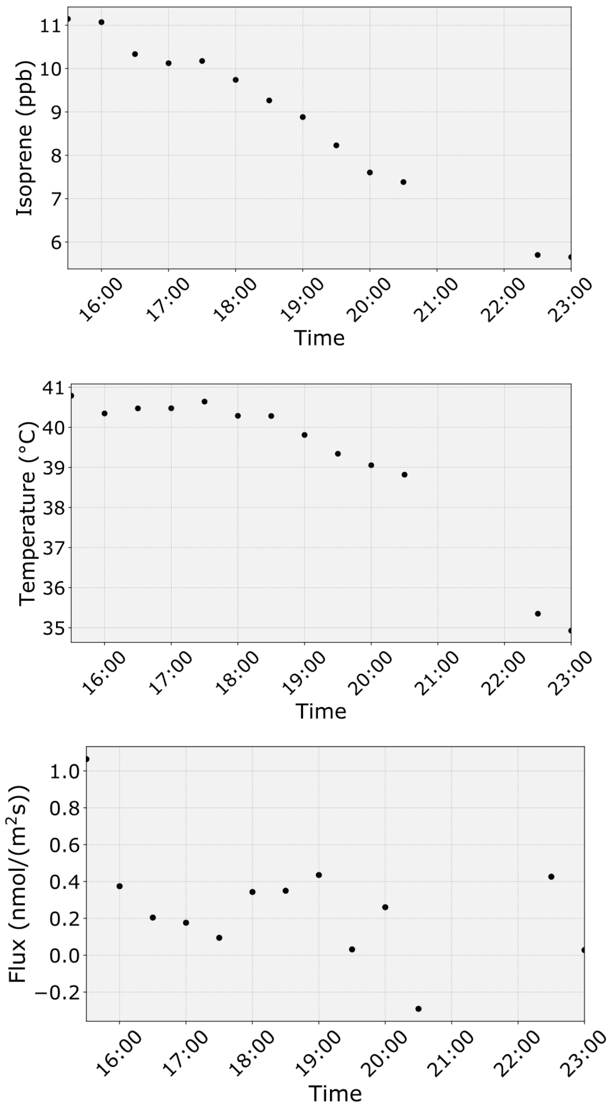
* **Miech, Herckes, Fraser, Arellano, Mirrezaei and Guo (2024)** ***Atmosphere*** 15(5) 555

BVOC Field Flux Results at WPHX

30 April-02 May 2024



29 July 2024



*** Trinity Olquin (LICOR Connect Meeting, February 2025, Tucson AZ) presentation**

Identification of Chemical Regime

Data and Methods:

1) MCAQD Surface Concentration (CH_2O, NO_2, O_3)

Data Source : MCAQD (LCS -NO_2, canister/PAMS-CH_2O)
Sampling Time : Hourly (June - August 2021), CH_2O 8-hr every 3-days
Sampling Coverage. : JLG, Buckeye, Pinnacle Peak, North Phoenix, Mesa
Indicator : CH_2O/NO_2 (FNR)

2) Satellite Retrieval Columns (CH_2O, NO_2)

Data Source : TROPOMI (NASA) , NO_2v2.20 (qa>0.75), CH_2Ov2.01 (qa>0.5)
Sampling Time : Daily (2019-2022), 130pm
Sampling Coverage. : Global (~7km)
Indicator : CH_2O/NO_2 (FNR)

3) Model Surface Concentration (CH_2O, NO_2, O_3)

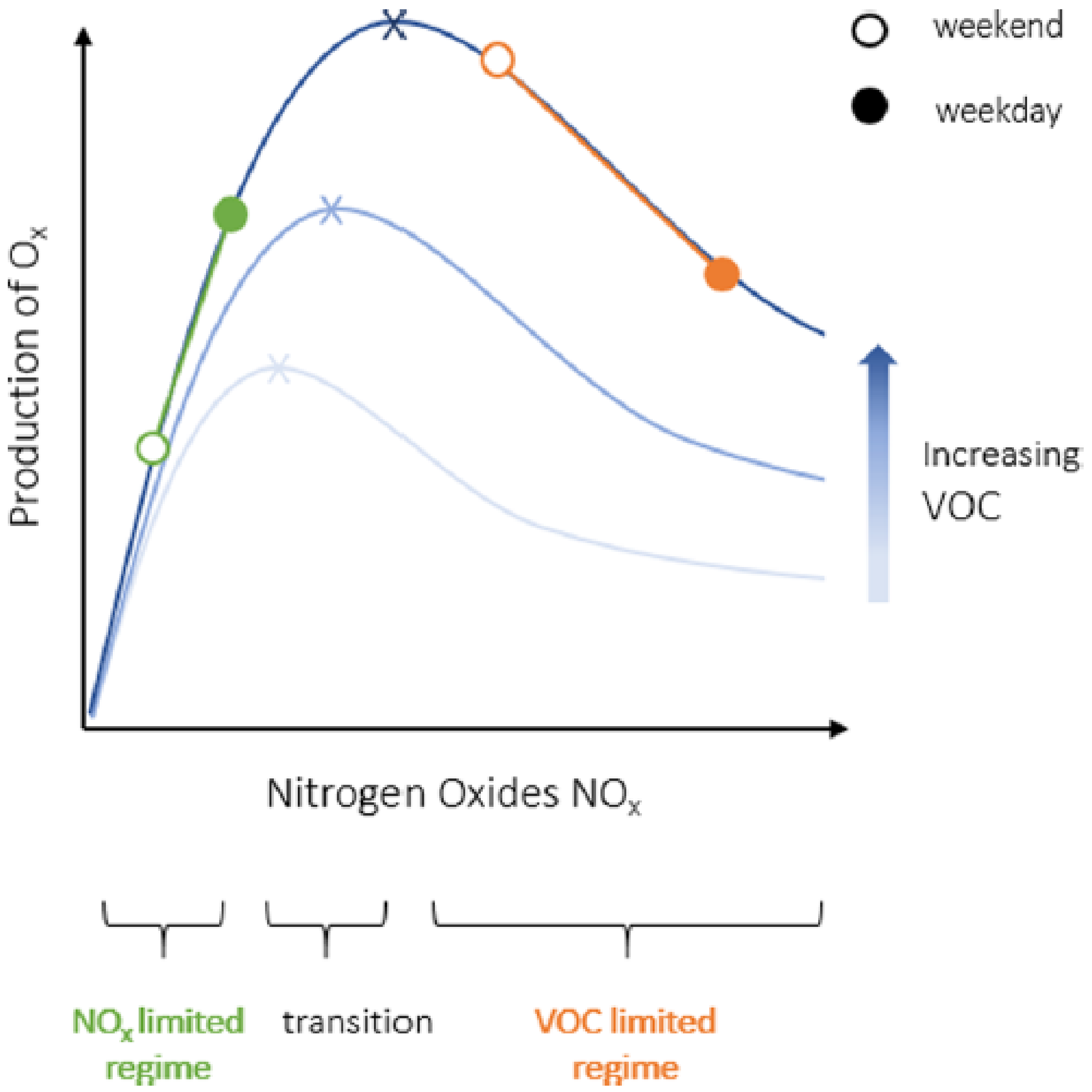
Data Source : WRF-Chem4.4 (NEI 2017, FINN2.5), MDA8: AQS Daily
Sampling Time : Hourly (Jun 2017-2021, Apr-Aug 2017)
Sampling Coverage : Arizona (3 km)
Indicator : CH_2O/NO_2 (FNR)

4) Surface Site Concentration (O_3, NO_2)

Data Source : USEPA AQS - ≤ 0 missing, <MDL=0.5MDL
Sampling Time : Hourly (2015-2021)
Sampling Coverage : JLG, Children's Park, Yuma, Alamo, Grand Canyon, Chiricahua
Indicator : Weekend/Weekday variation (Weekend Effect: VOC-Limited)

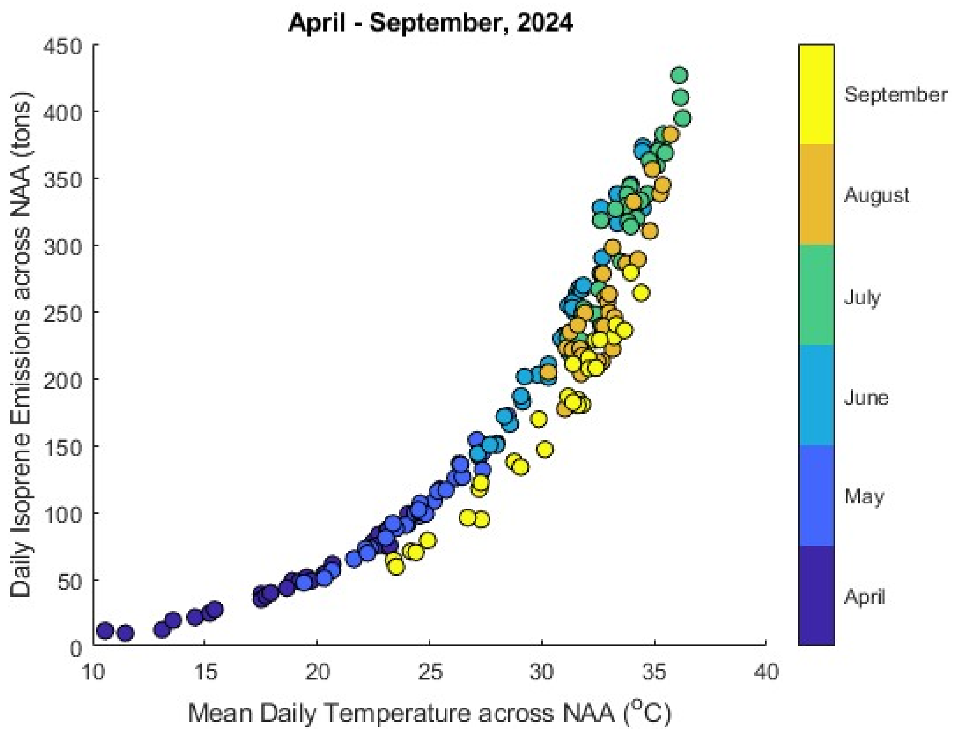
OZONE PRODUCTION DYNAMICS

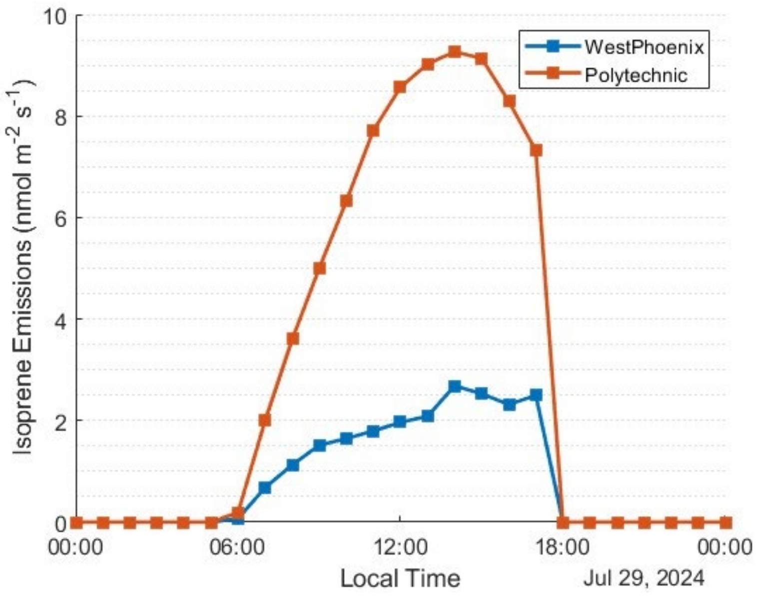
Source: Nussbaumer and Cohen, EST, (2020)



Summer 2024 BVOC Emissions Modeling

MEGAN shows dramatically higher BVOC emissions at elevated temperatures.





To corroborate these modeled emissions, ASU undertook field flux measurements at two sites (WPhx and ASU Polytechnic) in summer 2024 and will be out in the field in summer 2025 as part of GLOR.

*** Rachel Braun (Asst Research Professor) Unpublished Results**

Impact of Woodsmoke Episodes

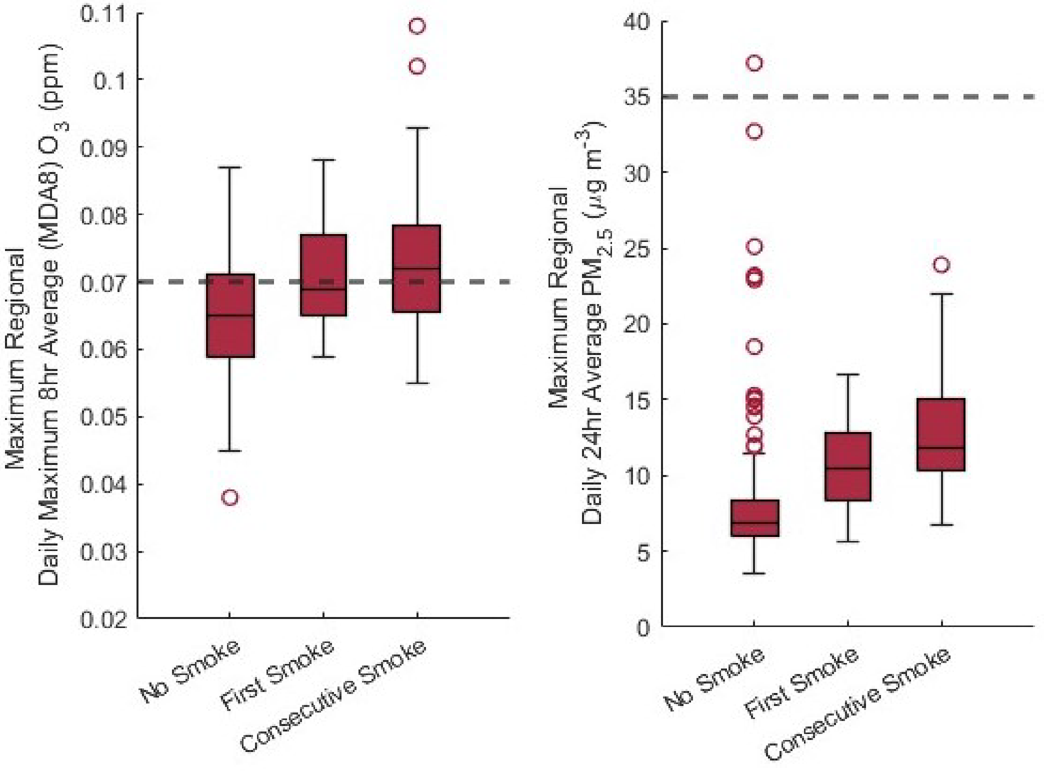


Figure 1. Comparison between no smoke, first smoke, and consecutive smoke days for maximum daily regional value of maximum daily 8 hr average (MDA8) O_3 and 24hr average $PM_{2.5}$. The dashed lines indicate the EPA 2015 8-hour NAAQS for O_3 and daily NAAQS for $PM_{2.5}$.

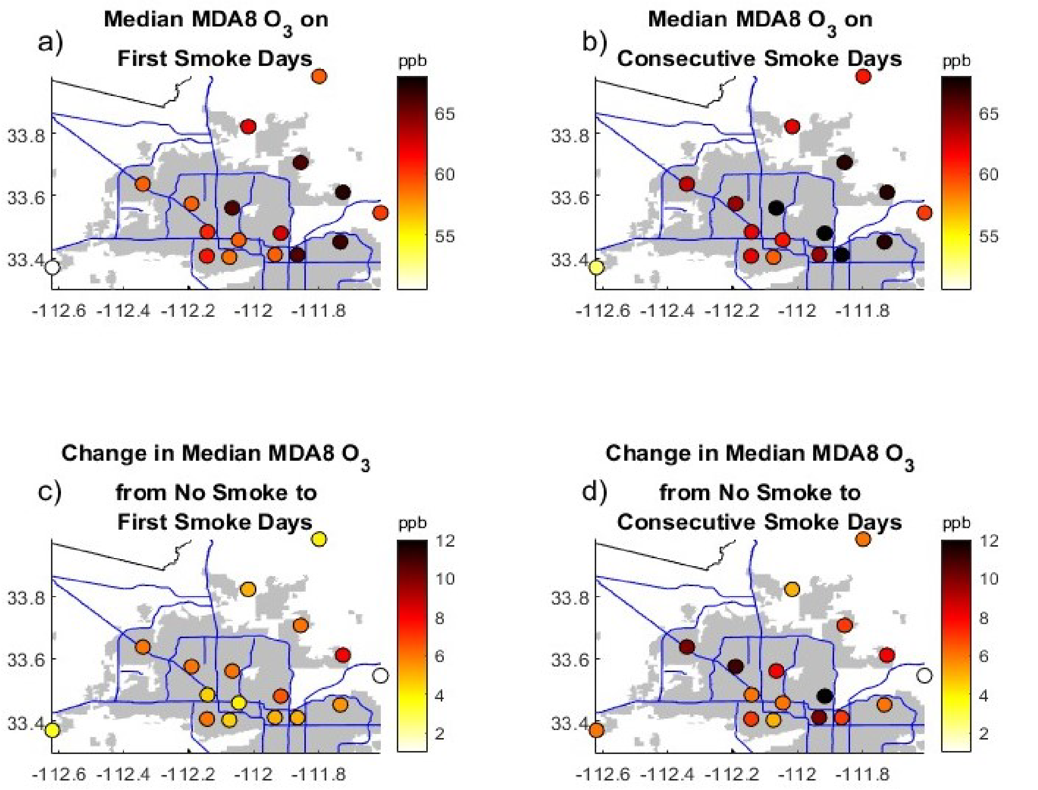


Figure 2. Median values of Maximum Daily 8hr Average (MDA8) O_3 for measurement sites across Metro Maricopa County for first smoke (a) and consecutive smoke days (b). Shown in panels (c) and (d) are the changes in median MDA8 O_3 from no smoke to either first smoke or consecutive smoke days. Census-defined urban areas are shown in grey, major roads are in blue, and county boundaries are in black.

*** Braun and Fraser (2025) submitted for publication in *Atmos. Environ.***

BVOC Field Flux Measurements

Eddy Covariance uses atmospheric motion and pollutant concentrations to calculate flux from the surface

High-speed (**≥ 10 Hz**) measurements of **wind speed/direction/sonic temperature** (all measured by *3D sonic anemometer*) and **gas concentrations** (measured by fast *gas analyzer*)

→

$$F = \overline{\rho}\, \overline{w' s'}$$

p= dry air density

w= vertical wind speed

s= gas mixing ratio (gas mass/dry air mass)

→

Flux

concentration/amount of gas of interest moving through unit area/per unit time

Additional sensors measure weather, radiation, vegetation, & soil variables

* **Trinity Olquin (AGU Fall Meeting, December 2024, Washington DC) presentation**