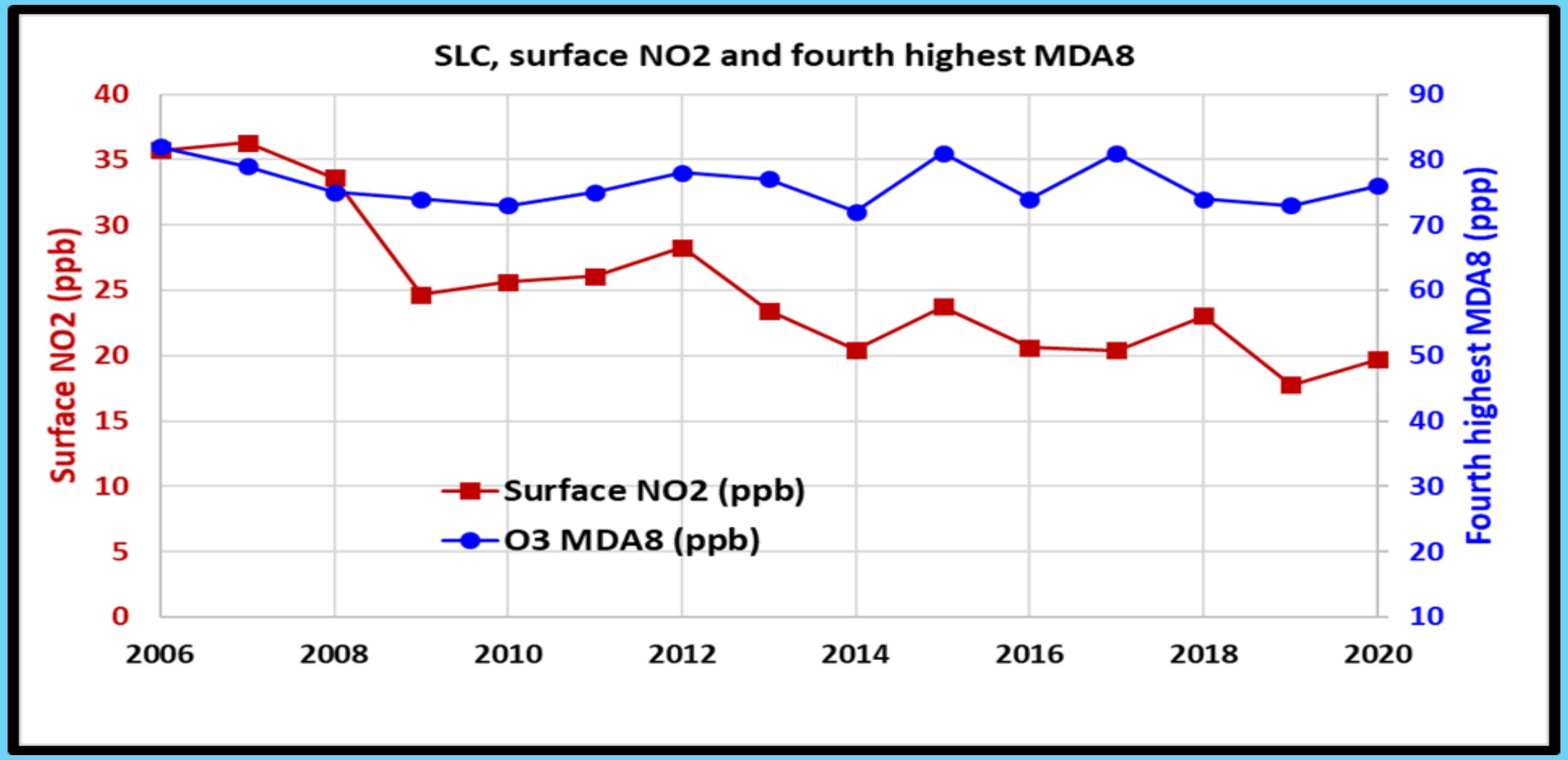
Surface NO_2 and fourth highest O_3 MDA8 (Hawthorne)



SAMOZA research questions and goals

1. **Do regulatory UV O_3 monitors exhibit bias during smoke events?**
2. **What are the best approaches to identify and quantify smoke influence on O_3 in urban areas?**
3. **How well can photochemical and statistical models reproduce O_3 concentrations for <u>smoke and non-smoke conditions</u>?**
4. **What are the controls on O_3 production (NOx vs VOCs) <u>in smoke and non-smoke conditions</u>?**

Specific tasks:

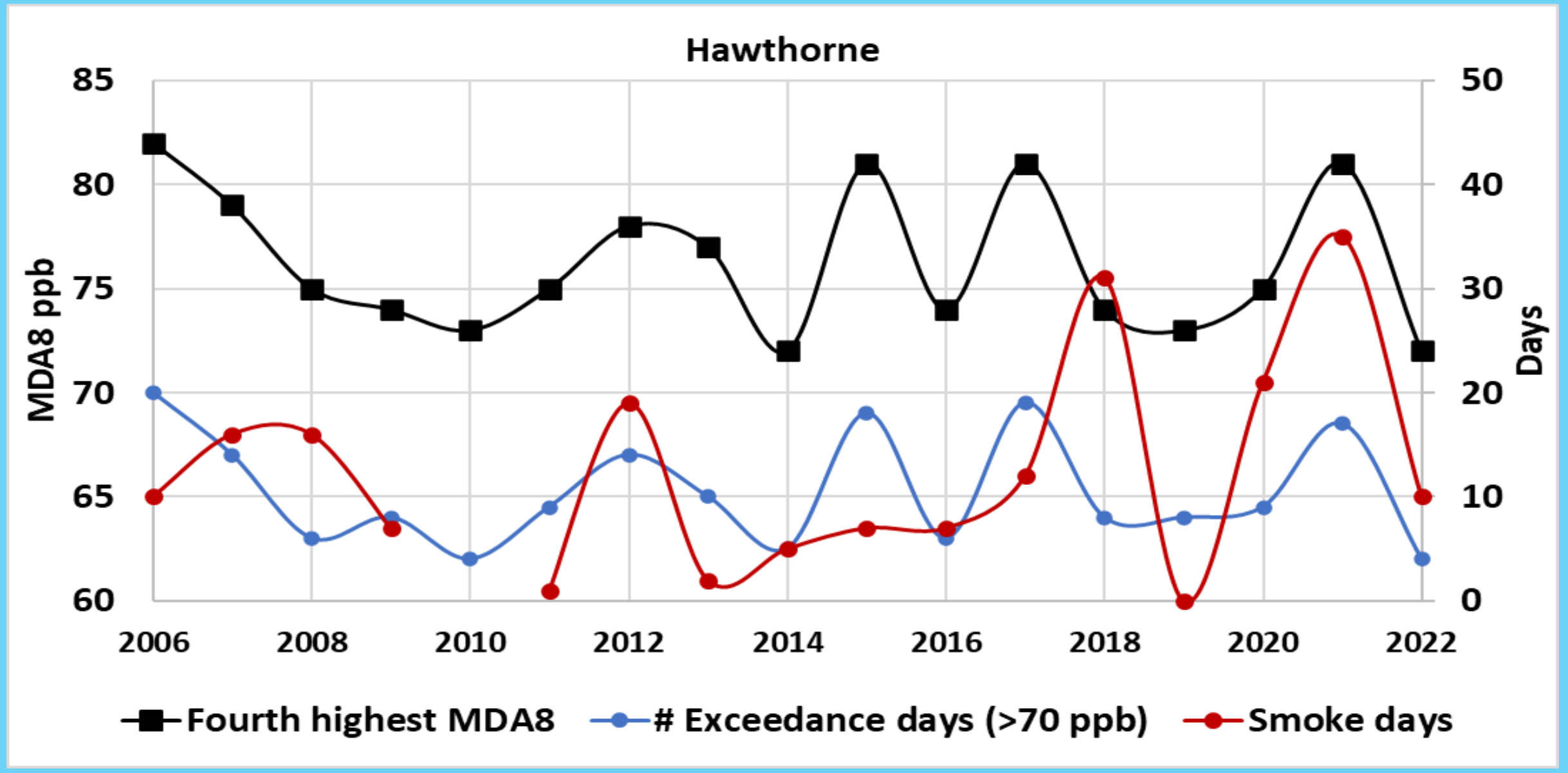
Observations in summer of 2022:

- ✓ **VOCs by PTR-MS.**
- ✓ **Aldehydes by DNPH cartridge method.**
- ✓ **O_3 using UV scrubber-less technology (Any evidence for bias with UDAQ O_3 instruments?)**

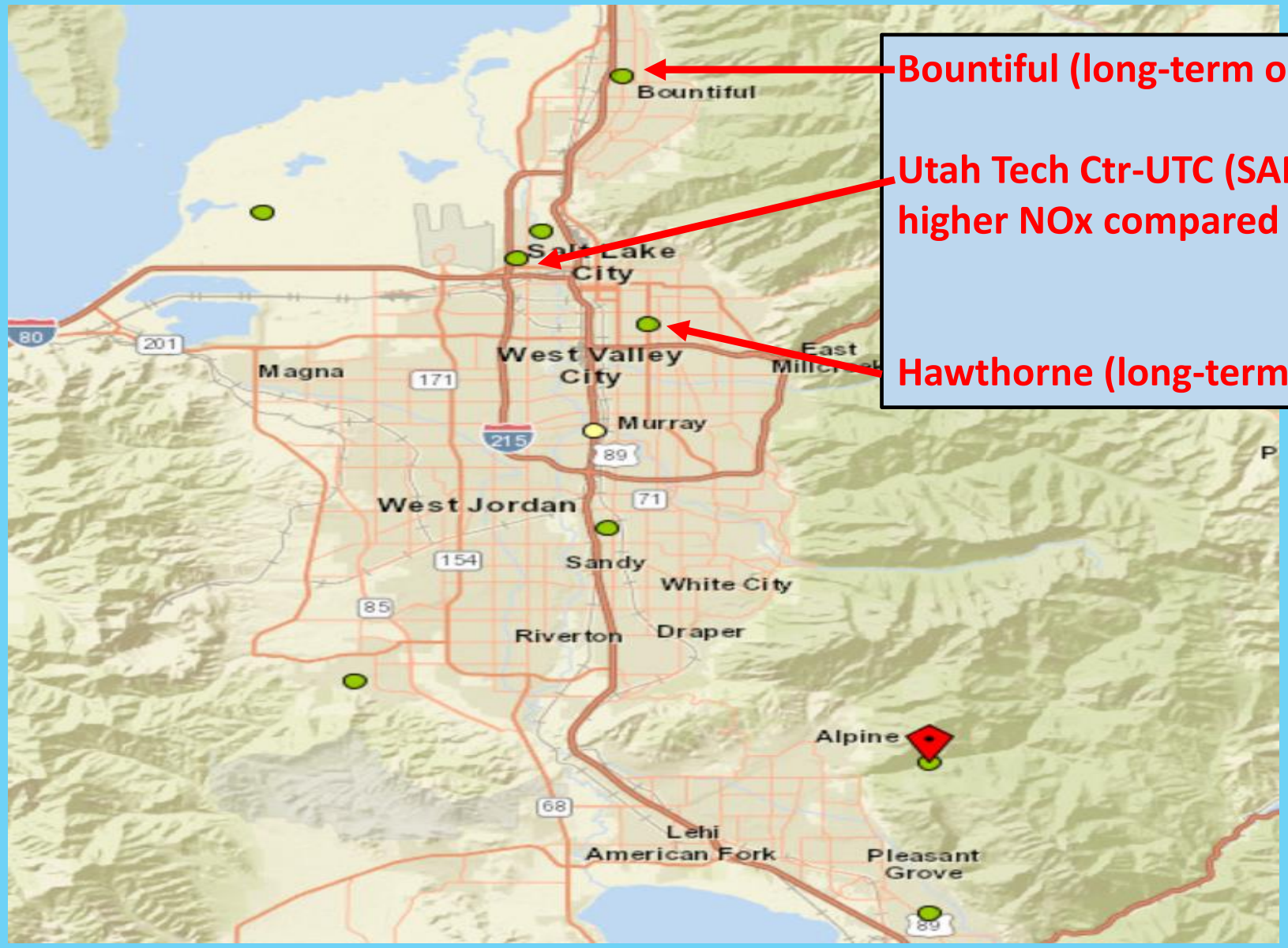
Analyses:

- ✓ **Compare regulatory O_3 at Hawthorne site with scrubber-less UV method on smoke influenced days. Quantify VOCs, NOx, PM, CO and O_3 on smoke and non-smoke days.**
- ✓ **Photochemical box modeling for smoke influenced and non-smoke conditions.**
- ✓ **Generalized Additive Modeling.**

Summer 2022 was a relatively low smoke and O_3 summer



Focus sites in SLC

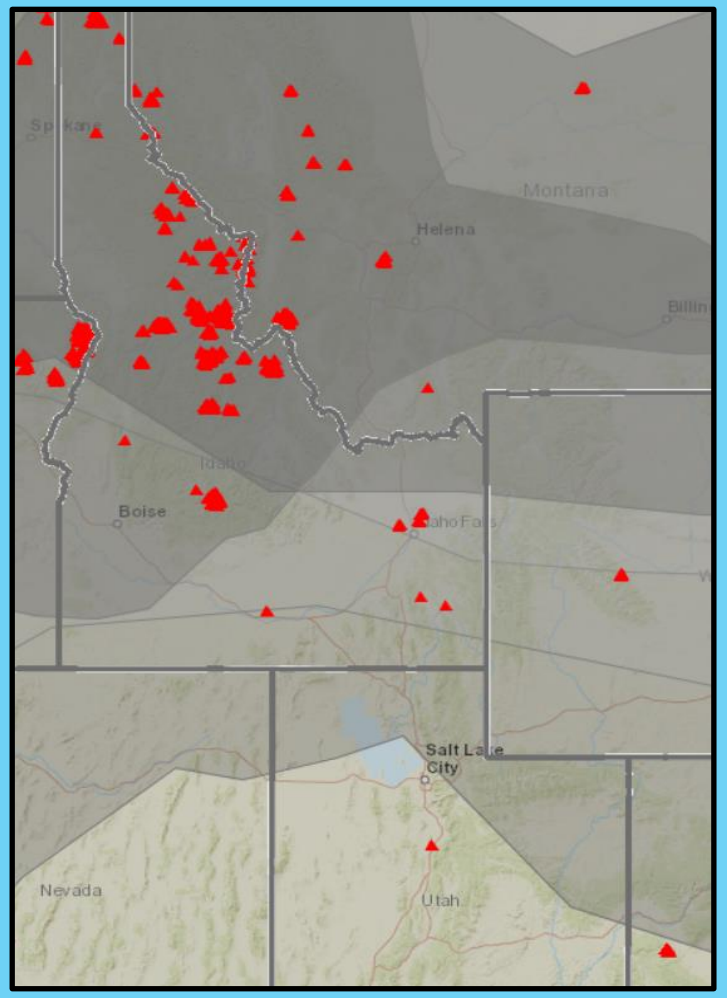


Bountiful (long-term obs.)

Utah Tech Ctr-UTC (SAMOZA): higher NOx compared to other sites.

Hawthorne (long-term obs.)

Identification of smoke days with NOAA HMS



HMS Fires and smoke over SLC
Sept. 12, 2022

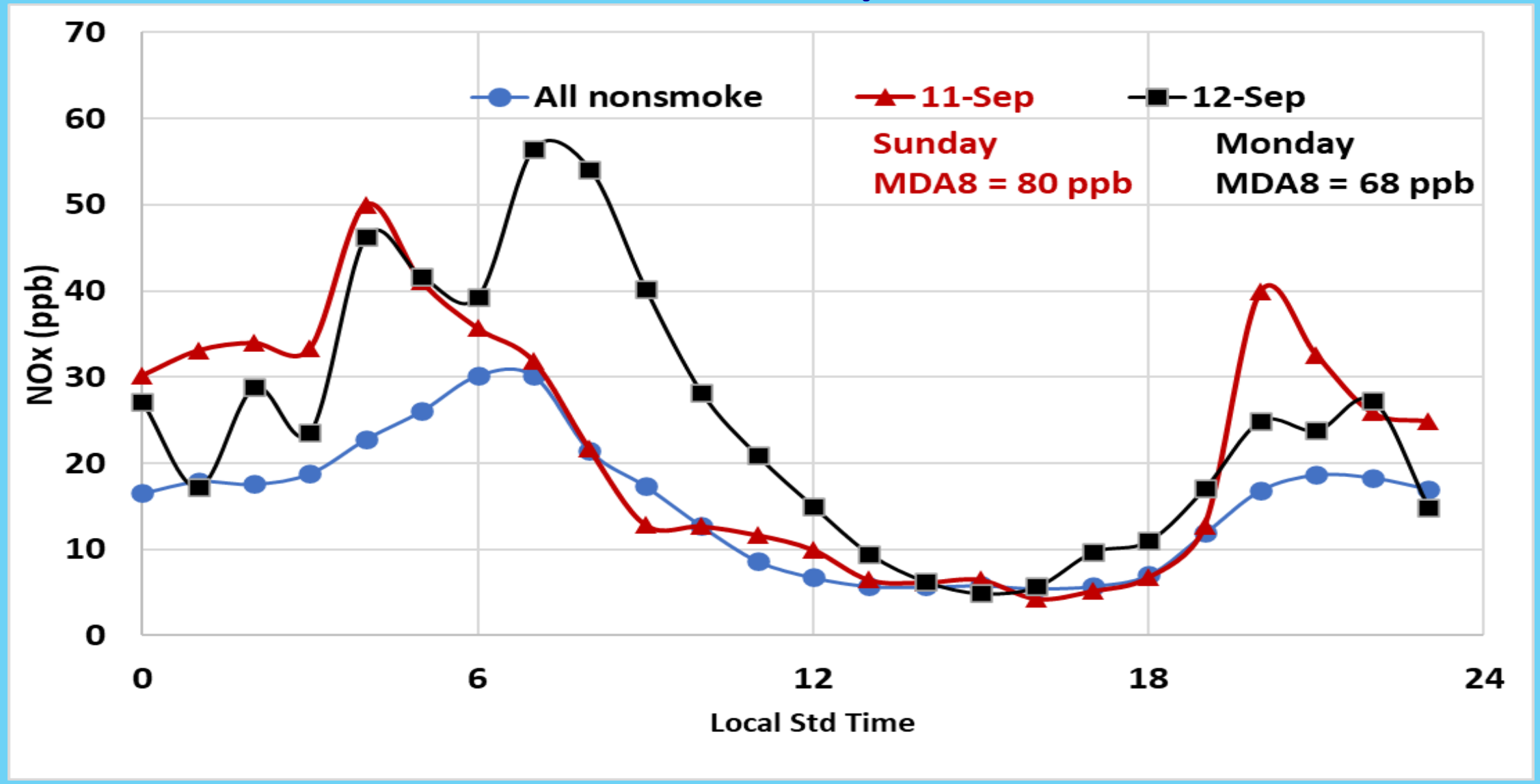
We use the NOAA HMS Fire and Smoke Product (HMS-FSP) to indicate <u>overhead</u> smoke (HMS =1 or HMS =0)

We use the term "smoke day" when $PM_{2.5}$ is more than a specific criteria (usually 1 SD above non-smoke mean)

SAMOZA data summary: Aug. 1-Sept 30, 2022

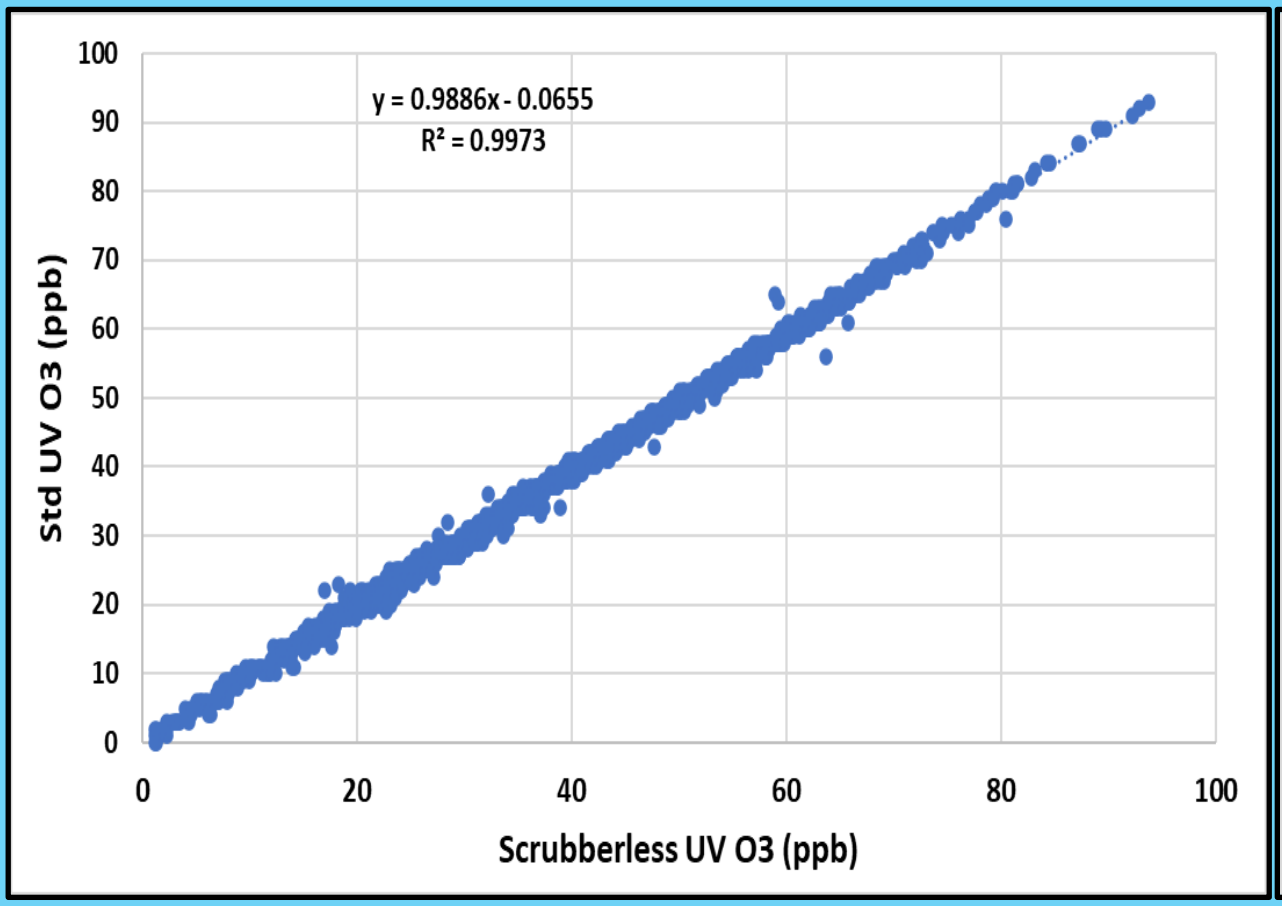
	No-smoke	Smoke
Count (days)	51	10
Avg MDA8 (ppb)	55.3	65.0
Avg NOx (ppb)	15.0	20.5
Avs ∑VOCs (ppb)	27.4	42.0
Average PM25 (µg/m^3)	6.1	17.3
Count (Exceedance days)	3	2
Avg MDA8 (ppb)	76.0	75.5
Avg NOx (ppb)	20	22.6
Avg ∑VOCs (ppb)	41.1	50.2
Average PM25 (µg/m^3)	8.5	17.8

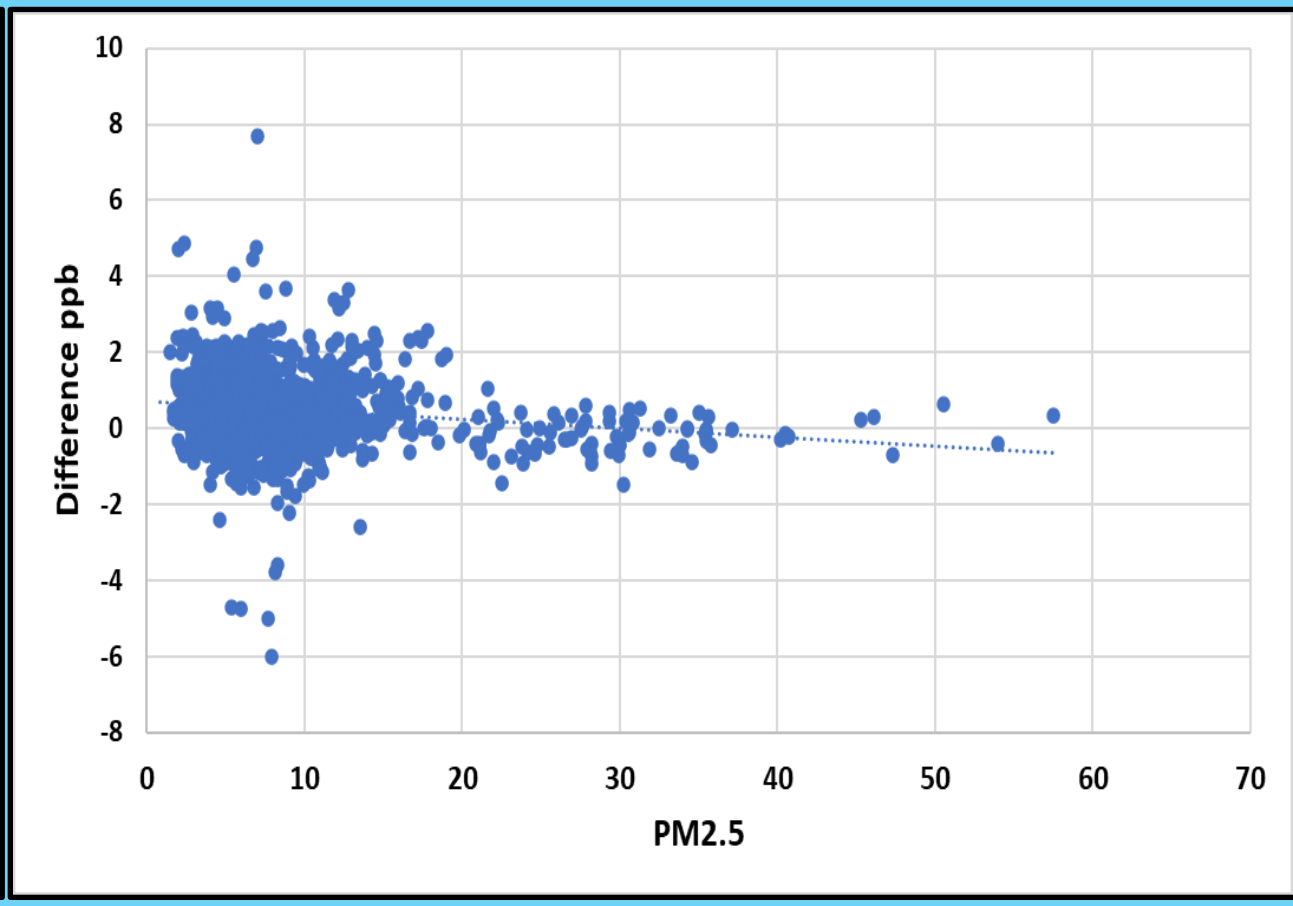
NOx on two days with smoke



- While both days have higher NOx than non-smoke days, the more important factor is day of week.
- The high NOx on Monday 9/12/22 probably suppressed O_3 formation.

Any evidence for bias in O_3 measurements at UTC site?





Comparison of O_3 measured using a TwoB Tech "scrubber-less" UV vs standard UV (Teledyne T400)

Past work on O_3 bias in smoke: Gao et al 2017; Long et al., 2021; Bernays et al., 2022

2022 Exceedance days in SLC

Hawthorne (4 days)	MDA8 (ppb)		Bountiful (9 days)	MDA8 (ppb)		UTC (6 days)	MDA8 (ppb)
8/4/2022	76		6/8/2022	74		7/21/2022	82
9/3/2022	72		7/21/2022	77		8/4/2022	75
9/7/2022	74		7/22/2022	72		8/9/2022	77
9/11/2022	81		8/4/2022	71		9/3/2022	76
			8/9/2022	84		9/7/2022	71
			9/3/2022	72		9/11/2022	80
			9/4/2022	76			
			9/7/2022	75			
			9/11/2022	74			

Smoke days in red

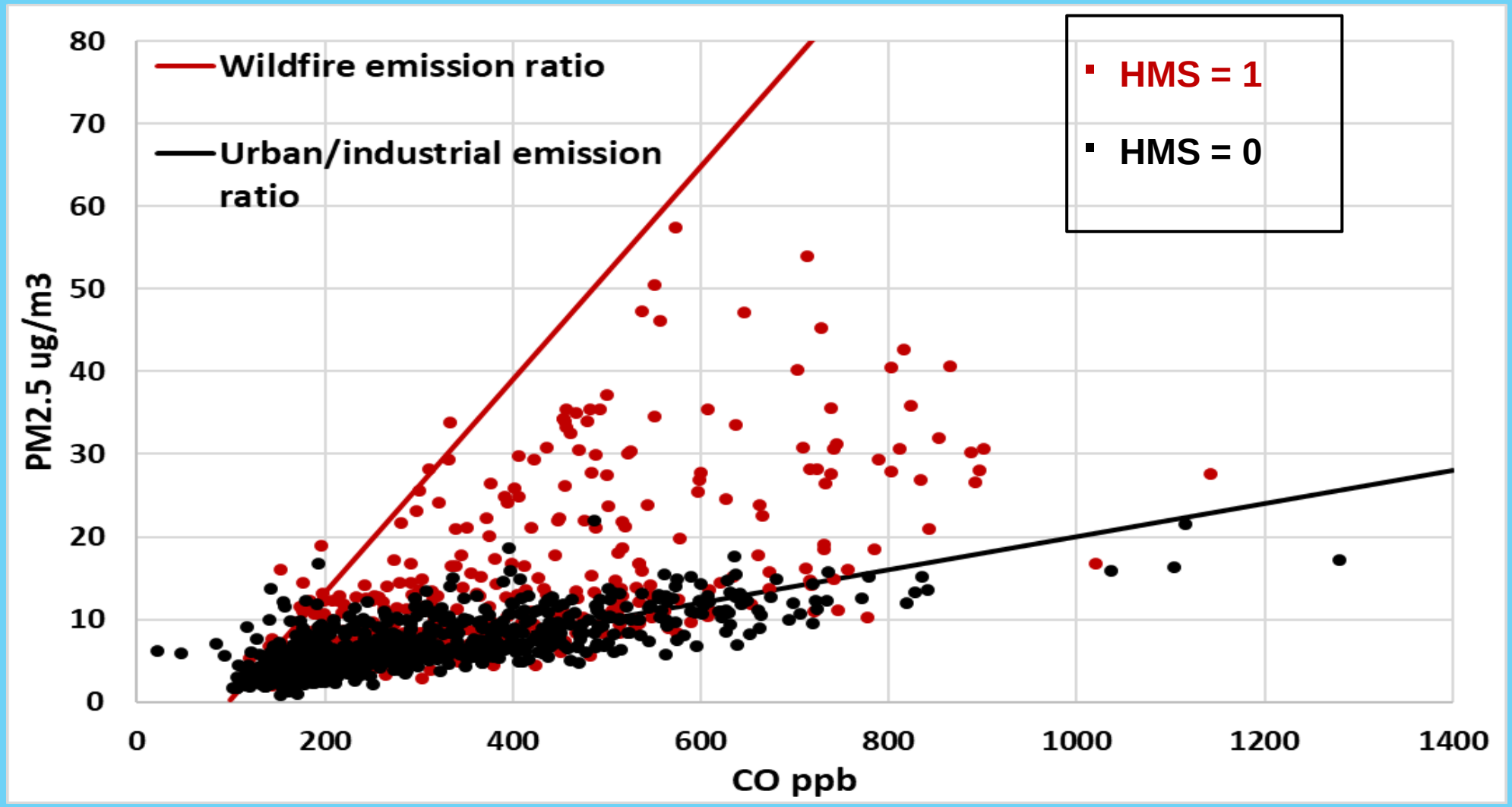
Yellow highlight is Sept 3 “mystery day” (high formaldehyde)

What happens to air quality when smoke comes to town?

1. $PM_{2.5}$ increases.
2. $PM_{2.5}$/CO increases and approaches the value from wildfire emissions.
3. VOCs increase, especially oxygenated VOCs.
4. NOx shows little to no increase.
5. O_3 increases more rapidly in morning and goes to higher concentrations.

Image from Salt Lake Tribune

UTC $PM_{2.5}$ vs CO sorted by HMS (summer 2022)



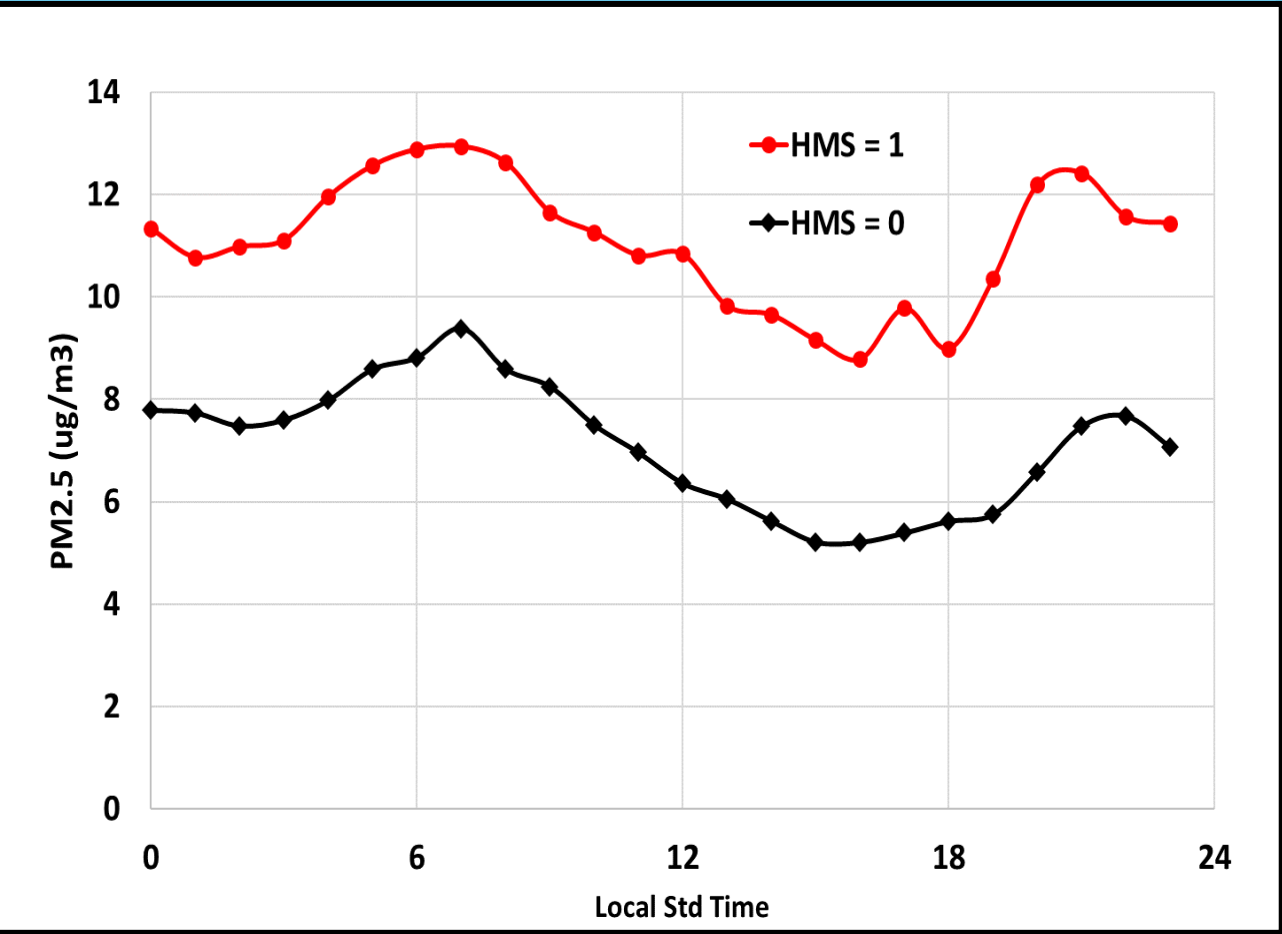
Use of $PM_{2.5}$ to CO ratio as an indicator of wildfire smoke in urban areas.

<u>But need high precision CO measurements.</u>

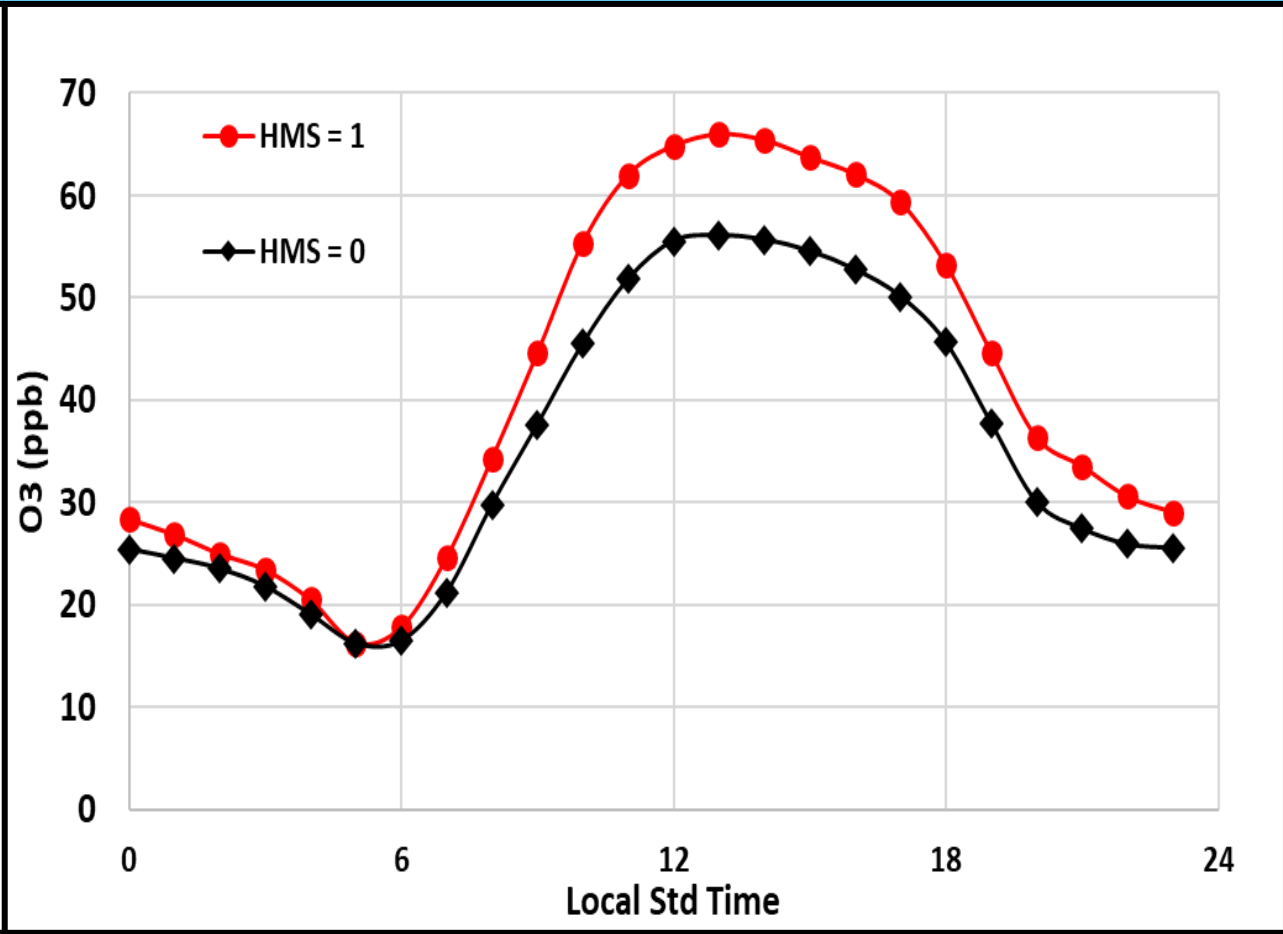
For 2022, this worked with SAMOZA obs, not standard UDAQ obs.

Jaffe et al, ACP, 2022.

UTC: July 1-Oct. 15, 2022 (sorted by HMS)



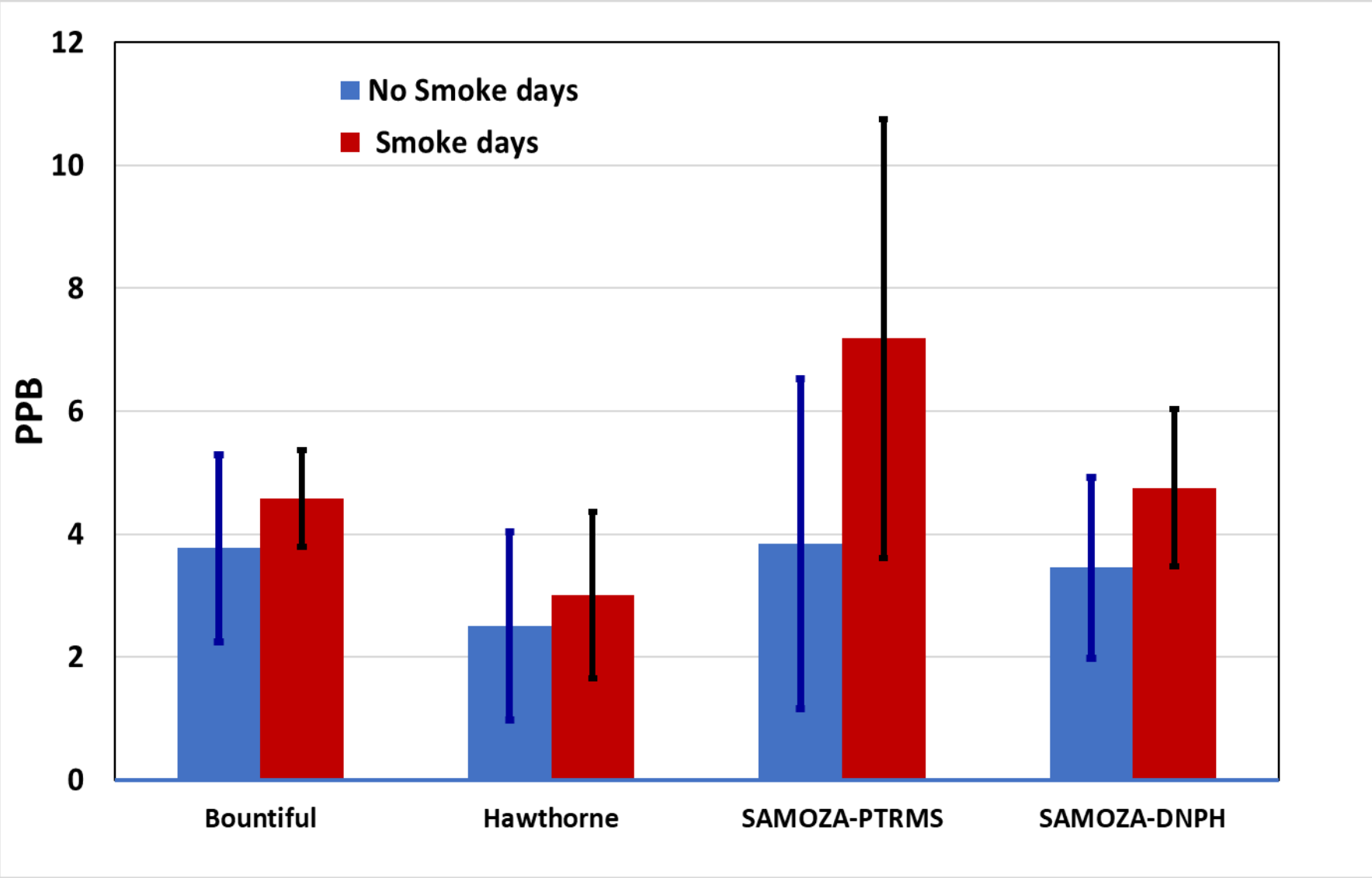
$PM_{2.5}$



O_3

- Lack of correlation between $PM_{2.5}$ and O_3 argues against a direct source from the smoke plumes. Instead O_3 must be locally generated, at least for SLC.

Formaldehyde data on smoke/no-smoke days



- Bountiful UDAQ data are 2017-2022 (n=145, ~10% are smoke)
- Hawthorne UDAQ data are 2020- Aug 2022 (n=185, ~10% are smoke).
- SAMOZA data are Aug-Sept 2022.

- On-going work by USU and UMt to compare CH_2O results.

How to quantify O_3 production?

- **Statistical methods (Generalized Additive Models)**
  - Give contribution to MDA8 from smoke.
- **Photochemical models**
  - Give VOC and NOx sensitivity on smoke and non-smoke days.

Useful to quantitatively compare these two approaches.

Photochemical Model Details for SLC

Model: Framework for 0-D Atmospheric Modeling (**F0AM**; Wolfe et al., 2016)

Constraints:

- **Meteorology:** temperature, RH and P are constrained to observations.
- **Chemistry:** NOx and suite of 34 VOCs are constrained to observations.

Other model details:

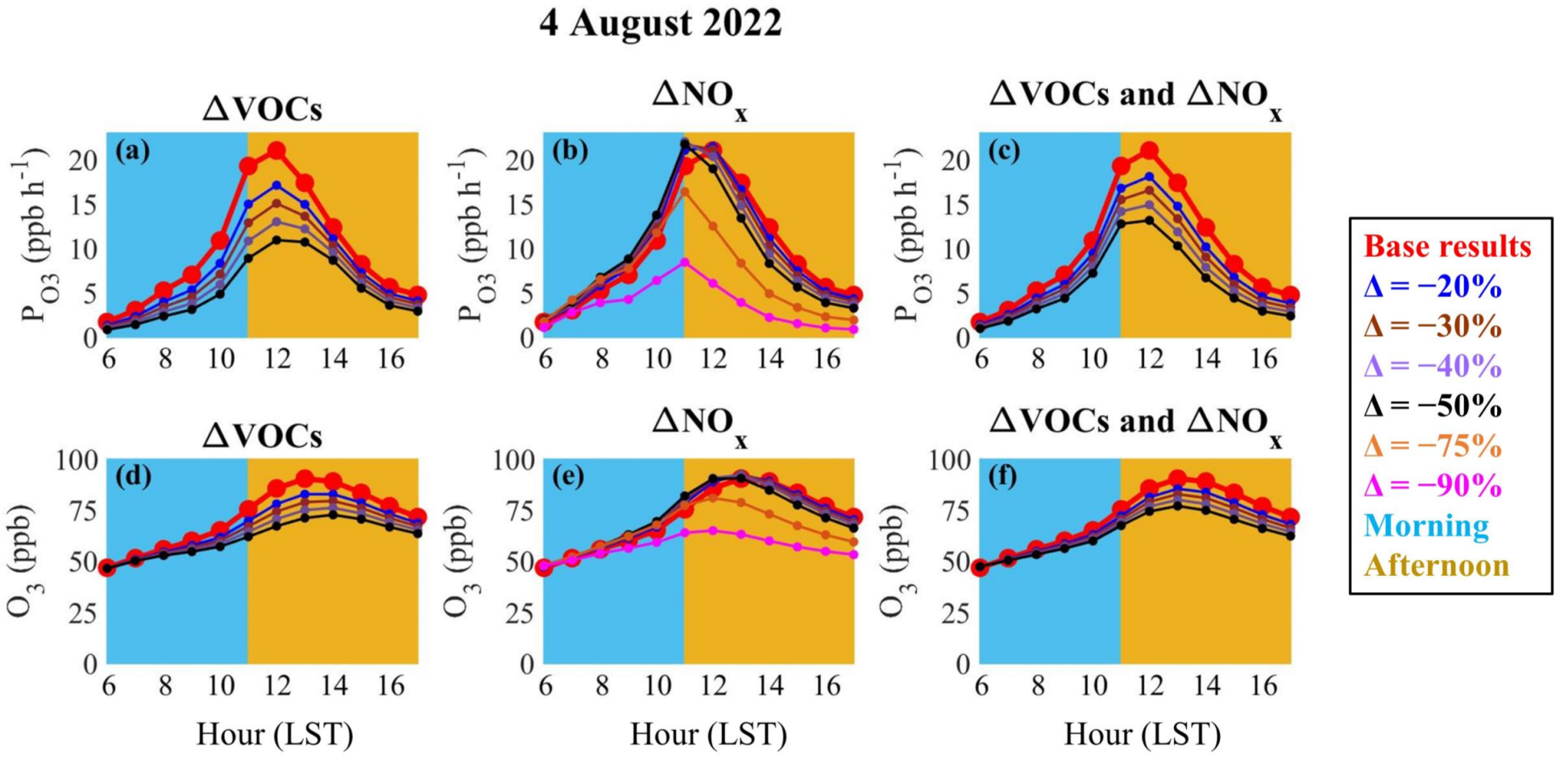
- Scaled all photolysis rates in reference to estimated observed NO_2 photolysis rates **(J_{NO2})**
- Added heterogeneous uptake of OH and HO_2 onto aerosol particles.
- Used the daily 25th-percentile concentration for odd oxygen **($O_x = NO_2 + O_3$)** to prescribe background O_3 concentrations on each case study day (~50 ppb≈ intermountain west bg O_3)
- A 24-h simulation was conducted from 0:00–23:00 LST on each case study day to get the model-predicted O_3 production rates (P_{O3}) and O_3 concentrations.
- Examine NOx and VOC sensitivity on smoke and non-smoke days by weekend/weekday.

Past use of FOAM for urban smoke: Ninneman and Jaffe (2021)

Photochemical modeling using FOAM (Framework for 0-D Atmospheric Modeling)

Date	Type of day	MDA8 O_3 (ppb)	24-h $PM_{2.5}$ (μg m^{-3})
08/4/2022 (Thursday)	Non-smoky weekday	75	10.7
09/03/2022 (Saturday)	Non-smoky weekend (morning peak in O_3 and CH_2O)	76	8.5
09/11/2022 (Sunday)	Smoky weekend	80	26.0
09/12/2022 (Monday)	Smoky weekday	68	21.5

VOC and NOx sensitivity tests- Aug. 4, 2023 at UTC (non-smoke day)



Rescale for avg NOx in metro area:

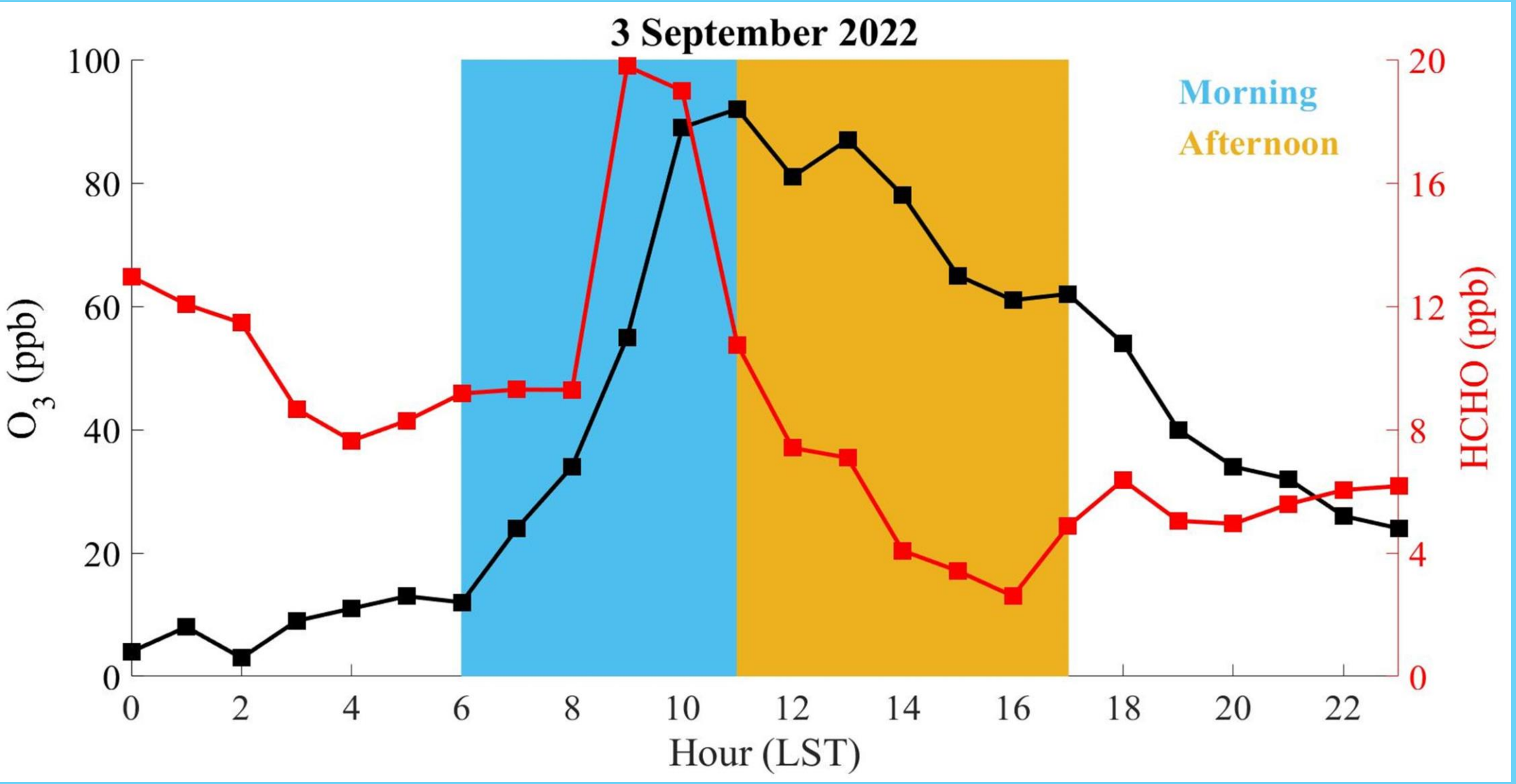
-10%

-25%

-60%

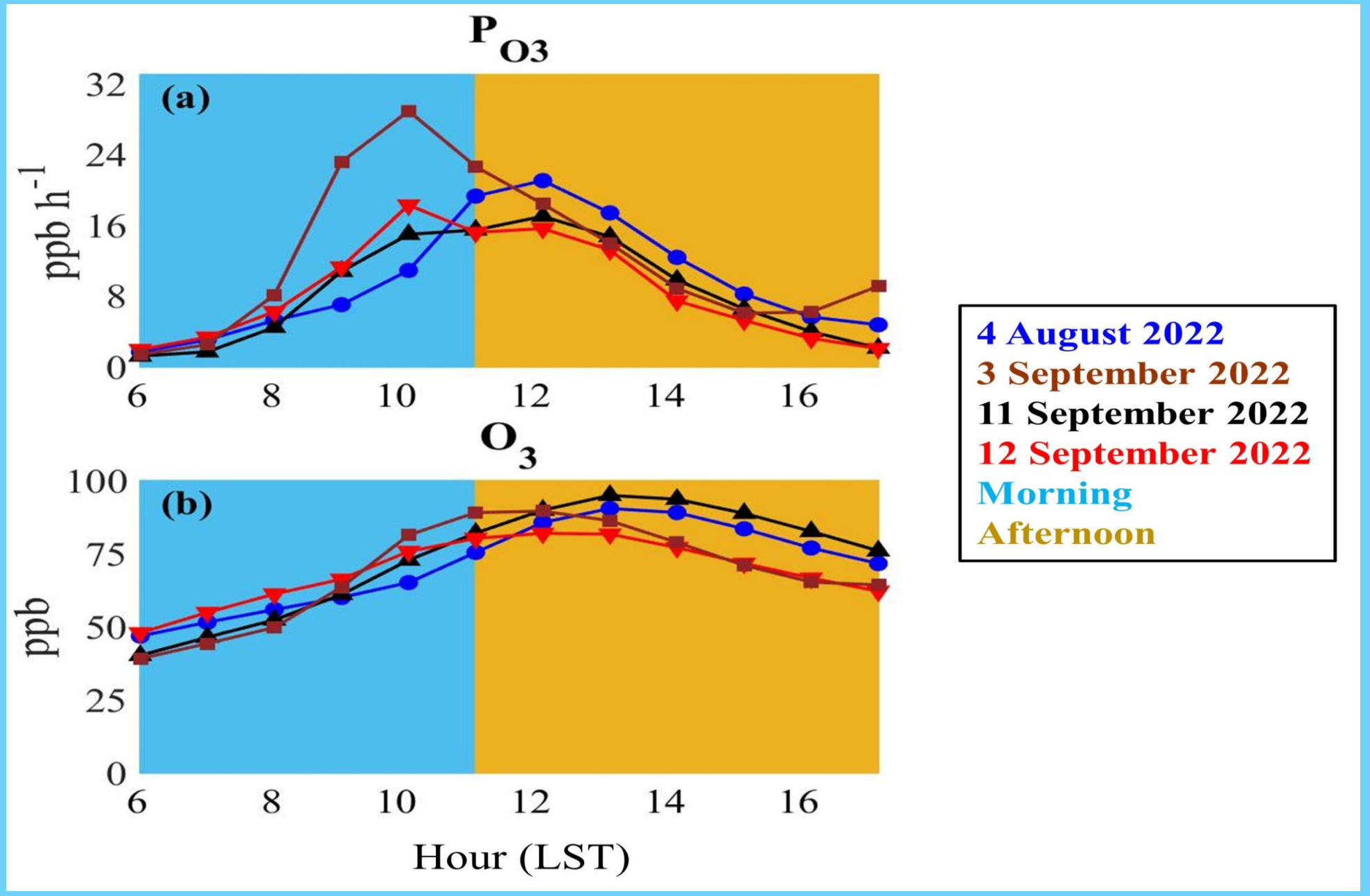
- O_3 production is very sensitive to changes in anthropogenic VOCs and only sensitive to NO_x when reductions are ≥ 60%
- UTC is highest NOx site in the region. Scaled results show NOx reductions needed across entire airshed.

9/3/22: The mystery day! Mornings peaks in O_3 and Formaldehyde



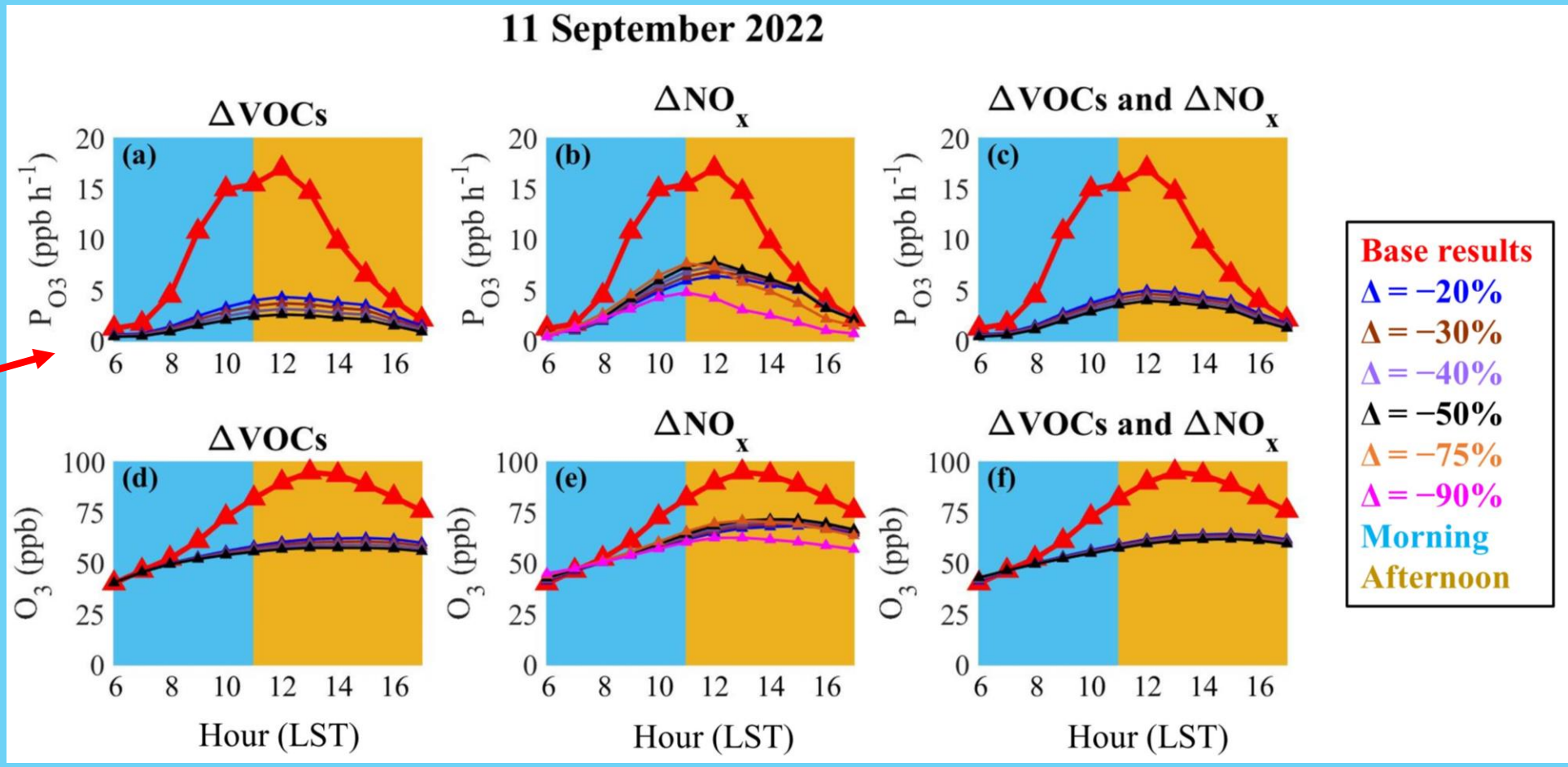
What was the source of CH_2O on 9/3/22 and is it controllable?

Modeled P_{O3} and O_3



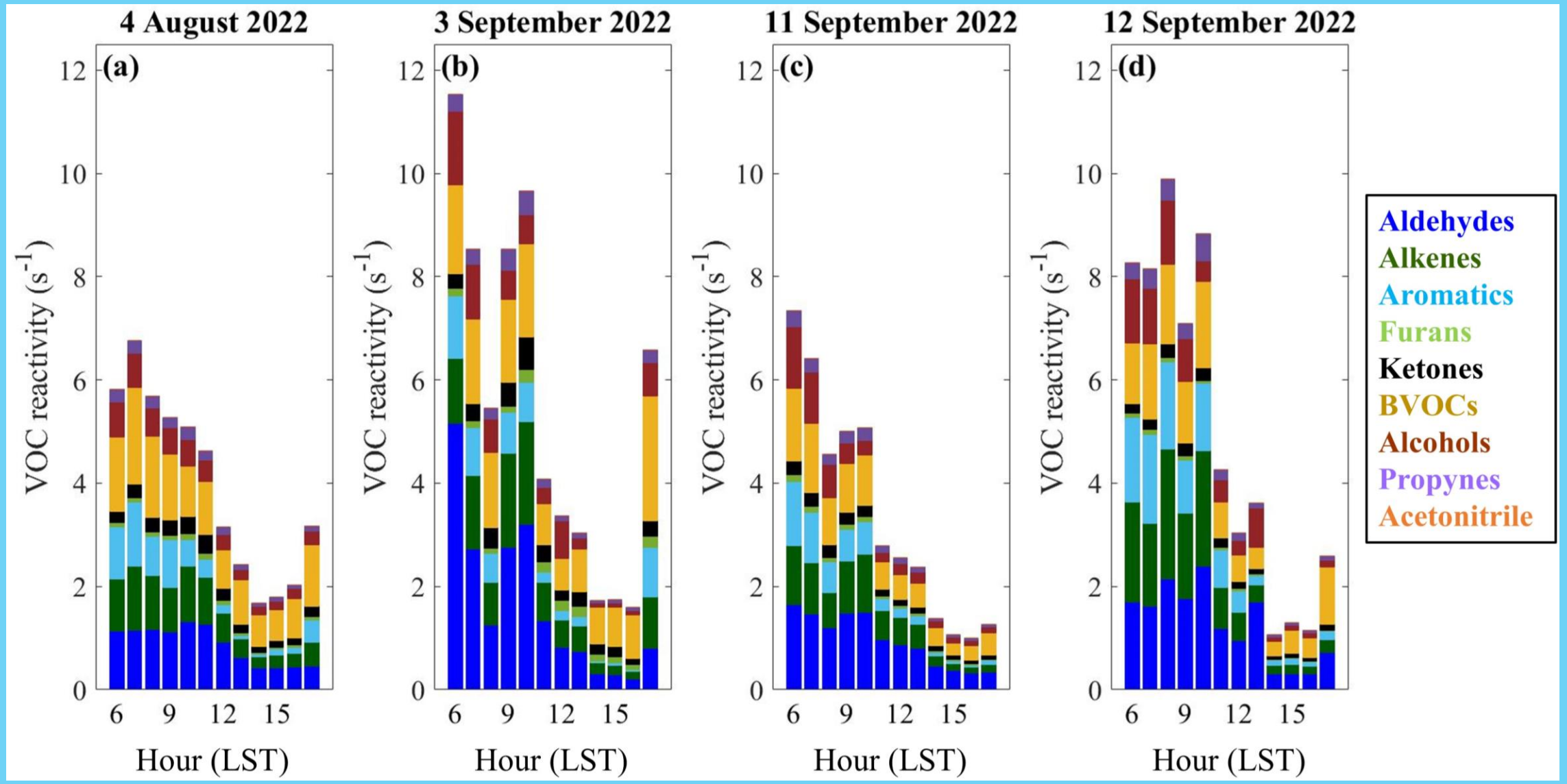
VOC and NOx sensitivity tests- Sept. 11, 2023 at UTC (smoke day)

Impacts of smoke VOCs on O_3 production.



- Peak hourly O_3 decreased from **~ 95 ppb** to **~ 70 ppb** after removing smoke-emitted VOCs
- Anthropogenic VOC and/or NO_x reductions = much smaller effect on O_3 concentrations.
- **Still working on best way to "remove" smoke influence…**

Observed Daytime VOC Reactivity



How to quantify the O_3 in an urban area due to smoke? Use machine learning to predict MDA8 O_3 w/wo smoke.

- Generalized Additive Modeling (GAM), is a type of machine learning that uses a training dataset to identify patterns and relationships. This approach can incorporate linear, non-linear and categorical relationships.

$$g(O_{3i}) = f_1(temp_i) + f_2(WS_i) + f_3(WD_i) + \ldots + residual_i$$

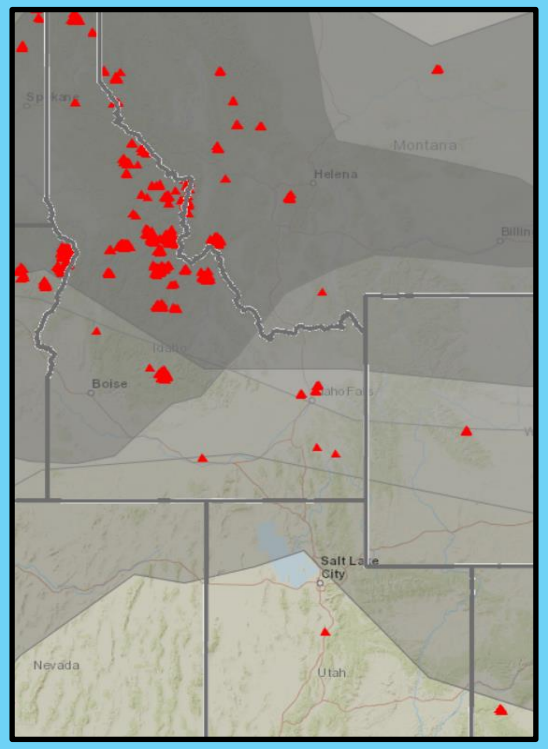
Where f_1, f_2, etc from spline fits to the obs. "*i*" refers to daily obs.

- Typical predictors are daily max temp, ws, wd, trajectory distance, RH, pressure, etc.
- The residual can indicate extra O_3 that is not accounted for by the meteorology.
- Residual = observed MDA8 - predicted MDA8

Camalier et al 2007; CARB 2011; Sun et al 2015; Gong et al 2017; 2018; Jaffe et al 2018; McClure and Jaffe 2018; Gao et al 2020.

Contribution of smoke to MDA8 in SLC

	Obs MDA8 (ppb)	Smoke contribution from stat model (ppb)	Smoke contribution from photochem model (ppb)
9/11/2022	80	21	21
9/12/2022	68	11	13



SAMOZA summary

1. **We collected a great set of observations in summer 2022 that will feed into both photochemical and statistical models and General Additive Models (GAMs).**
2. **Summer 2022 was a modest smoke and O_3 year with 4-9 exceedance days at UTC, Bountiful and Hawthorne sites. About 1/3 of these exceedance days had smoke influence.**
3. **No evidence for bias in smoke with the std UDAQ UV instrument. But levels of smoke were modest in 2022 (max 1-hour $PM_{2.5}$ = 57 ug/m^3).**
4. **VOCs, especially formaldehyde, are strongly enhanced during smoke influence and these enhance O_3 formation adding 5-10 ppb to the MDA8.**
5. **Some differences in PTRMS and DNPH measurements of formaldehyde.**
6. **The "Mystery day" (9/3/22) had high formaldehyde and O_3 in the morning, resulting in an MDA8 of 76 ppb at UTC. This is probably a controllable source.**
7. **Our modeling for <u>non-smoke days</u> suggests that meeting the O_3 NAAQS in SLC will require reductions in VOCs by ~30% and/or reduction in NOx by ~60%.**

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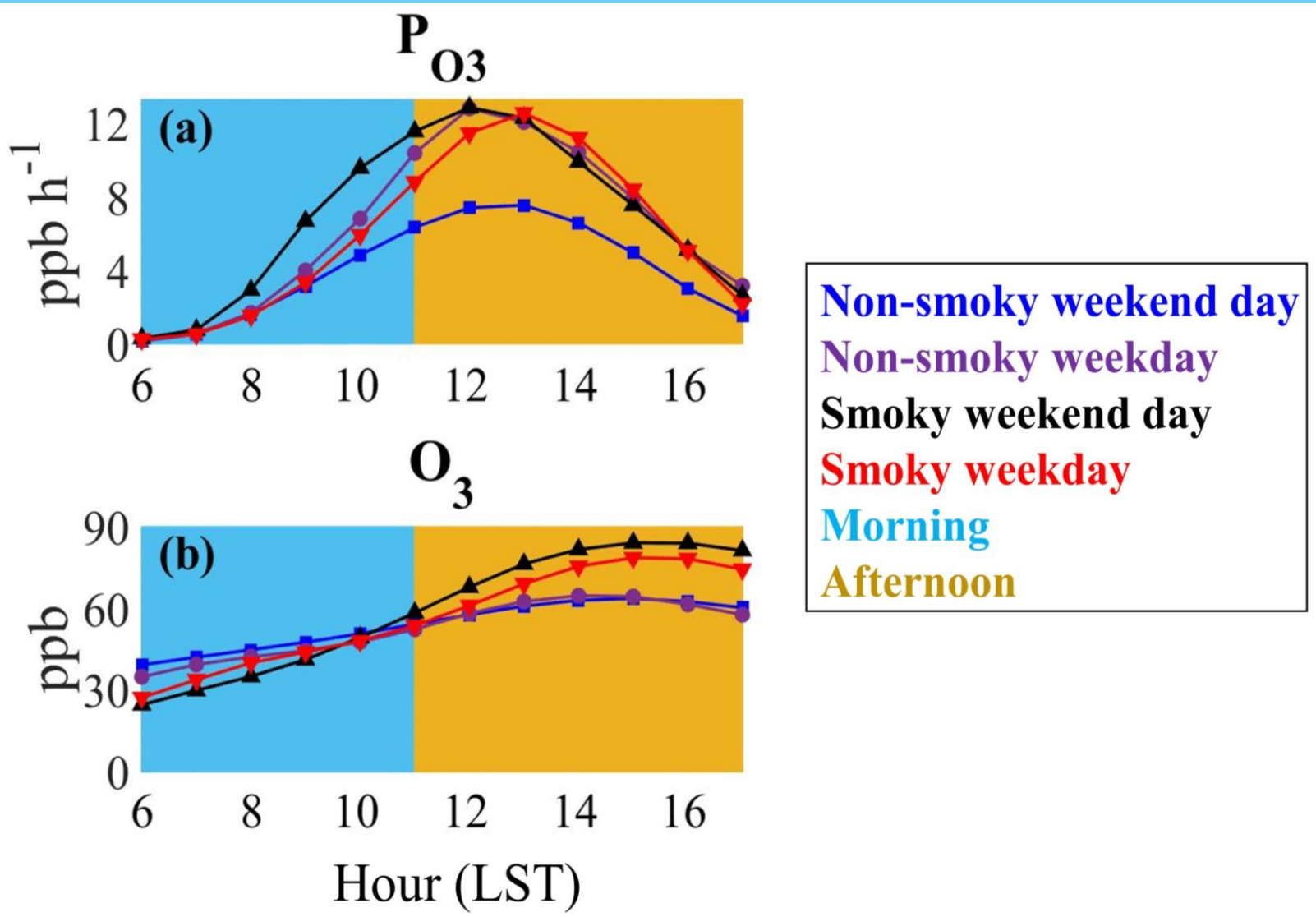
Extras

Tools to apply to smoke, photochemistry and EE cases

1. **Comparison with historical values (O_3, $PM_{2.5}$, VOCs, etc);**
2. **Satellite data (esp HMS, TEMPO, etc);**
3. **$PM_{2.5}$/CO ratio as indicator of smoke;**
4. **Statistical models (GAMs);**
5. **FOAM Photochemical model;**
6. **STILT fire footprint with PM and/or O_3.**

Preliminary Results: Modeled P_{O3} and O_3

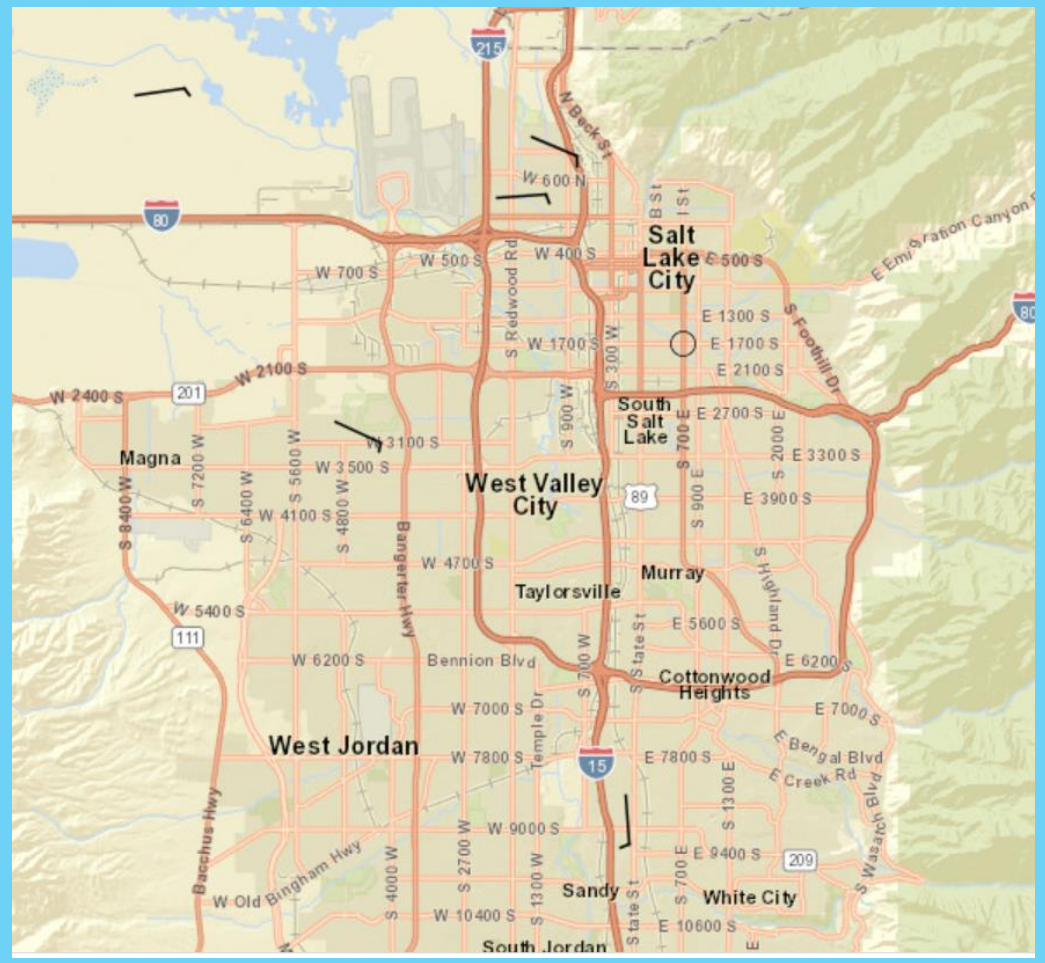


- O_3 in urban-smoke is enhanced due to local photochemical production.
- NOx appears to be largely from local sources (not the smoke).
- Smoke impacts are different on weekends vs weekdays and likely also different in high/low NOx environments.
- While many VOCs are important, formaldehyde seems to be the leader of the pack.

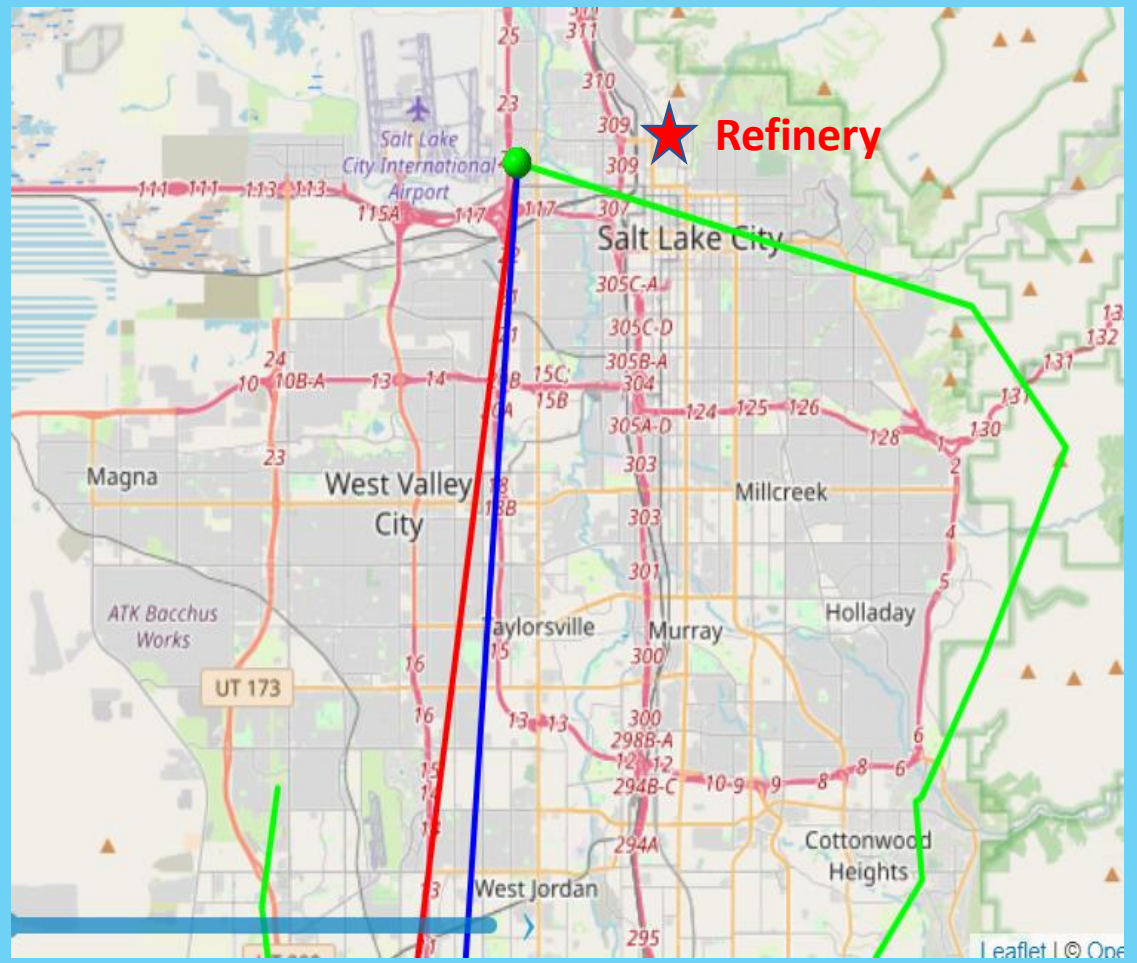
Average daily 1-hour max NO_2, Aug-Sept 2022 (regional mean is 20.5 ppb)

	Copper View	Erda	Haw-thorne	Herri-man	Inland Port	Lake Park	South SL (NR)	Rose Park	UTC
Mean (ppb)	22.9	6.9	18.1	9.3	20.5	19.7	31.7	24.3	31.0
% of regional mean	112	34	88	46	100	96	155	119	151

So what caused the spike in CH_2O on 9/3/2022 ?



Local wind barbs at 9am LST.
At UTC WDs are generally 90-160^0 at same time.



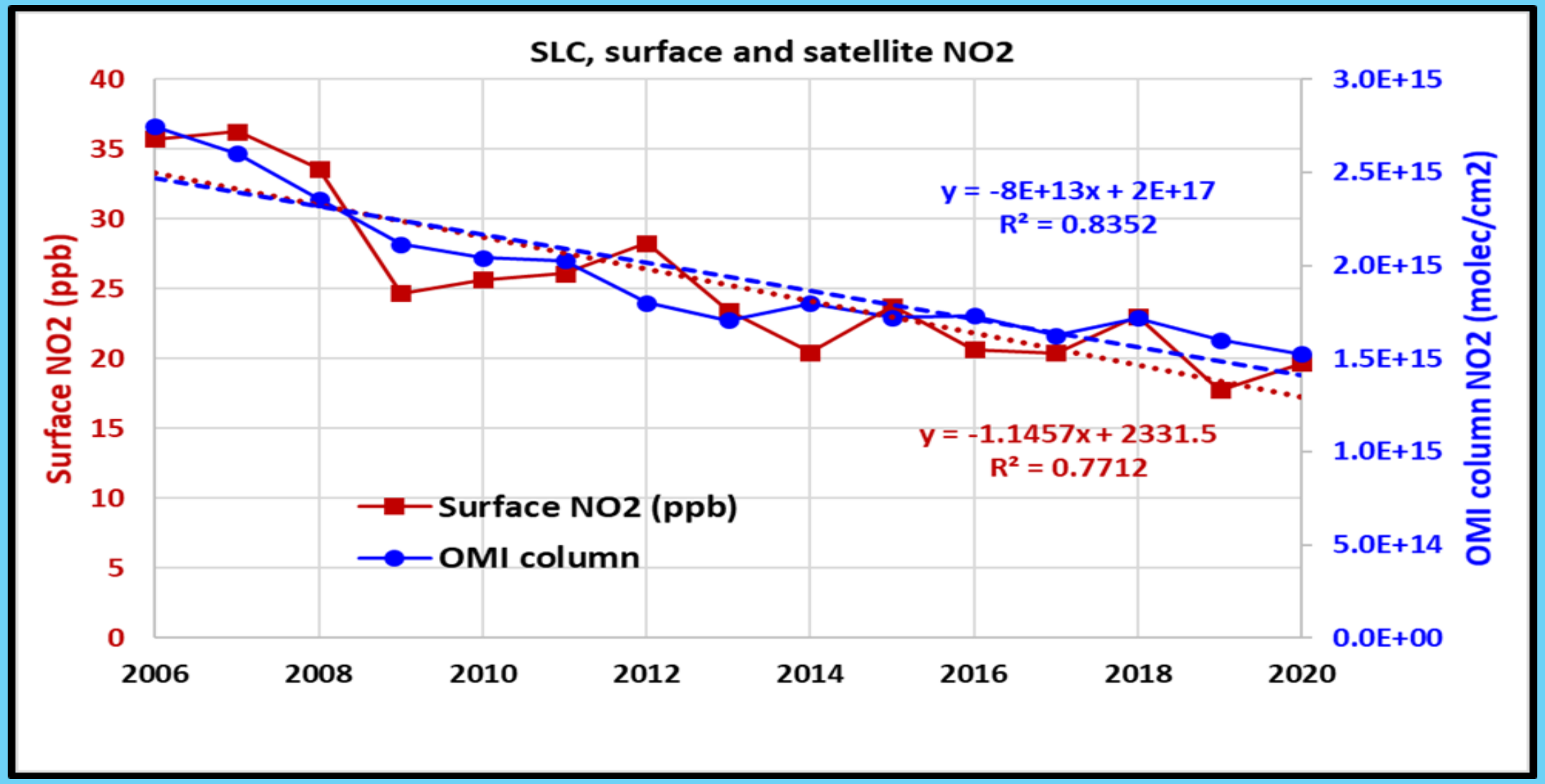
Hysplit back trajectory arriving at UTC at 9am LST using 3km res HRRR met data. Red, blue and green trajectories were initialized with arrival heights of 100, 200 and 500 MAGL, respectively.

Primary emissions of formaldehyde in Utah per NEI 2014

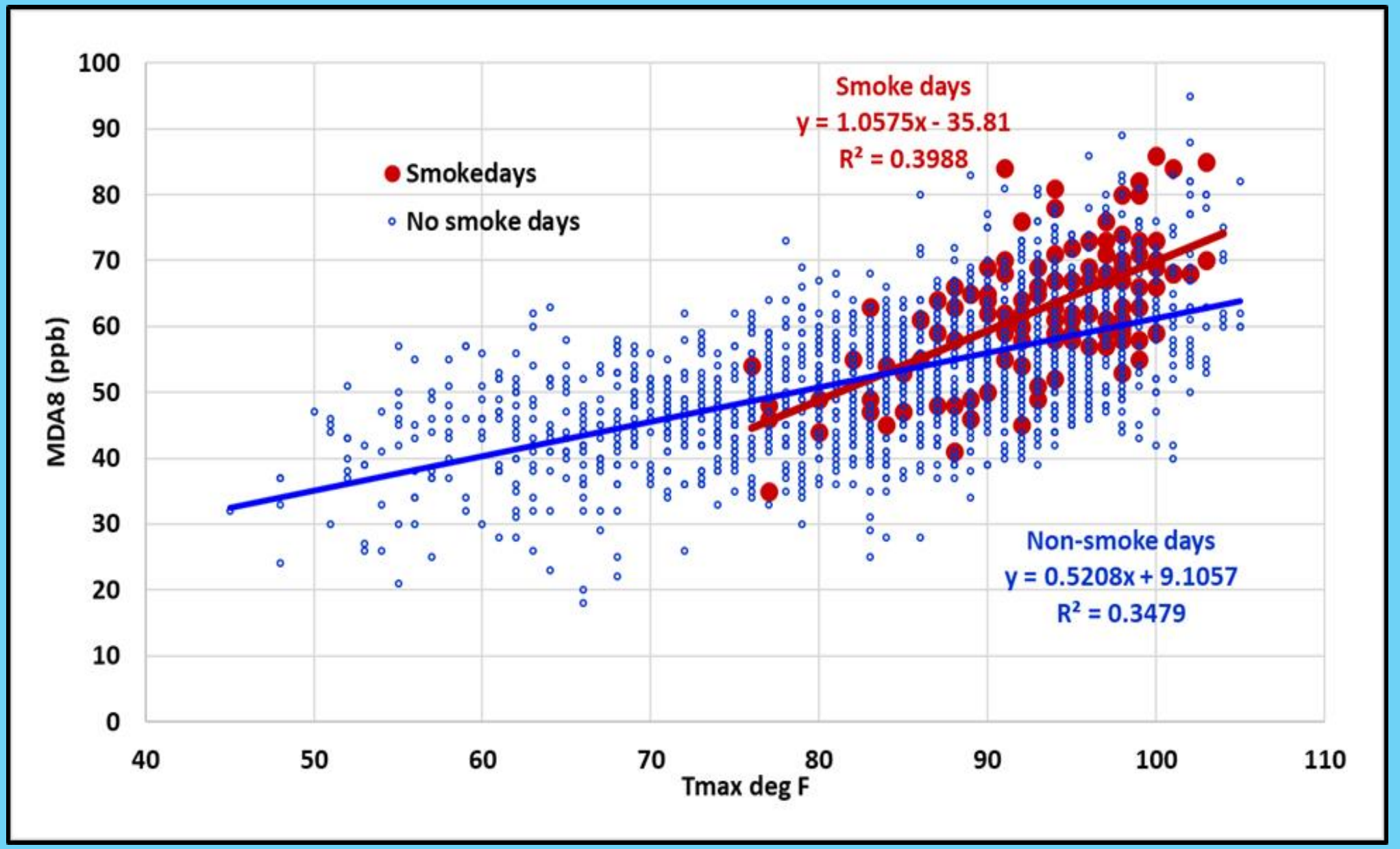
3.34E+07	Total emissions (lbs)
54.64	Biogenic
39.40	Fire %
5.96	Industry %

Facility	Tons per year	Location
EnerVest Operating LLC - Interplanetary Compressor Station	12.72	NESW, Sec. 13, T12S-R14E
Salt Lake City Intl Airport	12.33	Unknown
EnerVest Operating L.L.C- Sage Brush Flat Compressor Station	12.12	Remote location, Carbon County
PacifiCorp Energy- Lake Side Power Plant=OREM	11.81	1850 N Pioneer Ln
MICHAEL AAF (DUGWAY PROVING GROUND)	7.39	Unknown
Hill AFB Airport	7.3	Unknown
PacifiCorp- Currant Creek Power Plant	6.6	2096 West 300 North
Salt Lake City Muni 2	2.5	Unknown

Changes in SLC NO_2: 2006-2020 (May-Sept)



SLC smoke and non-smoke MDA8 vs daily max temp, May-Sept.

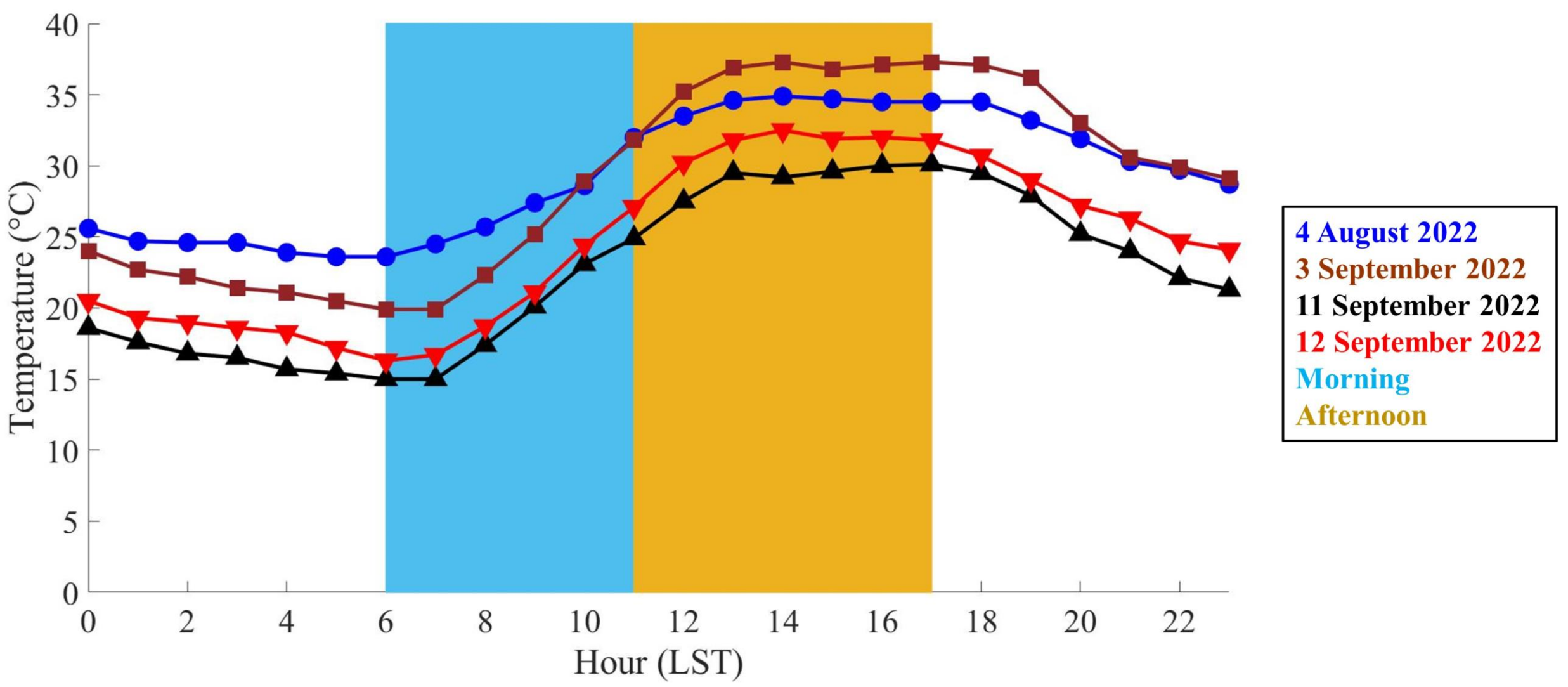


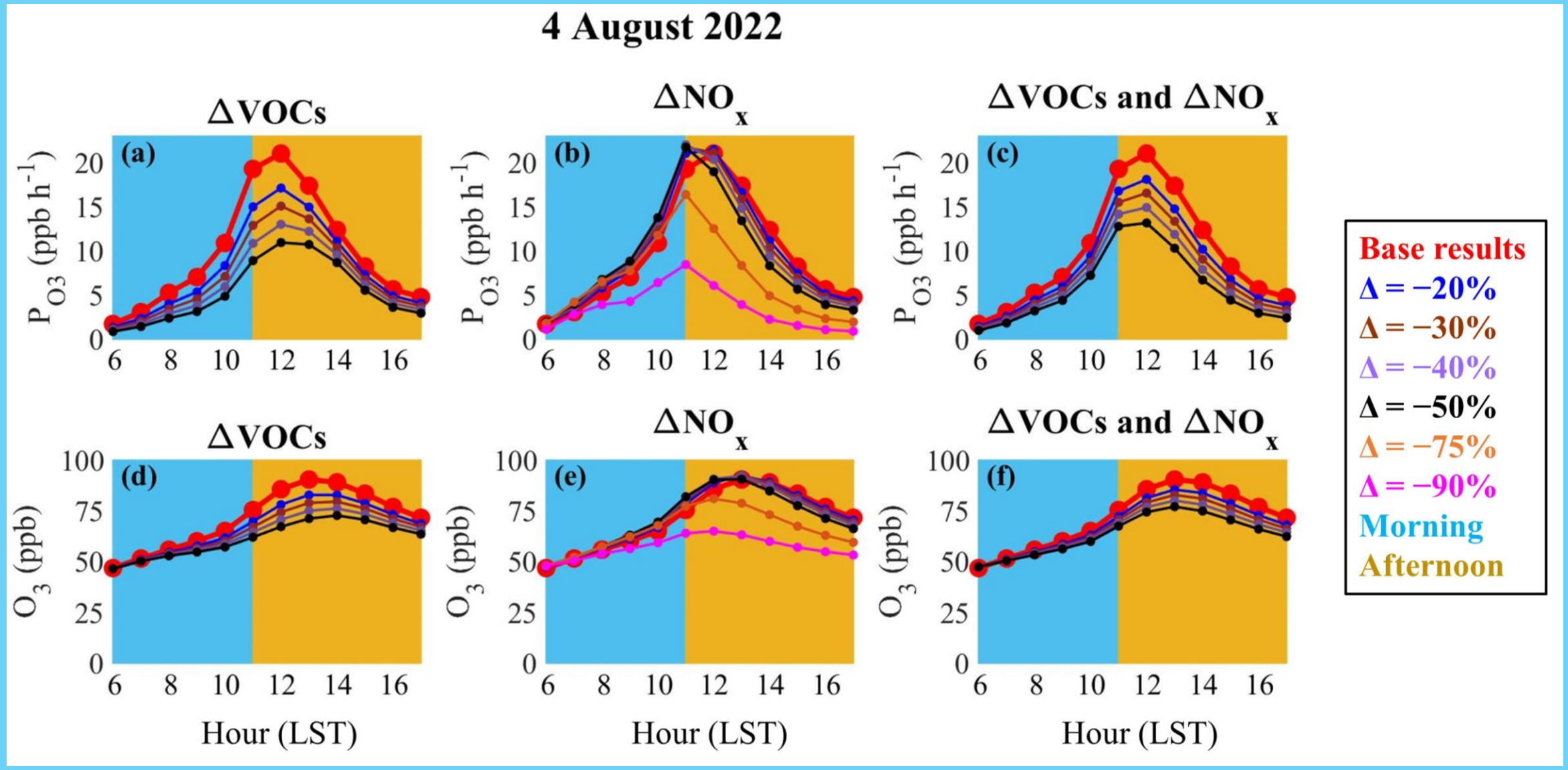
Data from SLC Bountiful site: May-Sept 2006-2018

Smoke days are warmer, but have more O_3 than expected for that temp.

Jaffe 2021

Observed Temperatures




4 August 2022
ΔVOCs
ΔNO$_x$
ΔVOCs and ΔNO$_x$
(a)
(b)
(c)
(d)
(e)
(f)
P$_{O3}$ (ppb h^{-1})
O$_3$ (ppb)
Hour (LST)
Base results
Δ = −20%
Δ = −30%
Δ = −40%
Δ = −50%
Δ = −75%
Δ = −90%
Morning
Afternoon