Mitigating Ozone and Secondary Products from a 222 nm Germicidal Lamp Using Scrubbers

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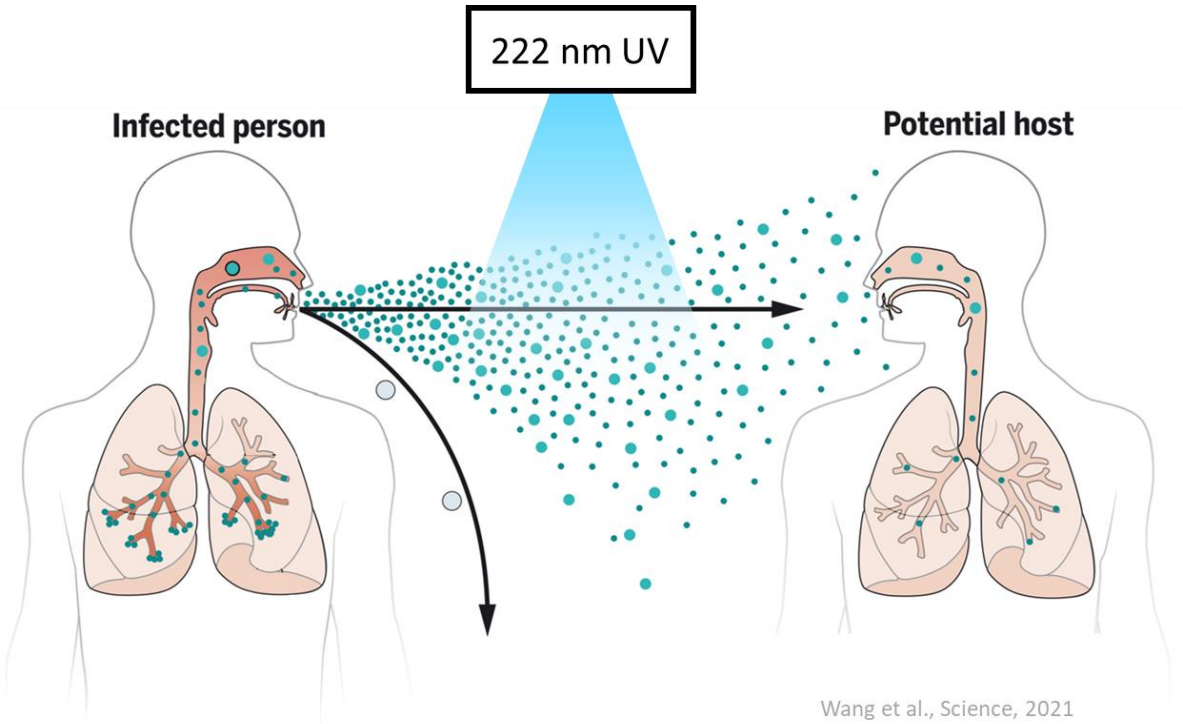
[4]OSLUV

[5]Blueprint Biosecurity

Germicidal UV (GUV) has health benefits

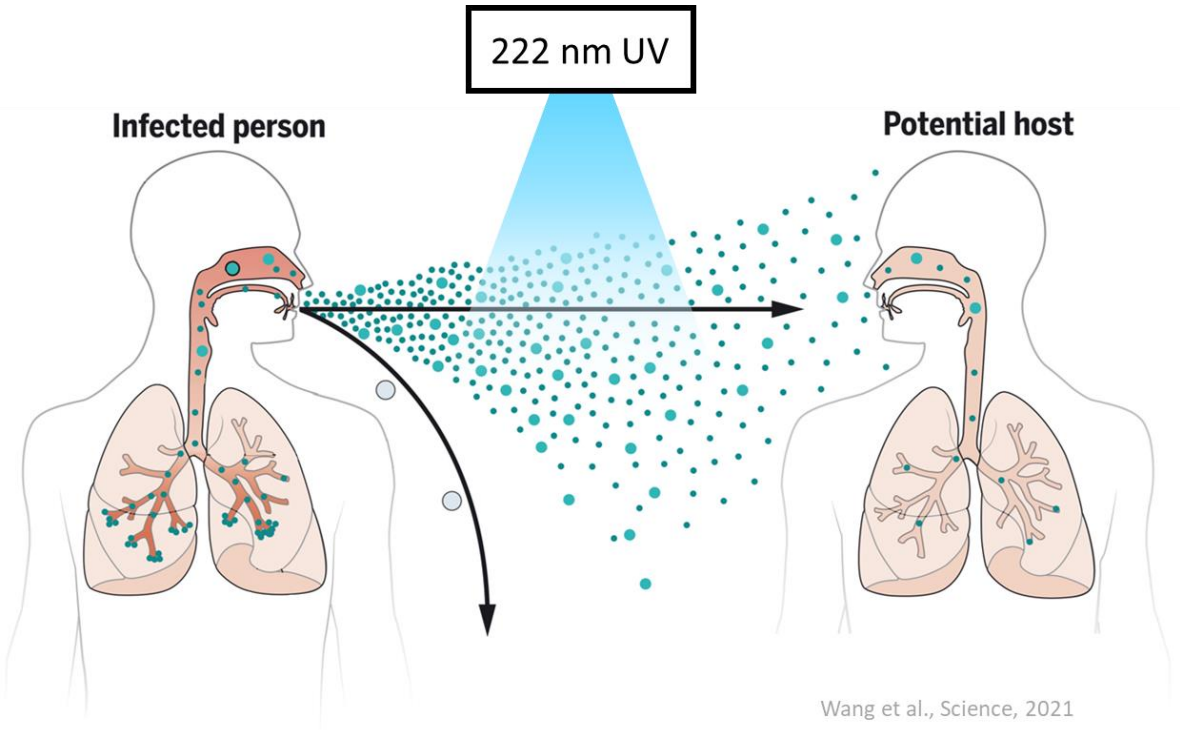
222 nm light effectively inactivates airborne pathogens while being safe for human exposure



Wang et al., Science, 2021

Germicidal UV (GUV) has health benefits with some potential drawbacks

222 nm light effectively inactivates airborne pathogens while being safe for human exposure



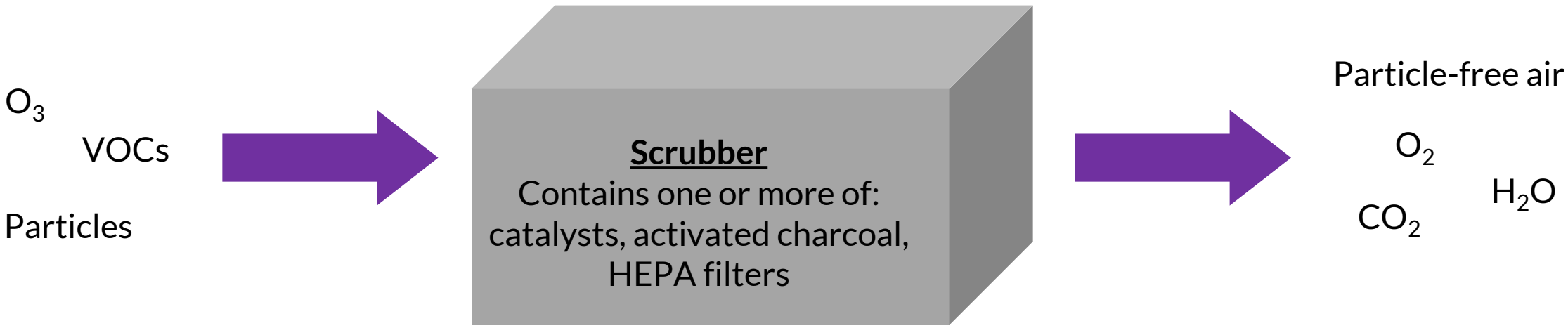
Wang et al., Science, 2021

But initiates unwanted chemistry…

$$O_2 + h\nu_{\lambda<242nm} \rightarrow O + O$$
$$O_2 + O + M \rightarrow O_3 + M$$
$$O_3 + h\nu_{\lambda<370nm} \rightarrow O_2 + O(^1D)$$
$$O(^1D) + H_2O \rightarrow 2OH$$
$$\text{Alkene} + O_3 \rightarrow OH + \text{other products}$$

Scrubbers pose opportunity to mitigate negative effects

Commercially available air cleaners ("scrubbers") can directly remove harmful byproducts



Is a commercially available ozone scrubber a viable solution?

CDA-250 Ozone Scrubber from Oxidation Technologies
Uses manganese oxide catalyst on aluminum honeycomb
Advertised to convert O_3 to O_2

- How well does this work to remove ozone produced by GUV?
- How does it behave when VOCs are present?
- Are there any side effects to be considered?

Experimental Setup

- Clean air (20LPM total)
- C_6F_6 (dilution tracer)
- Limonene

*no seed

222 nm lamp

~3 µW/cm^2

Environmental Chamber
7.5 m^3
20 °C
35% RH

Gas-phase inorganic species
- O_3 monitor
- NO_x monitor
- CAPS NO_2 monitor

Gas-phase organics
- GC-FID (limonene, C_6F_6)
- NH_4^+-CIMS (oxidized organics)
- FILIF (formaldehyde)

Particle-phase
- SMPS (particle size, number)
- AMS (aerosol mass, composition)

1) Running the scrubber alone

2) Running the scrubber with ozone

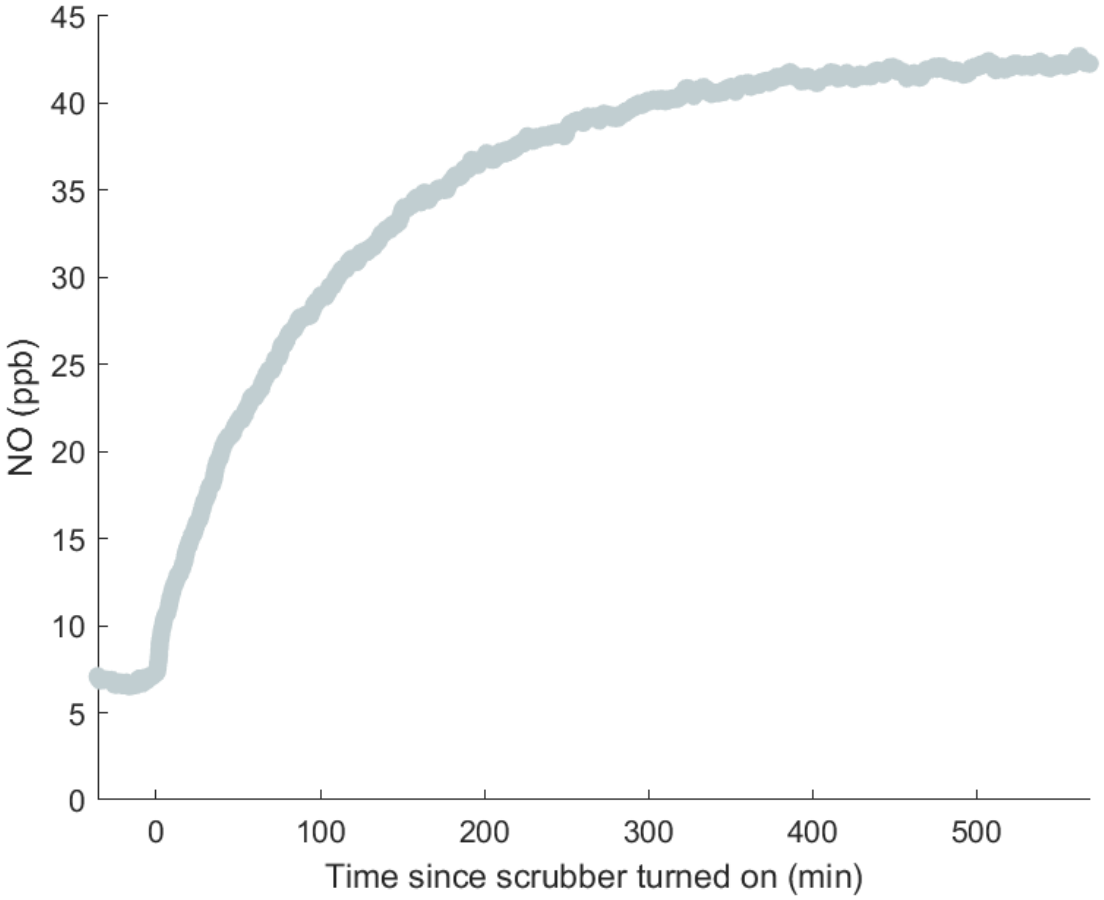
3) Running the scrubber with GUV

4) Running the scrubber with GUV + limonene

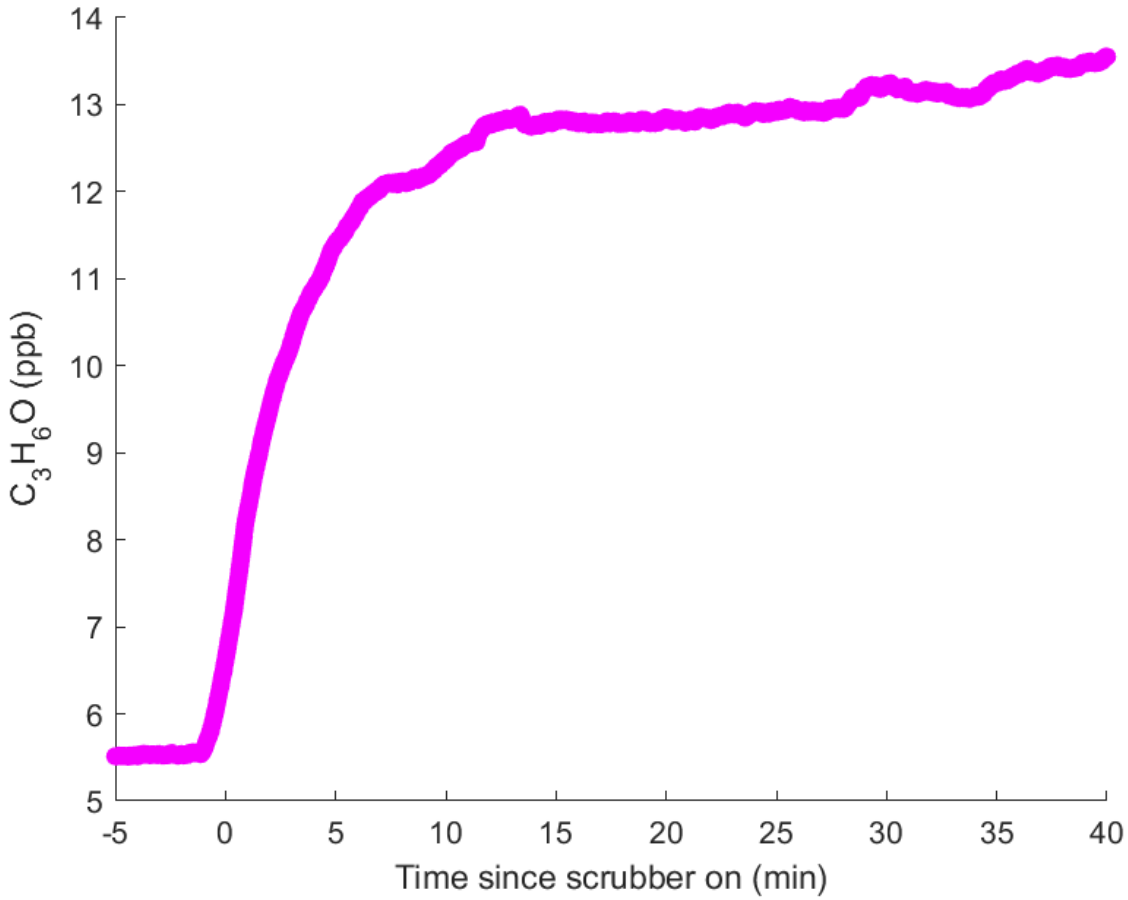
5) Running another scrubber (with GUV + limonene)

Scrubber emits NO and acetone

NO grows to a steady state of ~42 ppb



Acetone quickly increases by several ppb



1) Running the scrubber alone

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3) Running the scrubber with GUV

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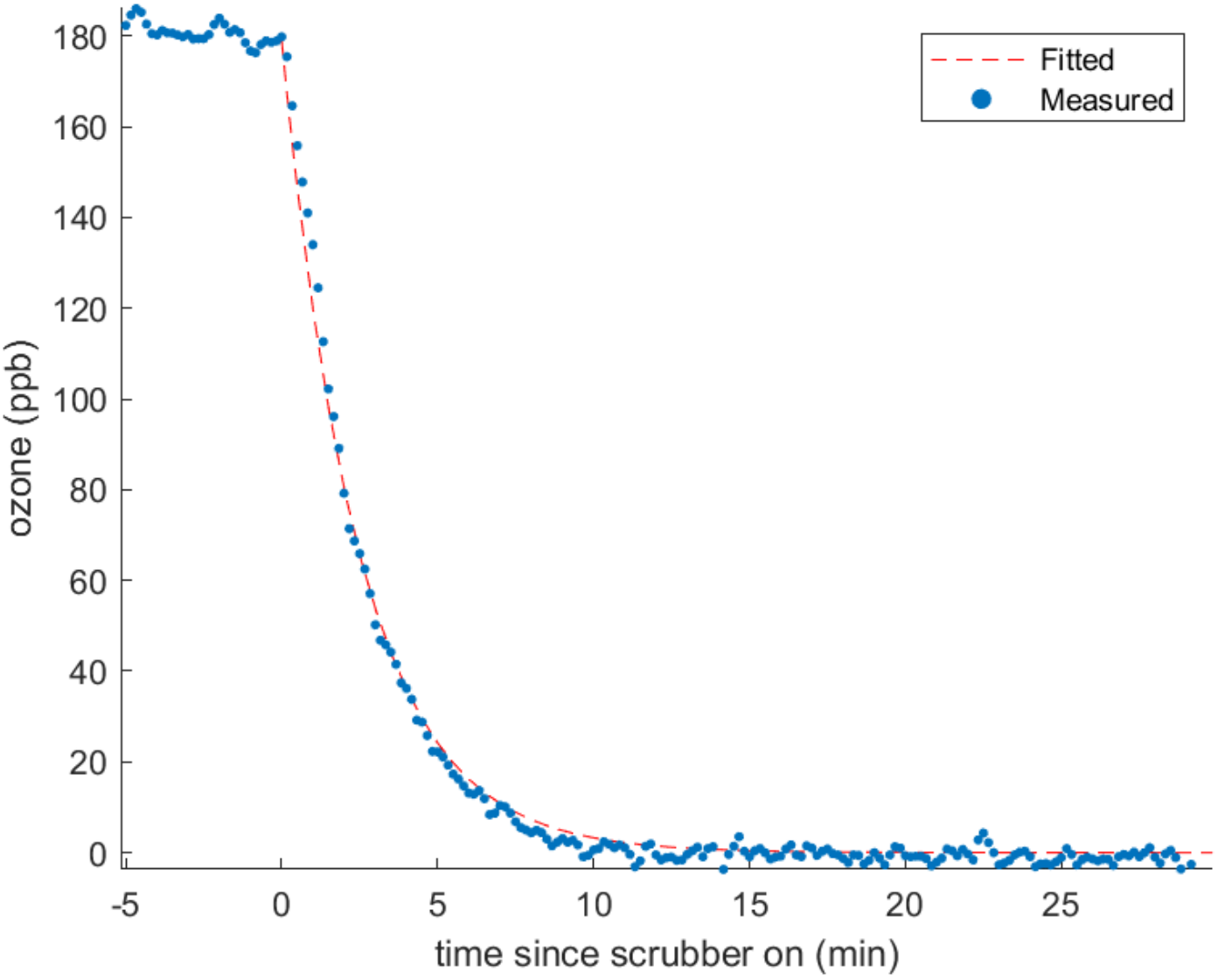
5) Running another scrubber (with GUV + limonene)

Scrubber quickly removes all of the ozone



Fitted rate: $k_{scrub} = 0.372\ min^{-1}$

1) Running the scrubber alone

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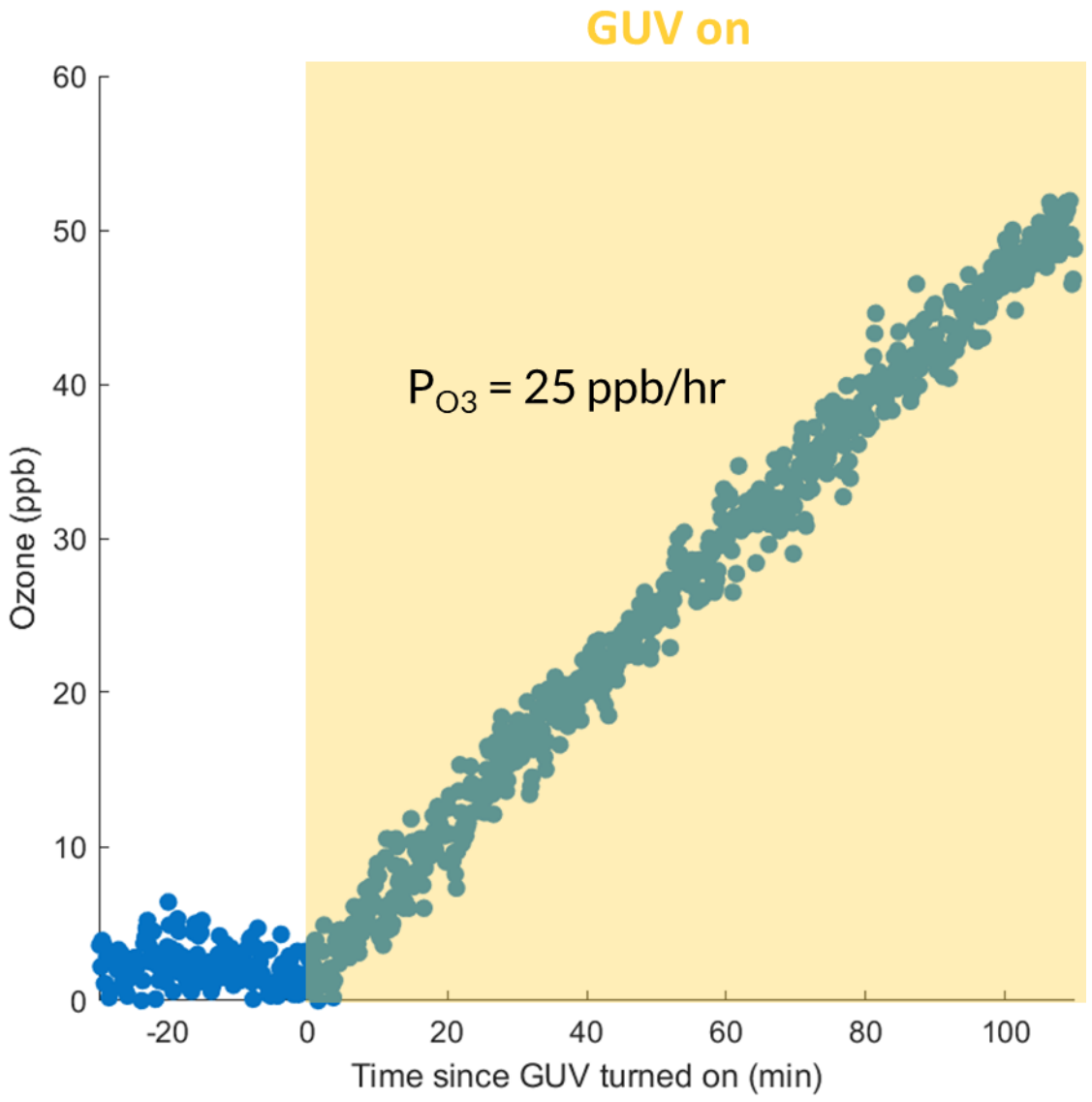
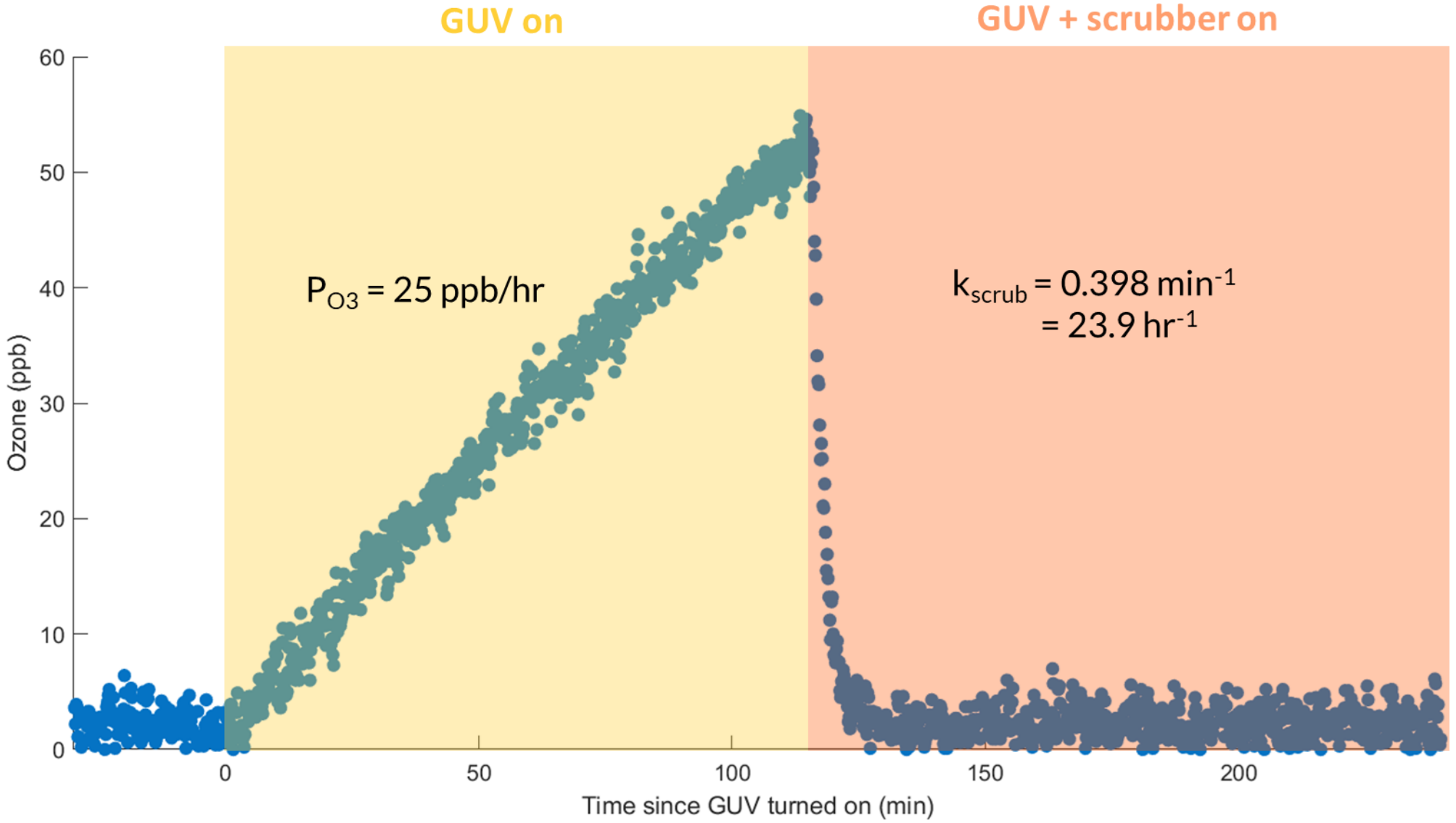
GUV produces ozone



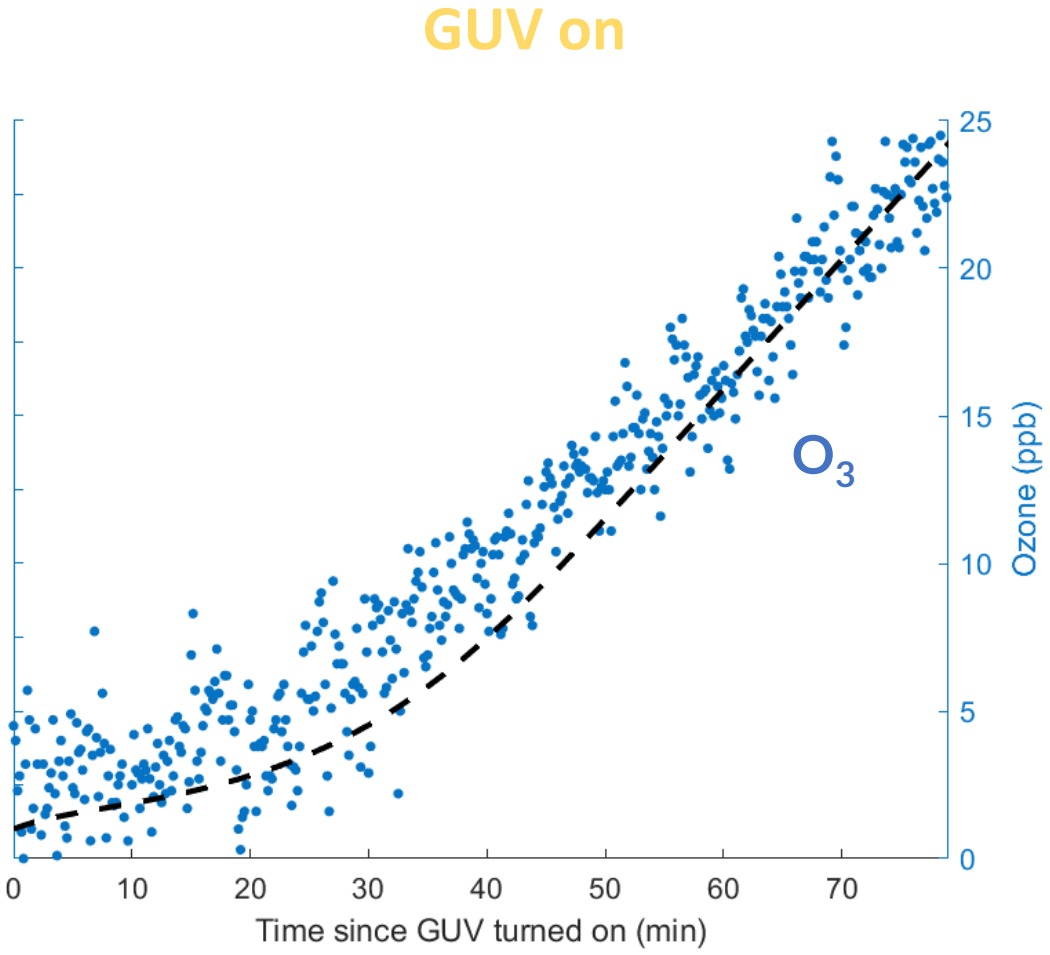
GUV produces ozone, which is removed when running scrubber concurrently



Modeling done with F0AM using MCM (+ added reactions for GUV and scrubber processes)

Ozone processes and reactions with NO_x are well-modeled

Modeling done with F0AM using MCM (+ added reactions for GUV and scrubber processes)



*dashed lines indicate model predictions

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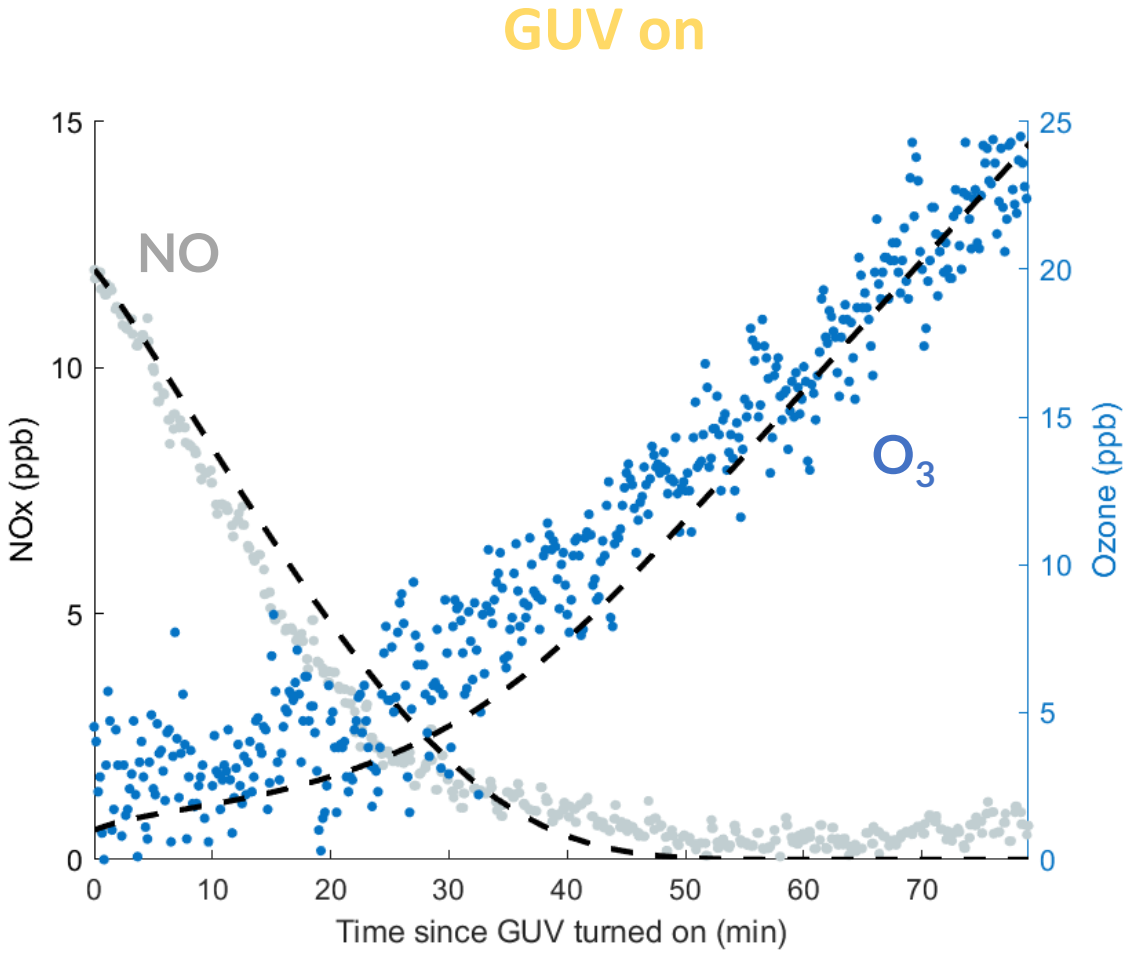

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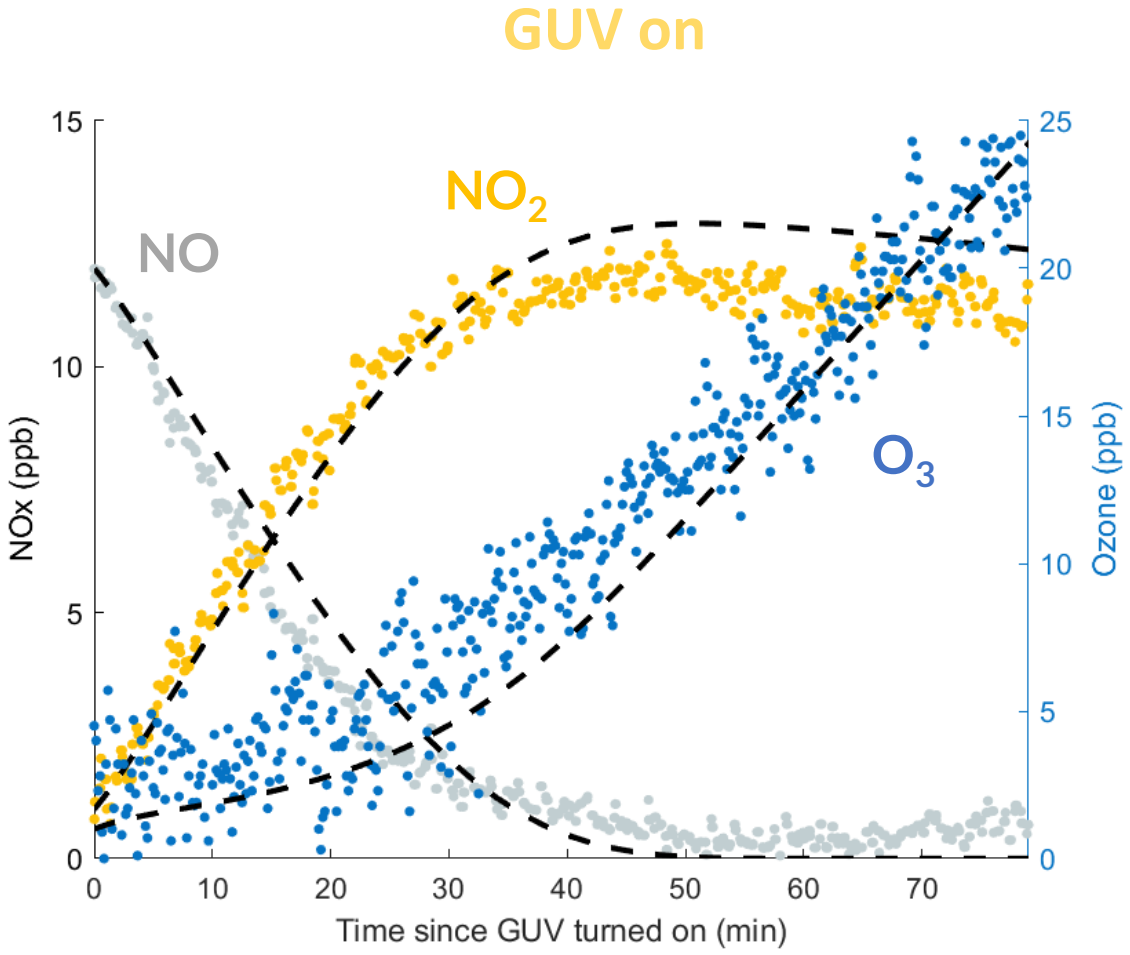

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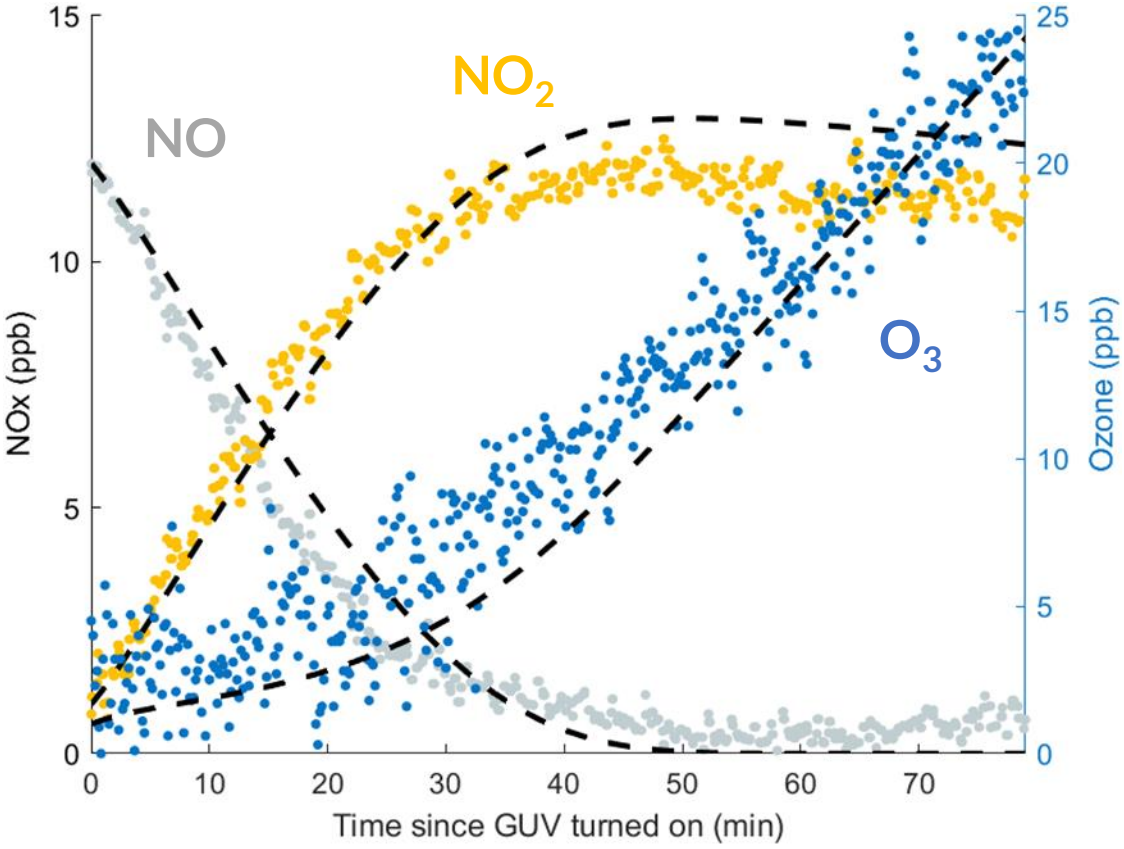
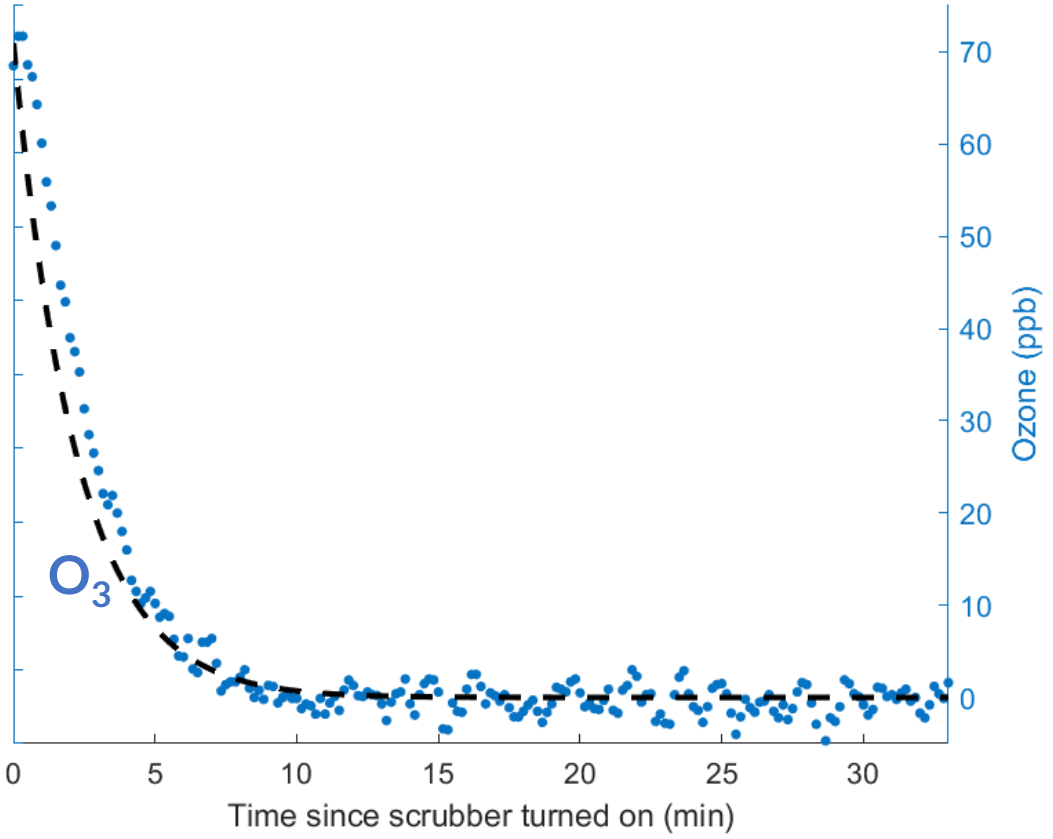
GUV on



Scrubber on



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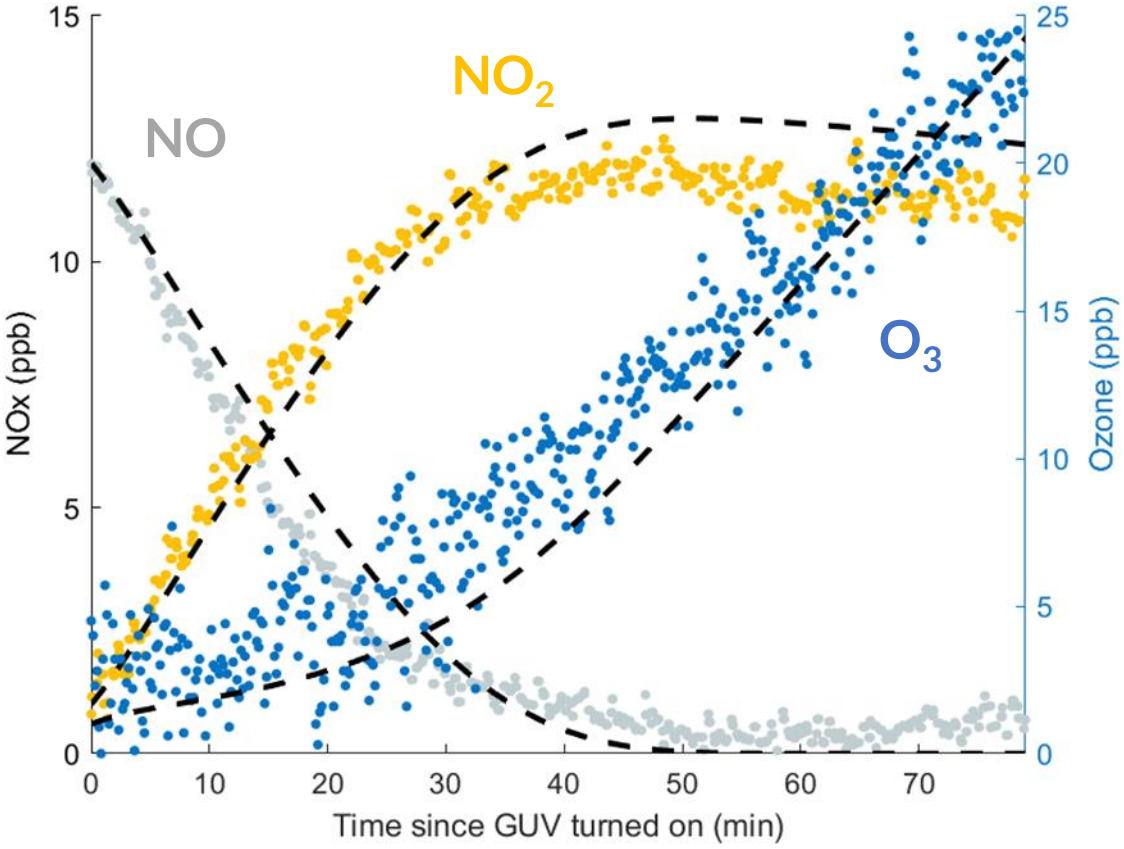
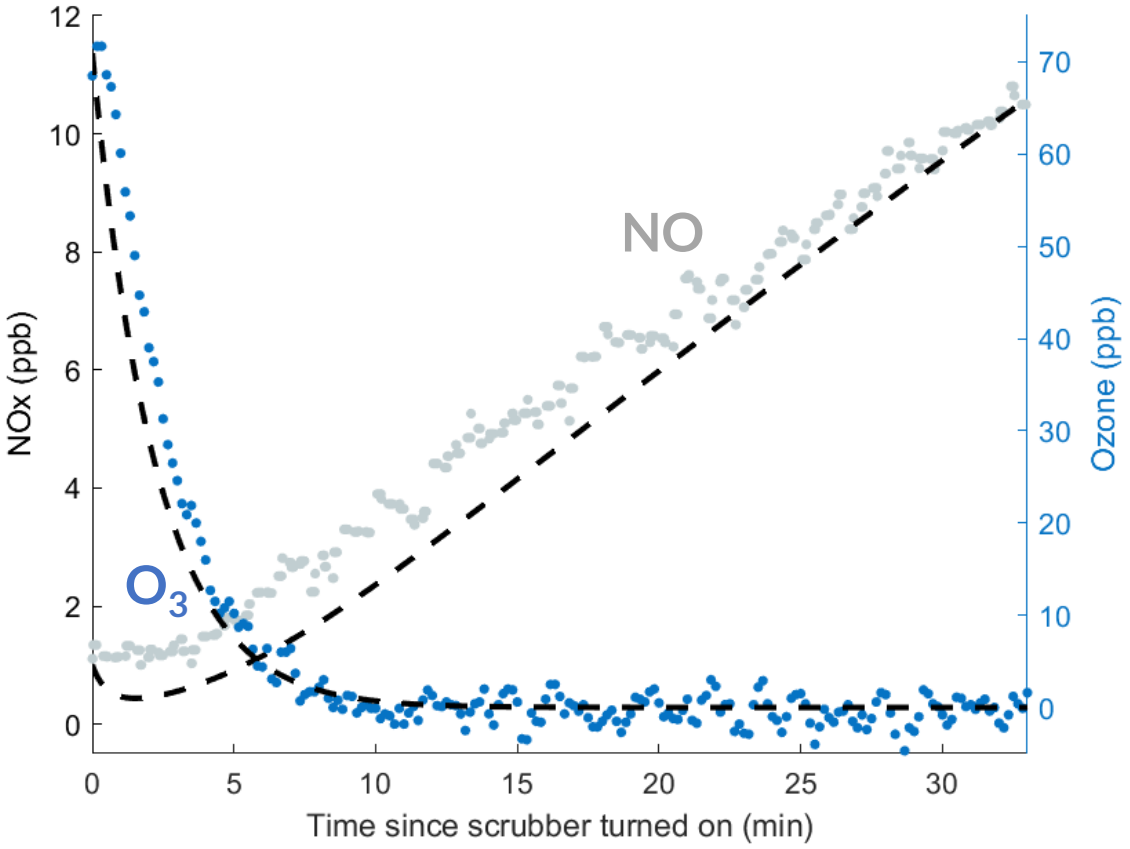
GUV on



Scrubber on



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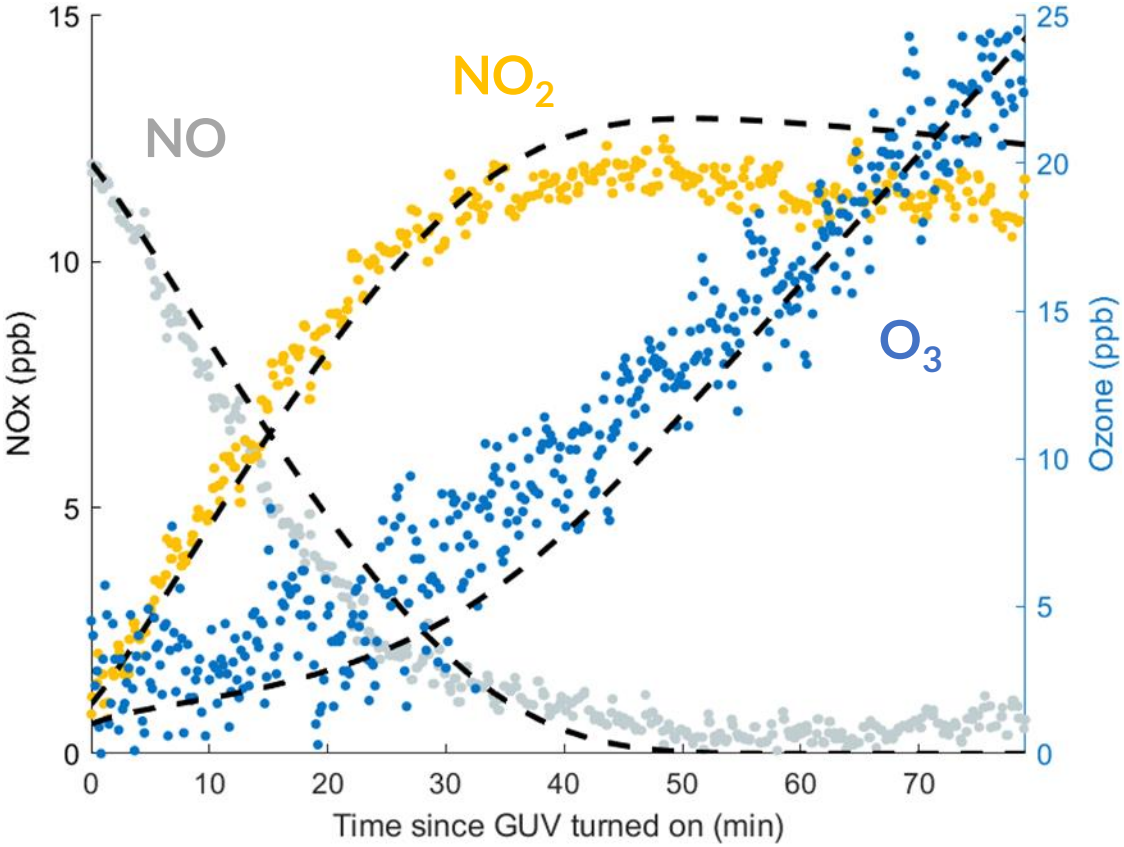
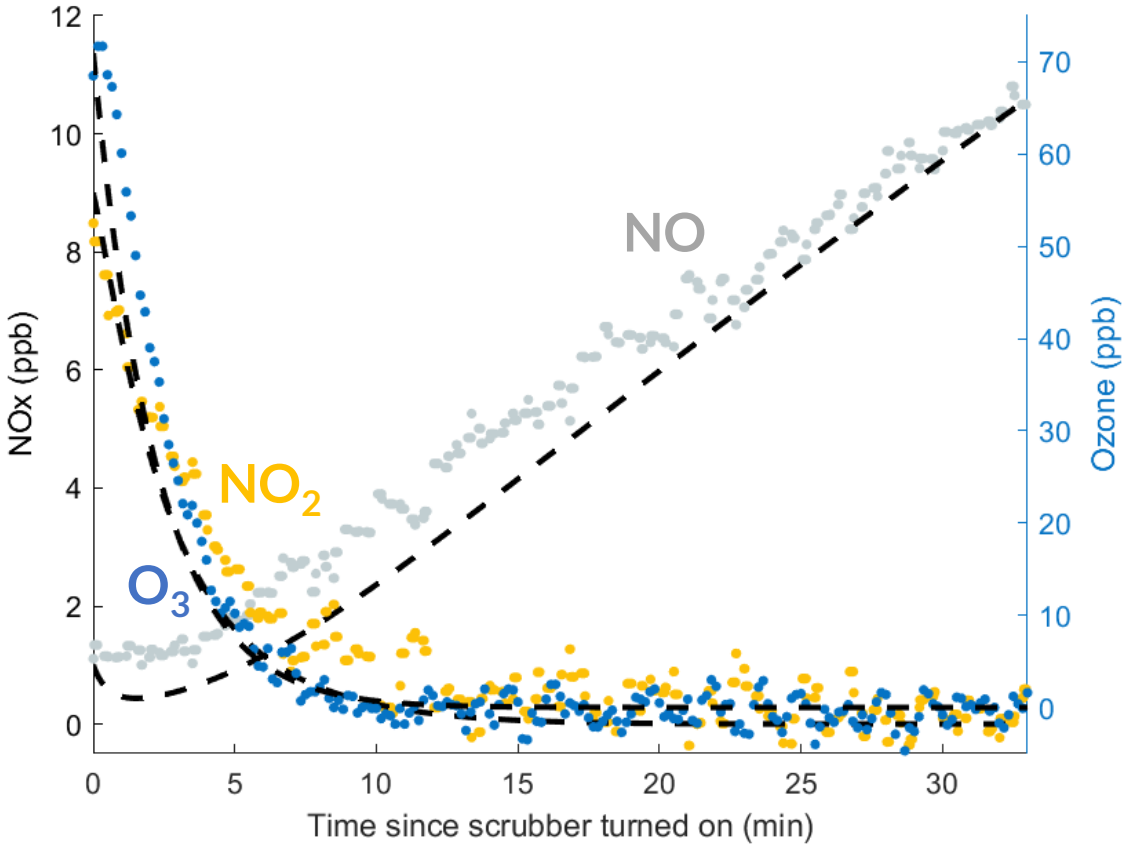
GUV on



Scrubber on



*dashed lines indicate model predictions

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2) Running the scrubber with ozone

3) Running the scrubber with GUV

4) Running the scrubber with GUV + limonene

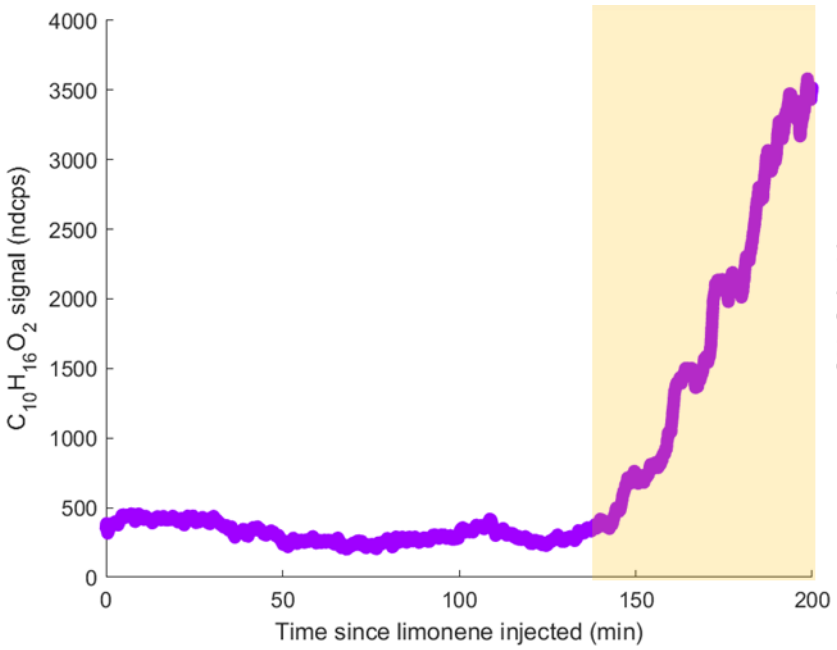
5) Running another scrubber (with GUV + limonene)

Adding limonene then turning on GUV forms expected products

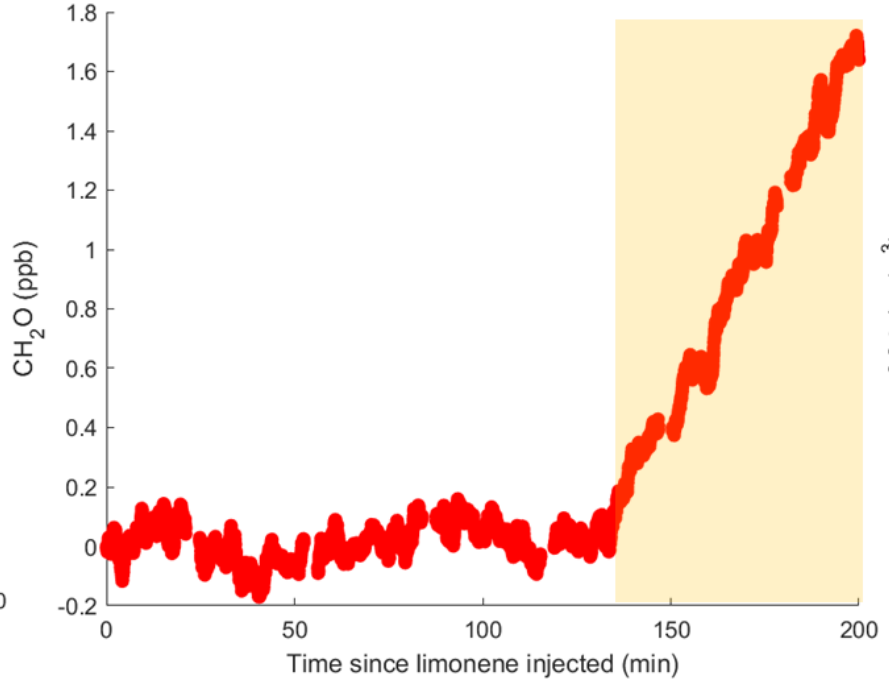
50 ppb limonene injection

GUV on

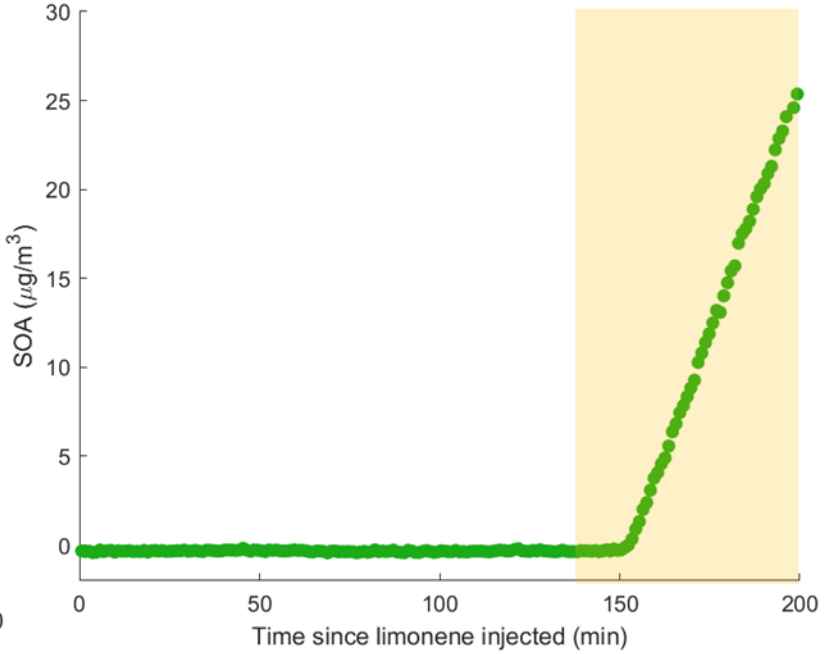
Limonaldehyde ($C_{10}H_{16}O_2$)



Formaldehyde



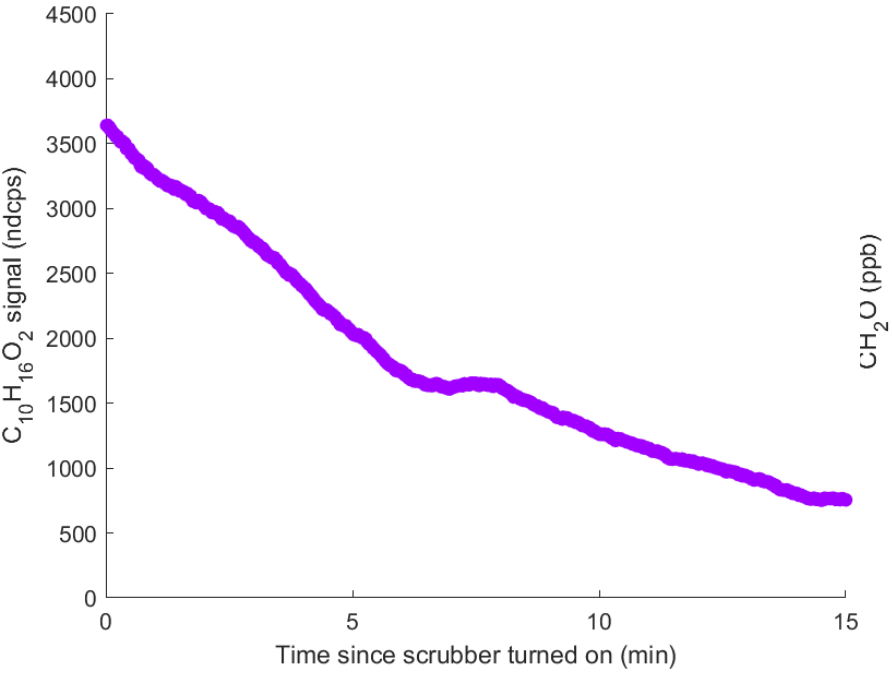
SOA



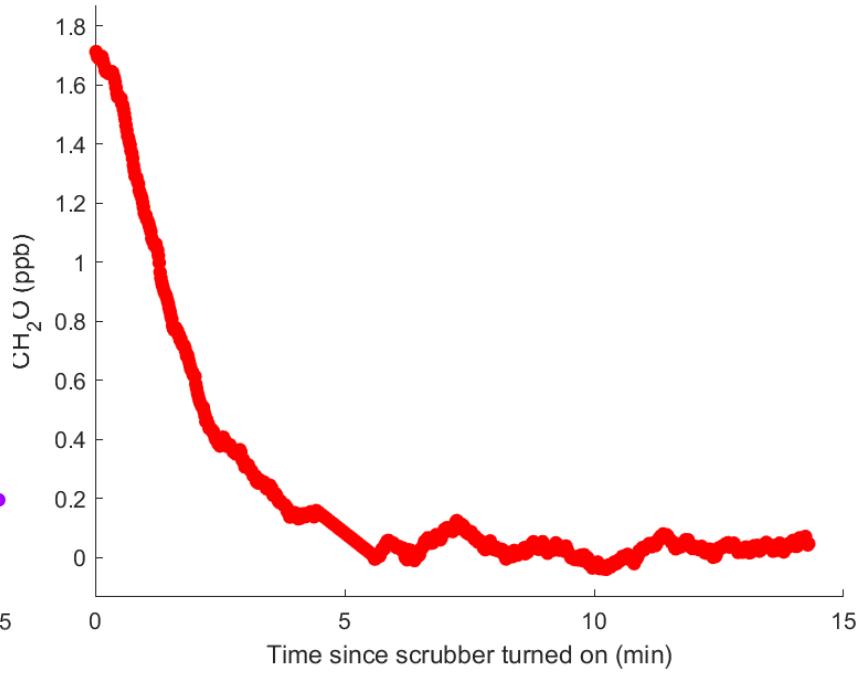
Oxidation products are removed by scrubber

Data corrected for dilution and wall loss

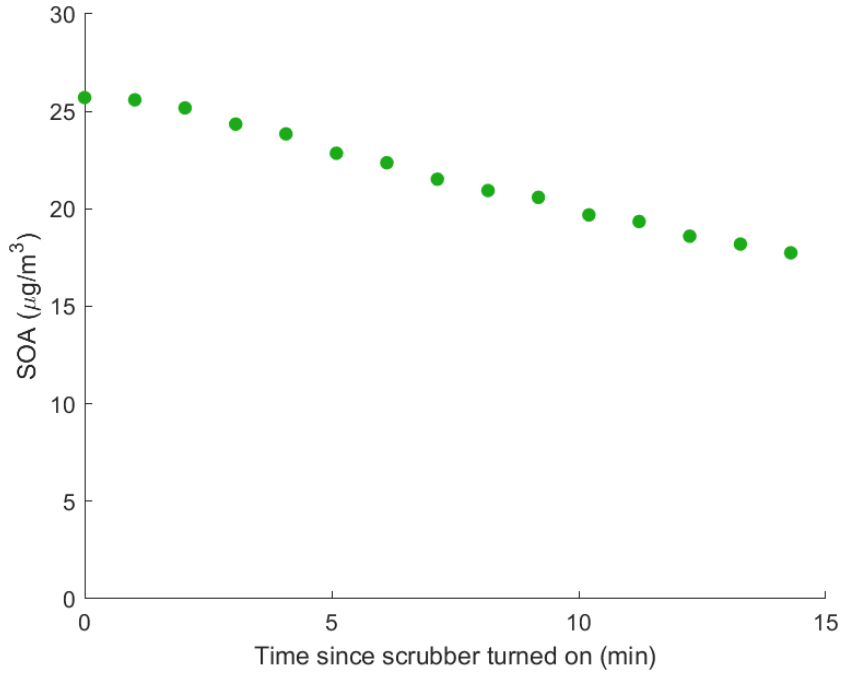
Limonaldehyde ($C_{10}H_{16}O_2$)



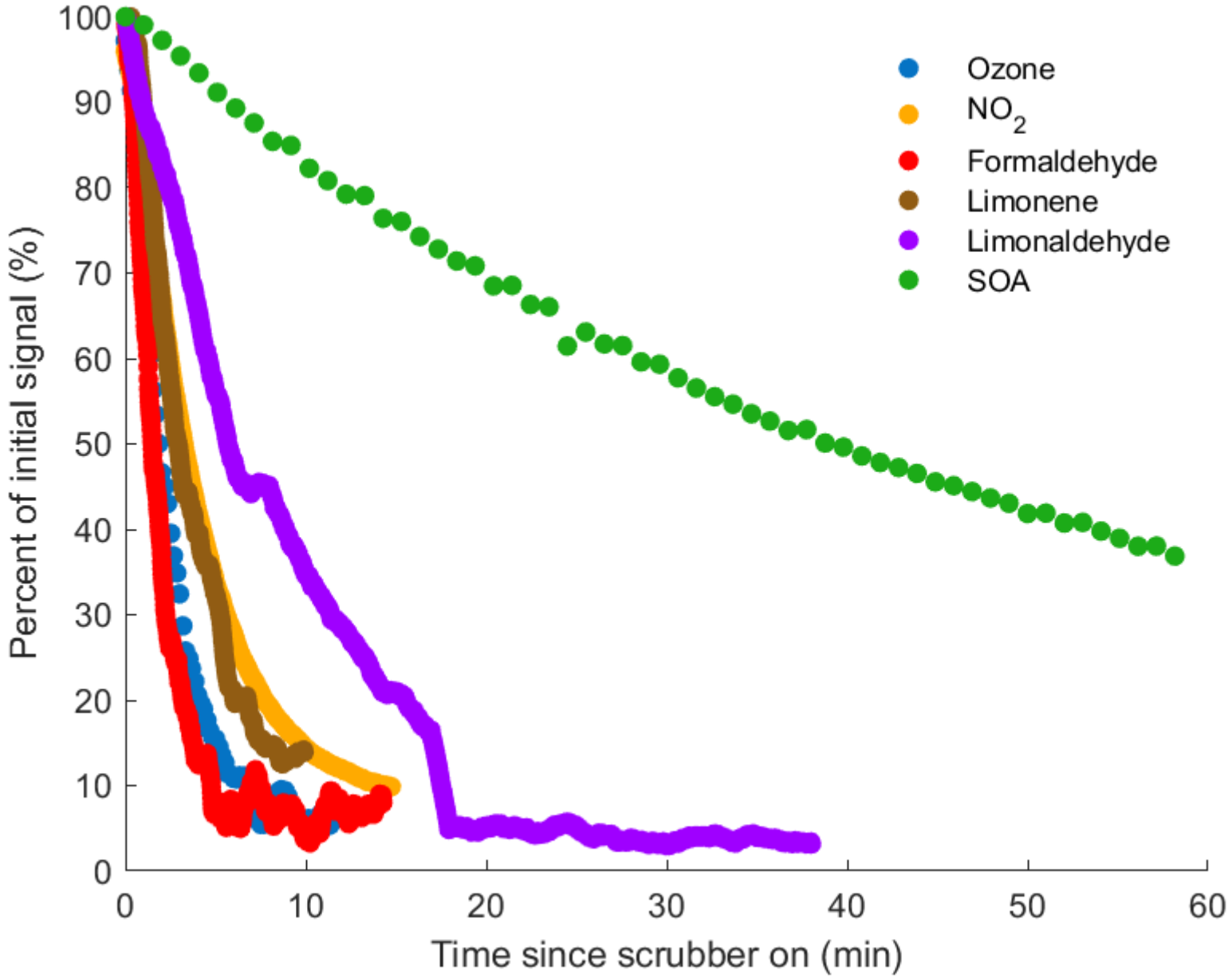
Formaldehyde



SOA



Scrubber works well to remove variety of species at varying rates



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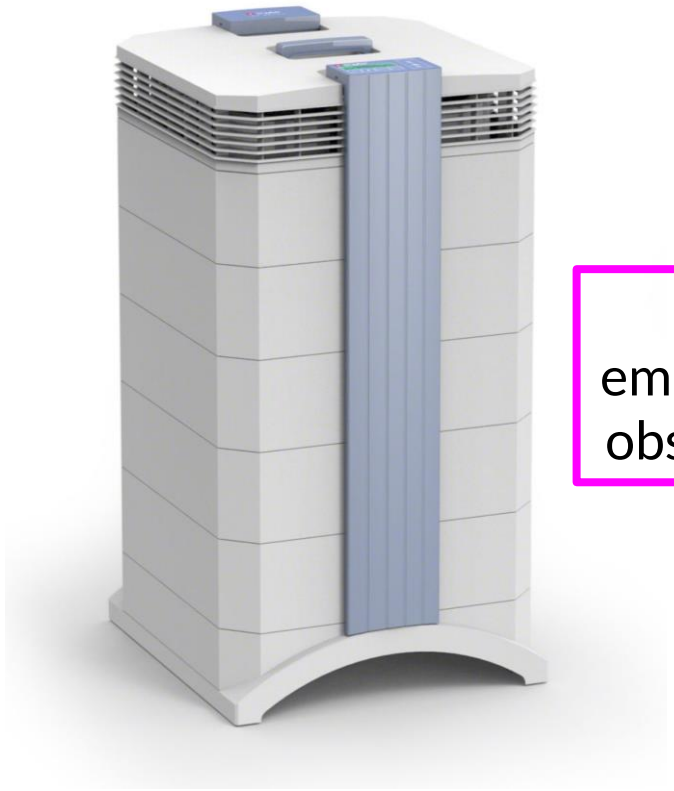
GC VOC unit from IQAir

Uses activated charcoal and HEPA filters

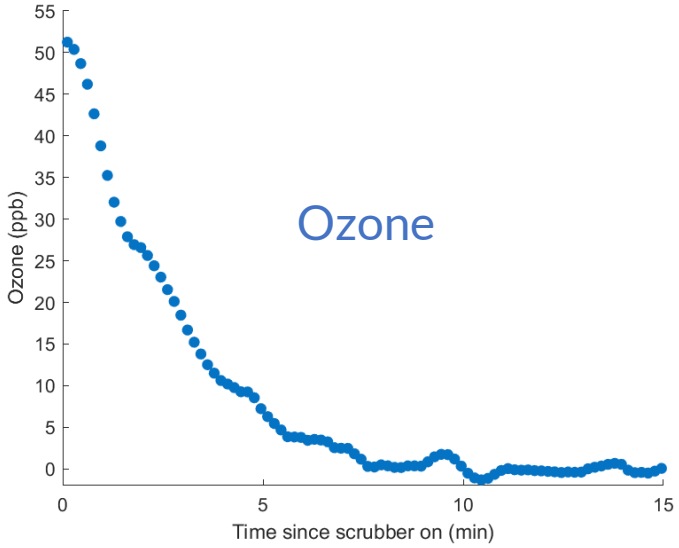
Advertised to remove VOCs and particles

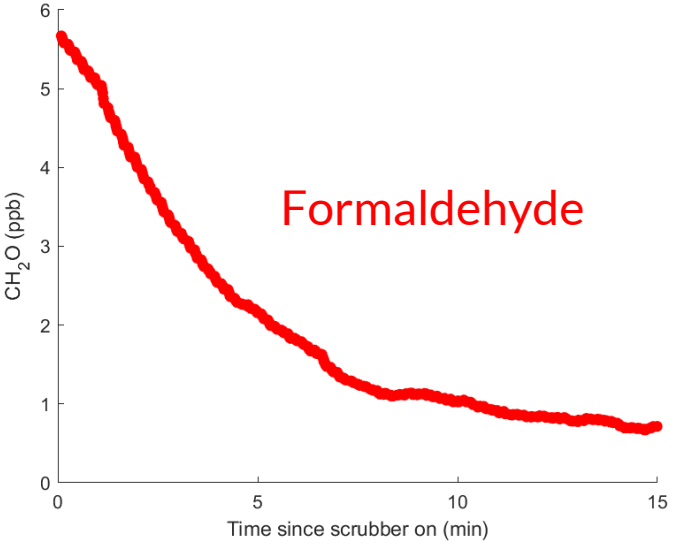
Using another commercially available scrubber allows species removal without undesired emissions

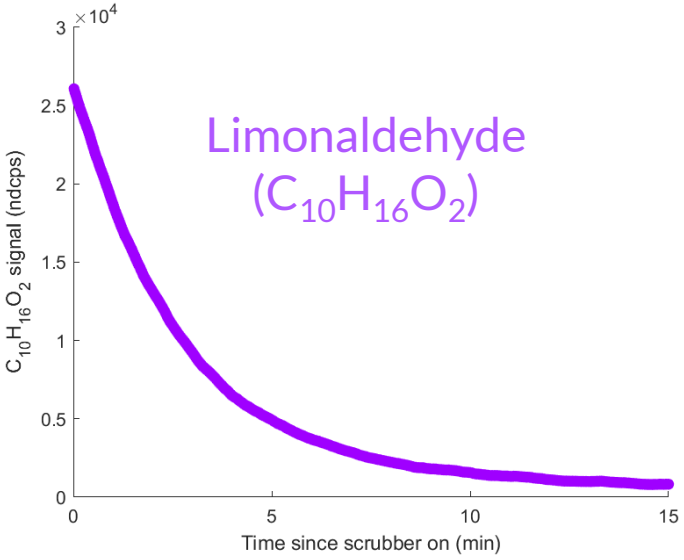


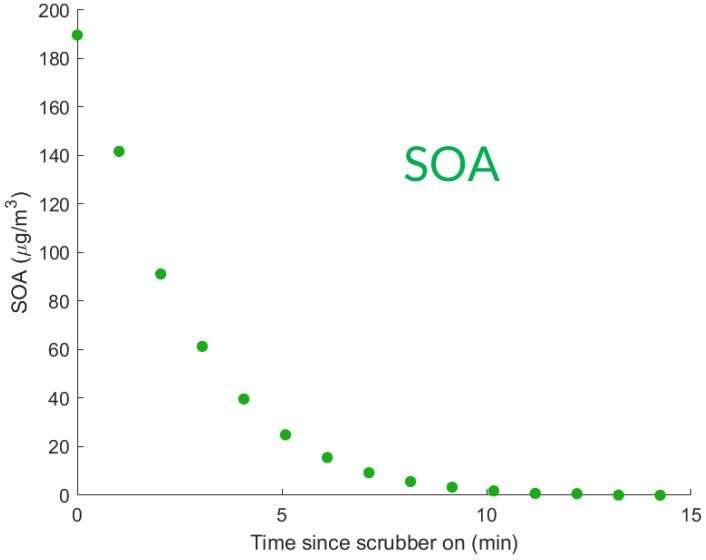
No emissions observed

GC VOC unit from IQAir
Uses activated charcoal and HEPA filters
Advertised to remove VOCs and particles



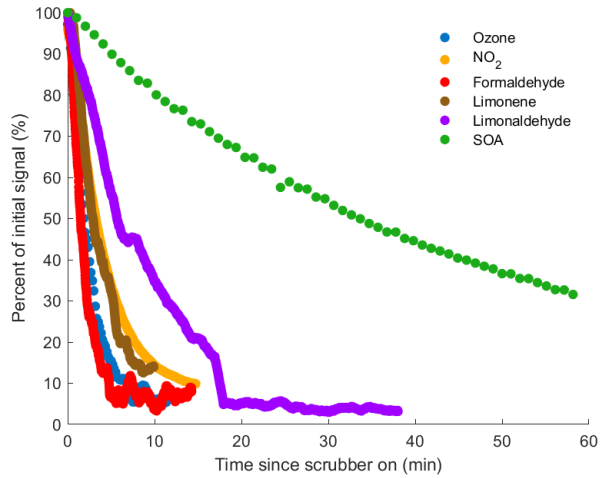






Summary

- Scrubbers are effective at removing multiple species produced when using GUV
  - Removal rates can vary
  - Processes and reactions are well-modeled



- Scrubber type is important to avoid unwanted emissions

Scrubbers can be a powerful tool to mitigate undesired effects of GUV and improve indoor air quality

Acknowledgements

Kroll Group

Keutsch Group

Yaowei Li

Jessica Smith

THE OSLUV PROJECT

Blueprint Biosecurity

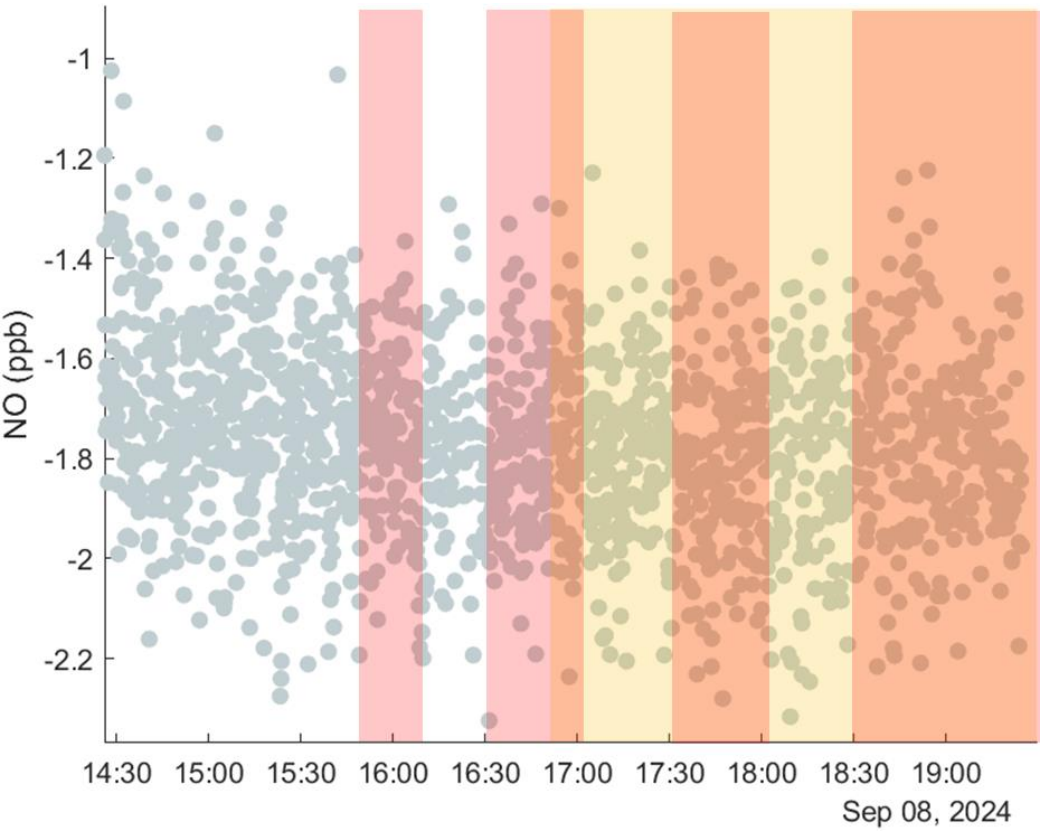
Supplemental slides

NO emitted from scrubber catalyst

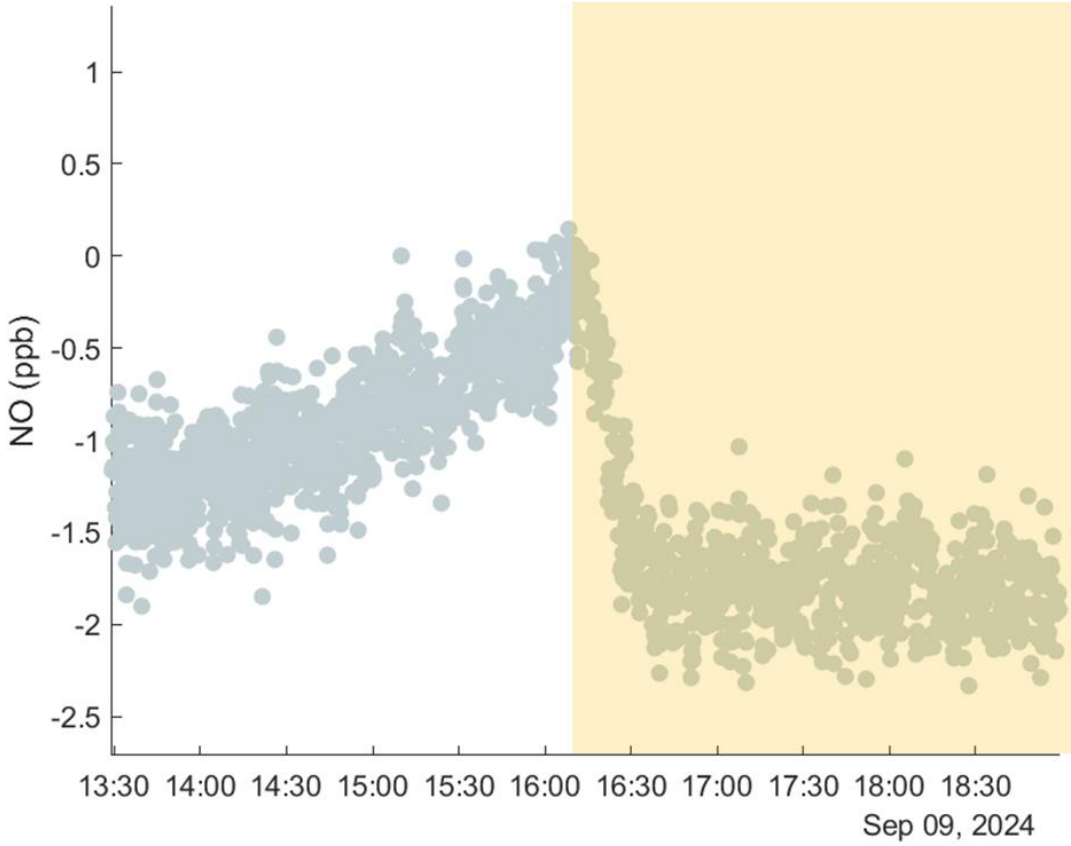
Scrubber on

GUV on

Using scrubber with catalyst removed:



Using catalyst alone:



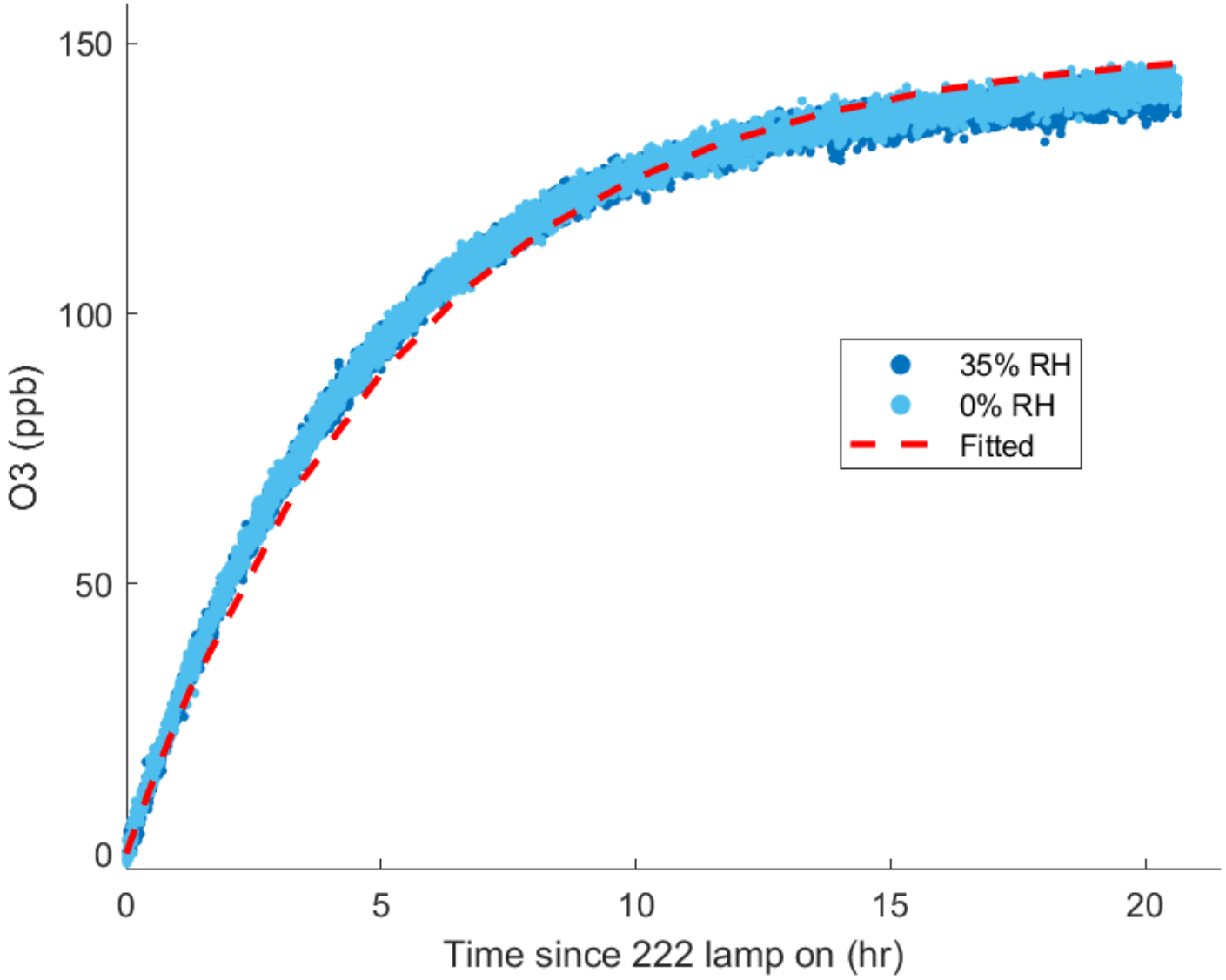
Ozone scrubber removal rates

Species	Removal rate (min^{-1})
Ozone	0.372
NO_2	0.182
Formaldehyde	0.540
Limonene	0.265
6-methyl-5-hepten-2-one ($C_8H_{14}O$)	0.295
Limonaldehyde ($C_{10}H_{16}O_2$)	0.087
SOA	0.0164

VOC scrubber removal rates

Species	Removal rate (min^{-1})
Ozone	0.416
NO_2	0.425
Formaldehyde	0.184
Limonene	n/a
6-methyl-5-hepten-2-one ($C_8H_{14}O$)	n/a
Limonaldehyde ($C_{10}H_{16}O_2$)	0.330
SOA	0.385

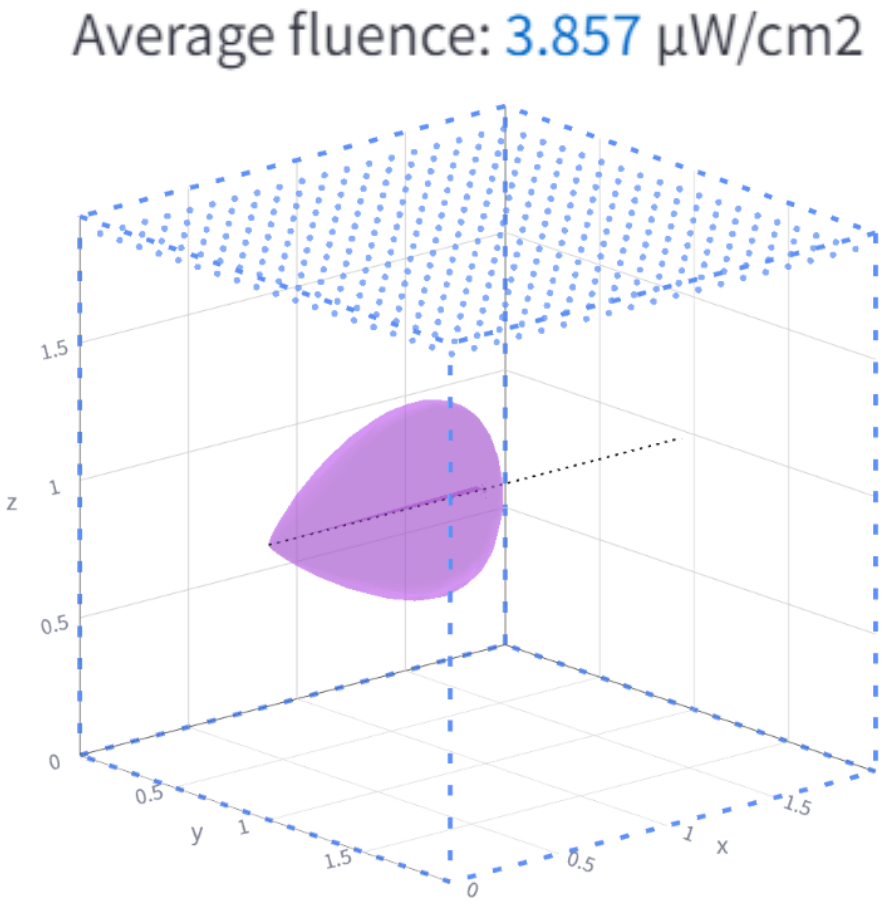
Ozone production from 222nm lamp



Fitted rate: P_{O3} = 25 ppb/hr

222nm lamp fluence rate

Using OSLUV Illuminate tool*:



*freely accessible at: illuminate.osluv.org

Using actinometry with C_2Cl_4:

Average fluence: 2.81 $\mu W/cm^2$