Reactive Nitrogen Partitioning and Pyrogenic VOCs Enhance the Contribution of Canadian Wildfire Plumes to US Ozone Air Quality

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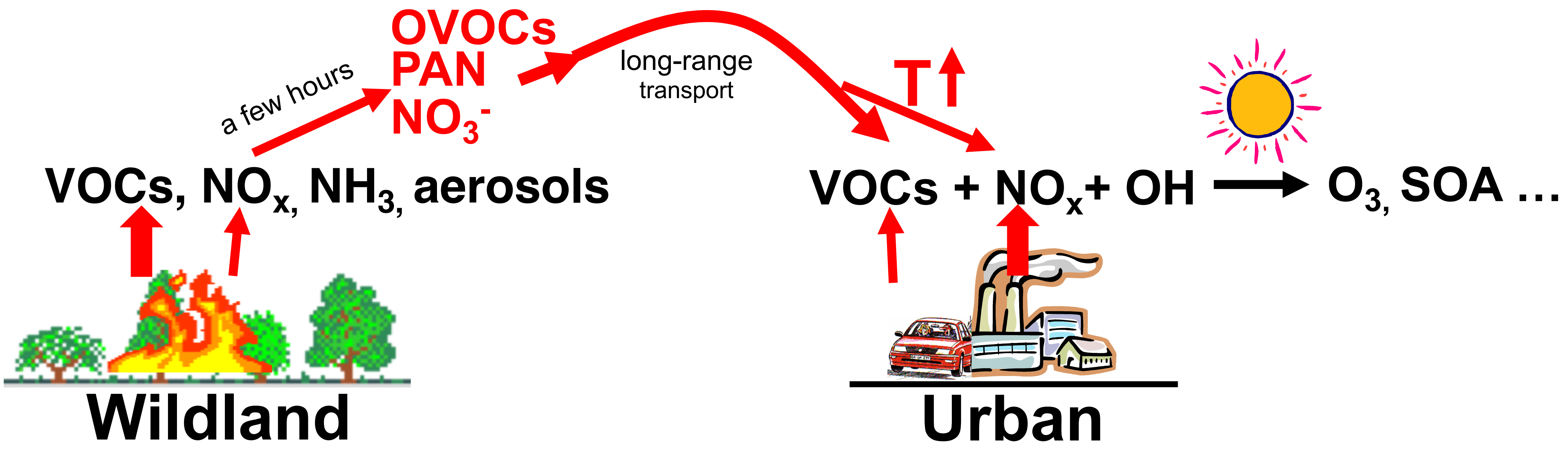
Geophysical Fluid Dynamics Laboratory

The Complex, Multi-Scale Nature of Wildfire Impacts on Ozone AQ



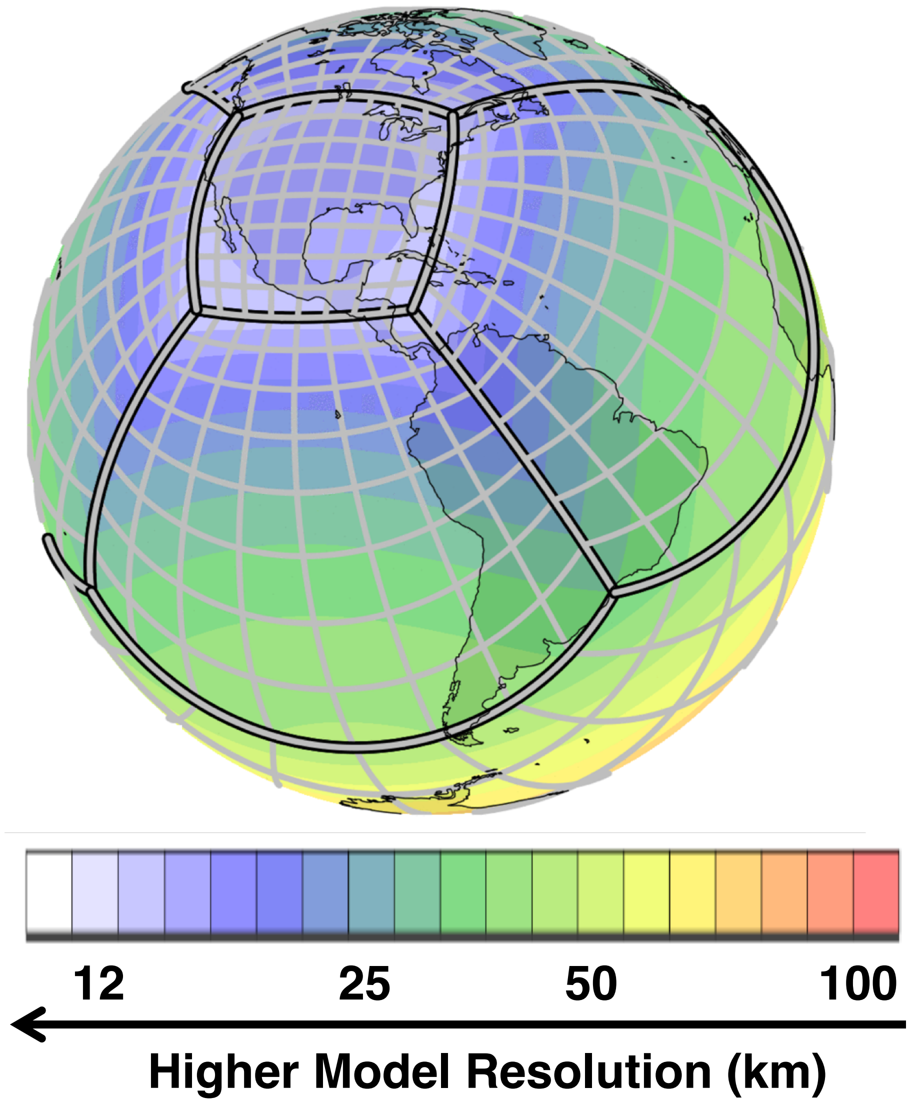
Challenges:

- Rapid conversion of NO_x to PAN and NO_3^- in fresh plumes [e.g., Juncosa Calahorrano et al., 2021; Xu et al., 2021]
- Long-range transport, in-plume chemical processes, and interaction with urban NO_x [e.g., Langford 2023; Ricky et al. 2023]
- Models: (1) too low VOCs; (2) not resolving rapid chemistry; (3) too high O_3 close to fires; too low O_3 in aged plumes

Policy Implication:
How much ozone is produced during smoke transport (uncontrollable) versus through interaction with urban NO_x (controllable)?

→ Parameterization of NO_y emission partitioning in AM4VR based on WE-CAN/FIREX-AQ OBS [Lin M. et al., GRL 2024]

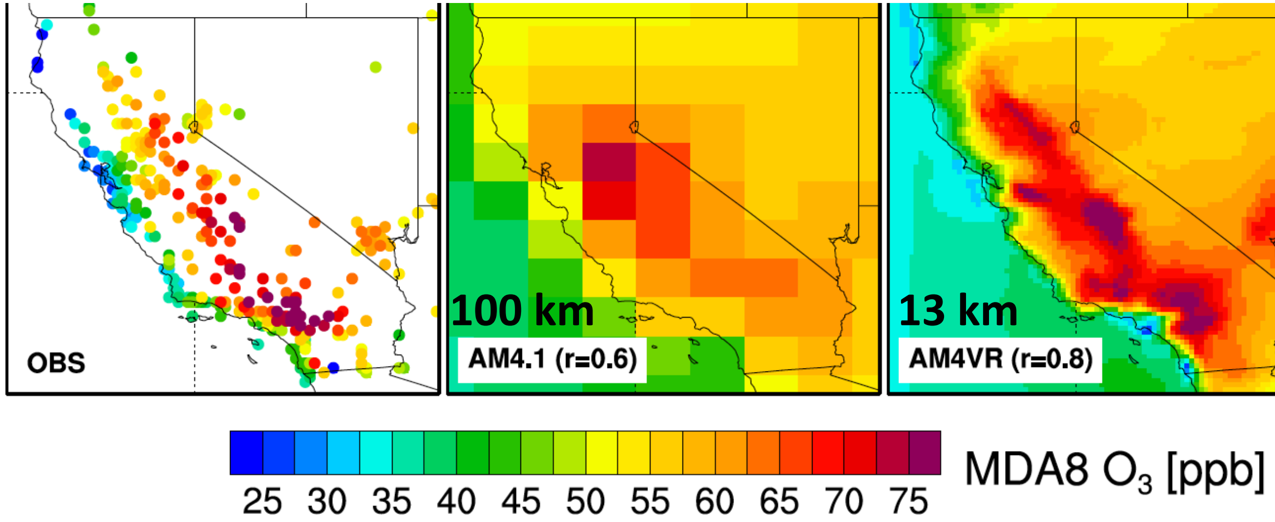
The GFDL Variable-Resolution Global Chemistry-Climate Model (AM4VR) for Research at the Nexus of U.S. Climate and Air Quality Extremes



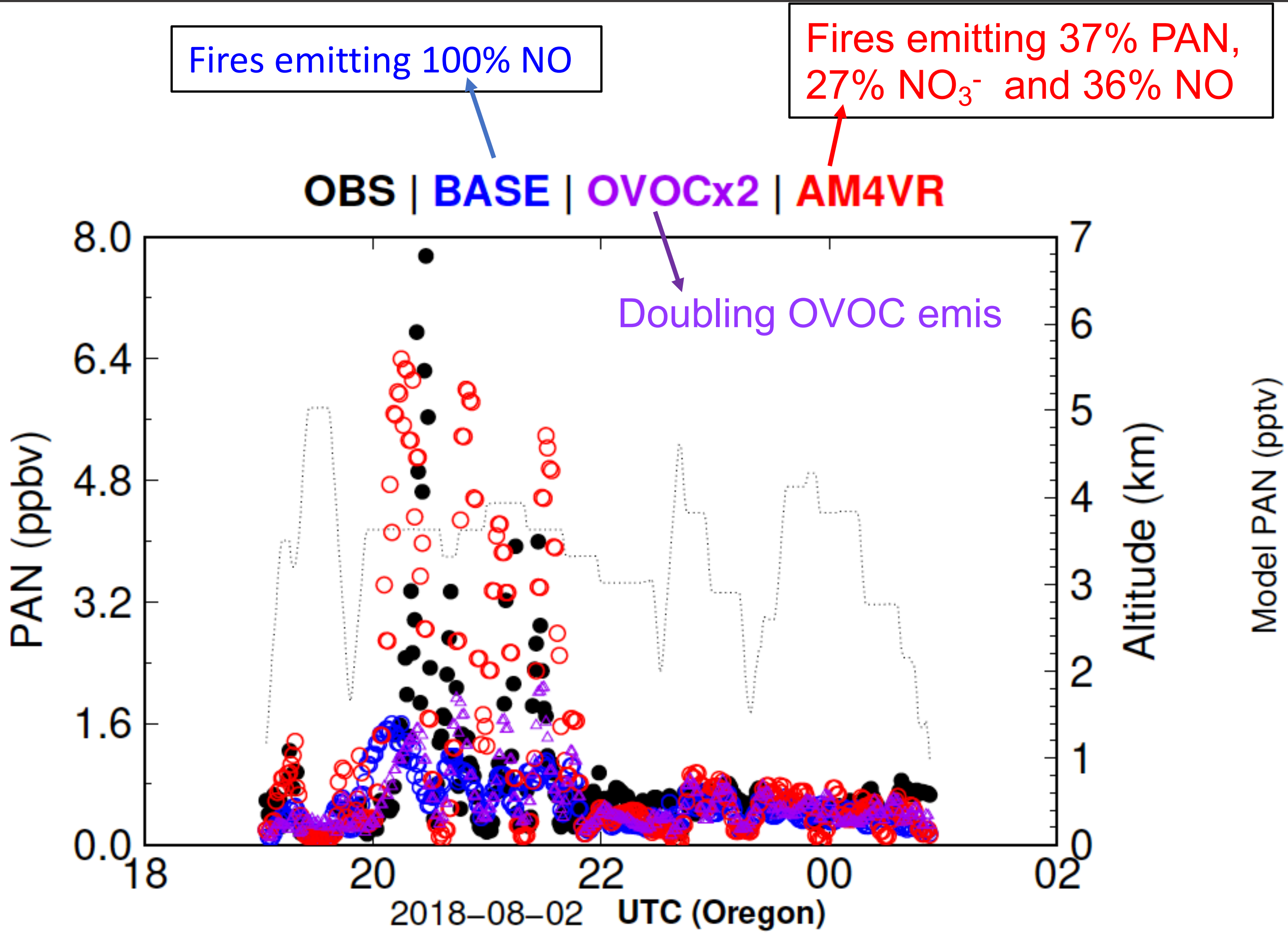
Meteorology-chemistry coupling, feedbacks & interactions:

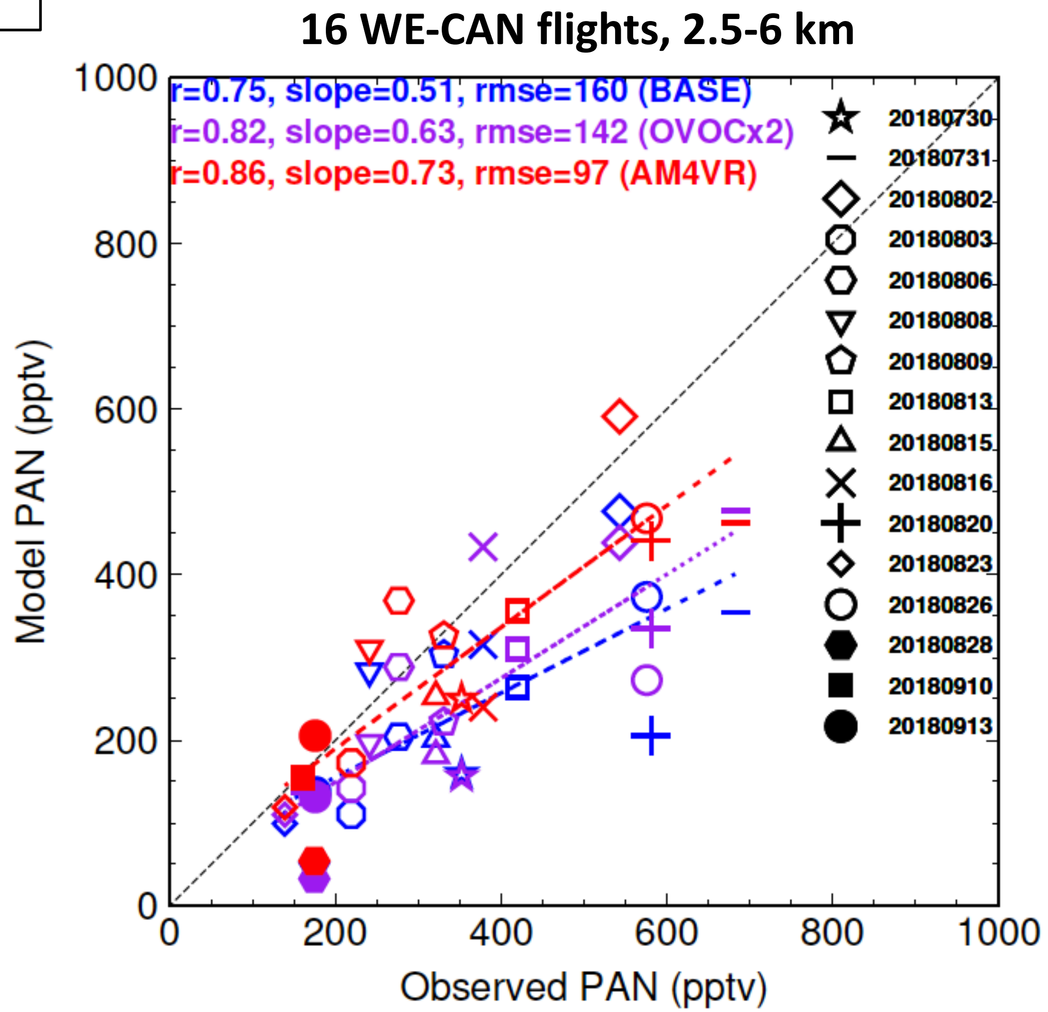
- 13 km spatial resolution over CONUS (GFDL FV3 Dynamical Core)
- Comprehensive gas-phase & aerosol chemistry
- Interactive removal of ozone and its precursors by vegetation, responding to drought and stomatal closure (Lin M. et al, Nature Climate Change 2020)
- High-resolution (0.1^{o}x0.1^o) anthropogenic emissions (CEDS-2021-04-21)
- Interactive BVOC emissions with updated land cover and EP (MEGAN2.1)
- **BB NO_y emission partitioning and increased OVOC emissions (GFED4s)**
- BB injection height currently based on MISR climatology; dynamic plume rise under development

Summer surface O_3 over California (2000-2020 climo)

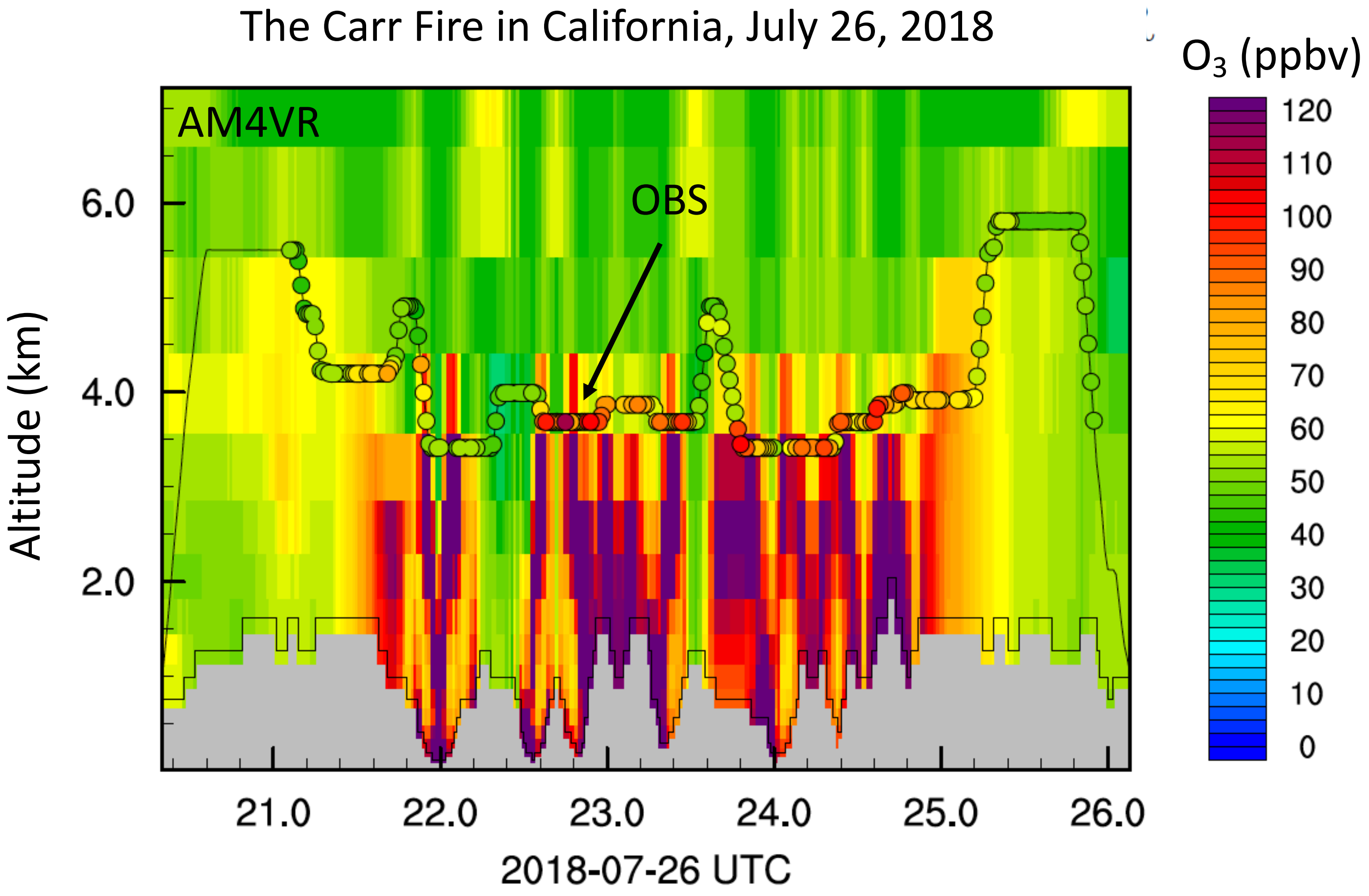


NOy partitioning increases simulated PAN in fresh smoke plumes sampled by the 2018 WE-CAN aircraft campaign

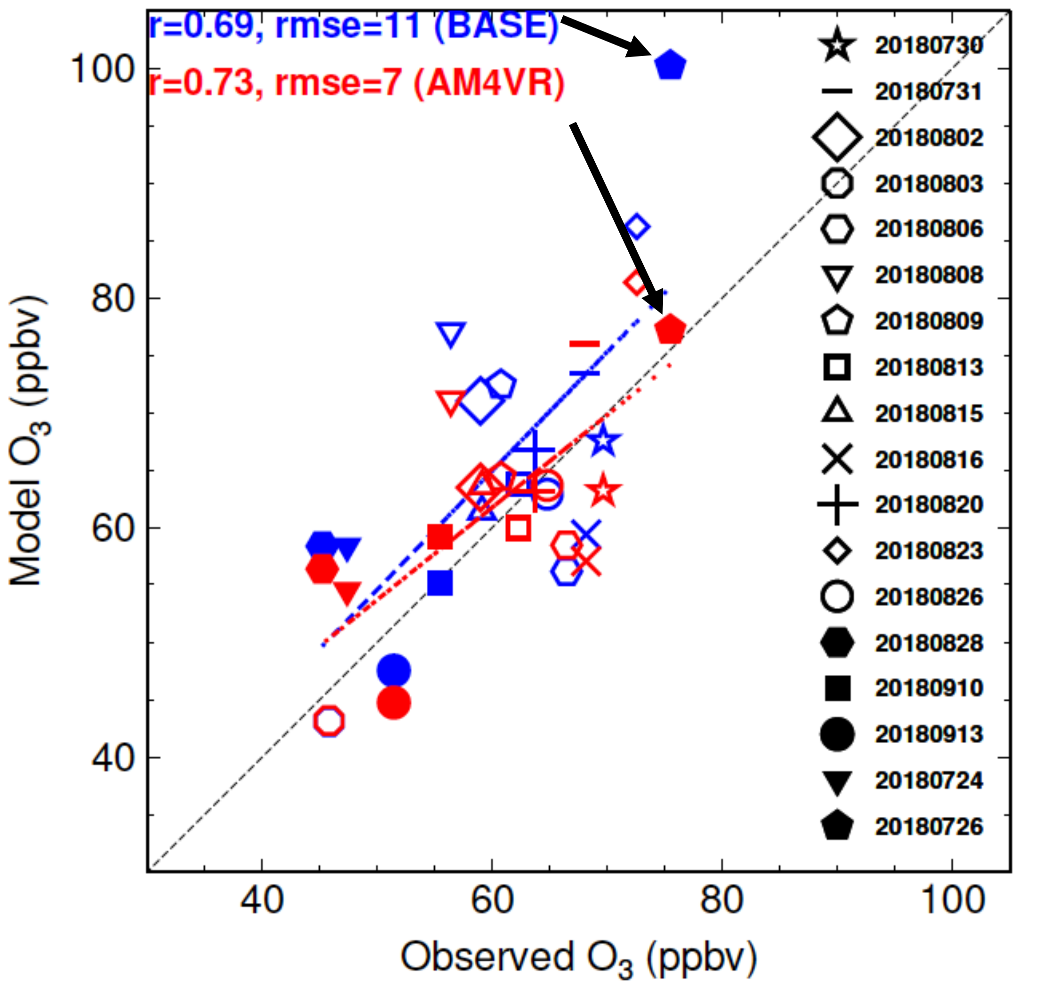




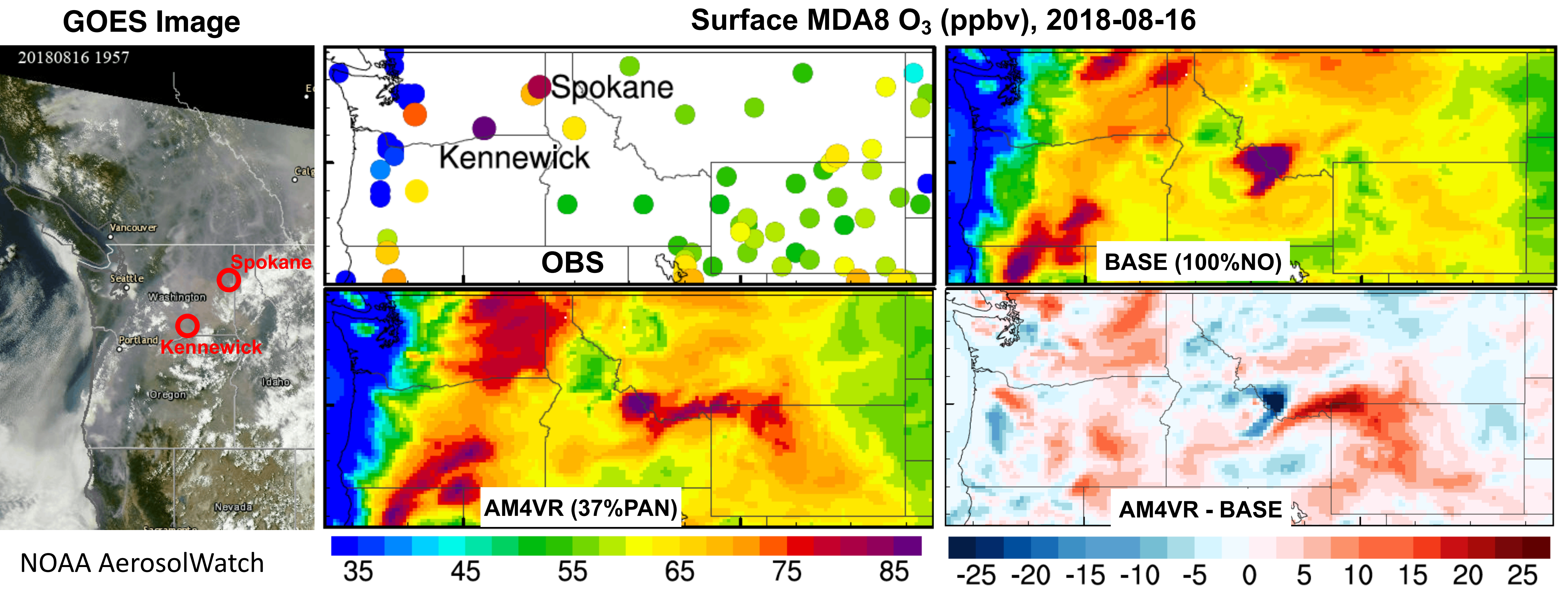
NO_y partitioning slows ozone formation in fresh smoke plumes sampled by the 2018 WE-CAN aircraft campaign



O_3 in fresh smoke, 18 WE-CAN flights, 2.5-6 km

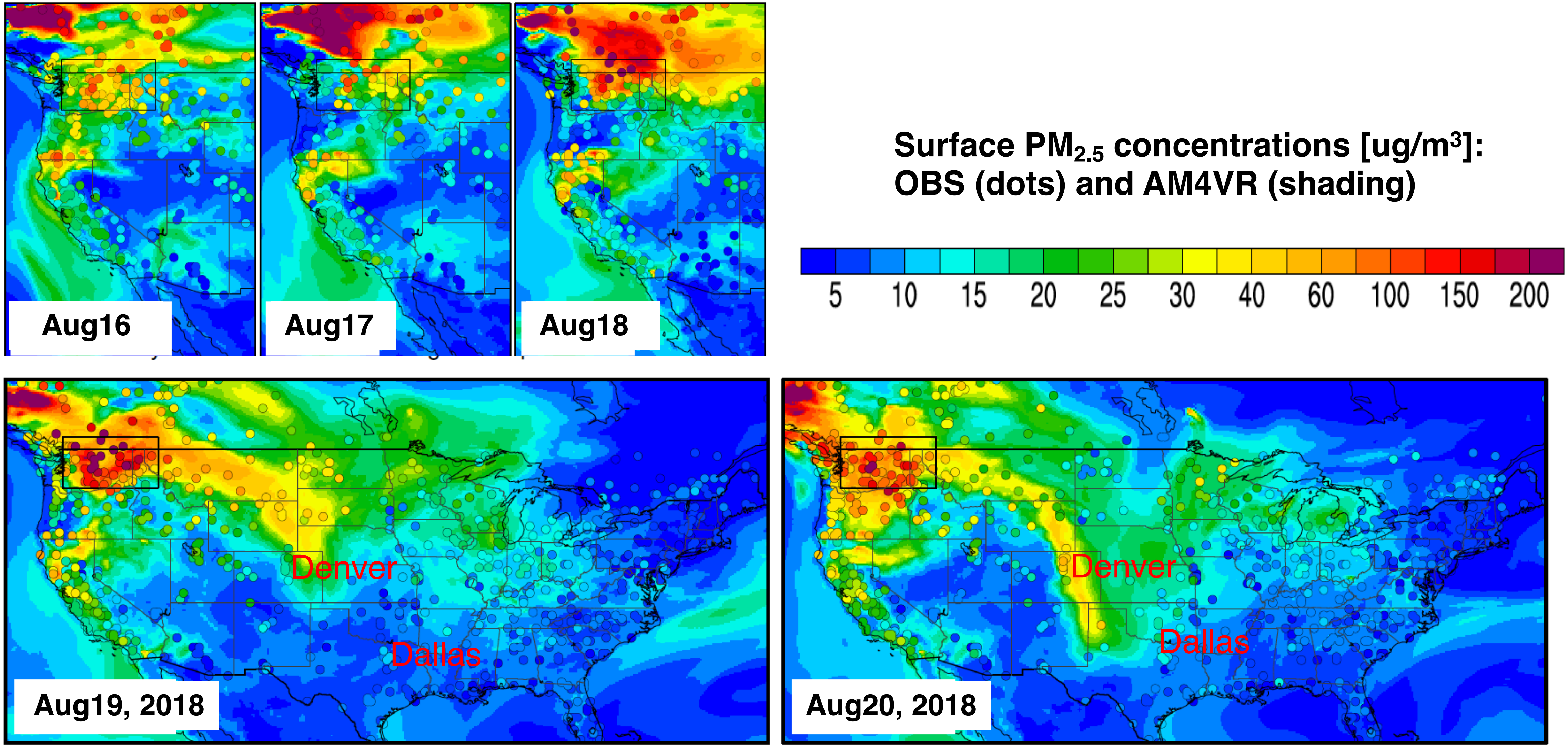


Sequestration of wildfire emissions as PAN enhances downwind ozone production during smoke transport

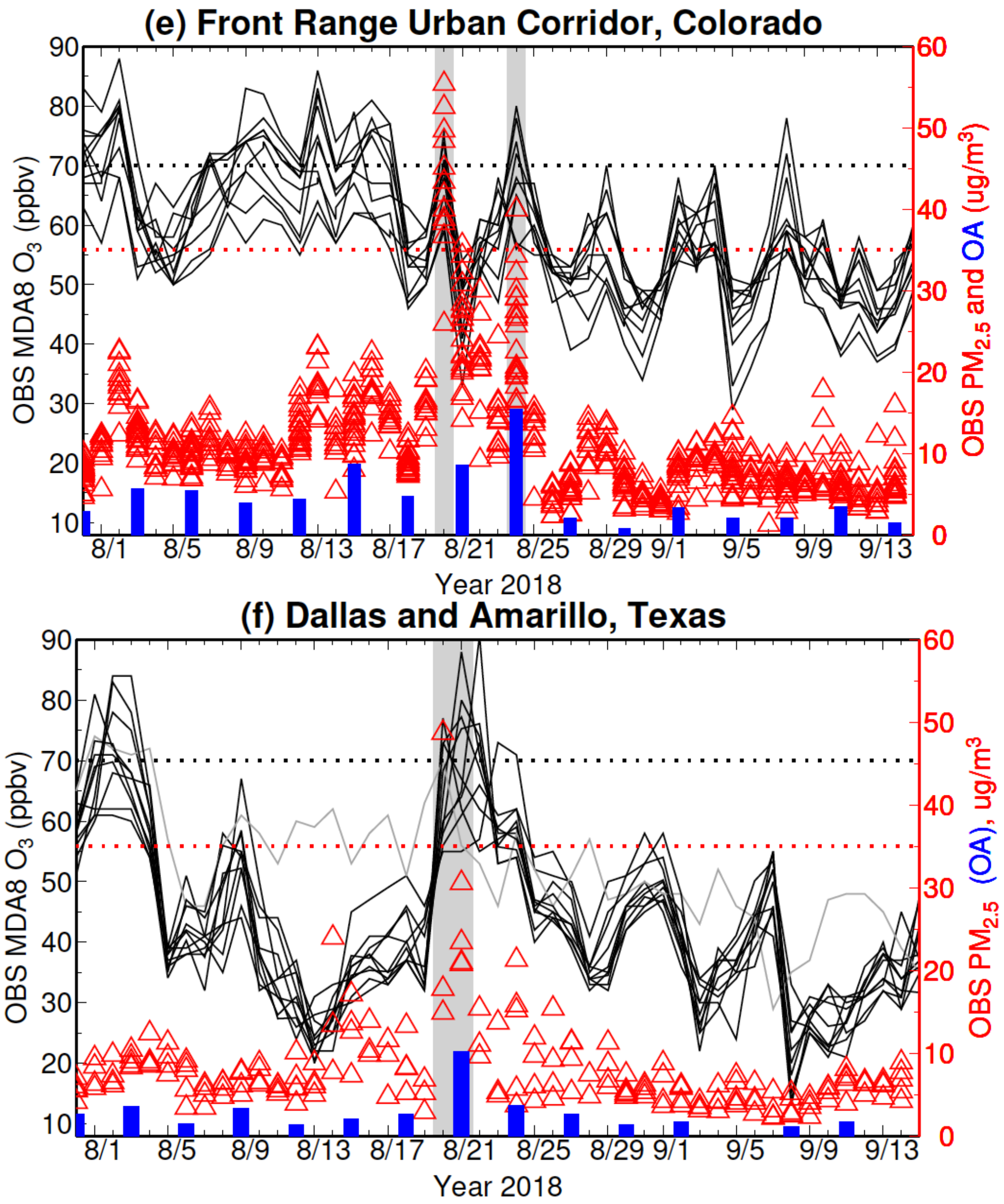


When NOy emissions partitioning is included, more PAN is formed in fresh plumes and subsequently decomposes during smoke transport, enhancing downwind ozone formation and increasing simulated O_3 at Spokane and Kennewick to ~80 ppb

Transport of Canadian Wildfire Plumes to Denver, Colorado and Dallas, Texas

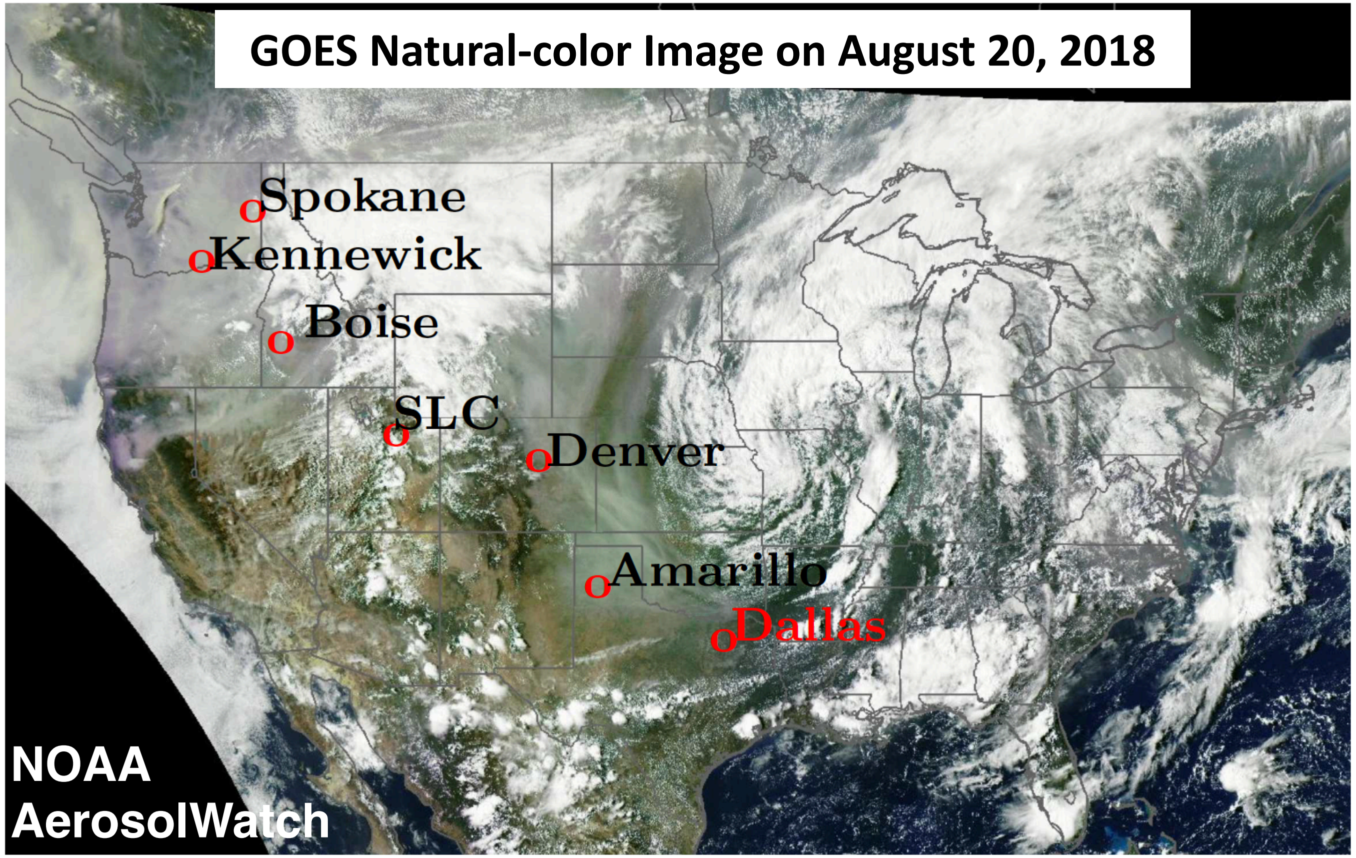


Observation-based indication of smoke-influenced high-O_3 episodes in Denver and Dallas



<-- Enhancements in $PM_{2.5}$ (30-60 ug/m^3)

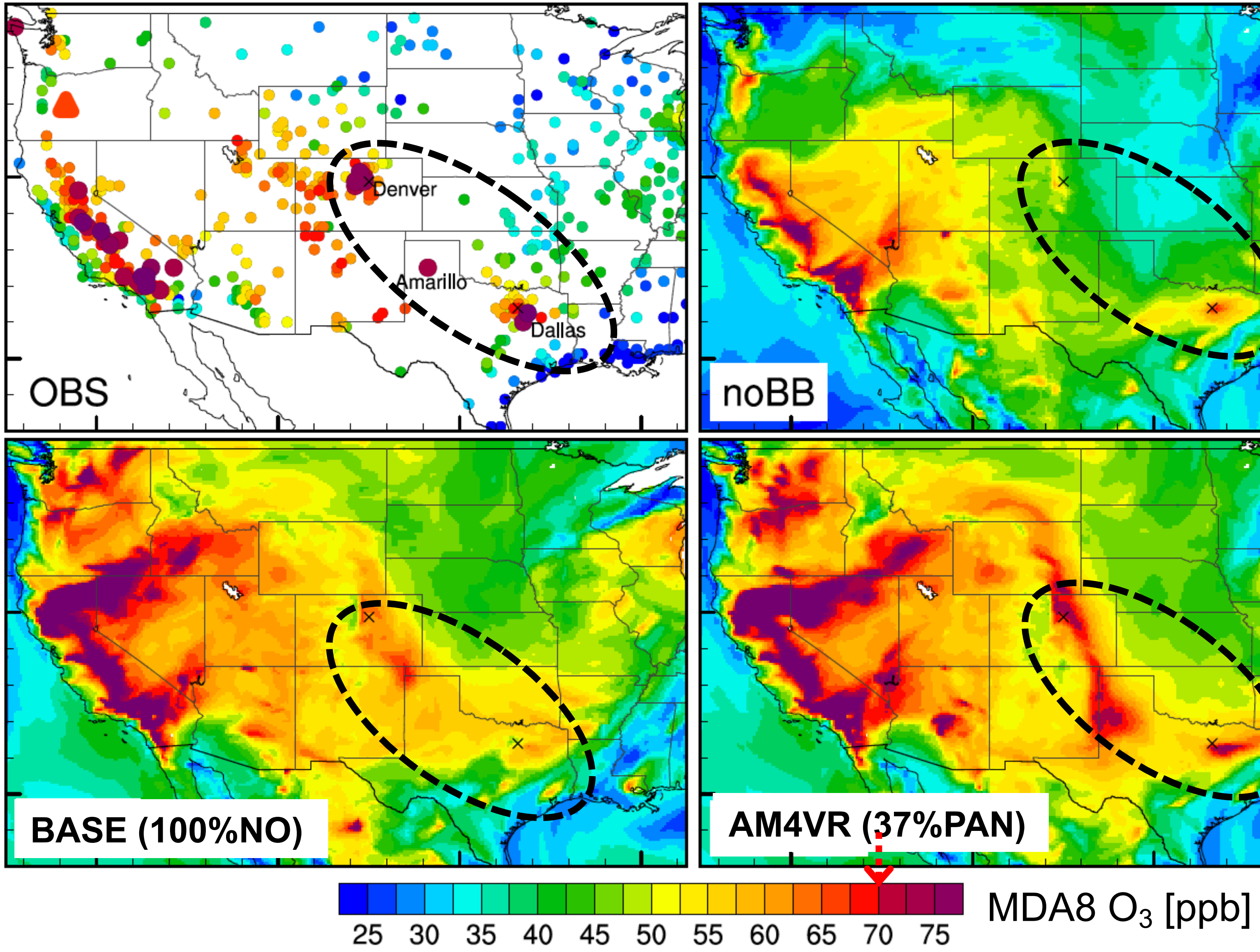
<-- Enhancements in organic aerosol (OA)

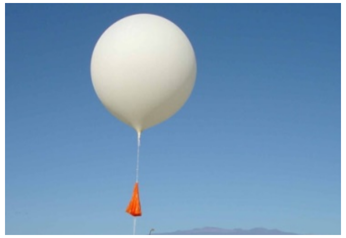


Lin M., LW Horowitz, Lu Hu, W. Permar [GRL, 2024]

NO_y partitioning Enhanced MDA8 O_3 by 5-12 ppbv (30-50%) as Aged Smoke from Canadian Wildfires Descended toward the US Deep South on August 20, 2018

Surface MDA8 ozone on August 20, 2018





Ozonesonde at Boulder/Colorado supports O_3 transported with the smoke (c/o A. Landford)

Lin M., LW Horowitz, Lu Hu, W. Permar [GRL, 2024]

Summary of smoke-impacted high ozone episodes in August 2018

Date	Location	OBS (ppbv)	noBB (ppbv)	BASE (ppbv)	AM4VR (ppbv)	AM4VR - noBB (total smoke impact)	AM4VR - BASE (Impact of NO_y parameterization)
Aug. 16	Spokane	80	59	74	78	19	4 (21%)
	Kennewick	86	54	72	78	24	6 (25%)
Aug. 20	Denver / Boulder (5 sites)	69–74	50–60	61–66	68–74 [a]	15–24	5–8 (30%)
	Amarillo	71	41	56	65	24	9 (37%)
	Dallas (3 sites)	73–78	60–66	60–66	68–73	10–18	5–12 (50%)
Aug. 21[b]	Dallas (4 sites)	75–88	65-70	70–78	70–75	5–8	N.A.
Aug. 22	Spokane	68	46	60	67	21	7 (33%)
	Kennewick	73	46	60	71	25	11 (44%)
	Portland	75	50	62	70	20	8 (40%)
Aug. 23	Salt Lake City (4 sites)	67–77	50-55	65-75	65-78	15–20	4 (< 20%)
Aug. 24[b]	Denver / Boulder (5 sites)	70–80	50-58	69-73	67-72	10–15	N.A.

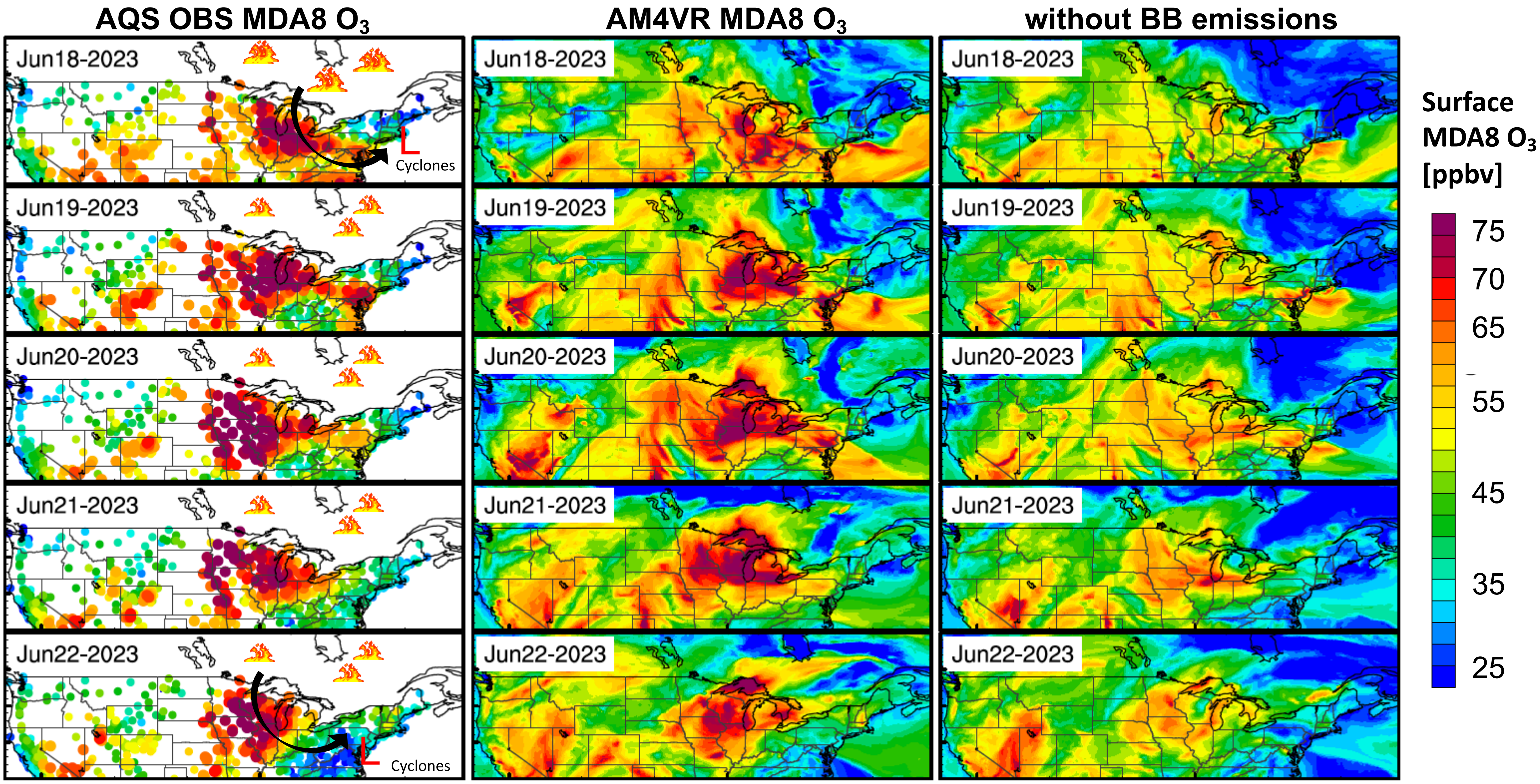
For rural areas and small cities, ozone produced during smoke transport is the main driver

For larger cities,

(1) O_3 transported with smoke

(2) O_3 produced locally from mixing of smoke VOCs + urban NO_x

Historic 2023 Canadian Wildfires:
Injection of PVOCs into NO_x-rich Midwest enhanced MDA8 O_3 by 10-25 ppbv



Case Study of July-26-2023 Ozone Exceedance in NYC: Contribution of biomass burning versus urban pollution?

July 26 AEROMMA DC-8 Flight to NYC

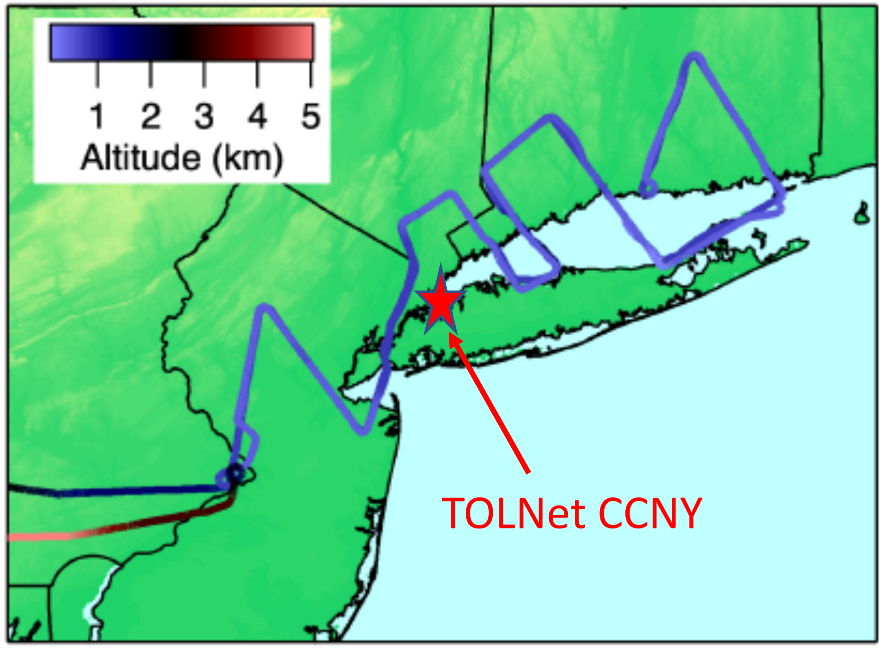
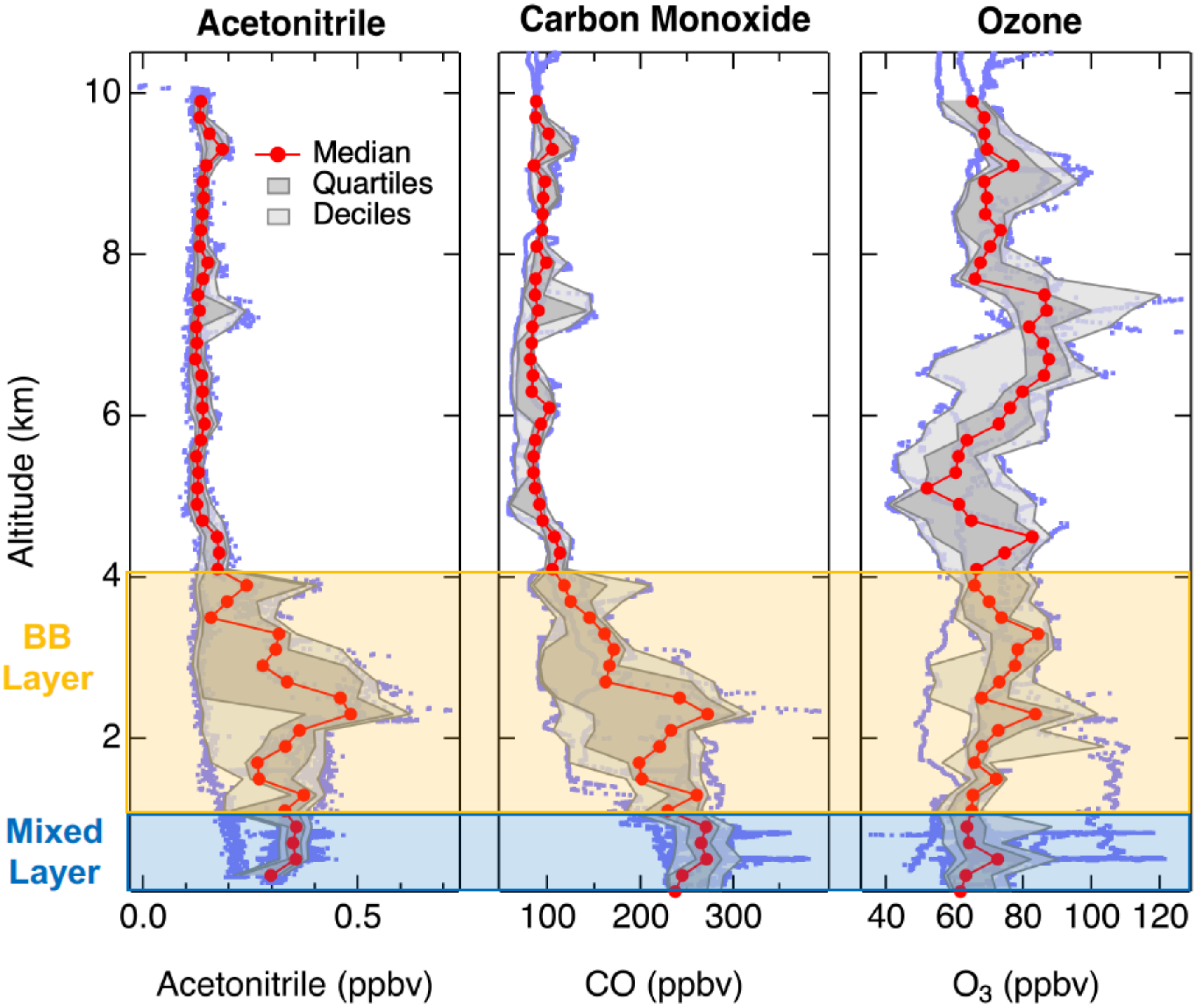
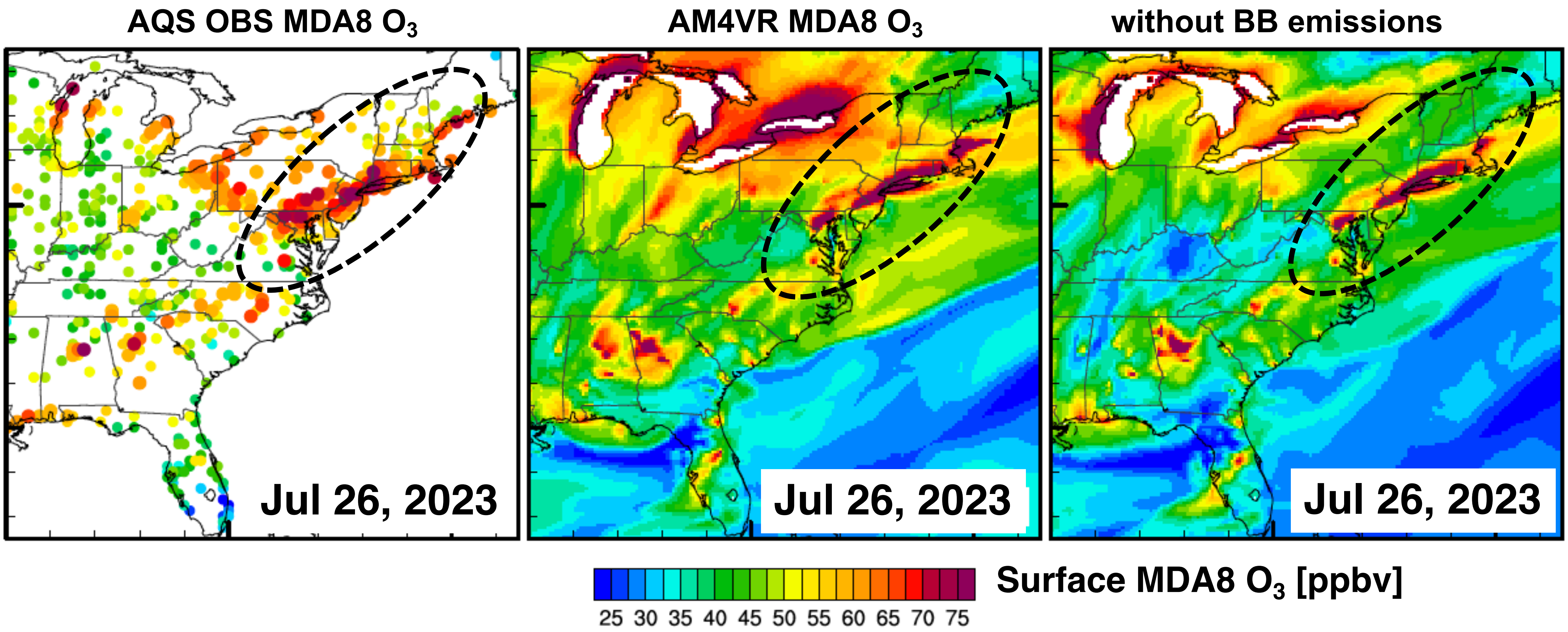


Figure courtesy of Steven Brown →

TOLNet LiDAR at Wisconsin (July 25) and NYC (July 26) also show high-O_3 in BB Layer and Mixed Layer (c/o M. Newchurch, Y. Wu, and F. Moshary)

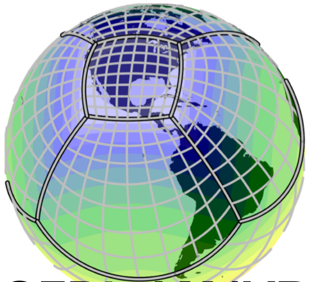


Case Study of July-26-2023 Ozone Exceedance in NYC: Model indicates a dominant contribution from urban pollution



Without BB emissions, Model captures the observed MDA8 O_3 exceedances in the NE urban corridor, indicating a dominant role of urban pollution. BB contributed 5 ppbv (larger in rural areas)

TAKE-HOME MESSAGE



GFDL AM4VR

- Aged smoke plumes from Canadian wildfires enhanced US regional O_3 by 5–25 ppbv (MDA8) during summer 2018 and 2023
- NO_y partitioning enhances O_3 production by 20-45% during smoke transport - the main driver for rural areas and small WUS cities.
- For larger cities, ozone increases through production during smoke transport + local production from reactions of smoke VOCs and urban NO_x
- Concurrent production of O_3 from urban pollution complicates the attribution; need integrated observational + modelling analysis.

Read more:

- **Lin, M.**, et al., *Reactive nitrogen partitioning enhances the contribution of Canadian wildfire smoke plumes to US ozone air quality*. **Geophysical Research Letter**, https://doi.org/10.1029/2024GL109369, 2024.
- **Lin, M.**, et al. *The GFDL Variable-Resolution Global Chemistry-Climate Model for Research at the Nexus of US Climate and Air Quality Extremes.* **Journal of Advances in Modeling Earth Systems**, https://doi.org/10.1029/2023MS003984, 2024 [Editor's Highlight].

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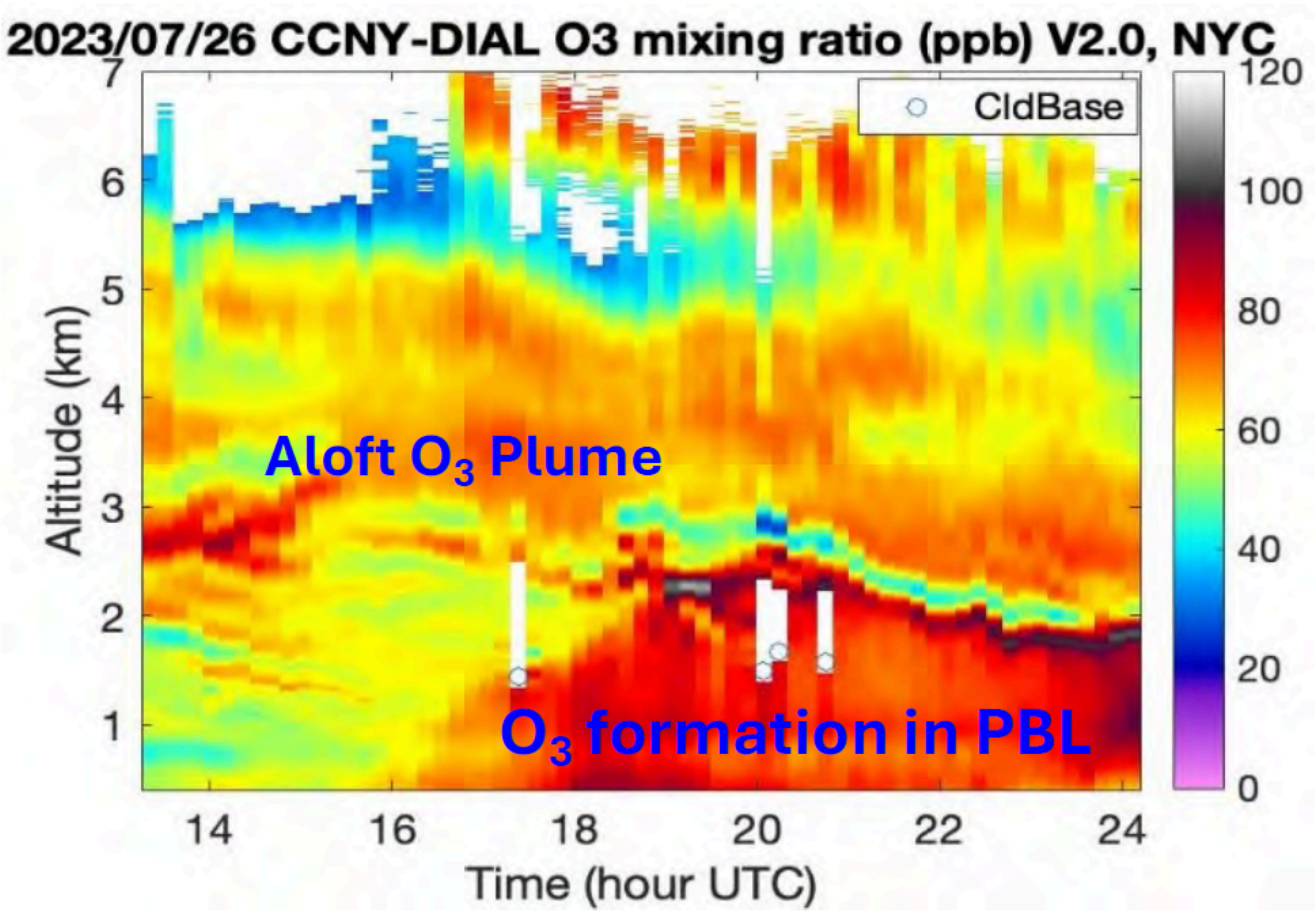
Slides for Q and A

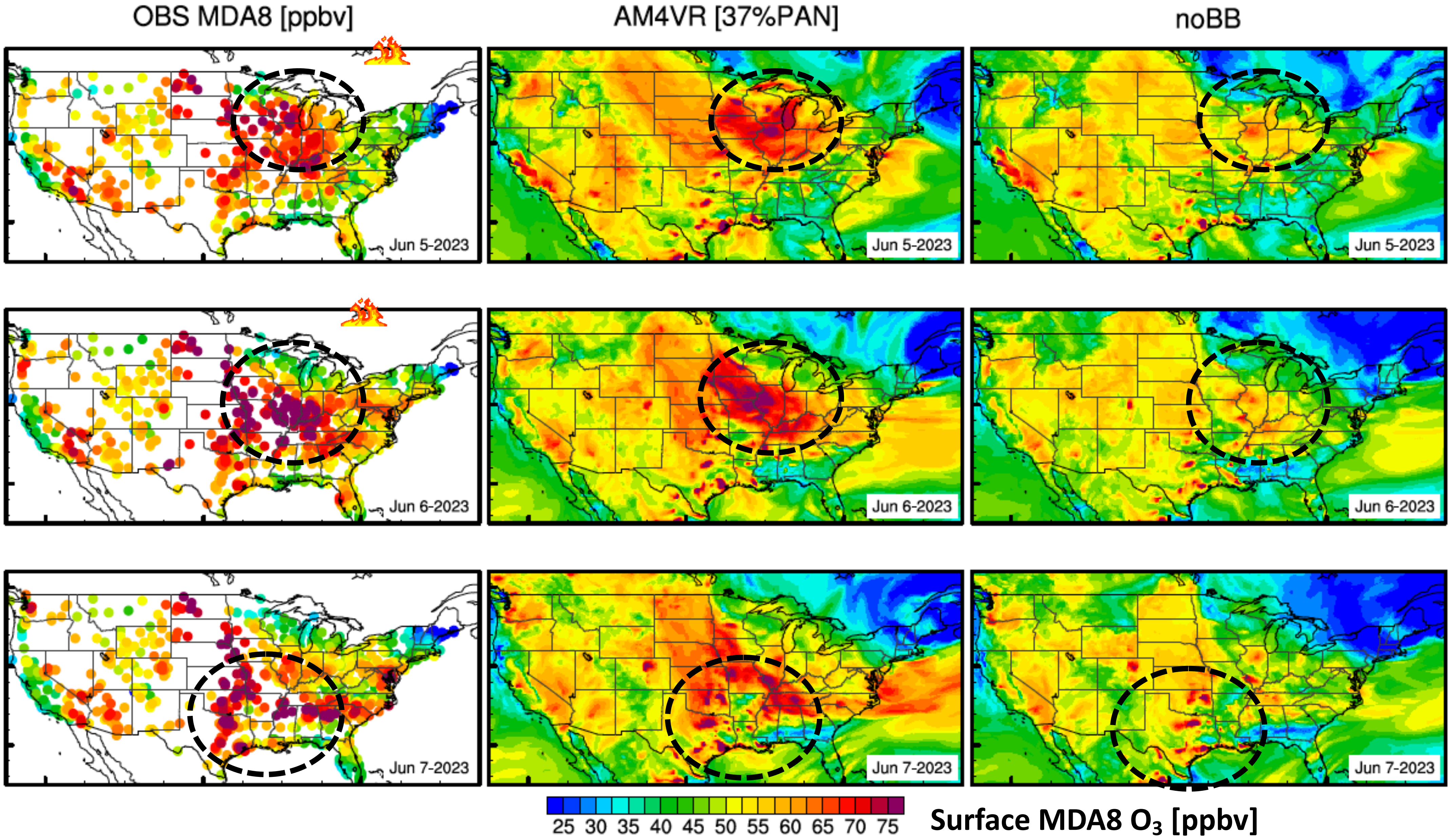
Case Study of July-26-2023 Ozone Exceedance in NYC: Aloft biomass burning plumes observed by TOLNet LiDAR



TOLNet LIDAR at Chiwaukee Prairie, Wisconsin also observed high-O_3, high-aerosol layers from surface to 2 km altitude on July 25 (c/o M. Newchurch)

Figure courtesy of Yonghua Wu and F. Moshary

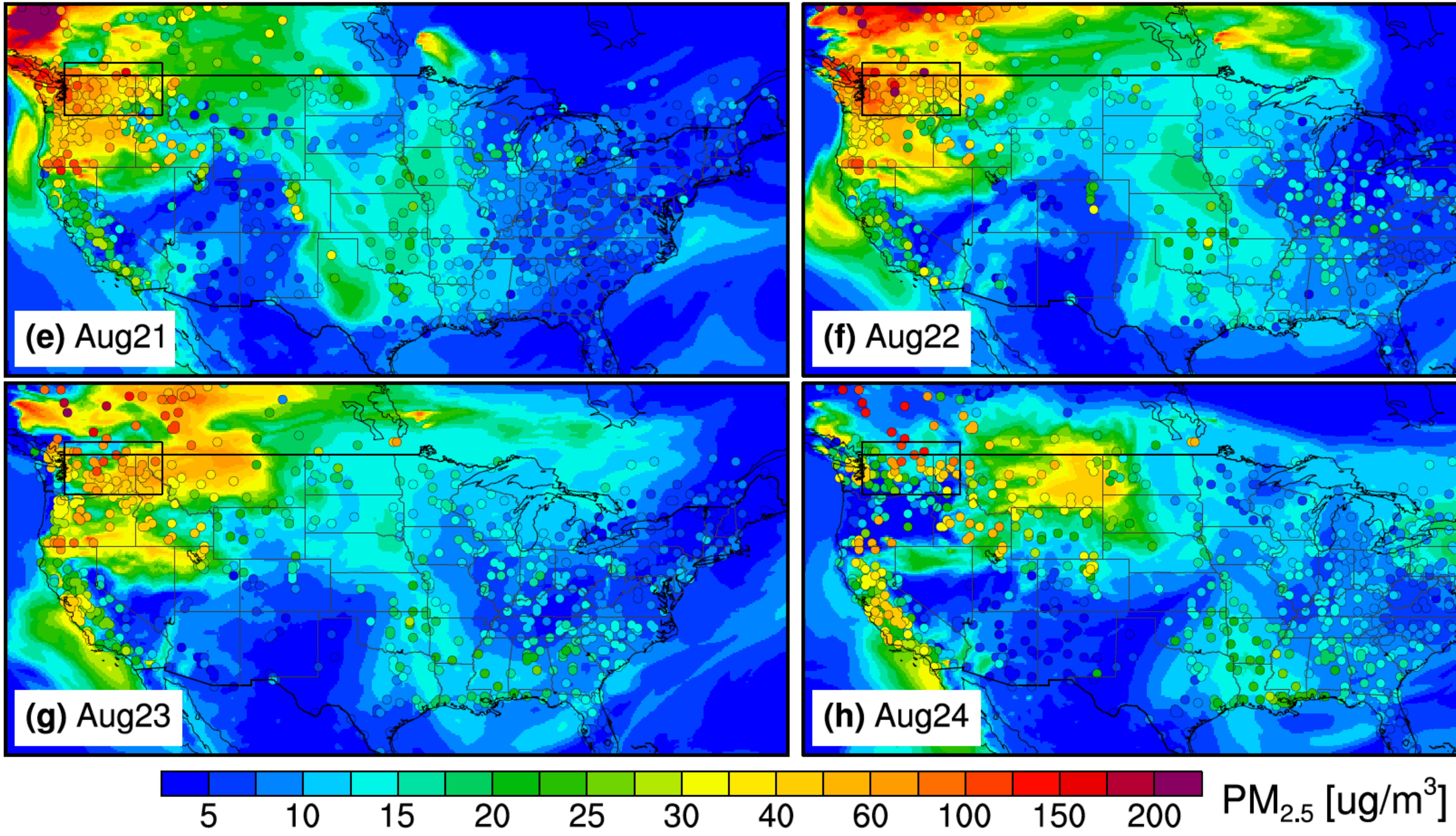
Impacts of Historic 2023 Canadian Wildfires on EUS Ozone Air Quality



Interaction of PVOCs with urban NO_x raised MDA8 O_3 by 15-20 ppbv

Concurrent production of O_3 from urban emissions

Surface $PM_{2.5}$



As smoke plumes mixed with urban pollution, additional O_3 was produced from reactions of smoke VOCs with urban NO_x