TOLNet: Wildfire Impacts Research, Tropospheric Composition Forecasting, and Satellite Validation

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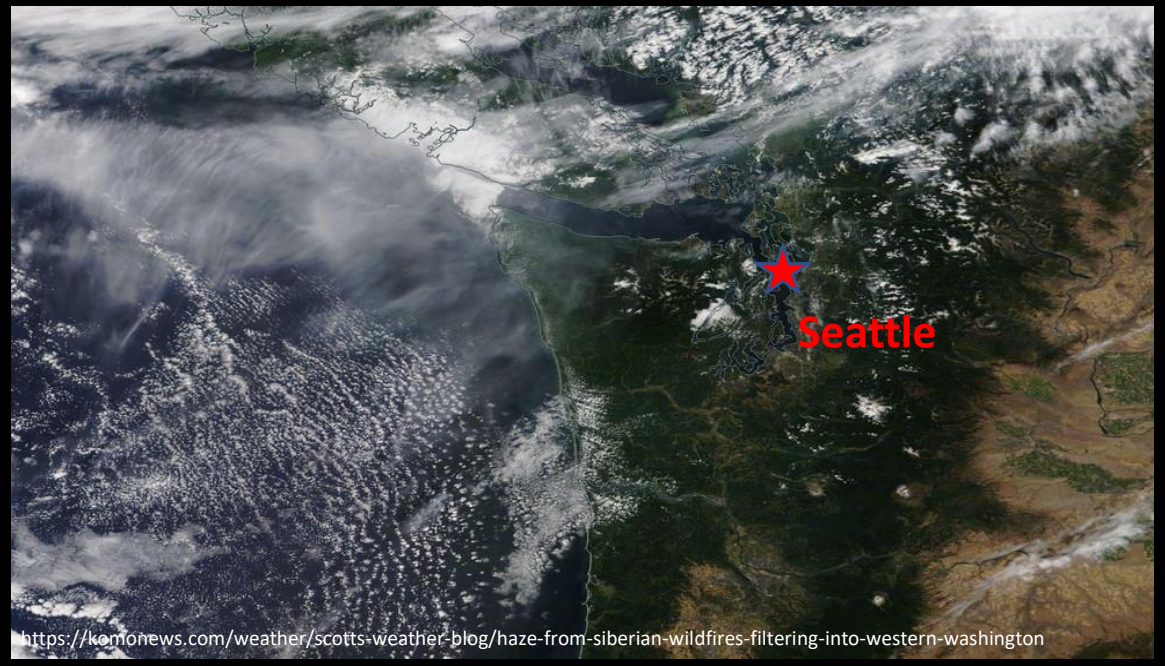
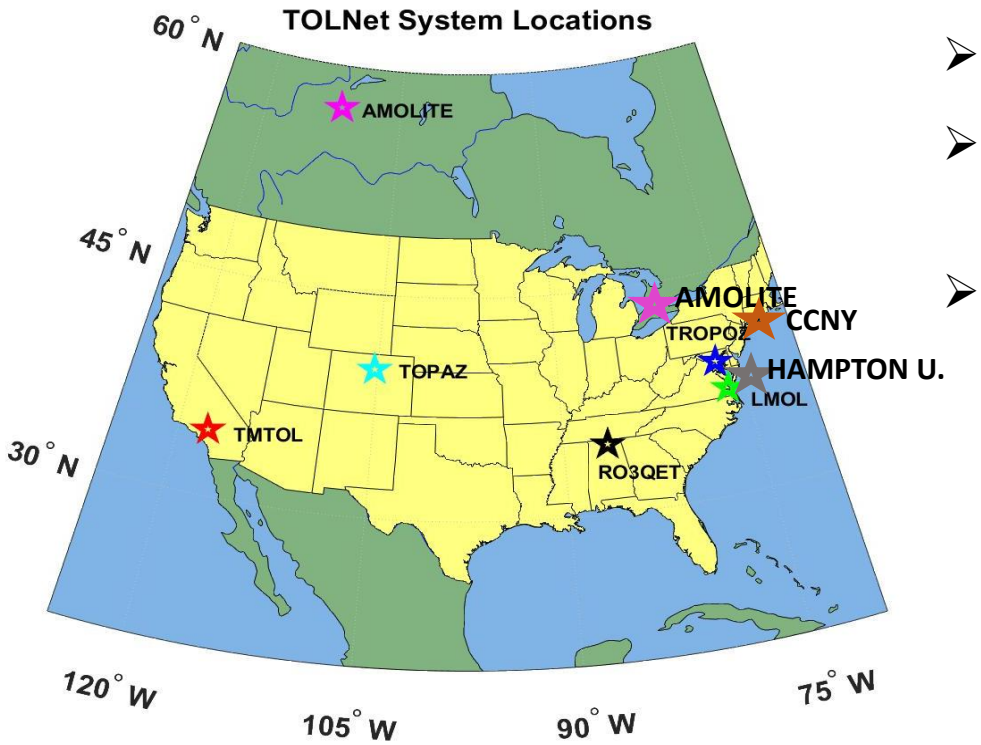


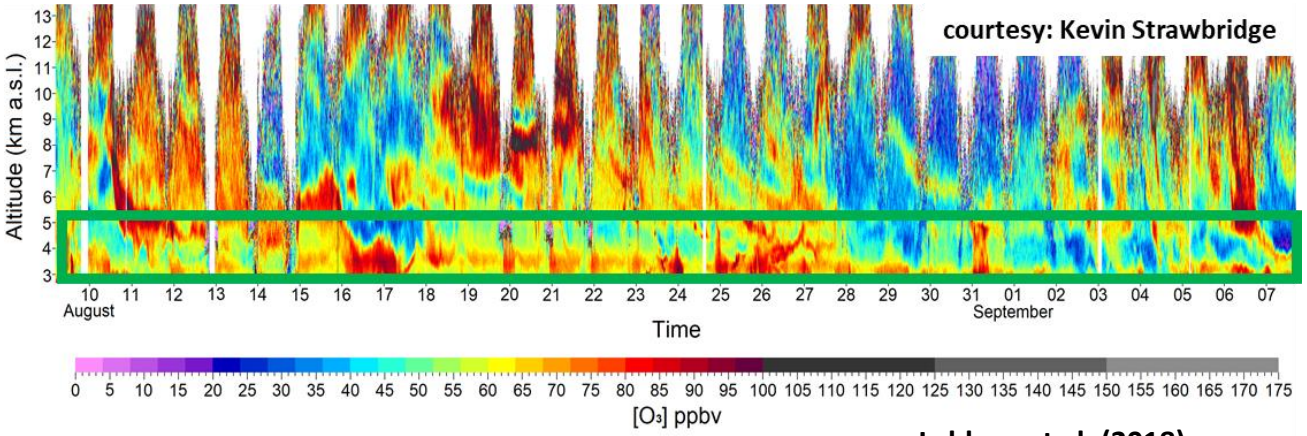
https://komonews.com/weather/scotts-weather-blog/haze-from-siberian-wildfires-filtering-into-western-washington

EPA Region 10 Wildfire Impacts Working Group
May 18, 2022

Tropospheric Ozone Lidar Network (TOLNet)



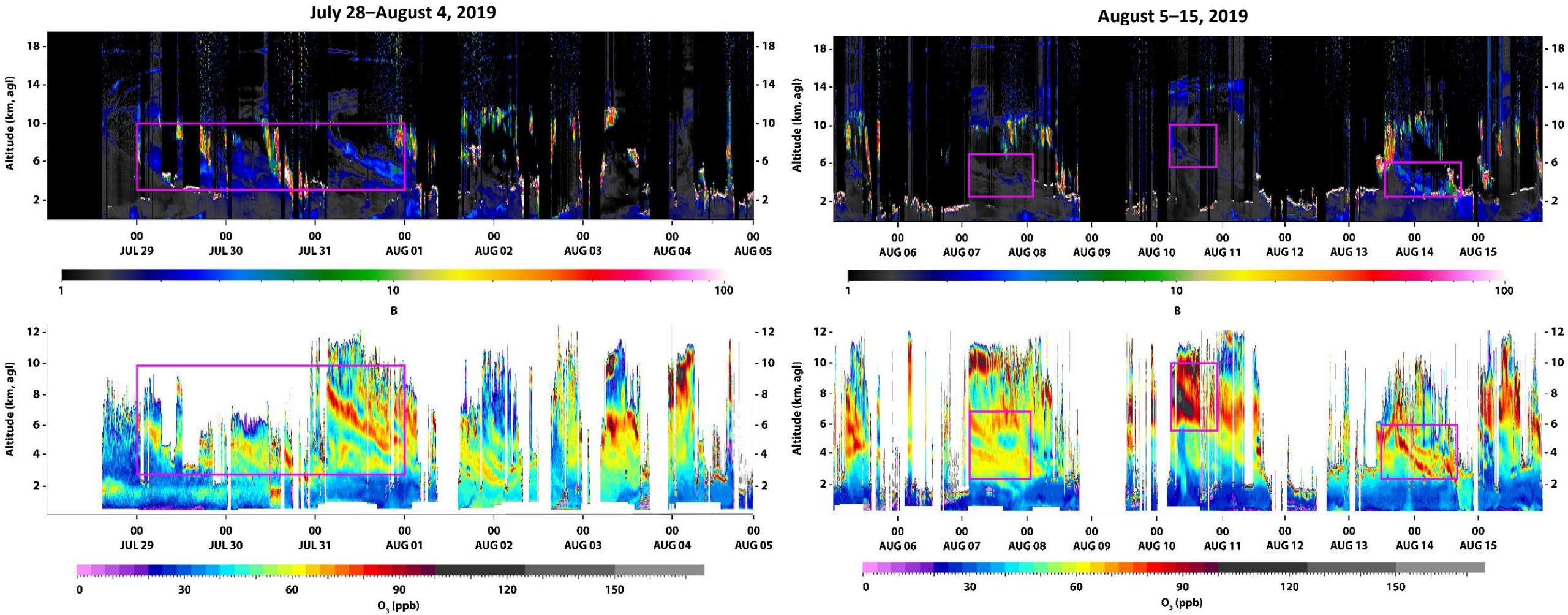
- Established in 2011 and consists of 8 lidar systems in North America.
- The 8 systems currently making routine measurements are: AMOLITE, TMTOL, TOPAZ, RO3QET, TROPOZ, LMOL, CCNY, and HU.
- Main goals are to provide data for:
  1. Understanding physiochemical processes controlling tropospheric O_3 concentrations and morphology.
  2. Evaluation of satellite products retrieving tropospheric O_3 (e.g., TROPOMI and TEMPO).
  3. Chemical transport and air quality model evaluation.



Leblanc et al. (2018)

- The ozone lidar data is highly accurate and consistent between systems.
- TOLNet often observes wildfire impacts on aerosol and O_3 (Johnson et al., 2016, 2021; Kuang et al., 2017; Strawbridge et al., 2018; Langford et al., 2020).

AMOLITE lidar observations during FIREX-AQ

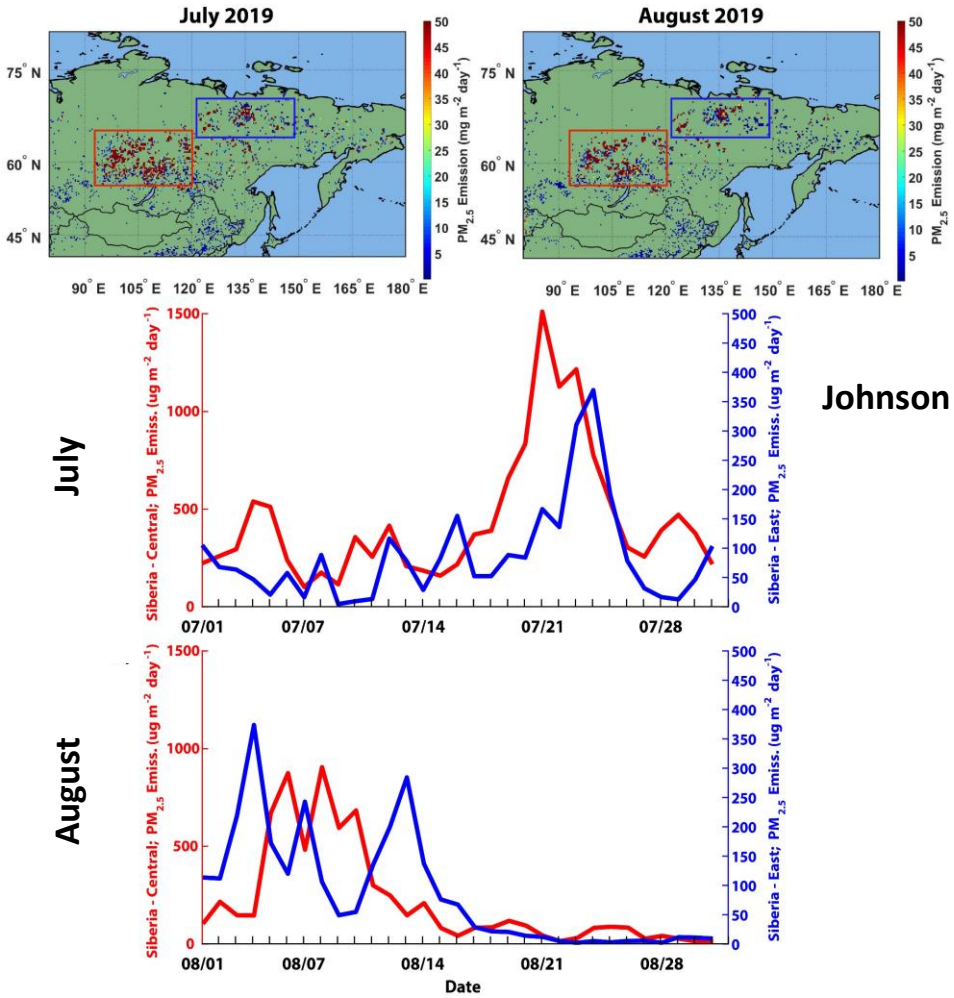


Aerosol backscatter ratio (B, @ 532 nm) and O_3 (ppb) observed by AMOLITE (57.18°N, 111.64°W)

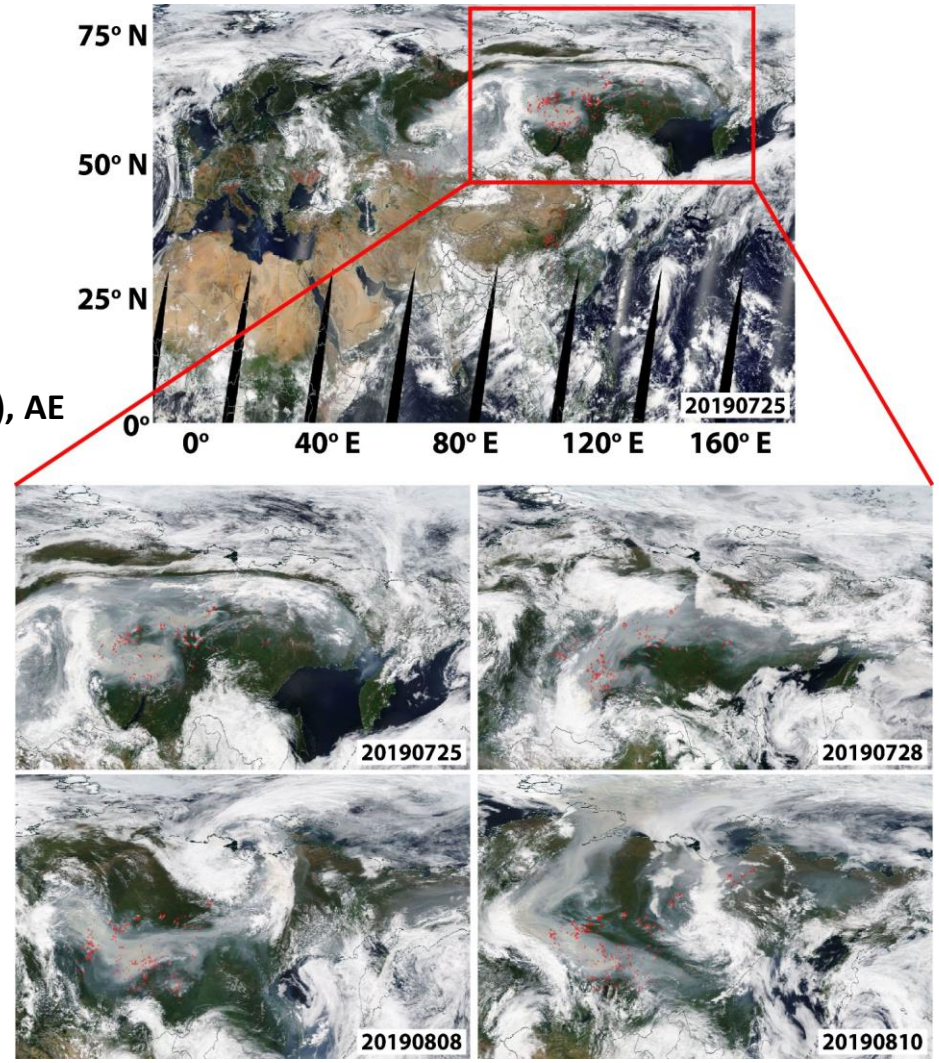
Johnson et al. (2021), AE

- **AMOLITE made regular measurements during the FIREX-AQ field campaign.**
- **Observed frequent tropospheric lamina of coincident aerosol backscatter and O_3.**

Siberian wildfire activity during 2019



Johnson et al. (2021), AE

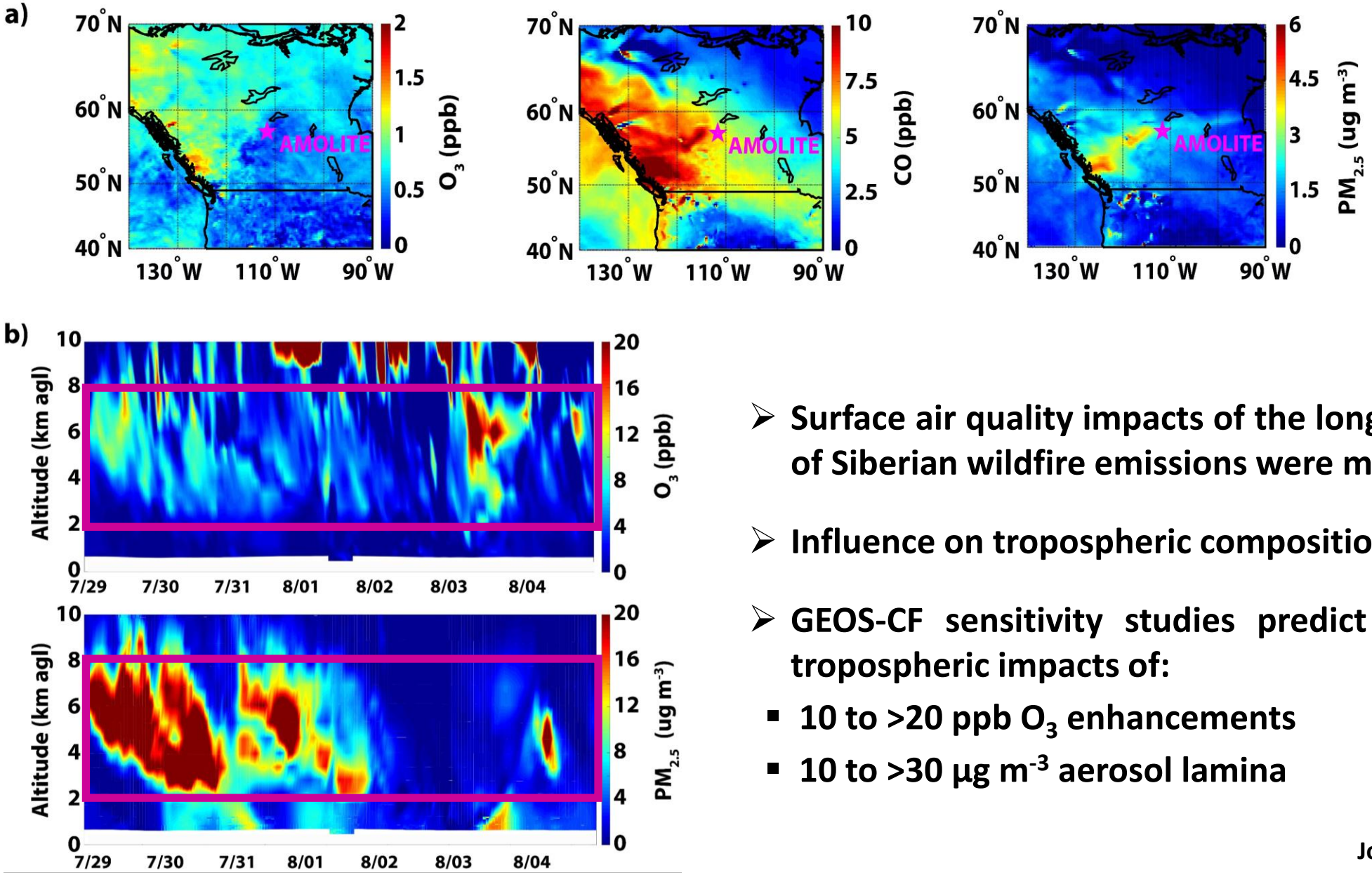


Monthly Quick Fire Emissions Dataset (QFED) $PM_{2.5}$ emissions and daily timeseries for central and eastern Siberia.

Terra MODIS true color images of smoke associated with wildfires in Siberia

- MODIS and QFED emissions indicate wildfire activity in Siberia (enhanced between July 18 and Aug. 14, 2019).

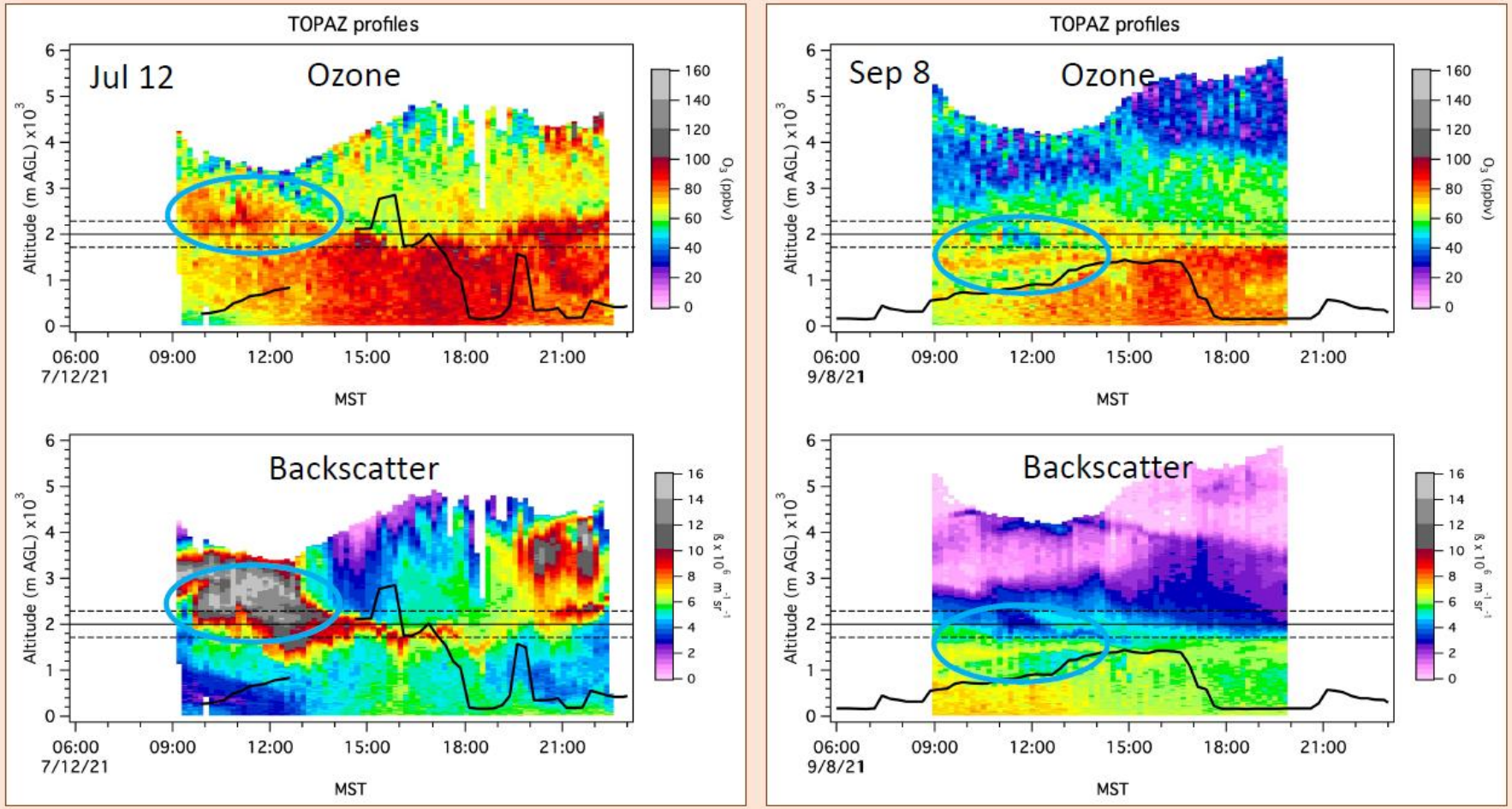
GEOS-CF Sensitivity Simulations: ΔO_3 and $\Delta PM_{2.5}$



- Surface air quality impacts of the long-range transport of Siberian wildfire emissions were minor.
- Influence on tropospheric composition was larger.
- GEOS-CF sensitivity studies predict mid- to lower-tropospheric impacts of:
  - 10 to >20 ppb O_3 enhancements
  - 10 to >30 µg m^{-3} aerosol lamina

Johnson et al. (2021), AE

Did the West Coast wildfires contribute to the high surface O_3 in the Denver area during 2021?



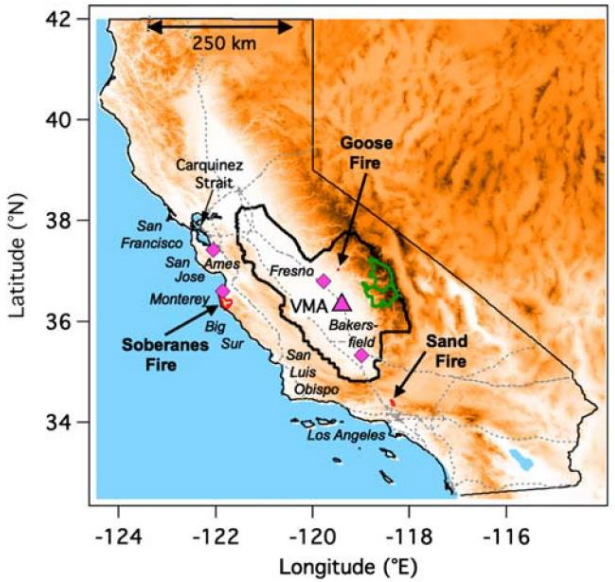
Examples of ozone enhancement in smoke plumes transported to Boulder near the top of the convective boundary layer and likely mixed to the surface

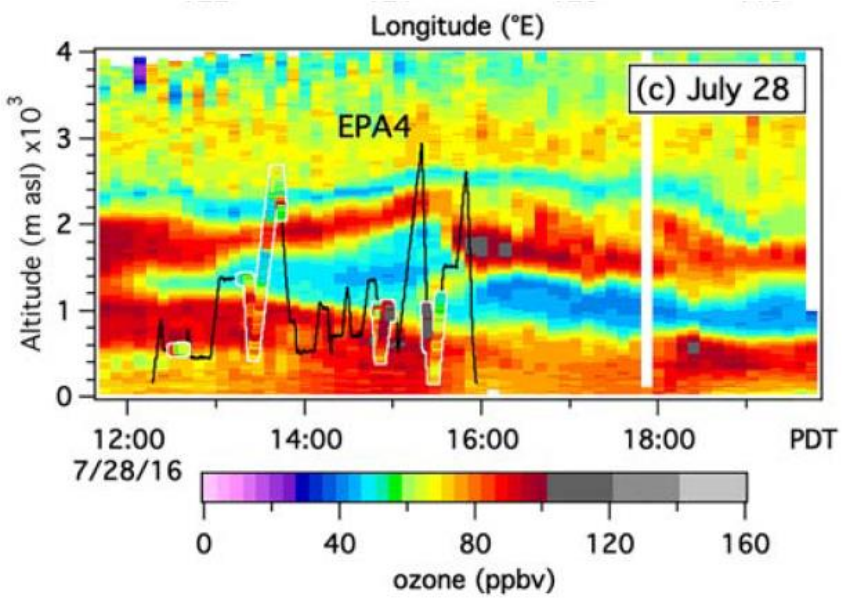
Courtesy of Andy Langford (andrew.o.langford@noaa.gov)

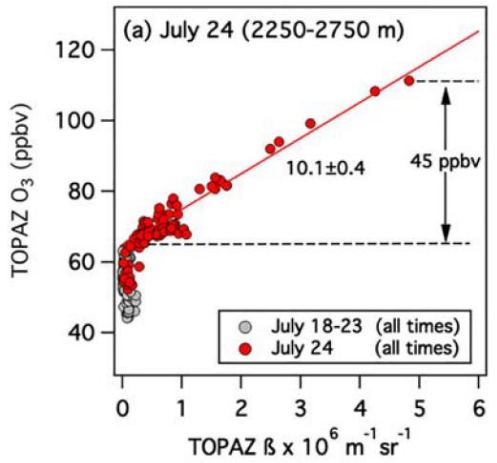
Ozone Production in the Soberanes Smoke Haze: Implications for Air Quality in the San Joaquin Valley During the California Baseline Ozone Transport Study

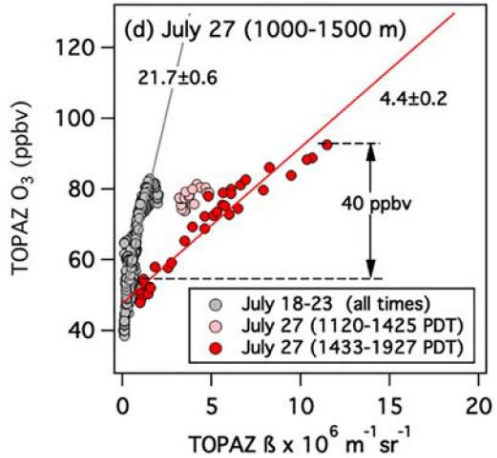
Langford et al. (2020), JGR-Atm

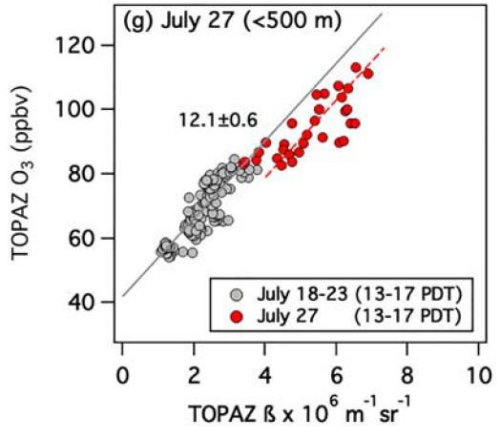
Andrew O. Langford[1], Raul J. Alvarez II[1], J. Brioude[2], Dani Caputi[3], Stephen A. Conley[4], S. Evan[2], Ian C. Faloona[3], Laura T. Iraci[5], Guillaume Kirgis[1,6], Josette E. Marrero[5,7], Ju-Mee Ryoo[5,8], Christoph J. Senff[1,6], and Emma L. Yates[5,9]







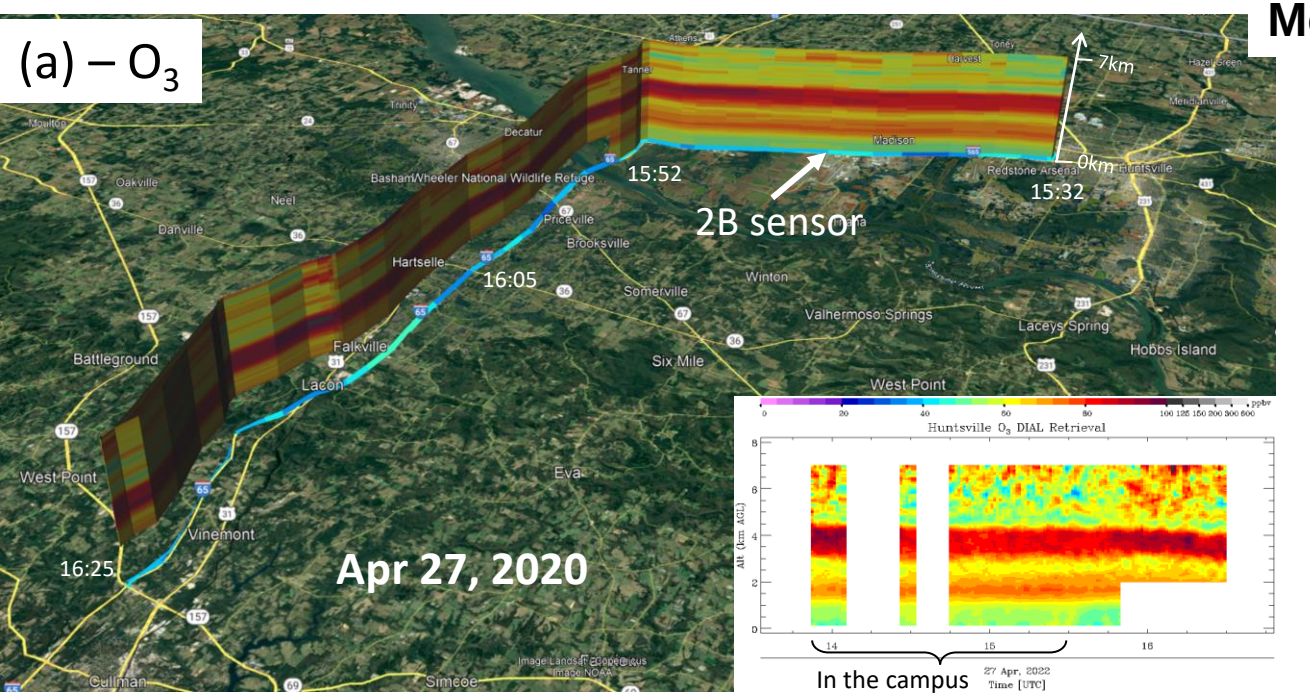


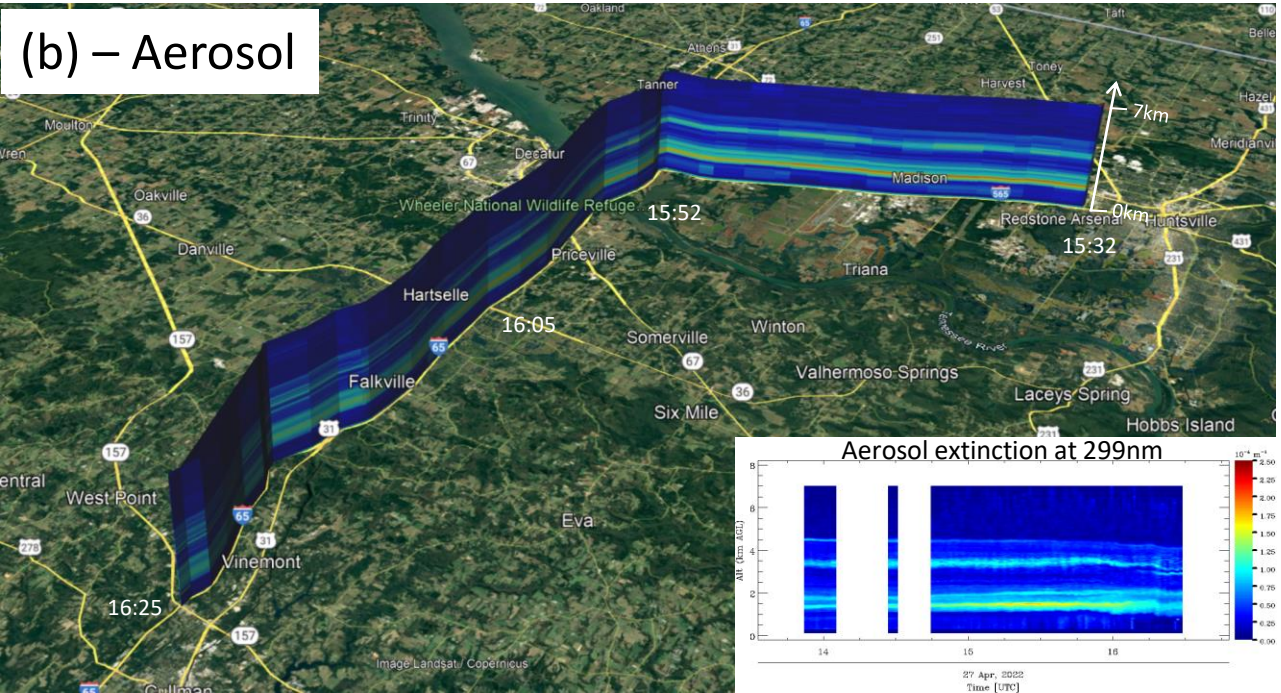


- **Lidar measurements were used to investigate impacts of the 2016 Soberanes Fire.**
- **Ozone enhancements >50 ppbv were measured between 1 and 3 km agl.**
- **No significant enhancements in surface ozone were observed.**

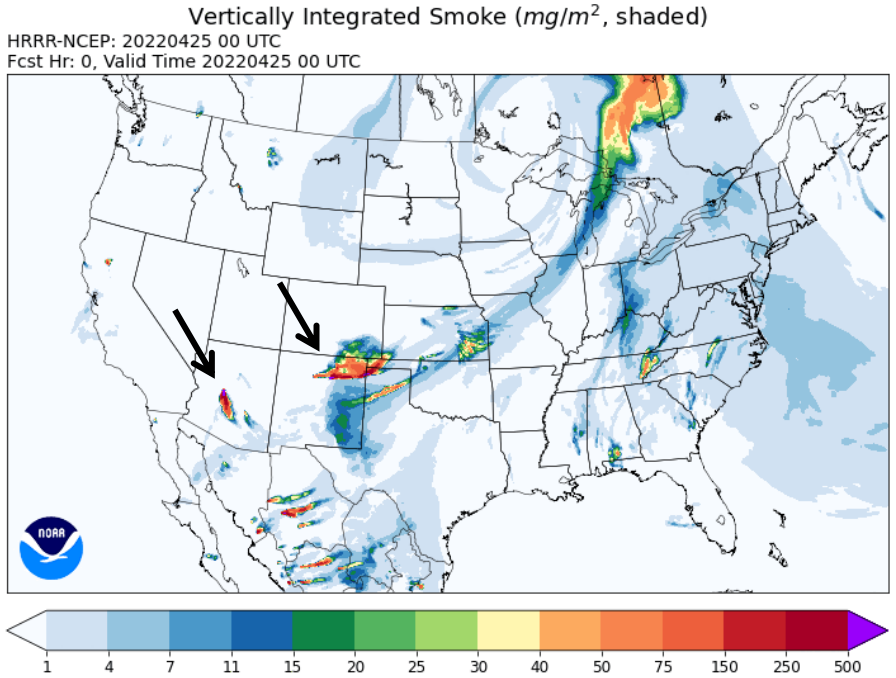
Mobile O_3 & Aerosol Profiling on Highway by UAH Lidar

Courtesy of Shi Kuang (kuang@nsstc.uah.edu)





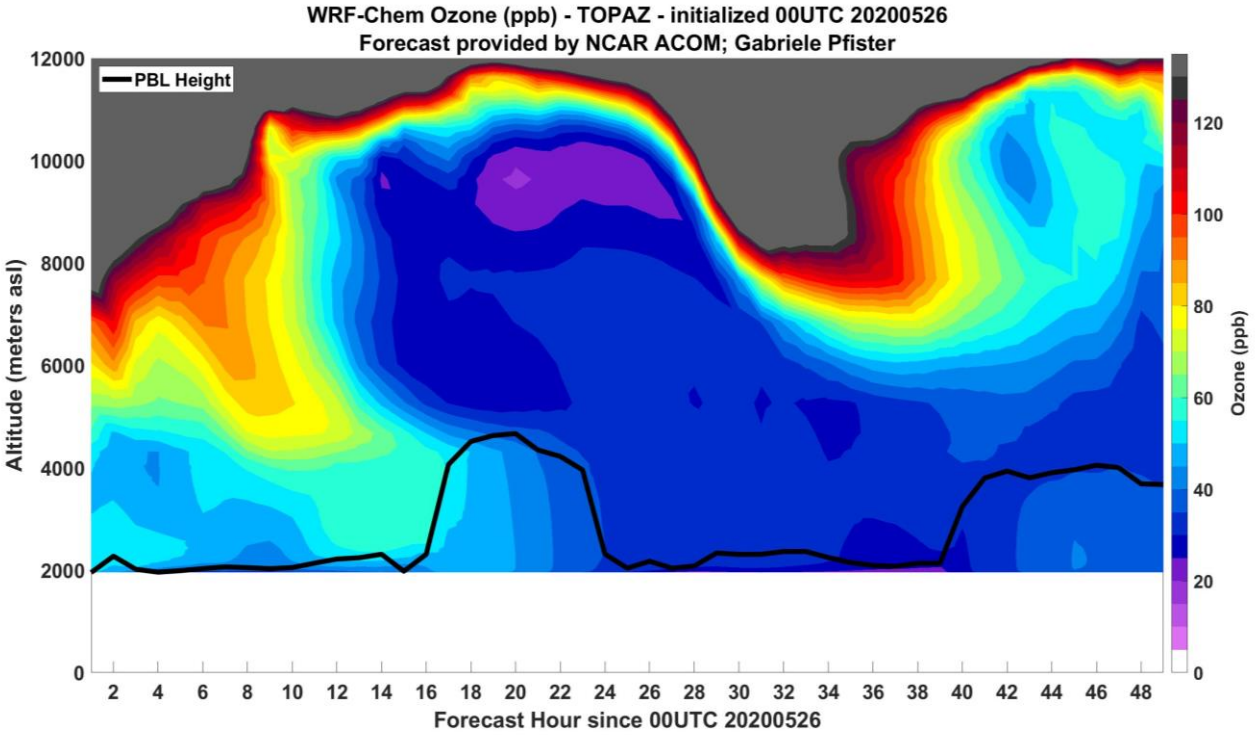
Smoke layers and enhanced ozone observed in free troposphere.

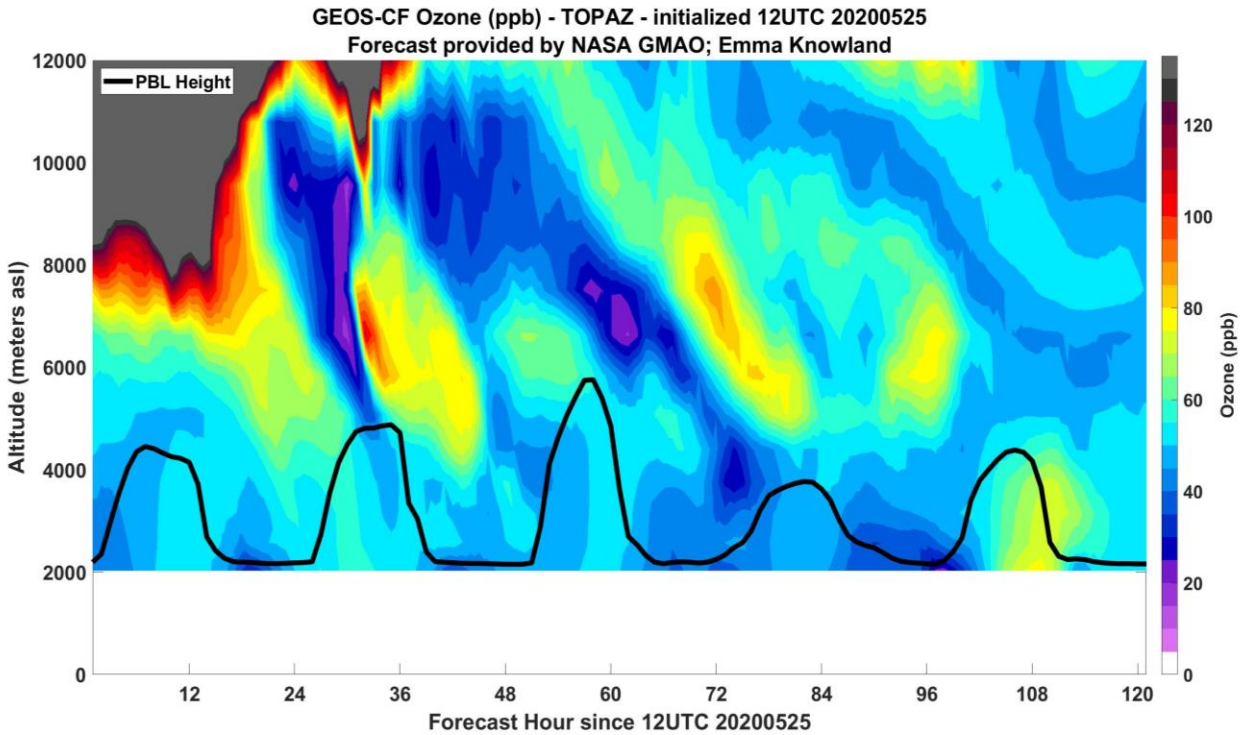


NOAA/NCEP High-Resolution Rapid Refresh (HRRR) vertically integrated smoke, 0425 00z – 0427 12z, 2022

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Automated O_3 and Smoke Aerosol Forecast Alerts

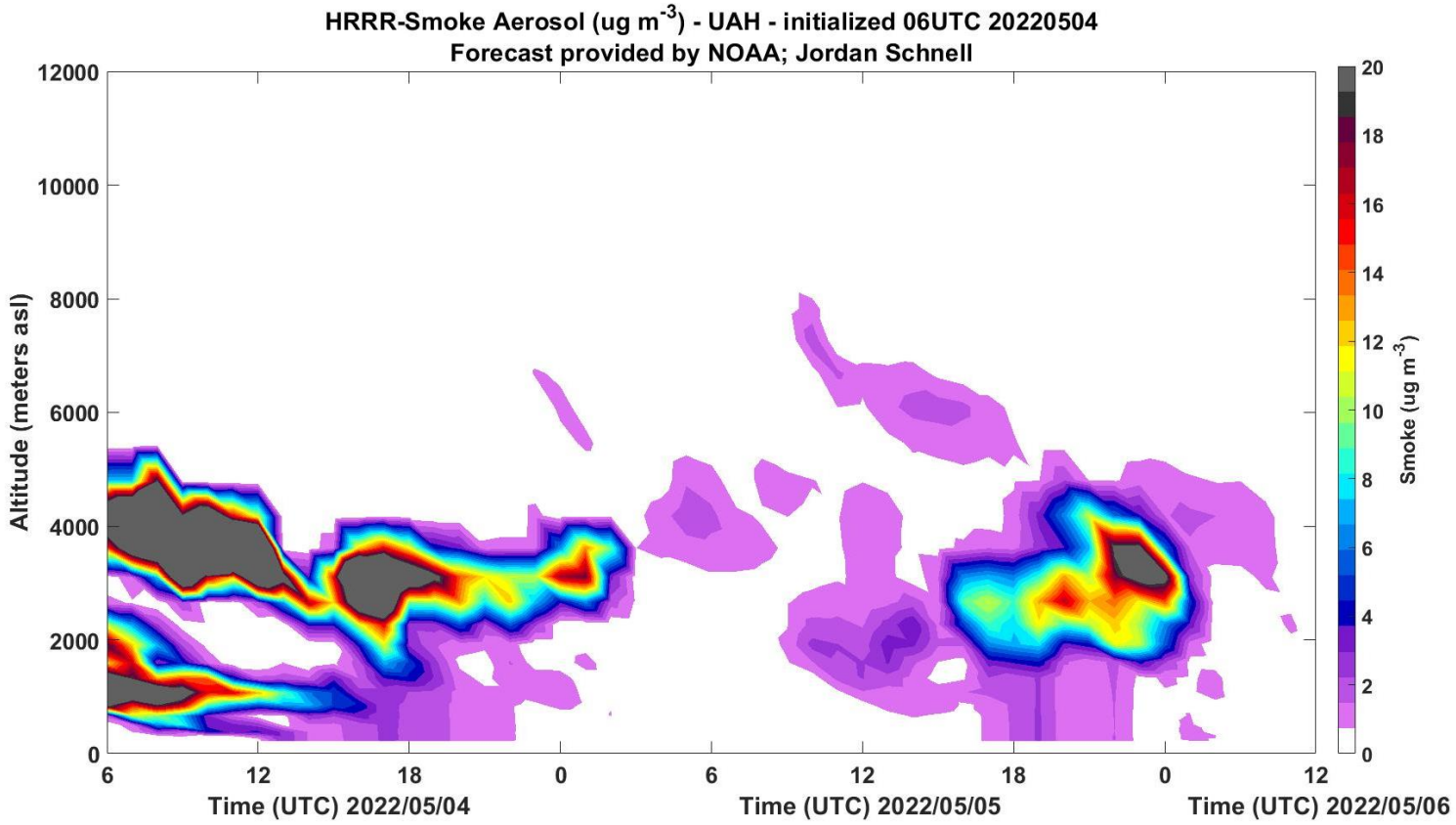




WRF-Chem 48-hour (left) and GEOS-CF 120-hour (right) O_3 forecasts for TOPAZ on May 26, 2020.

- **Daily automated NCAR ACOM *WRF-Chem*, NOAA *RAP-Chem*, NASA GMAO *GEOS-CF* O_3, and wildfire aerosol alerts from NOAA *HRRR-Smoke* are provided to the lidar groups to determine optimal days/times to take measurements.**

Automated O_3 and Smoke Aerosol Forecast Alerts



HRRR-Smoke aerosol (µg m^{-3}) forecasts for May 4, 2022.

- Daily automated HRRR-Smoke aerosol alerts are provided to the TOLNet lidar groups to help determine days/times to take measurements.
- Helpful for sampling wildfire influence.
- Including a biomass burning specific forecast model is beneficial.

Automated O_3 and Smoke Aerosol Forecast Alerts

- **<u>Automated task scheduler:</u> opens Matlab script to download daily sampled WRF-Chem, RAP-Chem, GEOS-CF, and HRRR-Smoke forecast profiles, processes data, determines if alert is necessary, sends emails to individual groups if alert is triggered.**

- **O_3 and aerosol alerts criteria are determined by each group (e.g., O_3 > 80 ppb; <5000 m asl); aerosol alerts (e.g., smoke aerosol > 15 ug m^{-3} anywhere in the troposphere).**

- **Alert criteria are easily adjustable.**

- **Made possible by forecast model data providers sampling profiles at the location of TOLNet lidars.**

- **WRF-Chem 48-hour forecasts; RAP-Chem 36-hour forecasts; GEOS-CF provides 5-day forecasts for long-range planning.**

- **HRRR-Smoke provides 48-hour forecasts of aerosol concentration directly emitted by fire.**

- **WRF-Chem forecasts initialized at 00Z; RAP-Chem initialized at 06Z and 18Z; GEOS-CF initialized 12Z (day prior); HRRR-Smoke initialized every hour.**

Targeted Lidar Observations for Air Quality Alerts

Andy Langford, C.J. Senff*, R.J. Alvarez II, S. Baidar*, B. McCarty*, S.P. Sandberg, and M. Zucker*, NOAA CSL and *CIRES, CU.
M. Johnson, NASA-Ames, E. Knowland, NASA-Goddard, and G. Pfister, NCAR.

The TOLNet lidars have the unique ability to continuously profile ozone aloft before it reaches the surface. This example shows how targeted observations guided by model forecasts can help regulatory agencies better serve the public.

How it might work

1. **NASA-Ames** disseminates **NASA-Goddard** GEOS-CF and **NCAR** WRF-Chem ozone forecasts in daily e-mail alerts to **TOLNet** stations.

2. **TOLNet** stations make targeted observations when the forecasts predict deep stratospheric intrusions or other potential high ozone events.

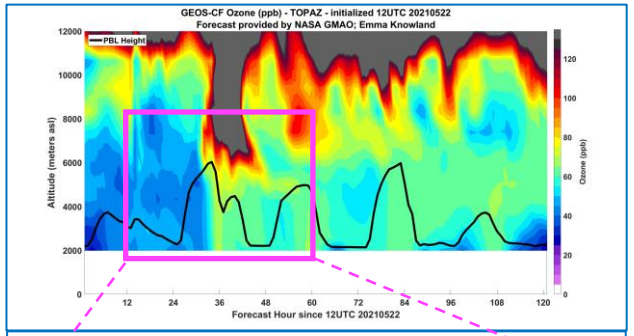
3. **TOLNet** operators advise state and local agencies to guide issuance of air quality advisories when warranted by observations.

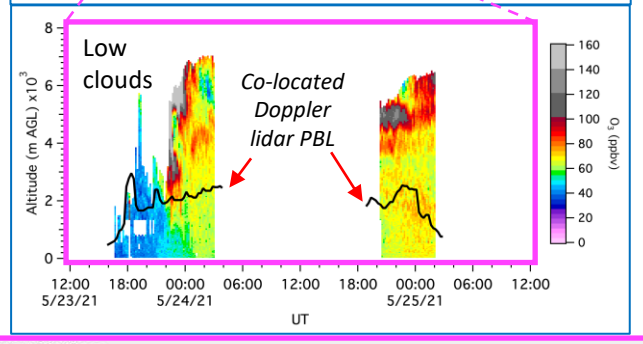
A real life example

TOPAZ *team alerted that WRF-Chem and GEOS-CF (right) models forecast deep stratospheric intrusion (SI) over Boulder on May 23-24, 2021.*

NOAA-CSL *team operates* ***TOPAZ*** *lidar on May 23-24. Measurements confirm models and show entrainment of SI into the PBL on May 24.*

TOPAZ *team notifies* ***CDPHE*** *which issues air quality advisory for affected areas. Aspen and Blackhawk monitors exceed the ozone NAAQS on May 24.*





Air Quality Health Advisory for Ozone

Issued for Summit, Eagle, Pitkin, and Lake Counties
Issued at 5:00 PM MDT, Monday, May 24, 2021

Issued by the Colorado Department of Public Health and Environment

Affected Area: Summit, Eagle, Pitkin, and Lake Counties. Cities and points of interest include, but are not limited to Breckenridge, Eagle, Aspen, and Leadville.

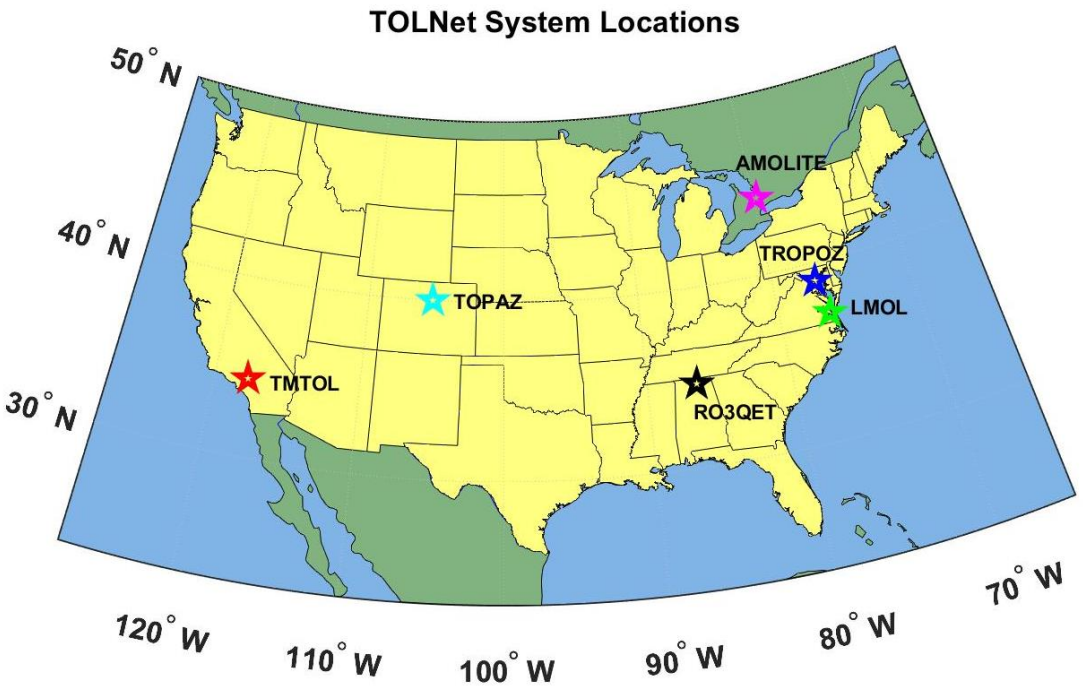
Advisory in Effect: 5:00 PM MDT, Monday, May 24, 2021 to 12:00 AM MDT, Tuesday, May 25, 2021.

Public Health Recommendations: *Active children and adults, older adults, and people with lung disease, such as asthma, should reduce prolonged or heavy outdoor exertion within the affected areas.*

Outlook: Lingering ozone from yesterday's stratospheric intrusion will allow ozone concentrations to reach the Unhealthy for Sensitive Groups category across the advisory area, especially for locations above 8000 ft. in elevation. Ozone concentrations will likely decrease gradually late Monday evening.

COLORADO Air Quality
Department of Public Health & Environment

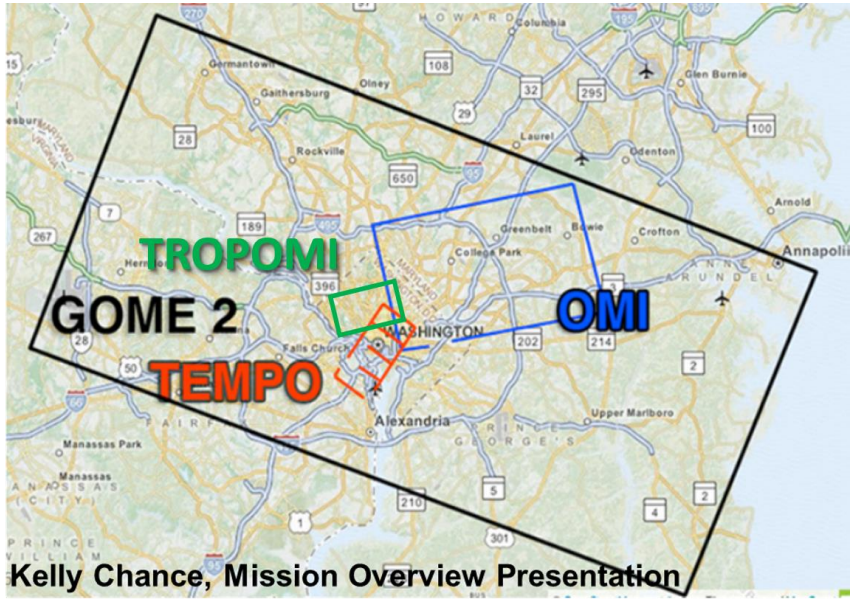
Network-wide TOLNet Validation of TROPOMI Ozone



- TOLNet data currently being used to validate TROPOMI O_3 profile retrievals.
- TOLNet measurements are a desirable validation dataset as the observations have:
  1. higher vertical resolution compared to satellite retrievals in the troposphere
  2. high accuracy
  3. minimal dependence on a priori information
- 100's of hours of correlative observations made during S5P overpass times (+/- 30 min.) from the six TOLNet systems.

- Provide novel information about the accuracy/precision of the O_3 profiles at all vertical layers of the troposphere (e.g., planetary boundary layer (PBL), free troposphere (FT), and the upper troposphere (UT).
- Geophysical validation (i.e., characterize accuracy (systematic and random bias) and precision) of the Level 2 (L2) ozone profile products ('full' and 'tropospheric') from S5P TROPOMI retrievals.

TEMPO Tropospheric Ozone Validation with TOLNet



TEMPO spatial resolution:

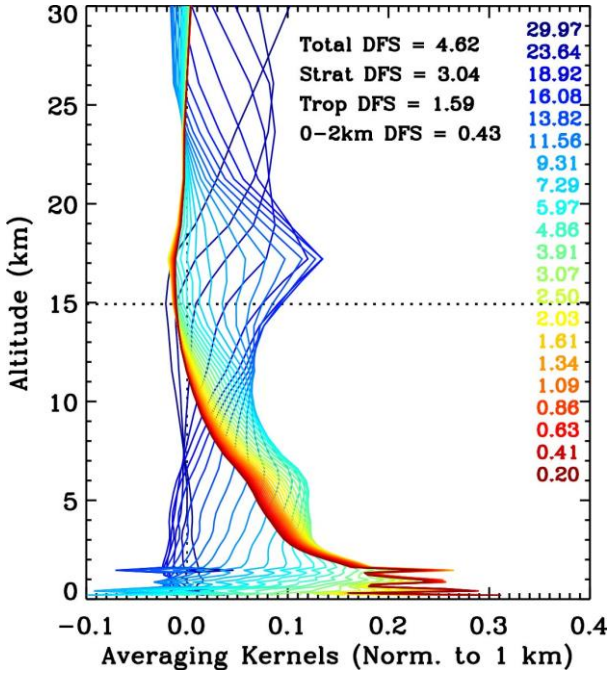
~2.1 × 4.4 km^2

~8.4 × 4.4 km^2 for O_3

~1/300 of *GOME-2*

~1/30 of *OMI*

~1/2 of *TROPOMI*

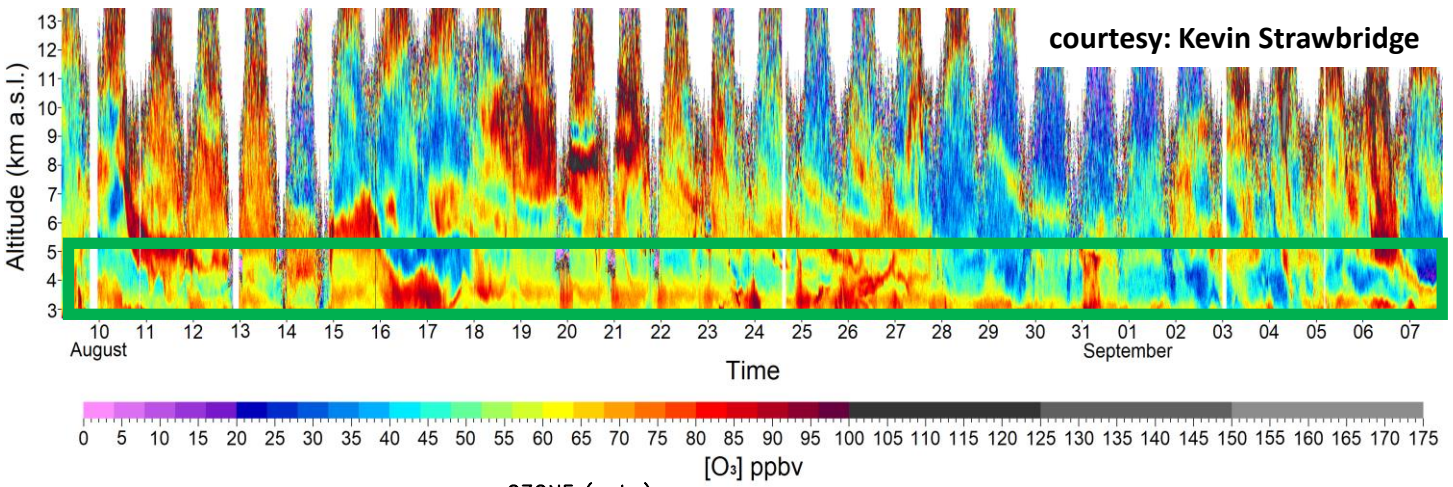


Normalized TEMPO averaging kernel for UV+VIS wavelengths (290-345 nm, 540-650 nm) from the surface to 30 km at the RO3QET TOLNet site.

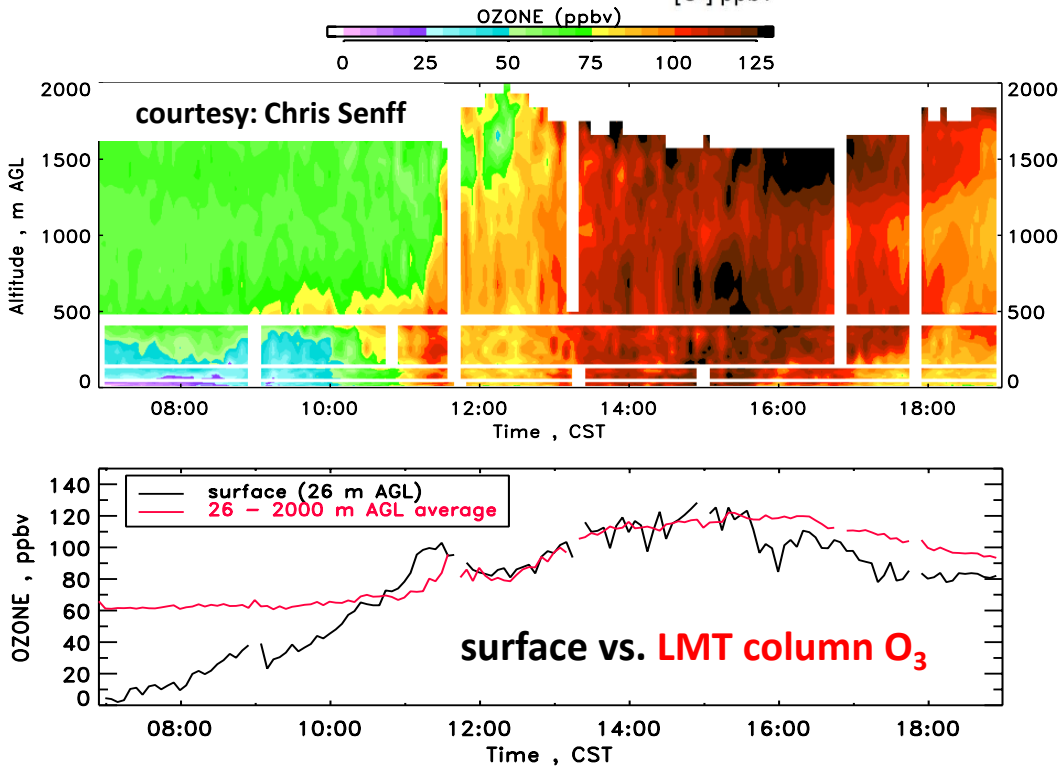
- ✓ A major goal of TOLNet is to validate TEMPO tropospheric O_3 observations.
- ➢ TEMPO will provide hourly, high spatial resolution, data (such as O_3, NO_2, HCHO, etc.) to monitor air quality and tropospheric chemical composition in North America.
- ➢ Partial column products (such as lowermost tropospheric (LMT, 0-2 km) O_3) that will be used for air quality monitoring/forecasting.

- ➢ TOLNet helped to better understand the prior O_3 profile used in TEMPO retrievals (Johnson et al., 2018).
- ✓ TOLNet will provide vital information about the ability of TEMPO to retrieve LMT O_3.

TEMPO Tropospheric Ozone Validation with TOLNet



- Evaluation of TEMPO tropospheric column and O_3 profile.
- Diurnal and daily variability of the LMT (0-2 km) O_3 column product.
- TOLNet is a vital tool to evaluate how well TEMPO observes *vertical* and *temporal* variability of tropospheric and LMT O_3.



- TOLNet can help relate the TEMPO LMT O_3 product to surface air quality. This has been studied with TOPAZ lidar data from numerous field campaigns (e.g., Discover-AQ Texas (left)).
- 66% of LMT O_3 observations agree within 10 ppb of surface values, however, can differ significantly (up to 80 ppb).
- LMT O_3 compares best with surface observations when a deep mixed layer is present resulting in well mixed pollutants between the surface and 2 km agl.

Conclusions

Thanks!

- TOLNet provides accurate high spatiotemporal observations of O_3 and aerosol vertical profiles in numerous locations in North America.
- These lidars provide data which can be used for researching impacts of wildfires on tropospheric composition and air quality.
- An air quality forecast alert system (using WRF-Chem, RAP-Chem, GEOS-CF, and HRRR-Smoke forecasts) used to identify opportune times to make observations.
- Forecast alert system has been successful in predicting events leading to: observations being taken and local air quality agencies issuing health advisories.

  - TOLNet is being applied to validate and evaluate tropospheric O_3 column and vertical profiles from current satellite sensors (e.g., TROPOMI).
  - Significant effort within TOLNet for the next 3+ years will be allocated for the validation and evaluation of TEMPO O_3 retrieval products, with emphasis on the 0-2 km agl product.