TEMPO vs. TOLNet

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[10]St. Edward's University, Austin, TX, USA
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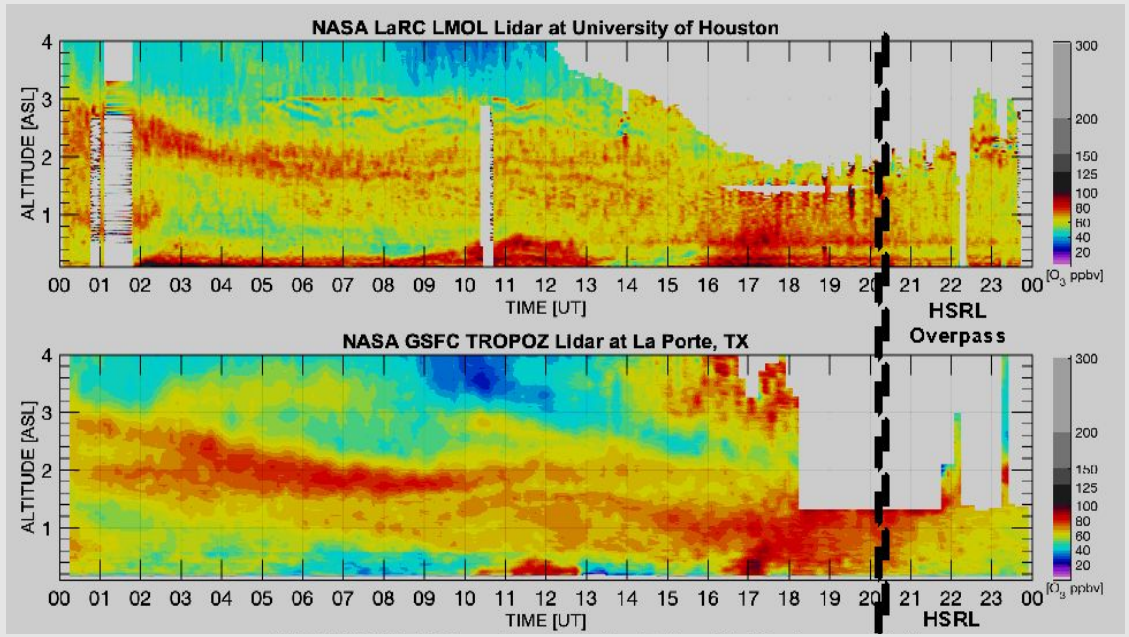
GeoXO ACX Science Team Meeting. National Center for Weather and Climate Prediction. College Park, MD 7-9 May 2024

NASA Tropospheric Ozone Lidar Network (TOLNet)

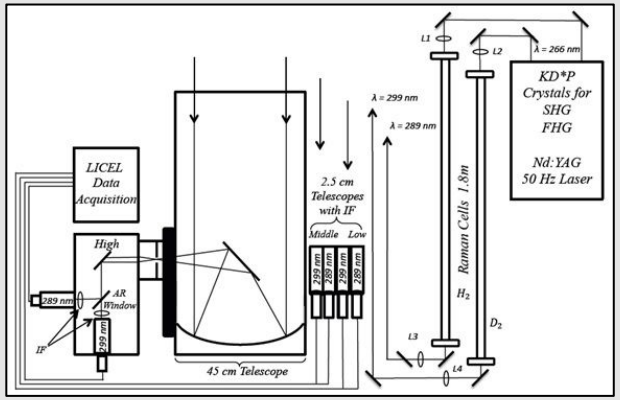
1. Observe high resolution PBL O_3 (***example below***)
2. Evaluate air-quality forecast and chemical transport models
3. Study the atmospheric structure for evaluation of current and future satellites (***this work and next steps in prep for TEMPO***)

Data below from NASA LaRC and GSFC lidars during a 2021 pollution episode in Houston, TX TRACER-AQ

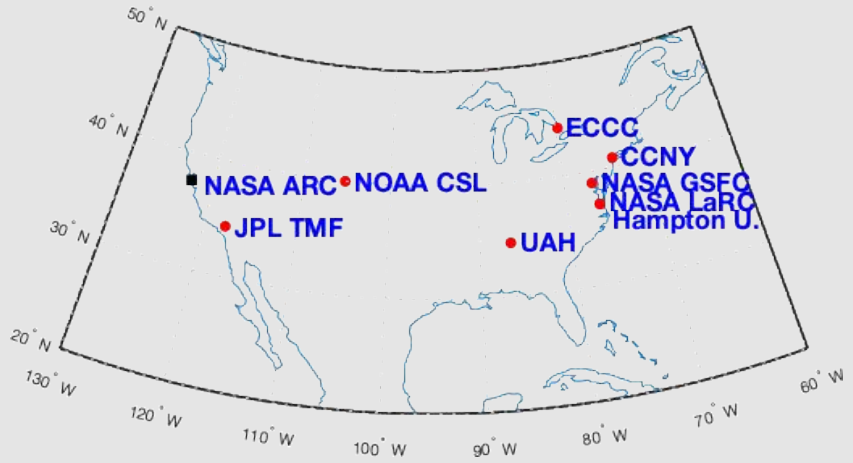


Network Instrumentation

Each TOLNet site consists of a unique UV lidar system. This includes a UV laser transmitter, receiver (telescope), and data collection system. Lidars are installed in portable containers for field efforts or stationary for long-term observations.



Network Map



Site	Institution
TROPOZ	NASA/GSFC
LMOL	NASA/LaRC
RO3QET	UAH
TOPAZ	NOAA/CSL
TMTOL (SMOL1/2)	JPL/TMF
AMOLITE	ECCC
HU-Lidar	Hampton U.
CCNY-Lidar	CCNY
Modeling	NASA ARC
Data Center	NASA/LaRC

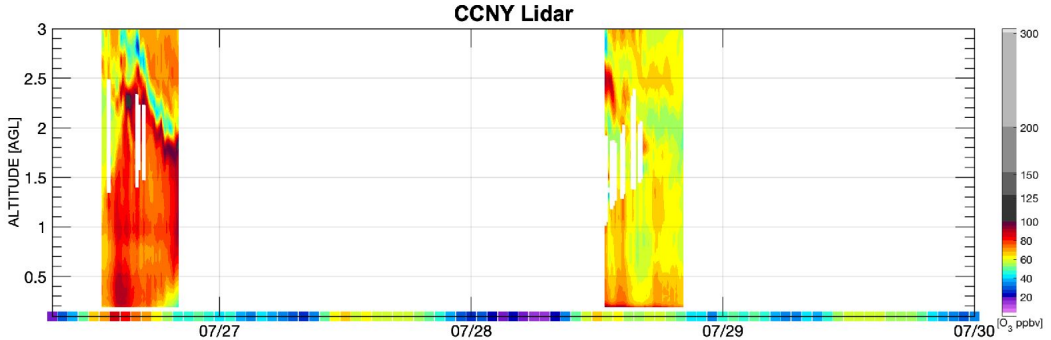
Network-wide TOLNet Validation of Satellite O_3 Profiles

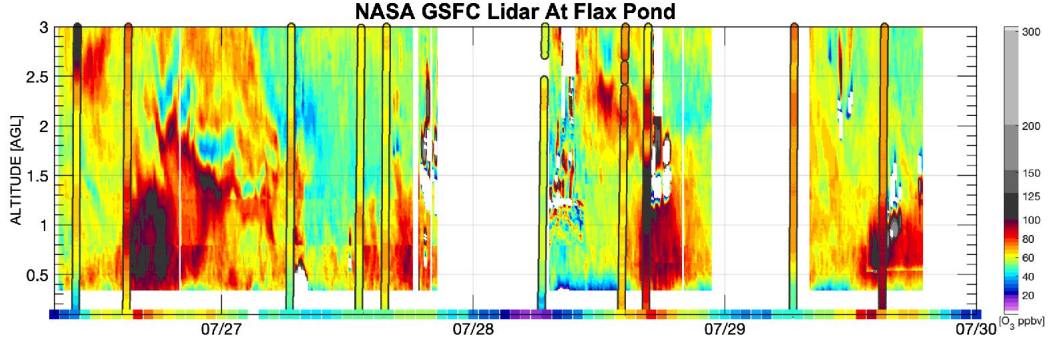
- TOLNet data was used to validate TROPOMI/CrIS Level 2 (L2) O_3 profile retrievals in the troposphere.

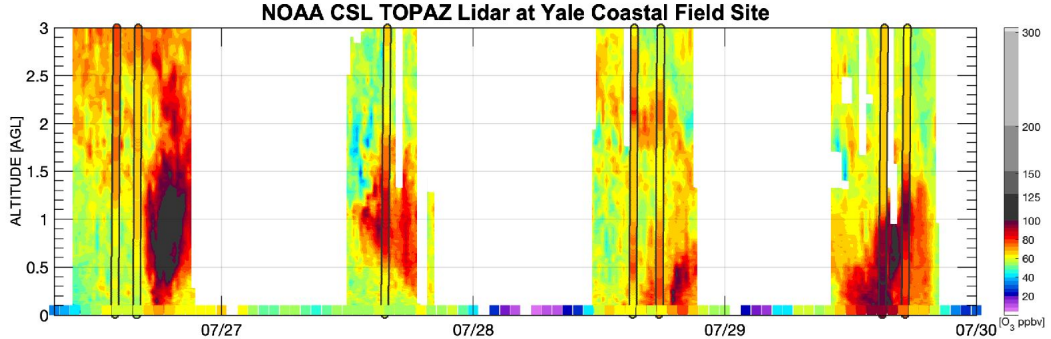
- TOLNet measurements are a desirable validation data set as the observations have:
  1. higher vertical resolution compared to satellite retrievals in the troposphere
  2. high accuracy
  3. no dependence on a priori information

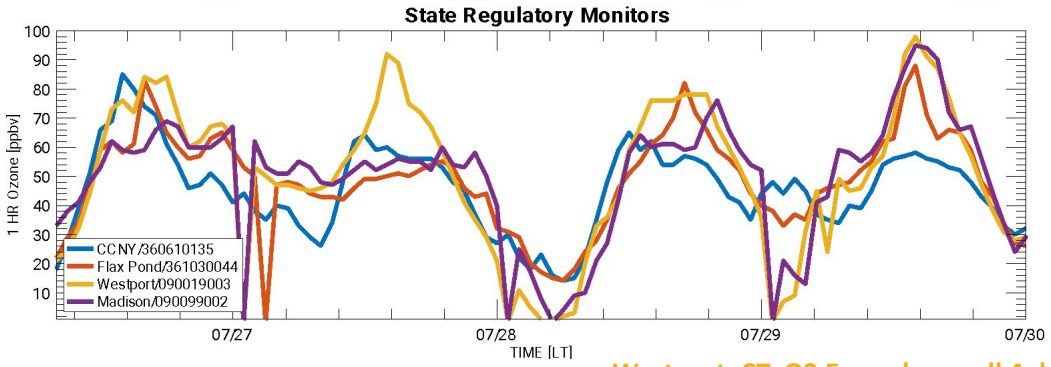
- 100's of hours of correlative observations made during S5P and Suomi-NPP overpass times (+/- 30 min.) from six TOLNet systems between 2018-2019.
- TOLNet includes a daily automated air-quality forecast system using five separate models.
- Provides novel information about the accuracy/precision of the O_3 profiles at all vertical layers of the troposphere (e.g., planetary boundary layer (PBL), free troposphere (FT), and the upper troposphere (UT). Ozone lidar data is highly accurate and consistent between systems (Leblanc et al., 2018).
- TOLNet frequently used for evaluating air quality models and satellite retrievals (Johnson et al., 2016, 2018; 2021; Zhang et al., 2020; Chouza et al., 2021; Knowland et al., 2022; Sullivan et al., 2022).
- Geophysical validation (i.e., characterize accuracy (systematic and random bias) and precision) of the L2 O_3 profile products from S5P TROPOMI and Soumi-NPP CrIS retrievals.

Using TOLNet to Contextualize Ozone Aloft and Surface Exceedances





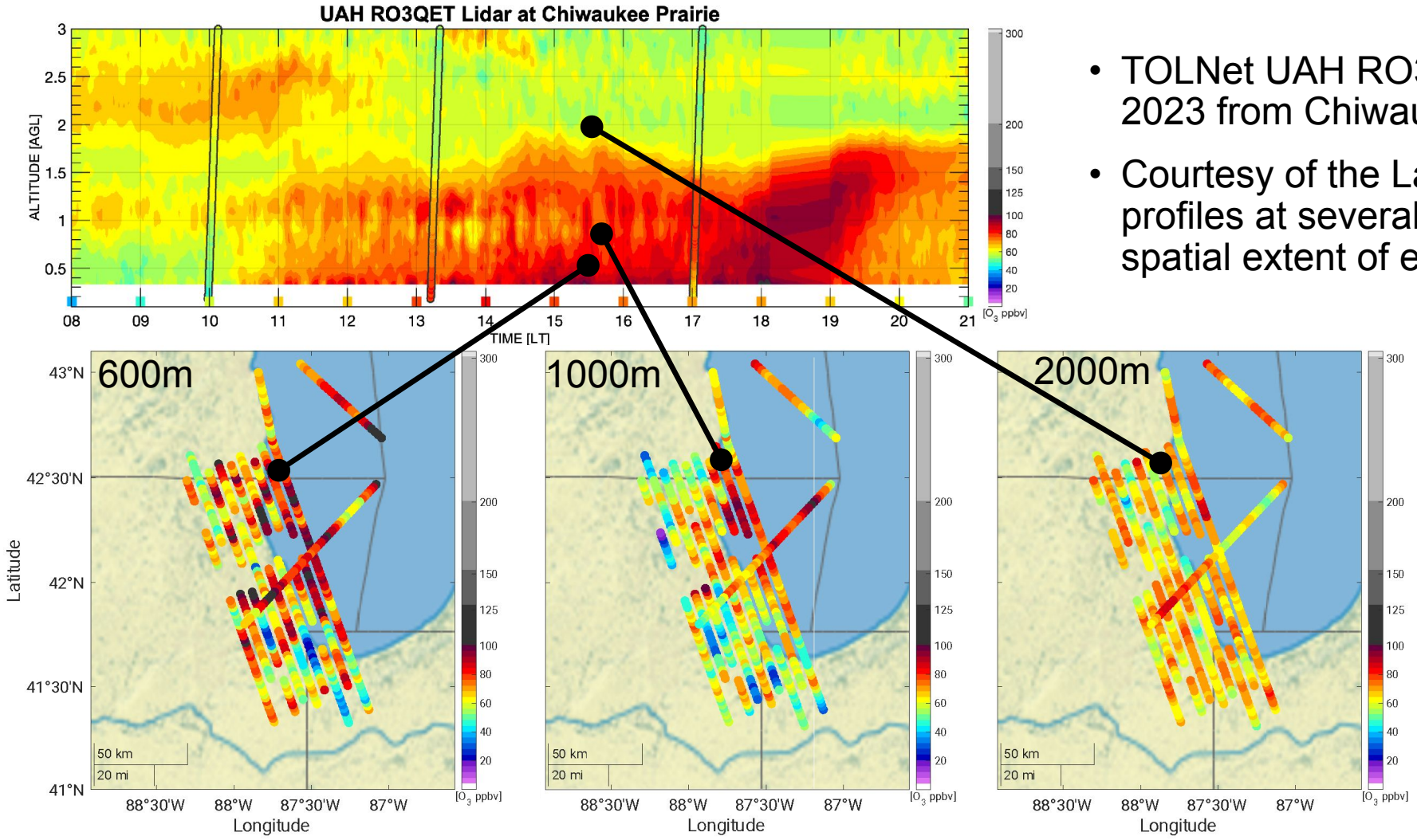




Westport, CT O3 Exceedance all 4 days

- TOLNet ozone curtains + sondes + surface ozone at multiple sites from July 26th to July 30th
- July 26th and July 28th aircraft flights from STAQS/AEROMMA/CUPIDS
- Elevated ozone indicated in all ozone lidars on July 26th and July 28th, with a delay in reaching the coastal sites (Flax Pond, Westport, and Yale Coastal).

Using TOLNet and HSRL to Contextualize Ozone Transport and Recirculation Over Lake Michigan



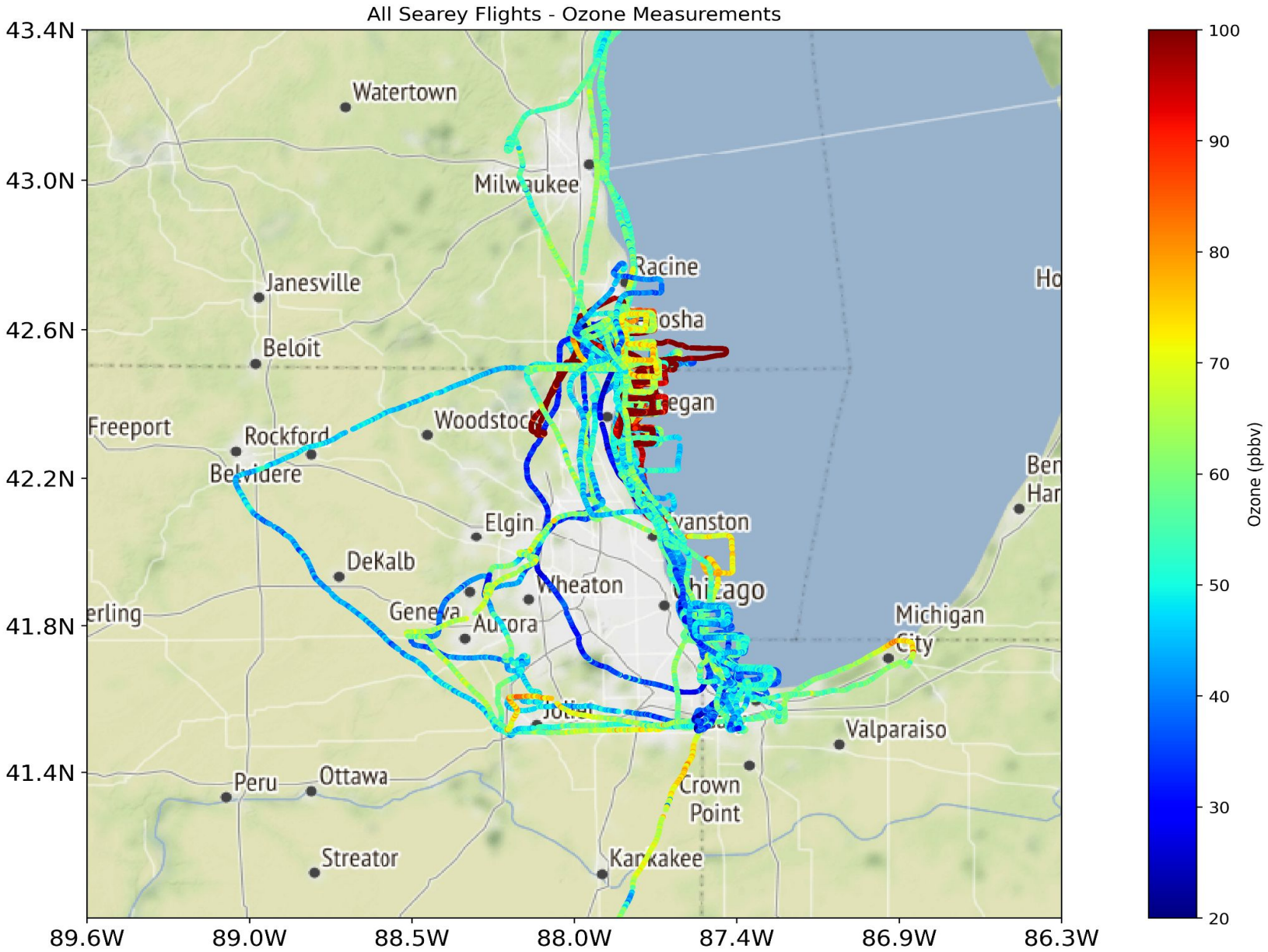
- TOLNet UAH RO3QET Curtain for Aug 2nd, 2023 from Chiwaukee Prairie, WI
- Courtesy of the LaRC HSRL Team, ozone profiles at several distinct altitudes highlight the spatial extent of enhanced ozone.

RO3QET collecting observations until 2100 LT, extending our knowledge of of the enhancement event and nocturnal decoupling from the surface

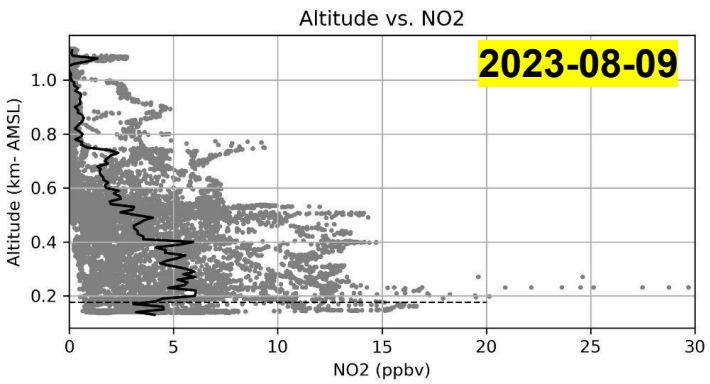
staqs-HSRL2_JSC-GV_20230802_RA.h5 (data from Raster 3 from 15:30 to 16:15 LT)

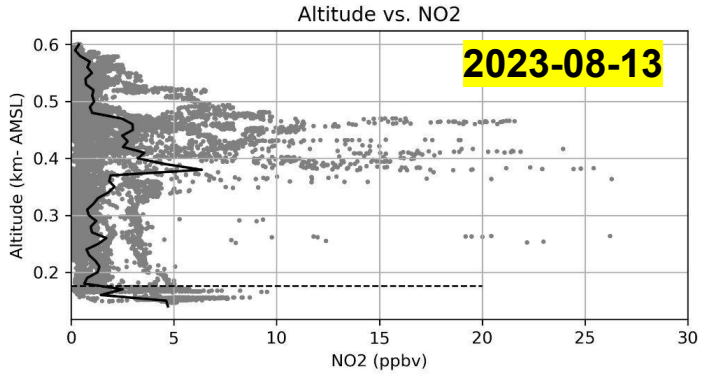
SeaRey Ozone Measurements near Chicago

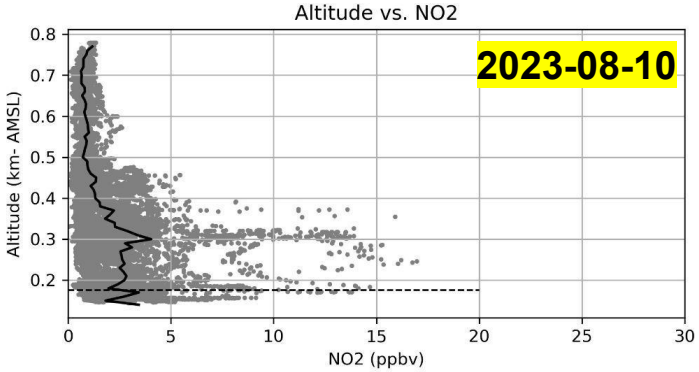
SeaRey observations of PBL ozone around the west side of Lake Michigan, reveal the large variability of low-level ozone (and NO_2)

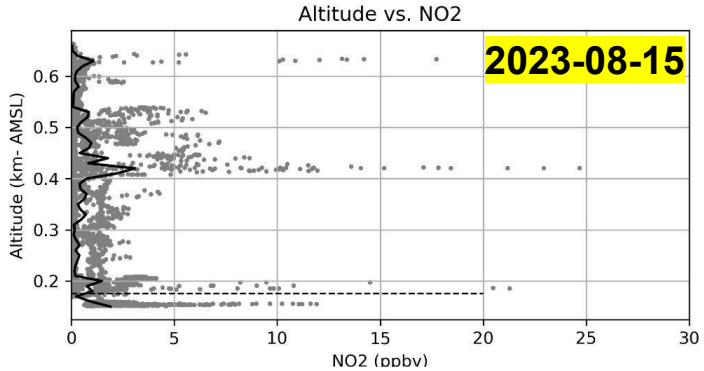


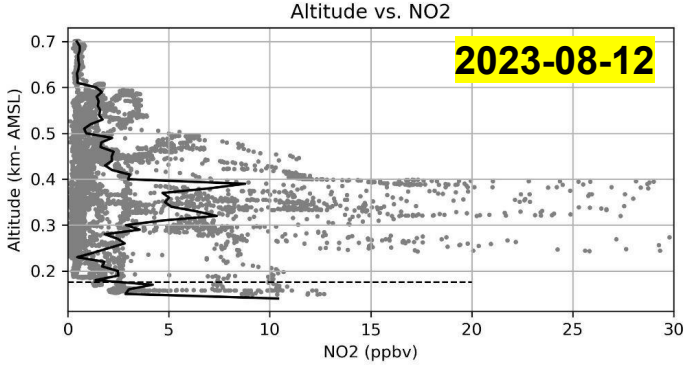
SeaRey Chicago Circuits - NO2 Profiles during 6 Days

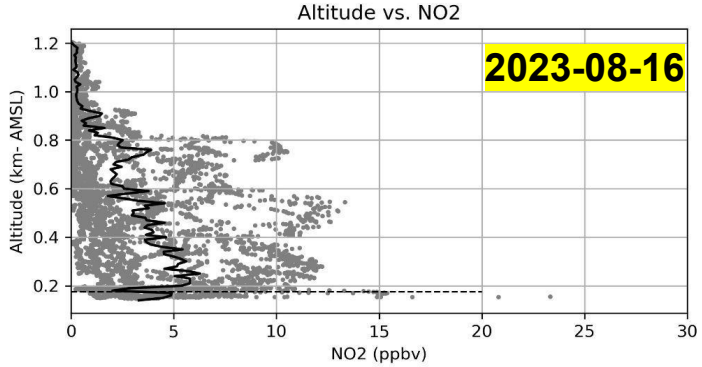












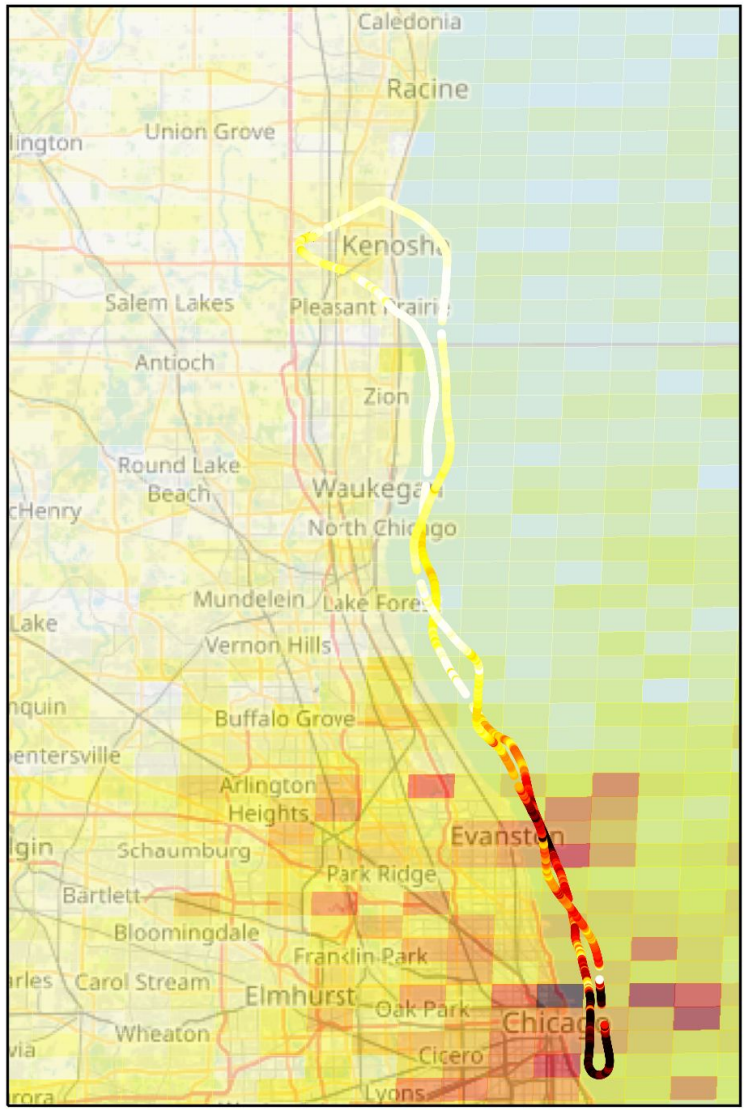
- **Lower PBL NO2** profiles measured by SeaRey do not support the assumption that NO2 decreases exponentially with height.
- Elevated levels of NO2, with a higher mixing ratio than at ground level, have been measured at **higher altitudes.**
- Possible **aloft plumes** that have found a stable equilibrium height?

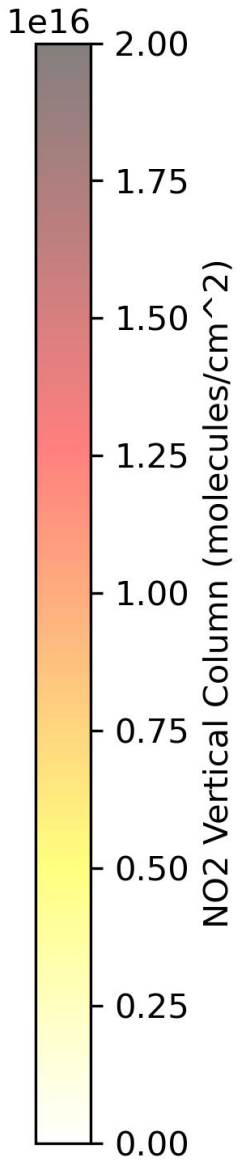
Left figures: SeaRey profiles of NO2 for flights around the Chicago area.

August 16th SeaRey vs. TEMPO

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

TEMPO NO2 Column
Scan Time (UTC): 2023-08-16 15:44:50

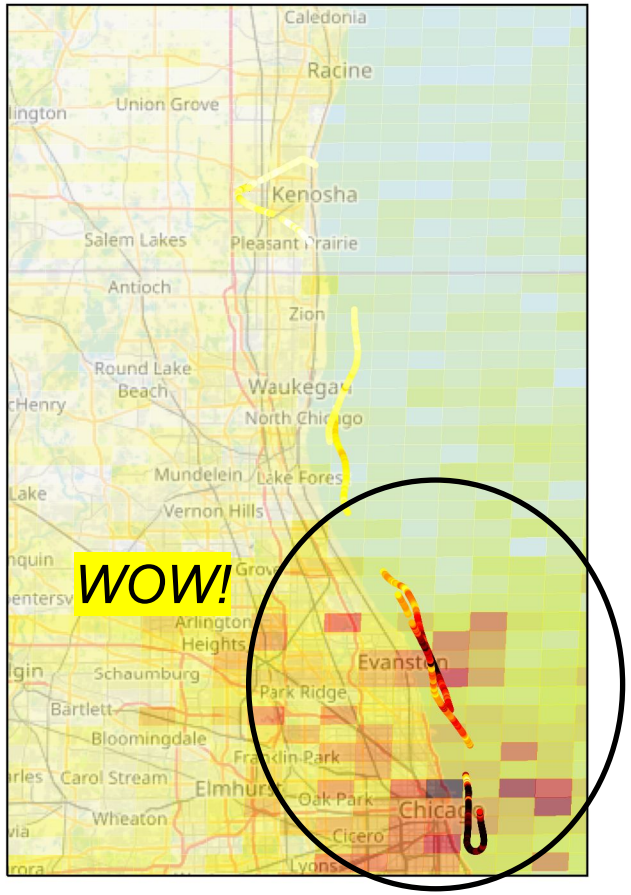




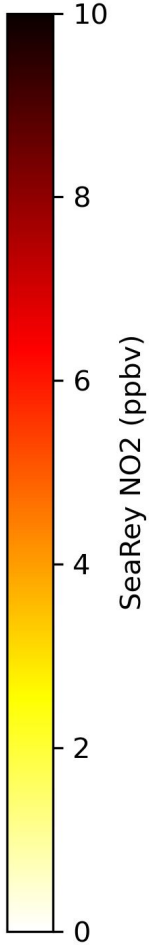
Unofficial TEMPO Data: Not for Public Release

Below 500 AGL SeaRey

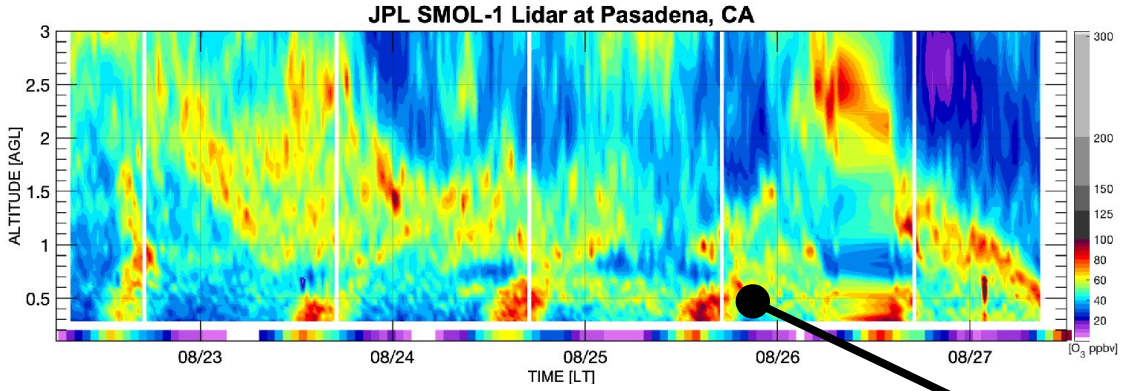
TEMPO NO2 Column
Scan Time (UTC): 2023-08-16 15:44:50

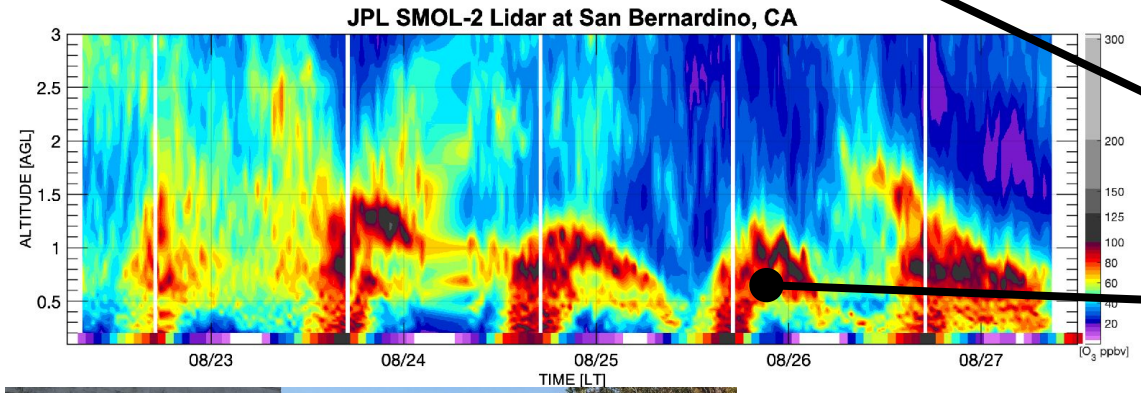


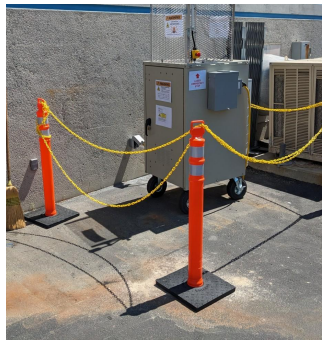
WOW!



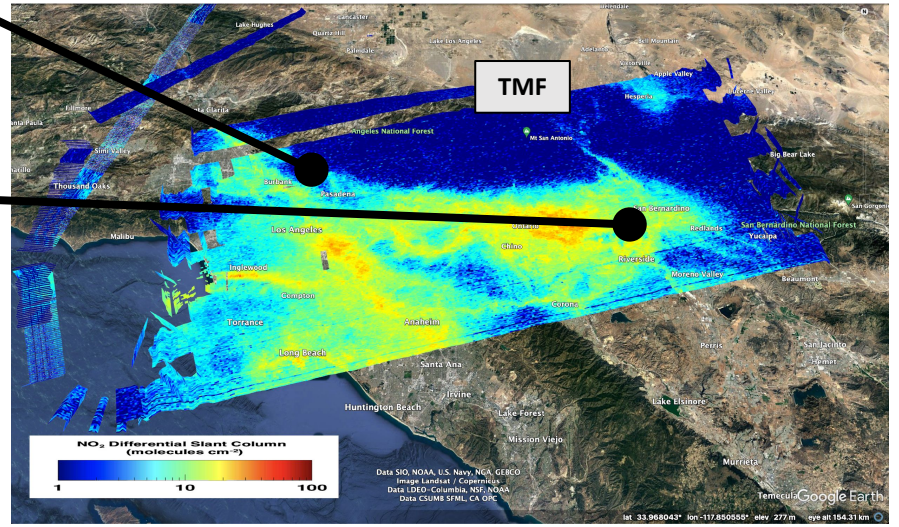
Using Multiple TOLNet lidars to Contextualize Ozone Throughout the Los Angeles Basin







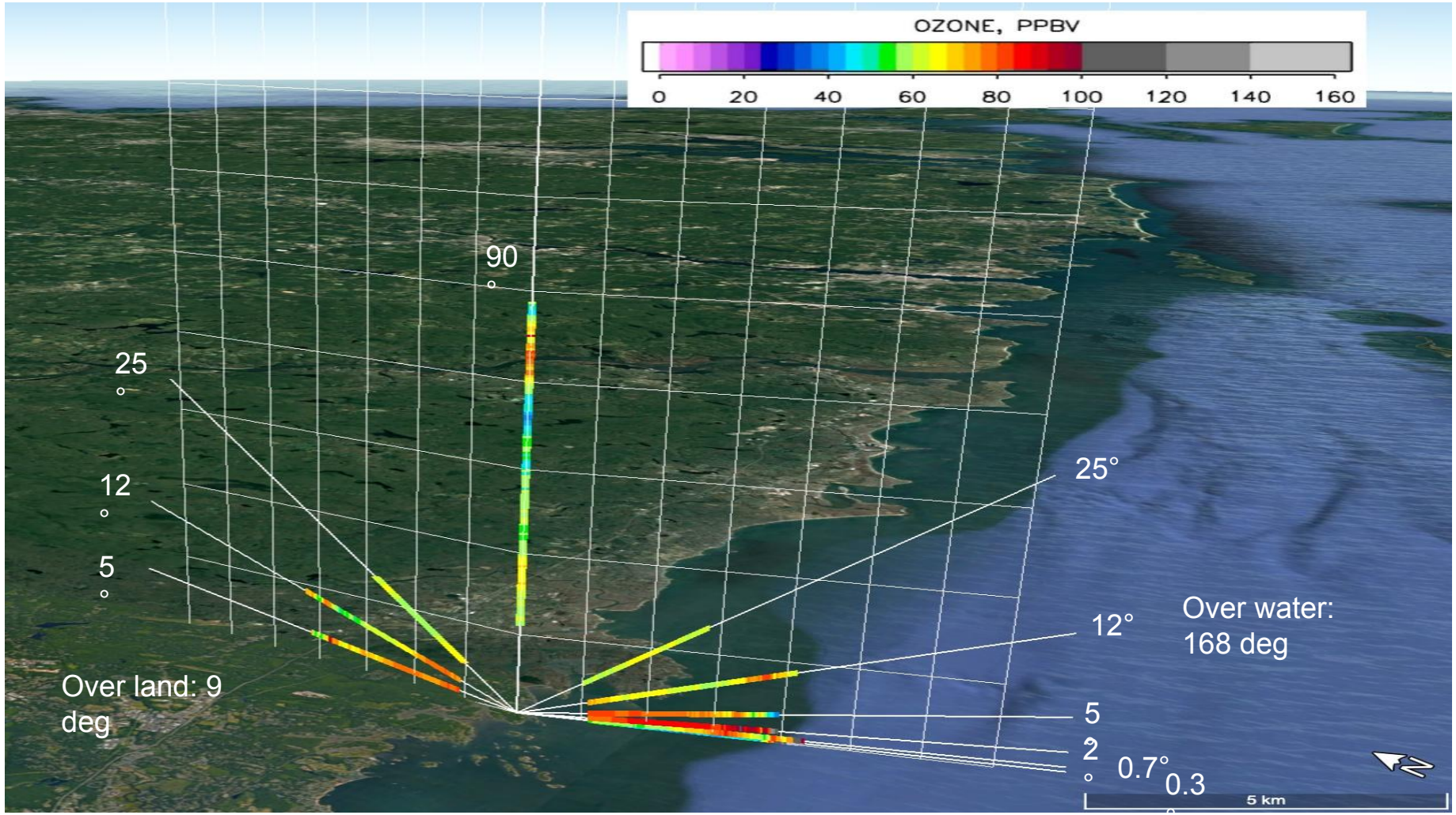
- TOLNet ozone curtains Aug. 26-30th 2023
- SMOL-1/2 Deployed (data image left, below)
- Continuous ozone profiling utilizing a centralized processing algorithm GLASS. Next steps: incorporate GLASS within all of TOLNet data for use in various continental scale needs (*e.g.* model/satellite cal/val).



GCAS NO2 Slant Columns for LA Basin on Aug 26th, 2023

NOAA/CSL TOPAZ scan sequence (~ every 20 min)

Example: 12 JUL 2023, 9:55 – 10:15 EST



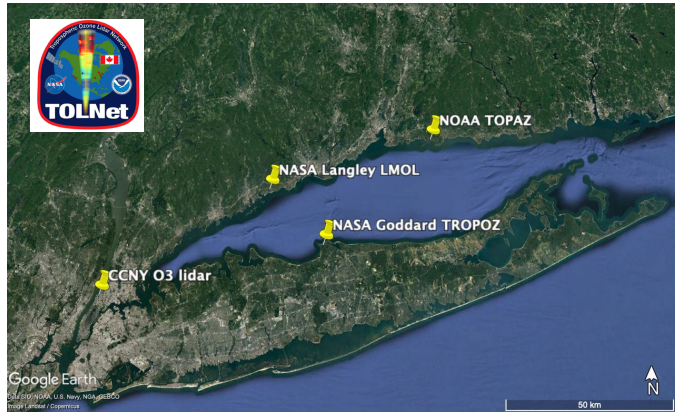
Langford, Sennff, and Alverez

NOAA TOPAZ O_3 lidar and Doppler wind lidar @ YCFS

R. Alvarez II, S. Baidar, A. Brewer, A. Langford, B. McCarty, S. Sandberg, C. Senff, M. Zucker

- Deployment:
  - Yale Coastal Field Station (YCFS) from 3 July – 15 August 2023
- Observations:
  - TOPAZ lidar: O_3 and aerosol backscatter profiles
  - DALEK 2 Doppler lidar: wind speed & direction profiles, turbulence, 2-d surface winds (over water)
- Main Science Objectives:
  - Document the effect of the land - sea breeze circulation on distribution of O_3 and aerosol concentrations in the urban outflow downwind of NYC.
  - Evaluate the capabilities of high-resolution air quality models to replicate observed O_3 concentrations in the NYC area.
  - Validate TEMPO O_3 observations. Assess the accuracy of the 0-2 km AGL O_3 column product and study O_3 variability within individual TEMPO ground pixels.

NOAA Doppler lidar and TOPAZ O_3 lidar trailer at YCFS (photo: A. Langford)



4 TOLNet O_3 lidars around the Long Island Sound

Final data

TOPAZ O_3 lidar: https://tolnet.larc.nasa.gov/download

DALEK 2 Doppler lidar: https://csl.noaa.gov/groups/csl3/measurements/2023cupids/dalek02/

CCNY Mobile Ozone Lidar Observation during 2023 NYC regional Air Quality Campaign

Dingdong Li, Thomas Ely, Yonghua Wu, Thomas Legbandt, Fred Moshary

Background:

- New York City and downwind areas frequently experience ozone pollution during the summer due to the combined effects of photochemical reactions, emissions, transport, and meteorological conditions.
- A mobile ozone lidar was developed at the City College of New York (CCNY) and made observations at Columbia University's Lamont-Doherty Earth Observatory (LDEO) in Palisades, NY in summer 2023.

Analysis:

- We validated the mobile O3 lidar against the CCNY lab O3 lidar.
- Synergistic observations from two ozone lidars are presented to characterize the ozone formation within the PBL and ozone/aerosol plume transport in the NYC region.

Findings:

- During a heatwave event, high-level O3 formation (≥70ppb) within in the PBL at LDEO at 16:00-21:00 UTC. The ozone level at LDEO is higher than the urban area (CCNY site) due to NO_2 transported from the NYC to the LDEO site under the prevailing S/SW wind

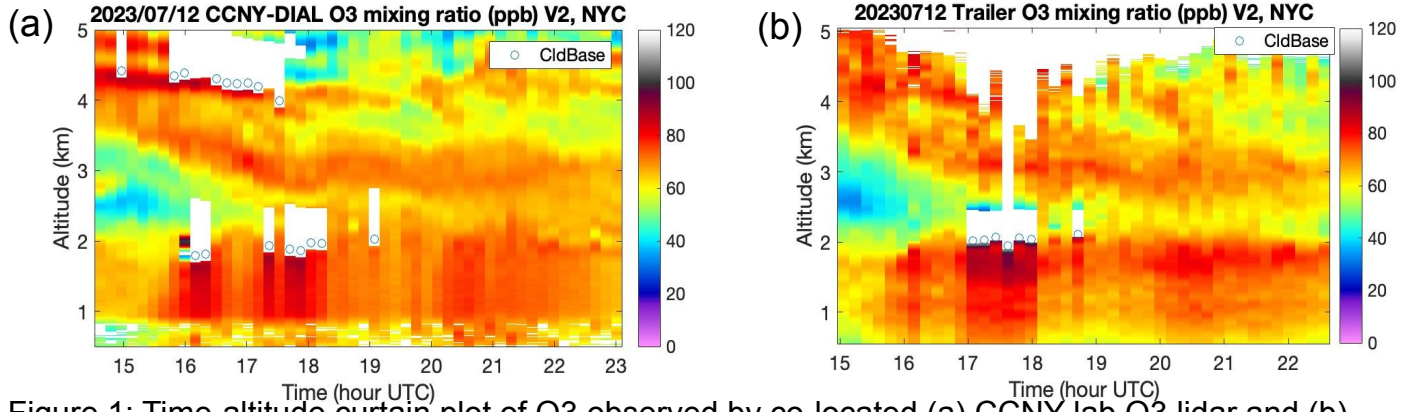


Figure 1: Time-altitude curtain plot of O3 observed by co-located (a) CCNY lab O3 lidar and (b) mobile O_3 lidar on 2023 July 12th at CCNY.

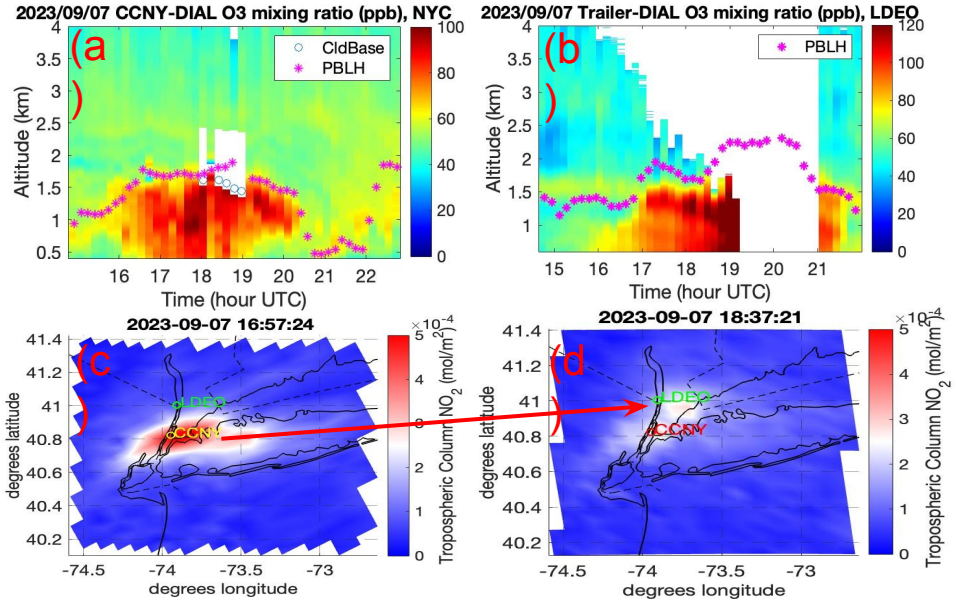
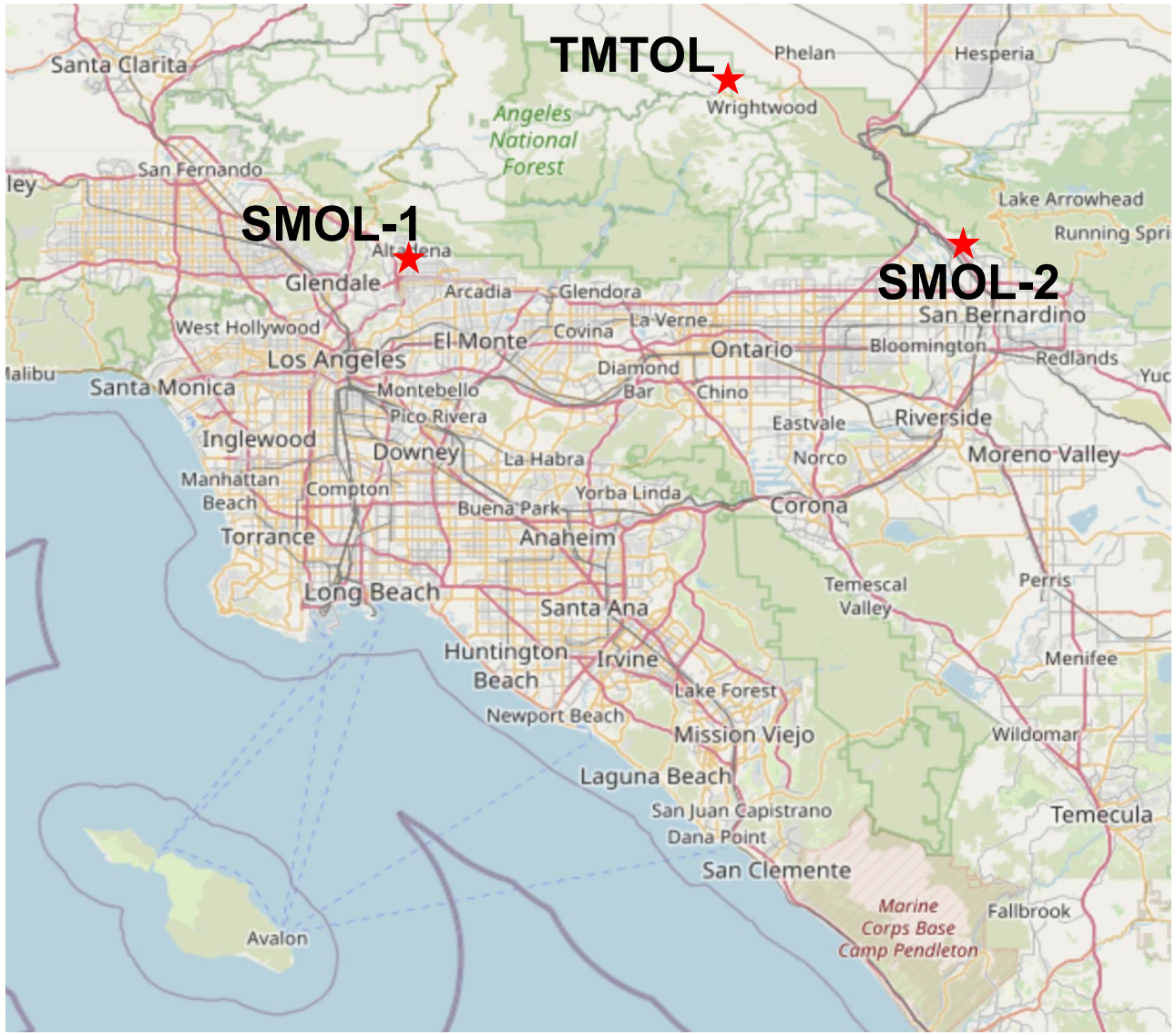


Figure 2: (a) Time-altitude curtain plot of O3 observed by O_3 lidar at CCNY (b) O_3 observed by mobile O_3 lidar at LDEO on 2023 Sep. 7th. (c) TROPOMI-derived level-2 tropospheric column NO_2 (mol/m^2) on September 7th, 2023, at 16:57 UTC, and (d) at 18:37 UTC.

From 16:57 to 18:37 UTC, the NO_2 plume shifted from NYC towards the LDEO site, which is in a NO2-limited regime, causing significant ozone production.

Summer 2023: AEROMMA and STAQS/TEMPO validation



TMTOL: *Fixed high performance NDACC ozone lidar located at JPL Table Mountain facility.*

SMOL-1: *Deployed at JPL in Pasadena.*
Pasadena exhibits a strong ozone diurnal cycle due to titration.

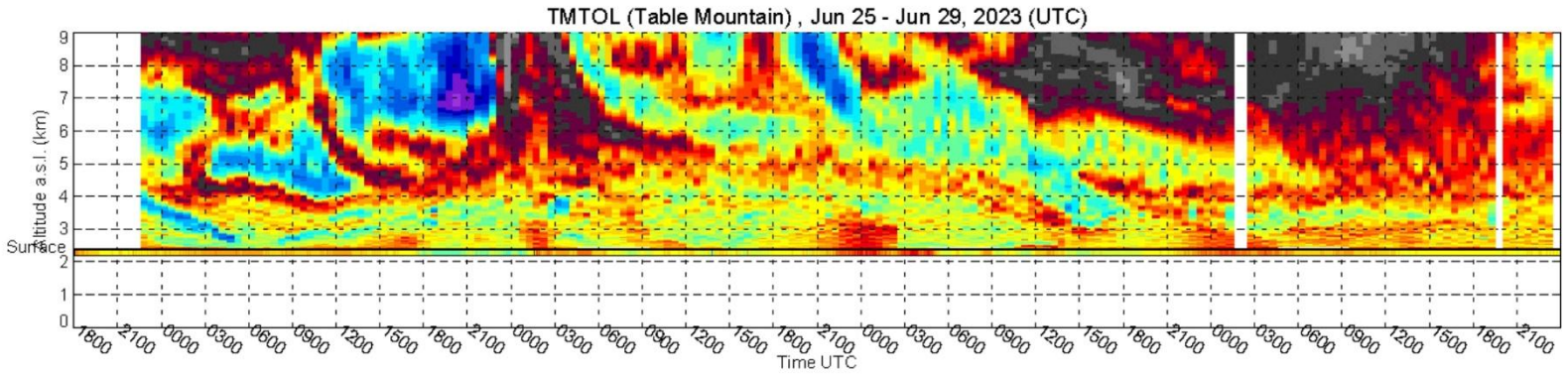
SMOL-2: *Deployed at CSUSB.*
San Bernardino county has the largest number of ozone exceedances in the US.

Courtesy of JPL Lidar Team
(T. Leblanc/F. Chouza)

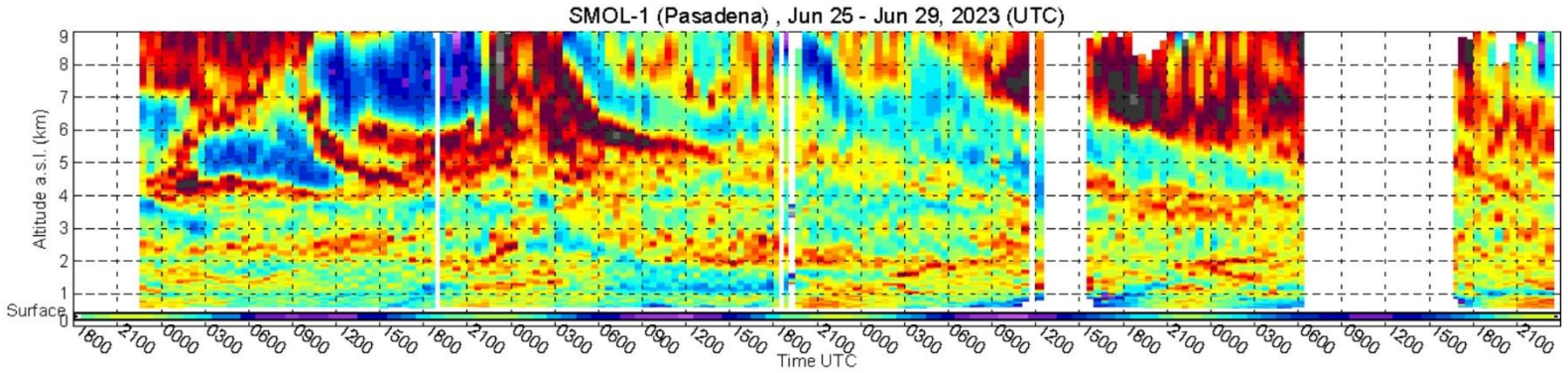
5-day continuous JPL Lidars measurements during AEROMMA/STAQS

June 23-29, 2023

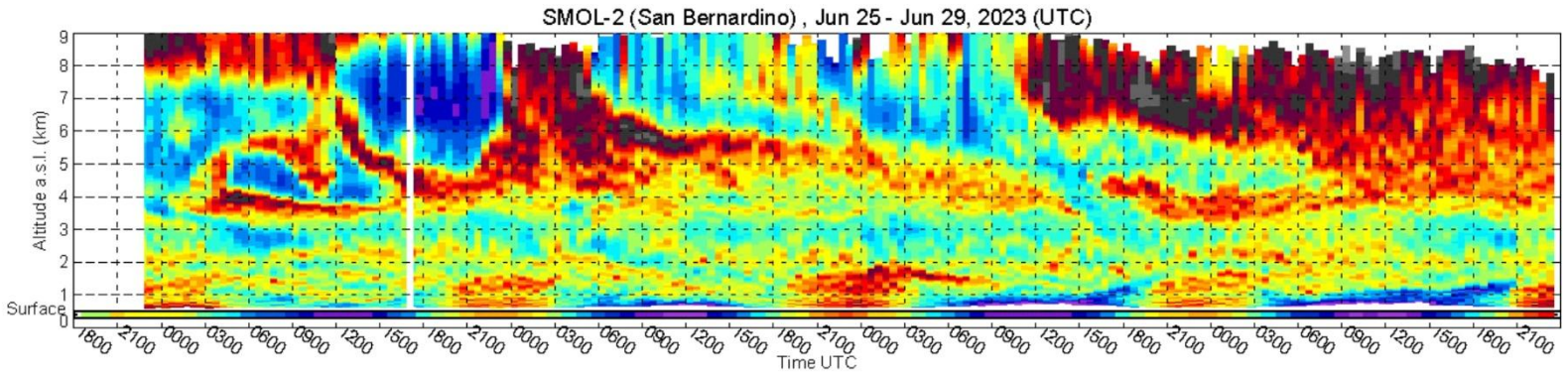
TMTOL

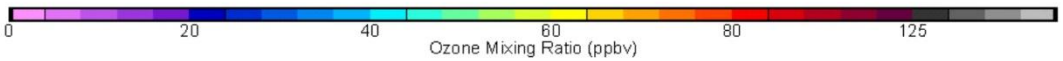


SMOL-1



SMOL-2





***Overall**:*
Excellent performance for both SMOL systems

***Common features,** including stratospheric intrusions, observed by all 3 systems for z > 3.5 km*

***Unique features** near surface:*

TMTOL (high elevation): No or little titration, vmr > 60 ppmv

SMOL-2 (San Bernardino): High O3 afternoon/evening, residual layer 1000 m above surface, strong titration overnight/morning

SMOL-1 (Pasadena): Smaller day/night amplitude

Courtesy of JPL Lidar Team
(T. Leblanc/F. Chouza)

TOLNet Website Update – How To Get the Data

Michael Shook[1], Gao Chen[1], Crystal Gummo[1,2], Ali Aknan[1,2]
[1]NASA, [2]SSAI

Background/Objective:

- Bring TOLNet website up to modern, state-of-the-art web standard
- Improve both look-and-feel and usability

Analysis:

https://tolnet.larc.nasa.gov/

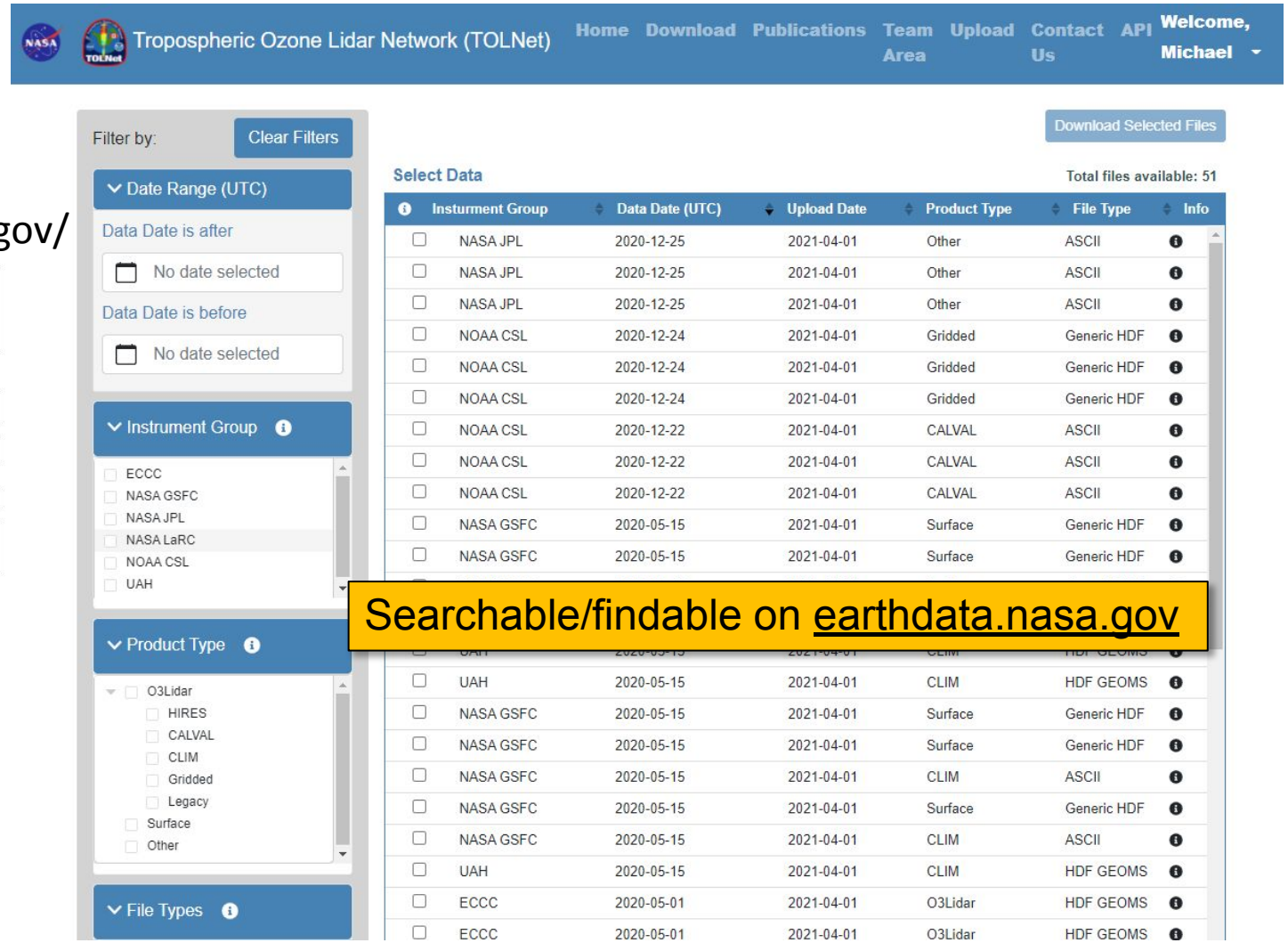
- Determined requirements, for example:
  - API
  - Graphing capability/Near-Real Time data viewing
  - Improved metrics/user management
  - More functional search features

Findings/Results so far:

- API infrastructure set up
- Pages for data download, publications, presentations built
- Ready for internal alpha testing

Significance:

✔ Easier data discovery and data management
✔ API for automation, future interface, and interoperability



https://tolnet.larc.nasa.gov/calendar

Tropospheric Ozone Lidar Network (TOLNet)

Home | Data Calendar | Download | Publications | Team Area | Admin | Contact Us | API | Welcome, Crystal

Filter by: Clear Filters

Instrument Group

- (●) NASA GSFC
- ( ) NASA LaRC
- ( ) NASA JPL SMOL-1
- ( ) NASA JPL SMOL-2
- ( ) NASA JPL TMTOL
- ( ) ECCC
- ( ) NOAA ESRL/CSL
- ( ) UAH

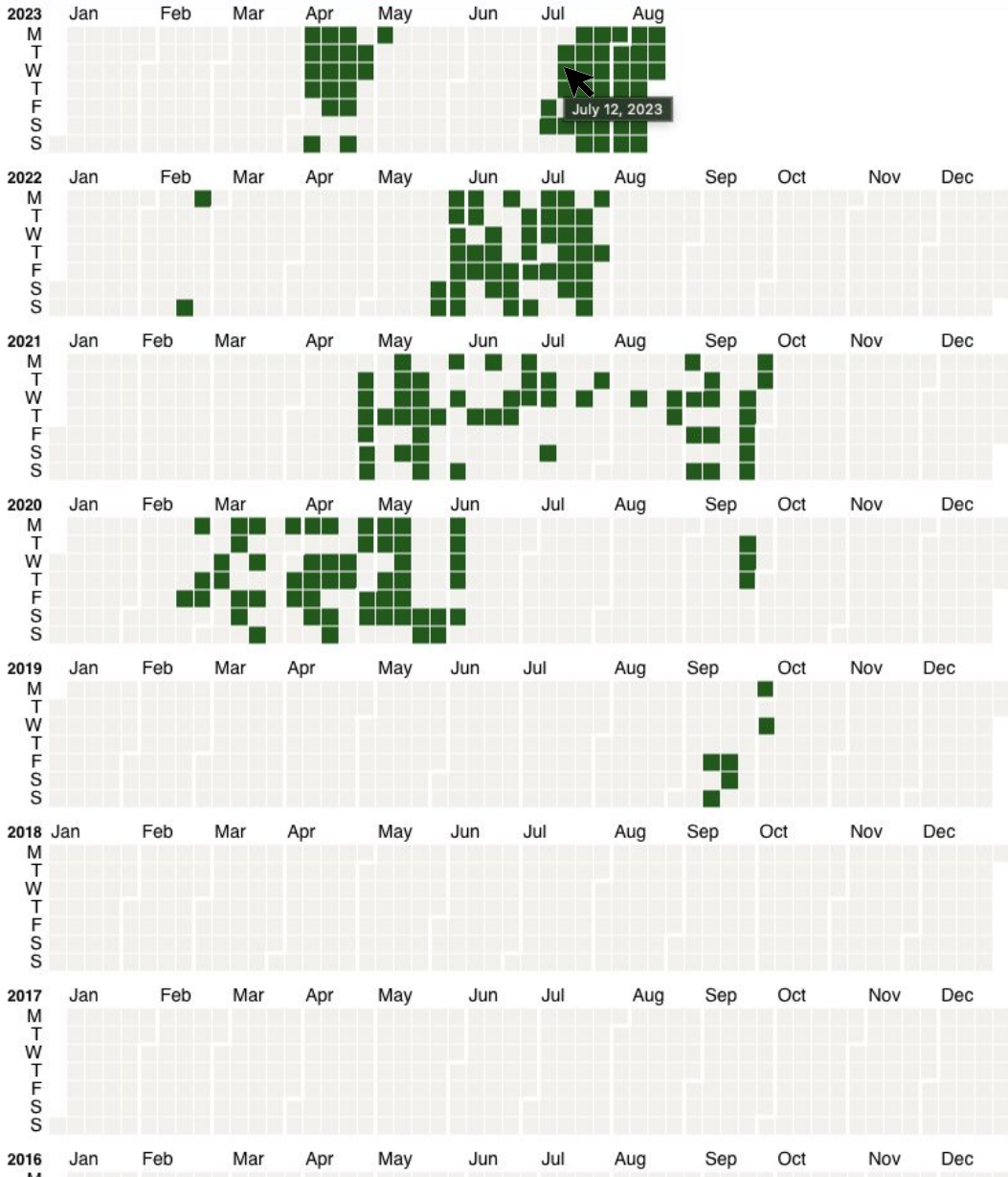
Product Type

- (●) HIRES
- ( ) CALVAL
- ( ) CLIM
- ( ) Gridded

Processing Type

- ( ) Centrally Processed (GLASS)
- (●) In-House Processed

Note: Only HDF4-GEOMS files are shown here. Other surface and profile data is available on the Downloads page.



https://tolnet.larc.nasa.gov/calendar

Tropospheric Ozone Lidar Network (TOLNet)

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Filter by:

Instrument Group
- NASA GSFC
- NASA LaRC
- NASA JPL SMOL-1
- NASA JPL SMOL-2
- NASA JPL TMTOL
- ECCC
- NOAA ESRL/CSL
- UAH

Product Type
- HIRES
- CALVAL
- CLIM
- Gridded

Processing Type
- Centrally Processed (GLASS)
- In-House Processed

Note: Only HDF4-GEOMS files are shown here. Other surface and profile data is available on the Downloads page.

Graph

Graph of groundbased_lidar.o3_nasa.gsfc003_hires_oldfield.ny_20230712t000000z_20230713t000000z_001.hdf

Download data.

Group	NASA GSFC
Location	OLDFIELD.NY
Lat	40.964
Lon	-73.14
PI	Sullivan;John
Date/Time (UTC)	2023-07-12 00:00:00 - 2023-07-13 00:00:00

Colorbar: Rainbow

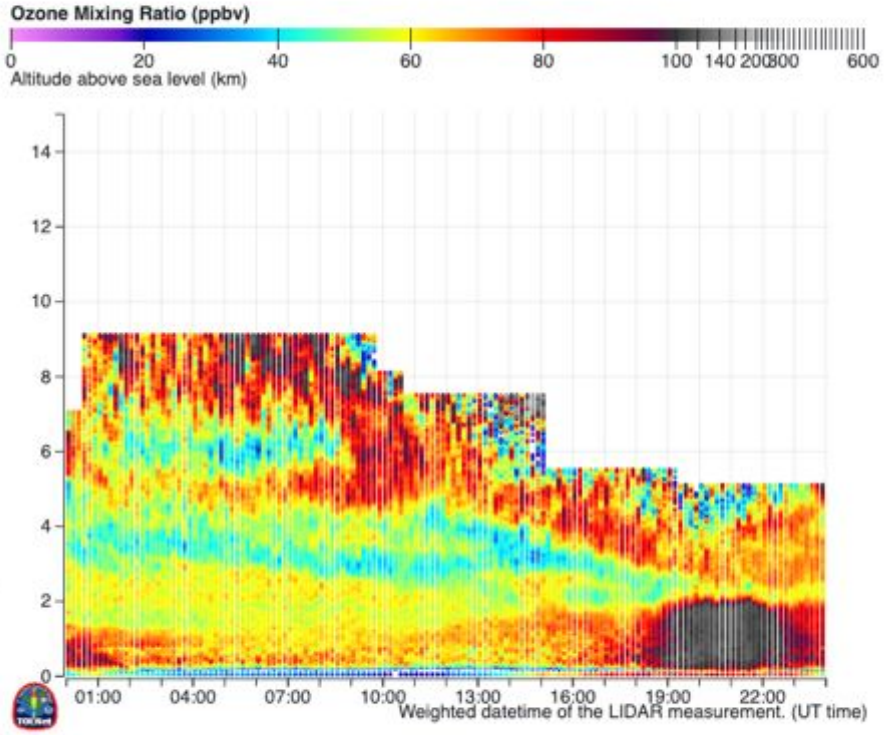
Y max: 15

Y min: 0

Re-graph

X min: 07/12/2023 00:00

X max: 07/13/2023 00:00



2018 Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Special thanks to NASA HQ/TCP, NASA TOLNet, STAQS Science Team

For website quick look reports and archive:

www-air.larc.nasa.gov/missions/staqs

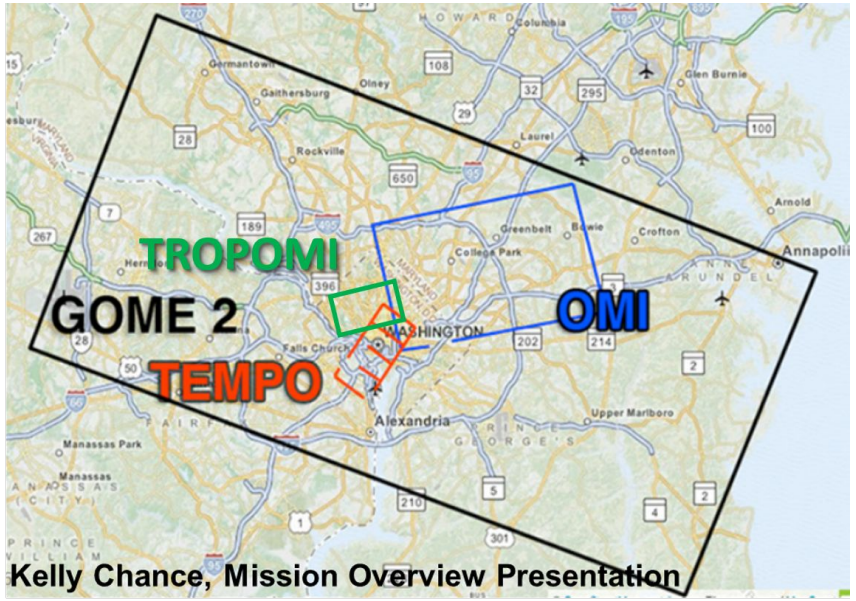
https://tolnet.larc.nasa.gov/

Come talk to me about the NPP Fellowship or Summer Program!

https://npp.usra.edu/opportunities/details/?ro=17768

https://nasa.force.com/Mentors/s/my-projects?isdtp=p1

TEMPO Tropospheric O_3 Validation with TOLNet



TEMPO **spatial resolution:**

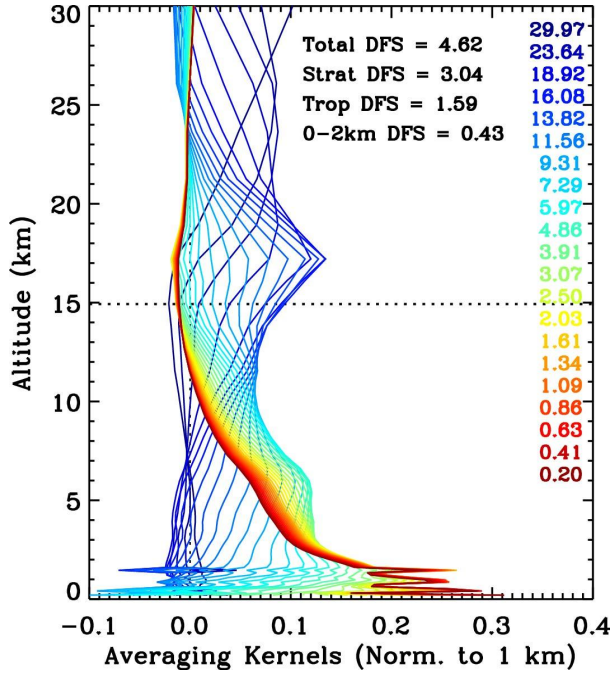
~2.1 × 4.4 km^2

~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.

✔ **A major goal of TOLNet is to validate TEMPO tropospheric O_3 observations.**

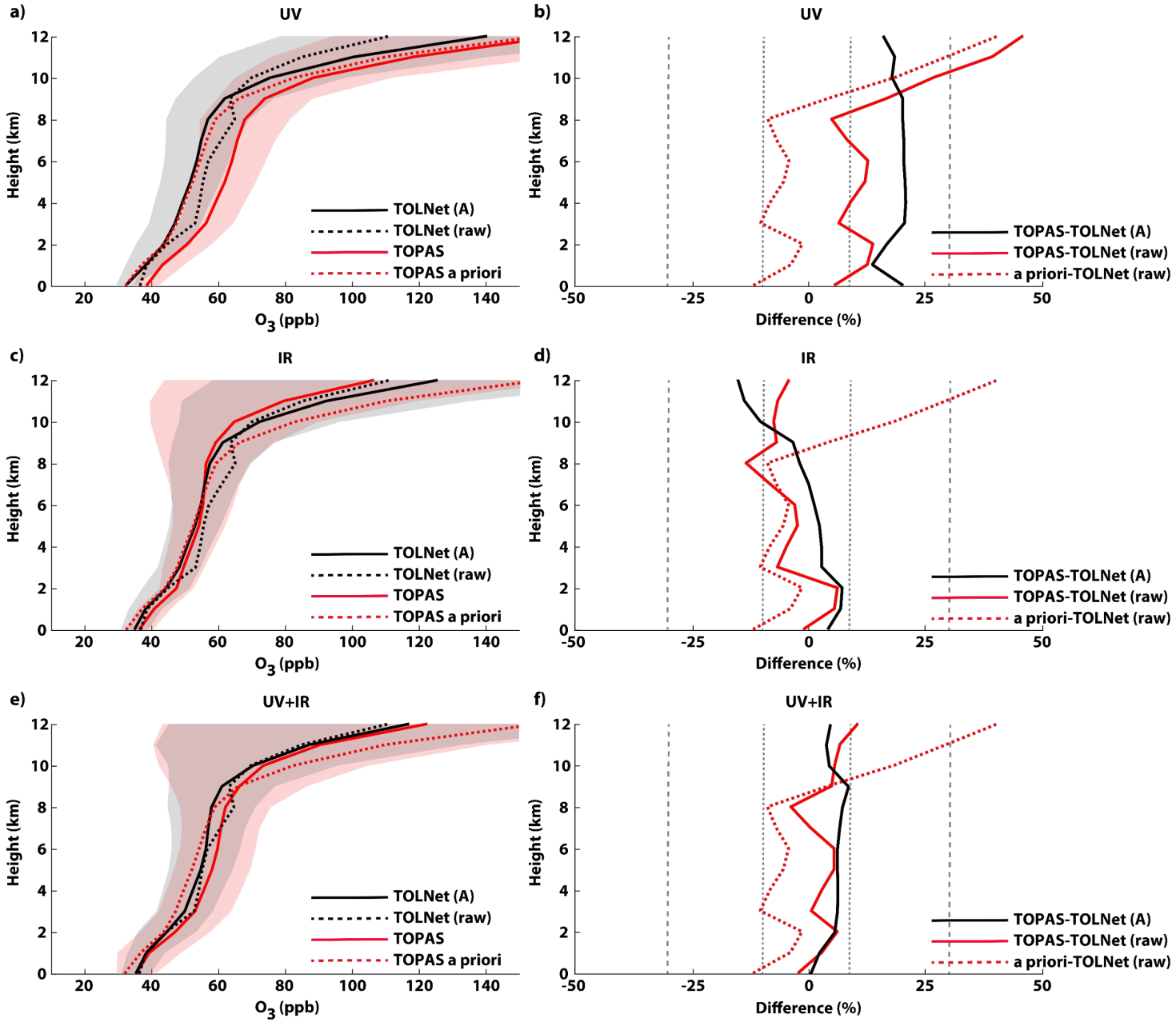
 TEMPO will provide hourly, high spatial resolution, data (such as O_3, NO_2, HCHO, etc.) to monitor air quality and tropospheric chemical composition in North America.

 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.**

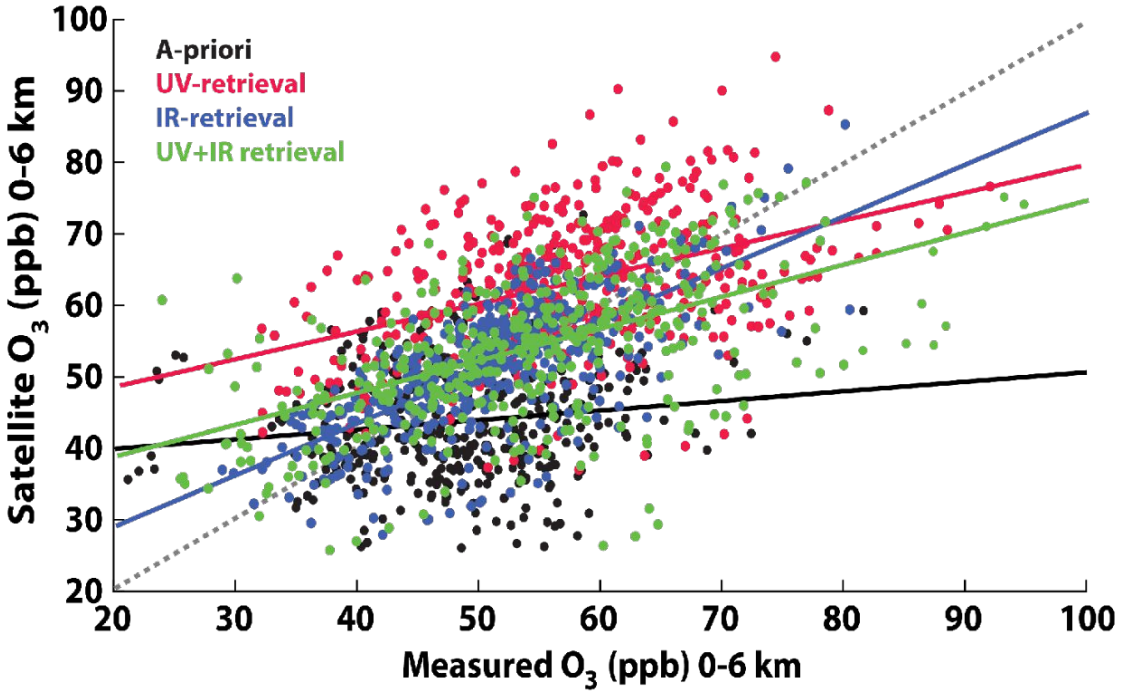
TOPAS TROPOMI/CrIS O_3 Profile Validation using TOLNet

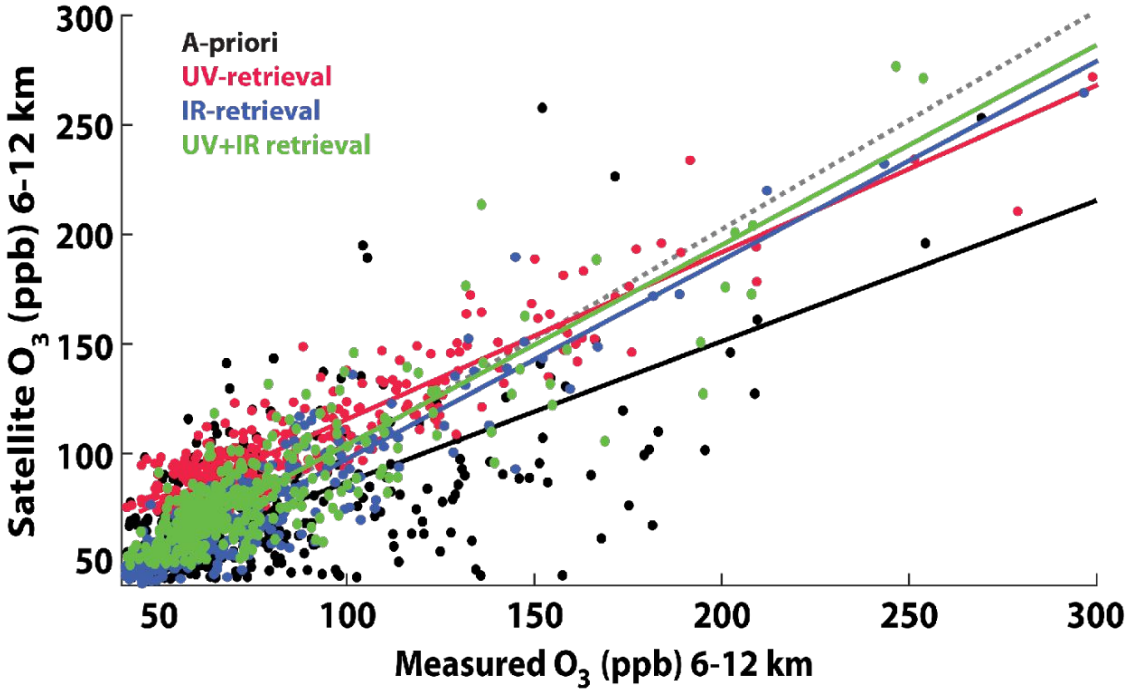


- Using all TOLNet lidar profiles collocated with TROPOMI and CrIS (N=89) between 2018/06 and 2019/10.
- Colocation criteria of 20 km and 2 hours.
- Average mean bias in the troposphere (0-12 km) was:
  - UV-only: ~11 ppb (~19%)
  - IR-only: ~-2 ppb (~-1%)
  - UV+IR: ~4 ppb (~5%)
- Average random error (RMSE) in the troposphere was:
  - UV-only: ~17 ppb
  - IR-only: ~11 ppb
  - UV+IR: ~14 ppb

Johnson et al. (2024)

TOPAS TROPOMI/CrIS O_3 Profile Validation – Vertical Layers





- Statistics (bias, root mean squared error, linear regression slope, and correlation) generally improved in TROPOMI/CrIS retrievals compared to a prior profiles at all vertical levels in the troposphere.
- Validation was conducted at 2 km vertical layers; here we show 6 km vertical layers to be more consistent with the vertical resolution of TROPOMI/CrIS in the troposphere.

Johnson et al. (2024)

Conclusions

- TOLNet is a well-established ground-based network of ozone/aerosol lidars providing high-resolution spatio-temporal data (2-min & 100 M in the PBL) for satellite validation (e.g., TEMPO and ACX) and scientific studies.
- TOLNet lidar data validated L2 TROPOMI UV, CrIS IR, and TROPOMI/CrIS UV+IR retrievals of vertical O_3 profiles in the troposphere (TOPAS retrieval algorithm).
- Retrievals including multiple wavelength regions (e.g., IR & UV or Vis & UV) provide superior products in the troposphere.
- TOLNet will be used to validate TEMPO O_3 retrieval products, with particular emphasis on the 0-2 km agl partial-column product.
- TOLNet can also characterize the geophysics of the PBL, FT, land-sea and land-lake breezes that are important to air quality studies.
- The well-developed data center provides efficient access these lidar data.
- The emerging scanning capabilities (TOPAZ, RO_3QET) and the Small (autonomous) Ozone Lidars (SMOL) will provide access to this measurement technique for a broader community.