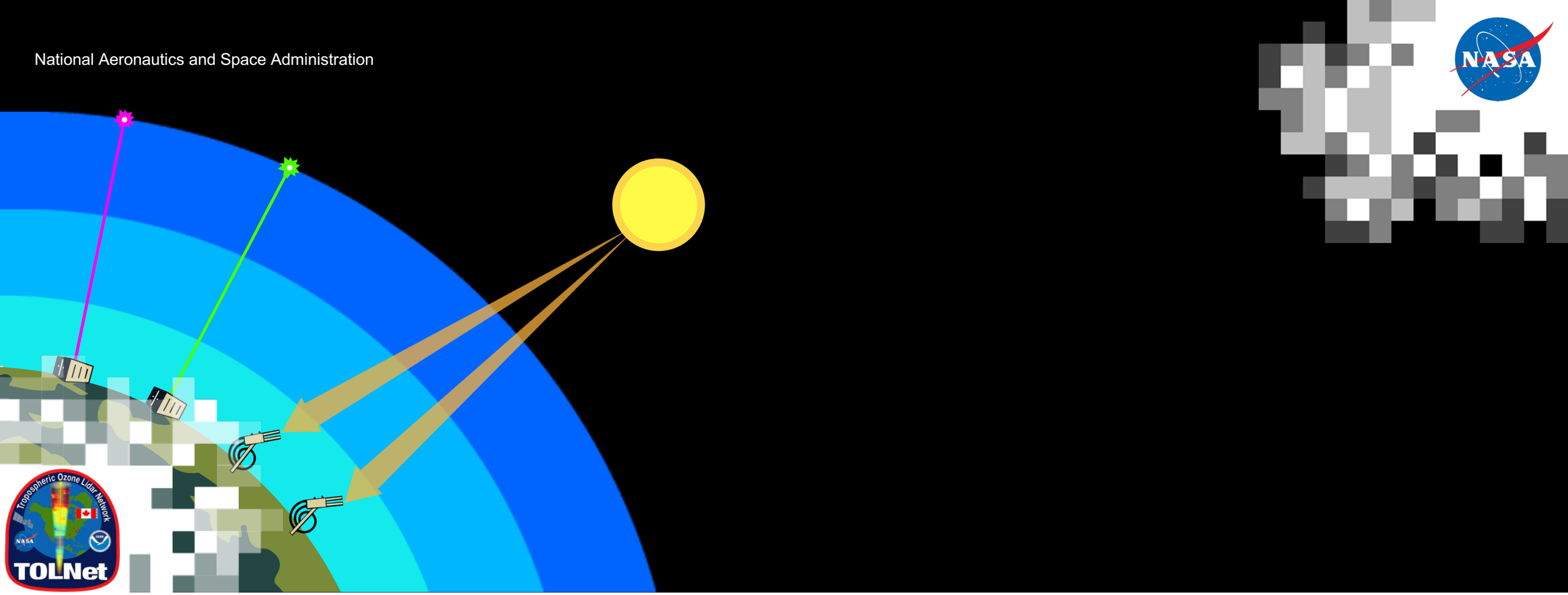
National Aeronautics and Space Administration



NASA Atmospheric Composition Ground Networks Supporting Air Quality and Climate Applications

Part 4: Introduction to the Tropospheric Ozone Lidar Network (TOLNet)

John Sullivan (NASA Goddard Space Flight Center) & Melanie Follette-Cook (NASA Goddard Space Flight Center)

August 20, 2024

Part 4 – Trainers

Dr. Melanie Follette-Cook
Project Scientist, ARSET
NASA GSFC

Dr. John Sullivan
Principal Investigator, TOLNET
NASA GSFC

Part 4 Objectives

By the end of Part 4, participants will be able to:

- Identify the basic characteristics of the TOLNet instruments used by NASA for ground-based active remote sensing of tropospheric ozone.
- Recognize how TOLNet supports air quality and climate applications and complements satellite observations.
- Access relevant TOLNet data for a given location and application purpose.

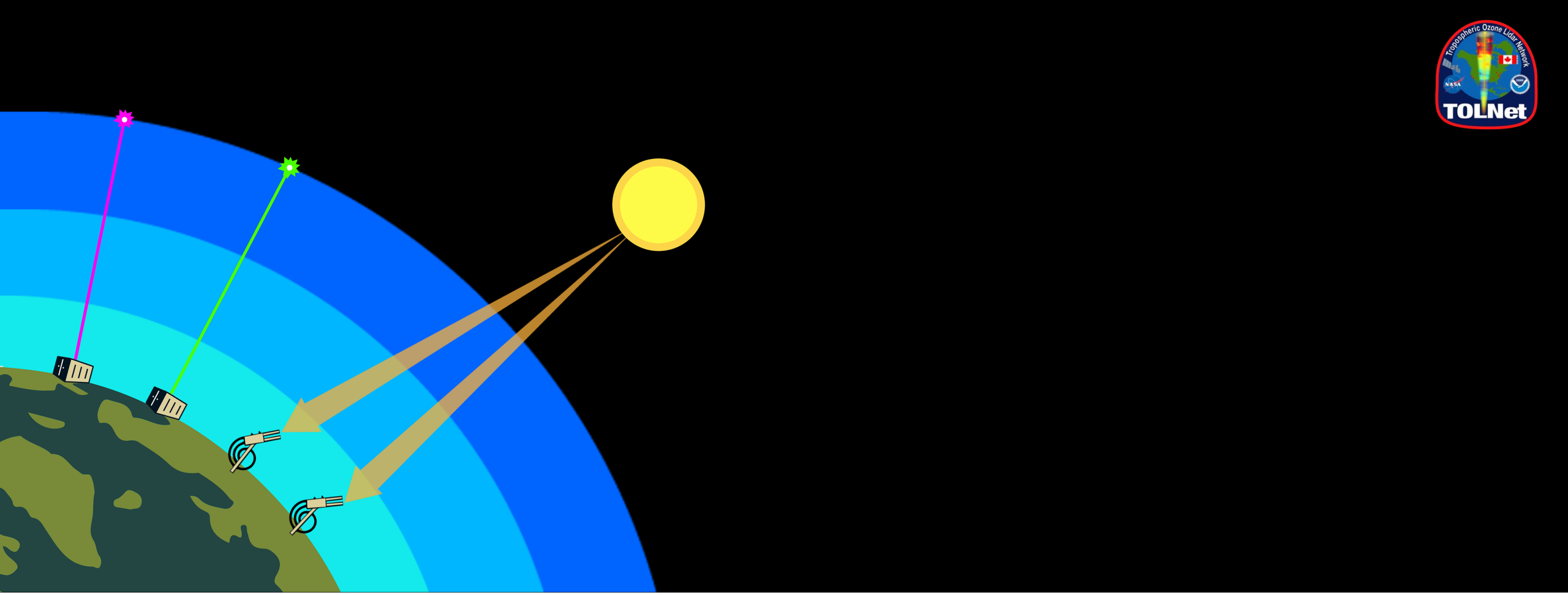
Review of Prior Knowledge

Network	Type	Primary Measurands	Number of Sites	Vertical Coverage
AERONET	Passive	Aerosols (Optical, Microphysical, Radiative)	~600 Active	Total Column
Pandora (PGN)	Passive	Trace Gases (Ozone, NO_2, Formaldehyde)	168 Official	Total Column, Near-Surface, Lower Tropospheric Profiles

- High levels of ozone in the upper atmosphere (stratosphere) make it difficult to remotely sense ozone in the lower atmosphere (troposphere) from space.
- Pandora instruments also only provide total-column ozone via direct sun observations.

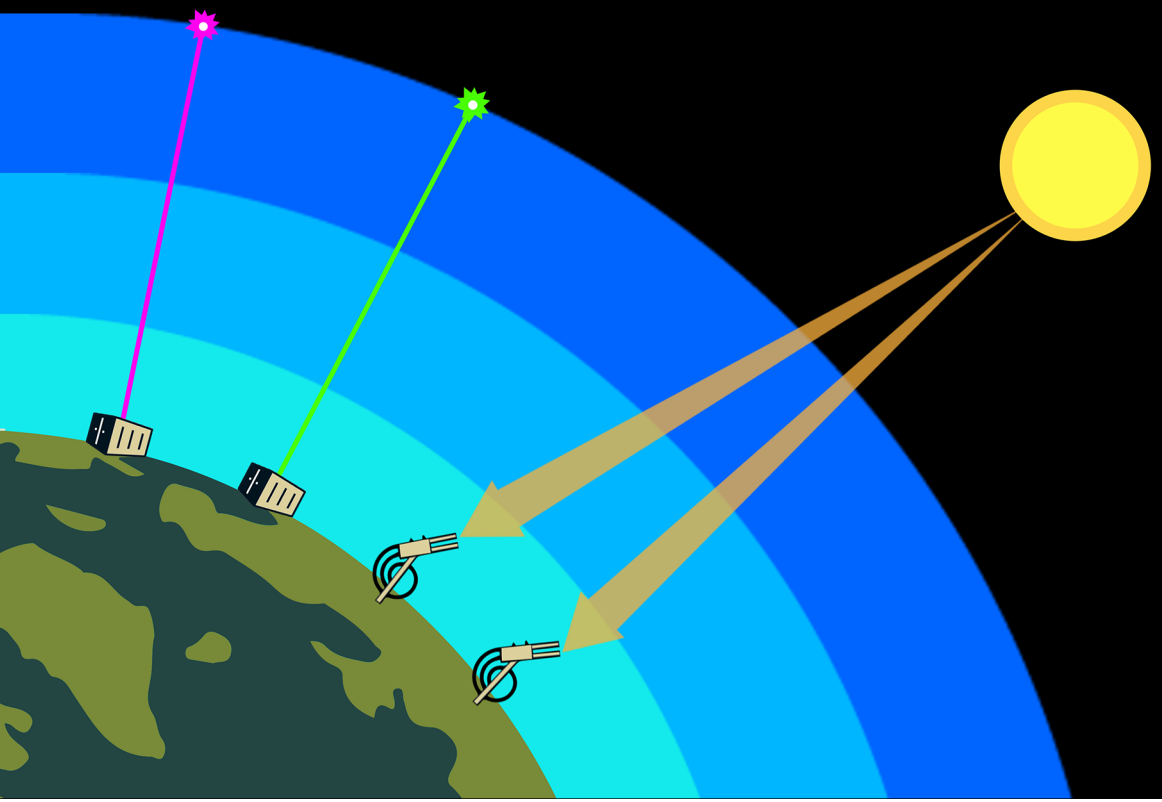
How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



Part 4:

Introduction to the Tropospheric Ozone LiDAR Network (TOLNet)



Overview of Ozone and the TOLNet Instruments

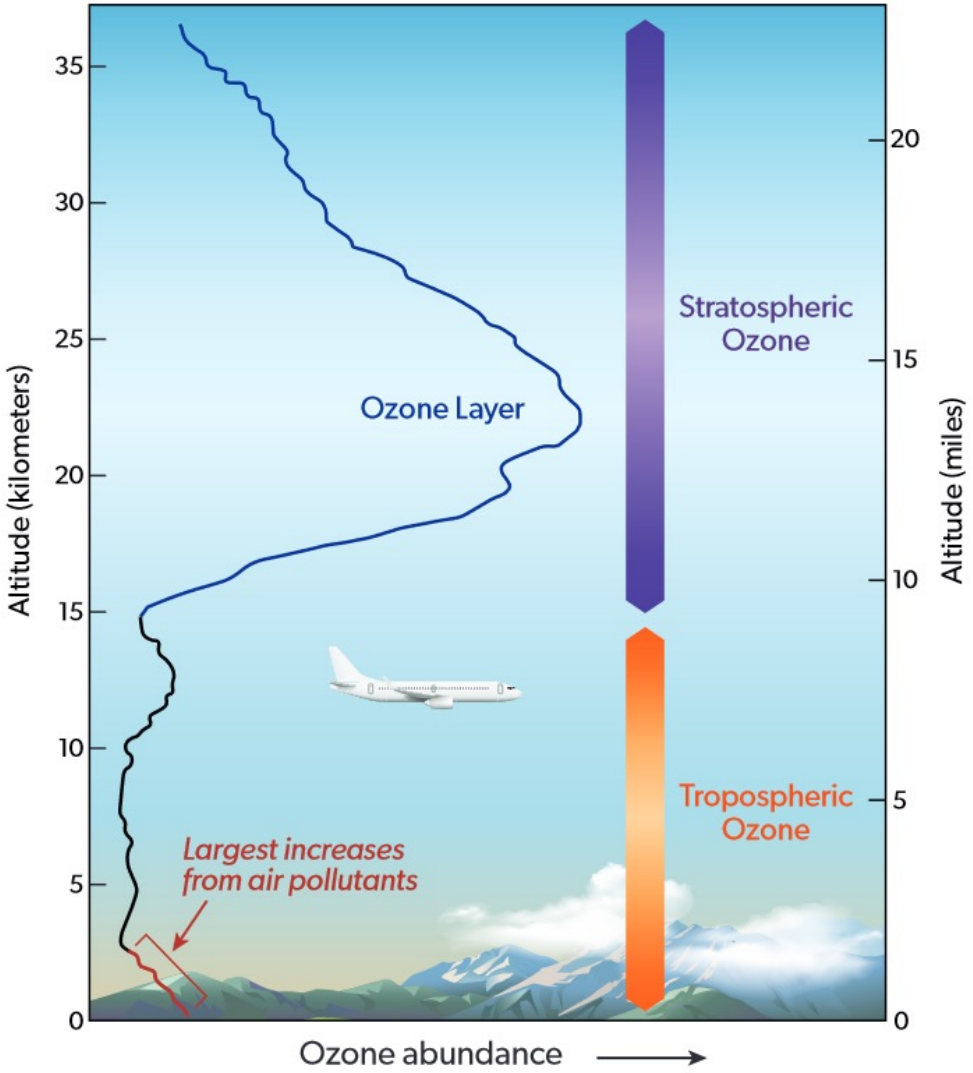
What levels of ozone are in the Earth's atmosphere?

- Ozone (or O_3) in the Earth's atmosphere is mostly located in the stratosphere (~90%) and in the troposphere (~10%).
- The troposphere and stratosphere are divided by a temperature inversion known as the tropopause.
- Generally, the dry atmosphere has this composition:

  N_2 – 78 %
  O_2 – 21 %
  Ar – 1 %

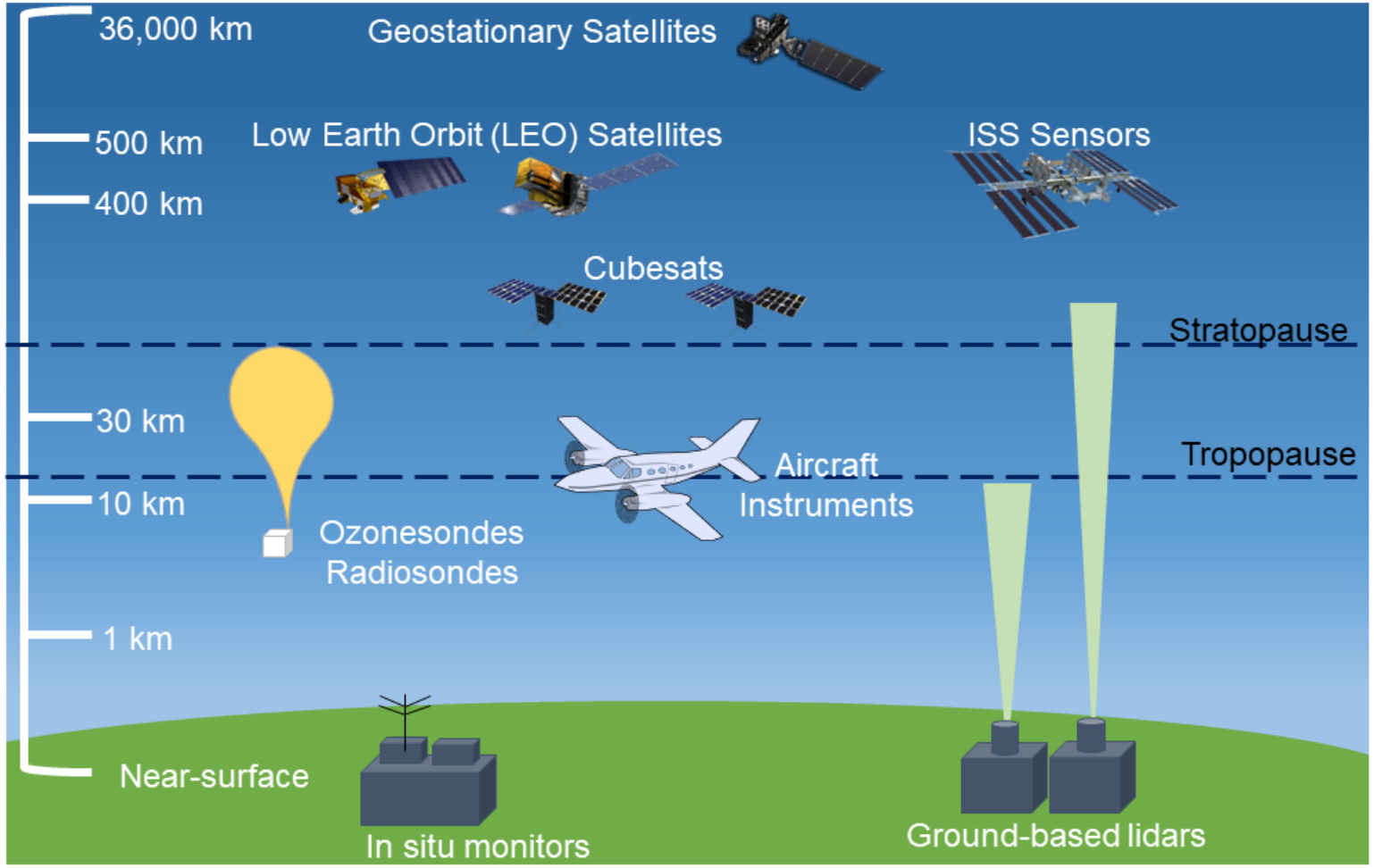
- Ozone, rather than being near constant, changes concentrations with altitude.

  Stratosphere, ~0-10 ppmv (parts-per-million-vol)
  Troposphere, ~0-100ppbv (parts-per-billion-vol)
  1 ppmv = 1000 ppbv



Credit: Scientific Assessment of Ozone Depletion, 2022

What are common measurement techniques of Ozone?



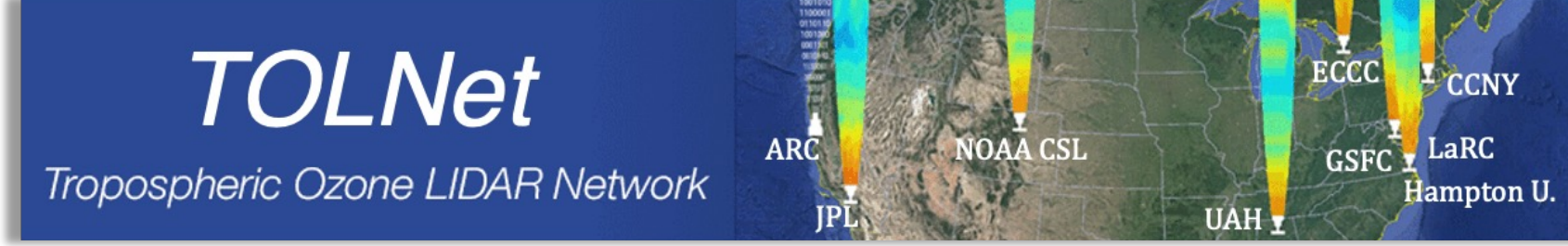
Adapted from Thompson et al., 2024

Satellites provide excellent spatial coverage, very expensive and generally columnar values.

LiDARs provide continuous vertical observations at a fraction of the cost of a satellite mission.

In situ monitoring provides continuous observations at the surface level only.

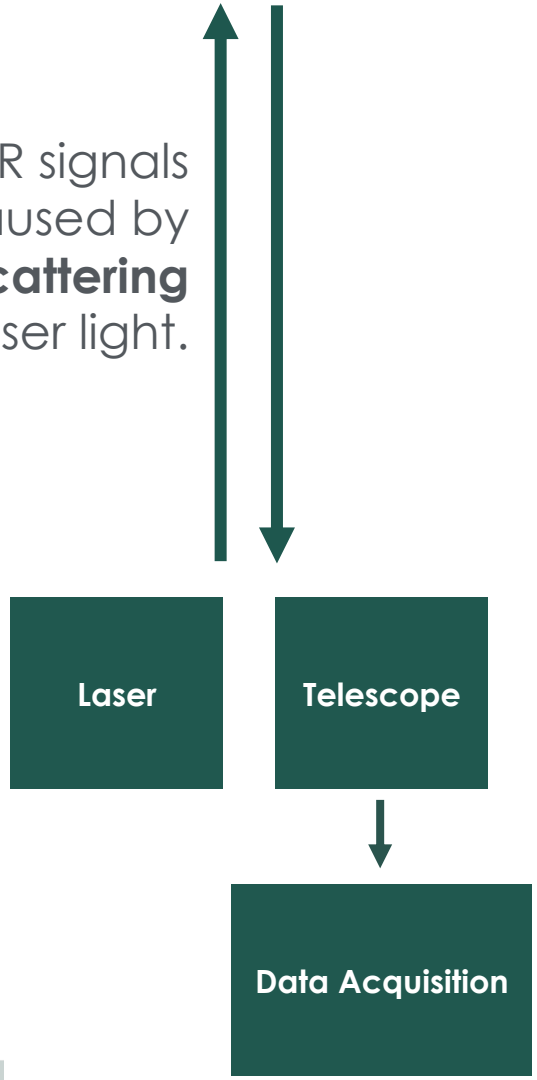
TOLNet – Tropospheric Ozone LiDAR Network



- Established in 2012
- Active remote sensing of tropospheric ozone profiles
- 8 Instrument Teams (Operating 12 LiDARs):
  - NASA JPL, LaRC, GSFC
  - NOAA Chemical Sciences Laboratory
  - Environment & Climate Change Canada
  - University of Alabama Huntsville, City College of New York, Hampton University
- Modeling (Ames) and Data Center (NASA LaRC/ASDC)

What are the major components to a TOLNet LiDAR system?

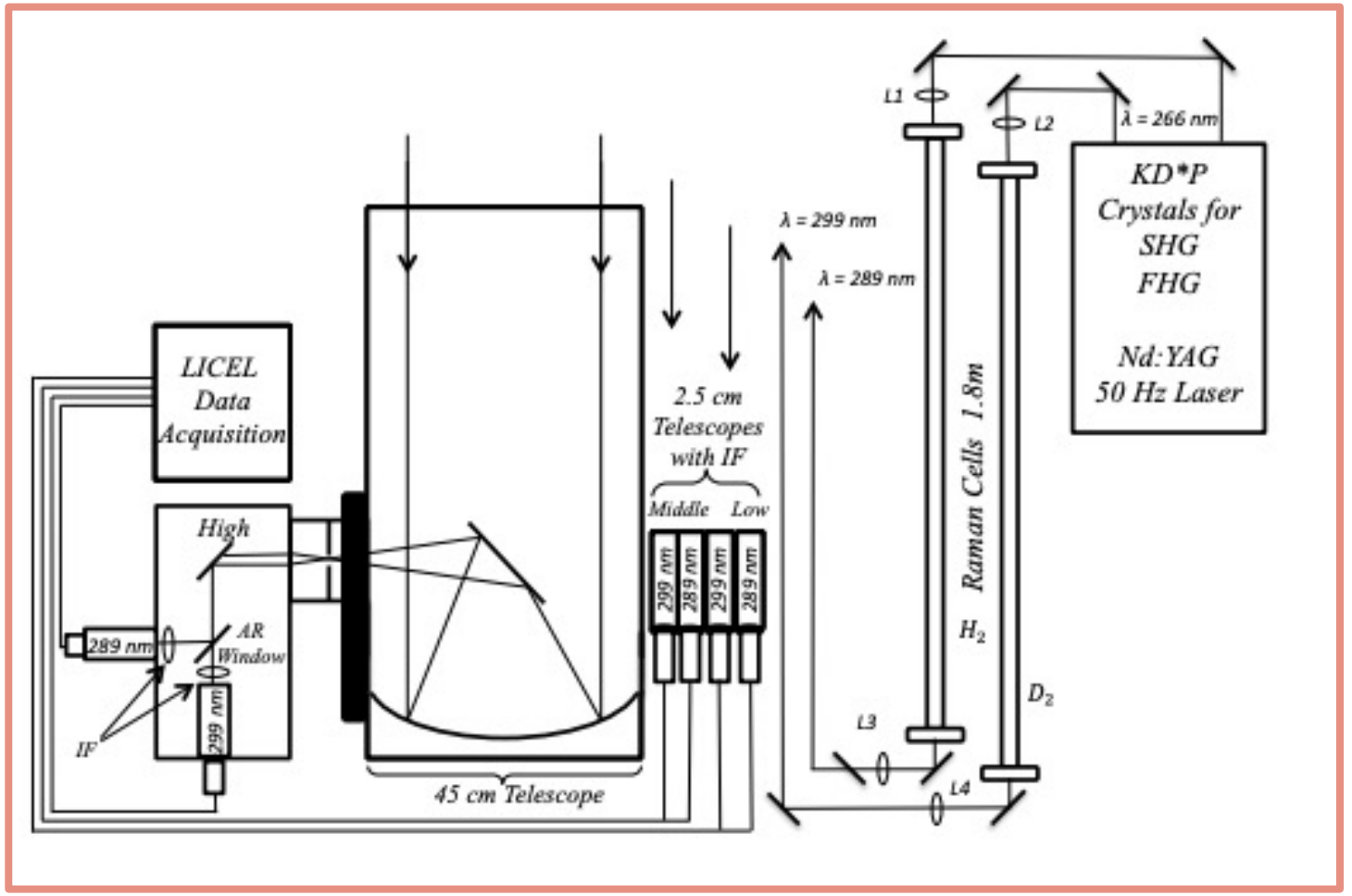
LiDAR signals are caused by **backscattering** of laser light.



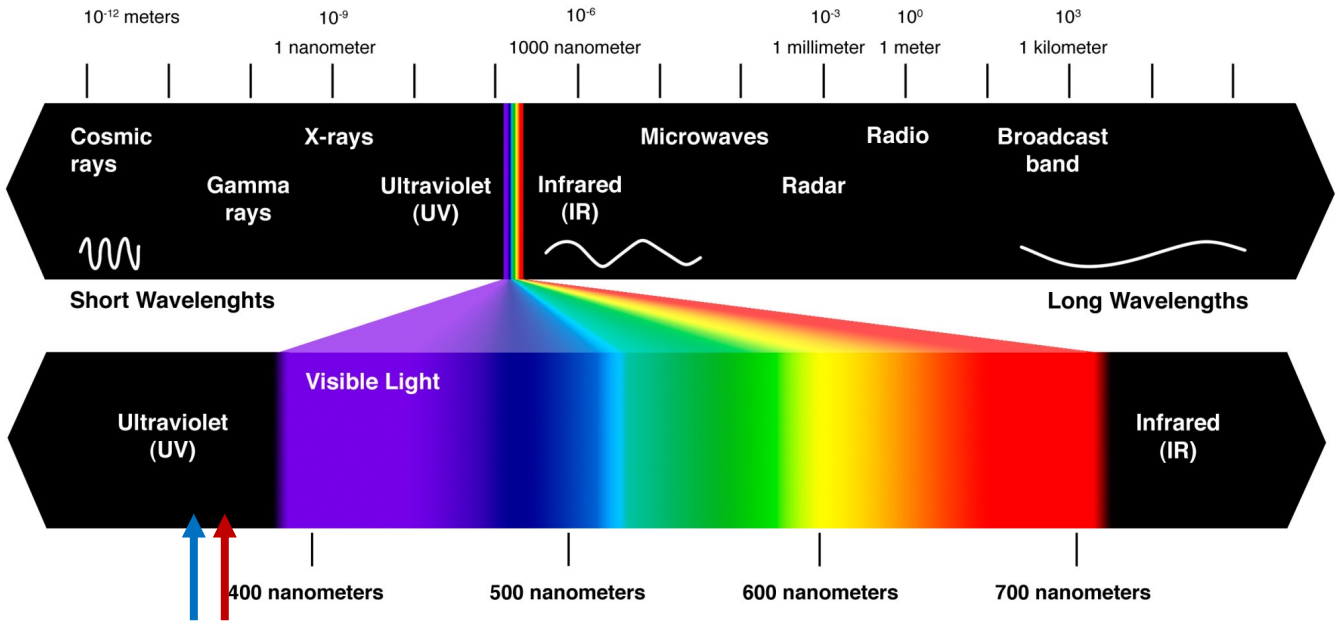
Simple

Diagram

TOLNet – Tropospheric Ozone LiDAR Network

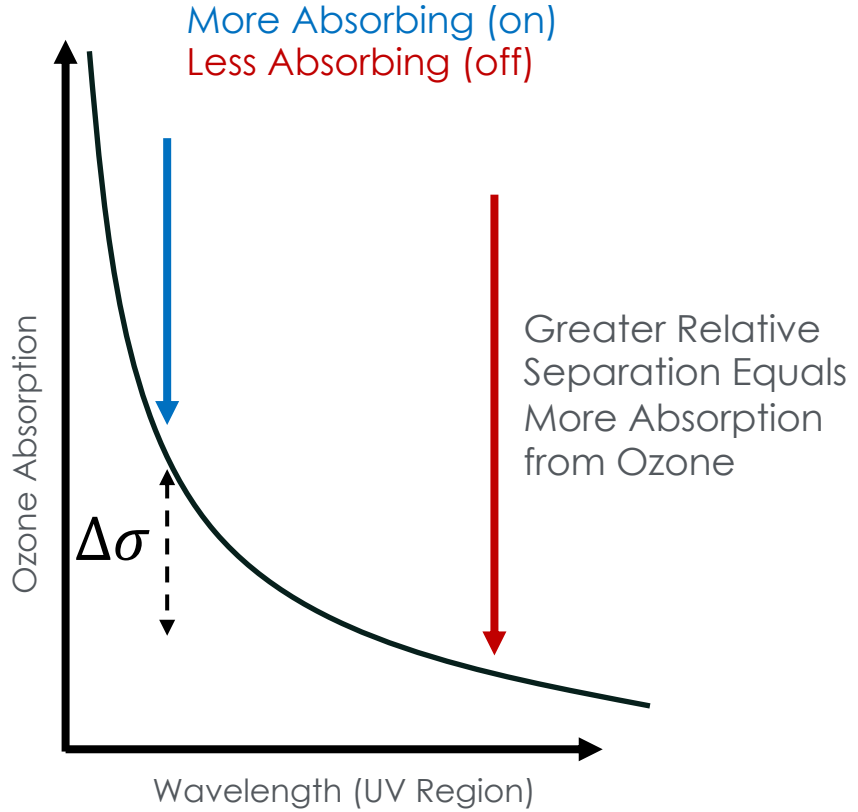


TOLNet operates in the Ultra-Violet (UV) region.

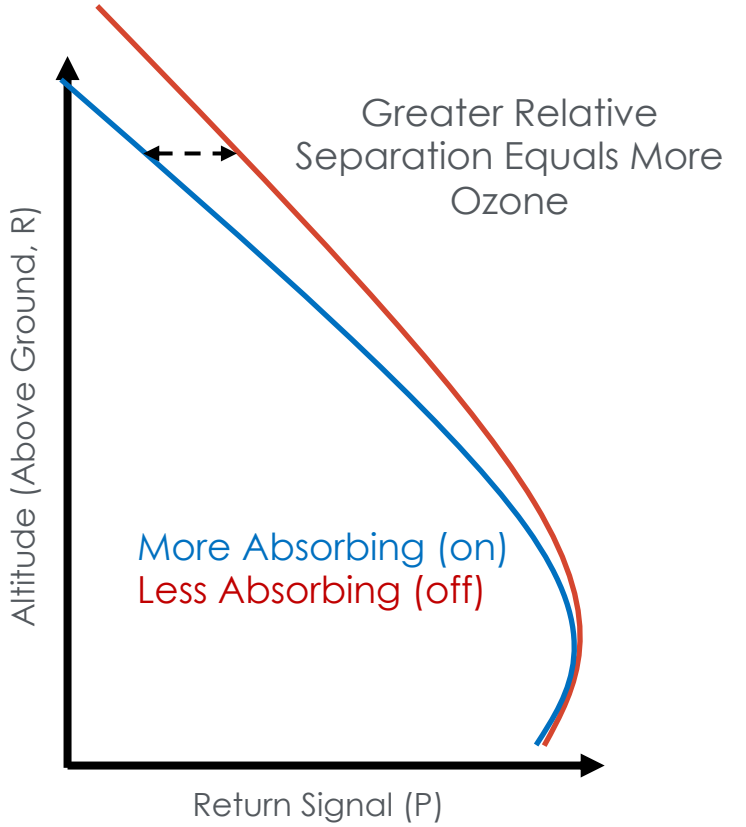


TOLNet

Differential Absorption Lidar (DIAL)



TOLNet uses a Differential Absorption Lidar (DIAL) Technique.



- The gas concentration profile of ozone $N(R)$ is then calculated by

$$N(R) = \frac{1}{2\,\boldsymbol{\Delta\sigma}\,\Delta R}\ln\left(\frac{P_{off}(R+\Delta R)}{P_{off}(R)}\frac{P_{on}(R)}{P_{on}(R+\Delta R)}\right)$$

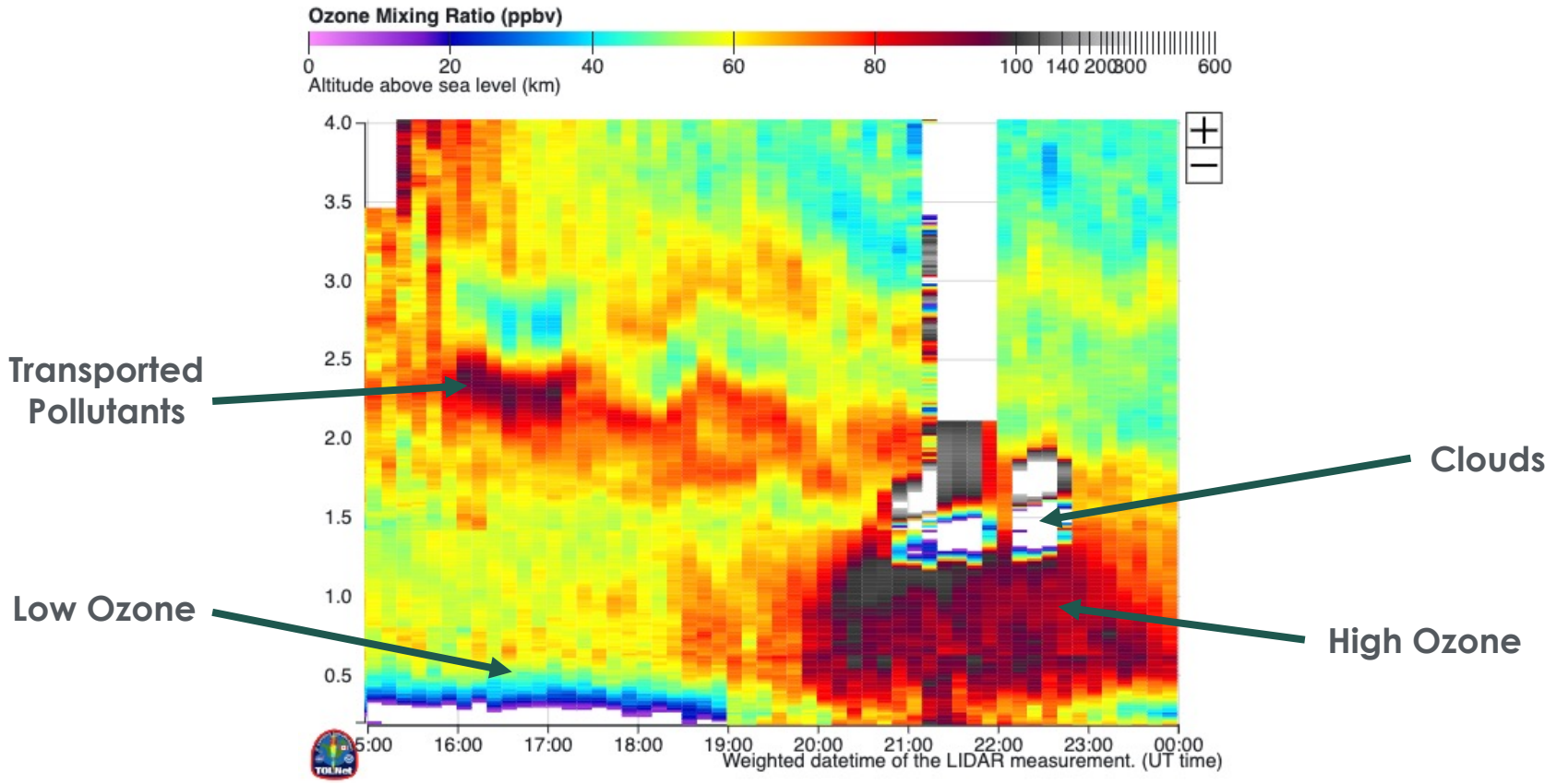
- P is power at R distance from laser

General Benefits of TOLNet LiDAR

- Obtain profiles of ozone, rather than a total column amount
- Generate your own light source, so both daytime and nighttime observations are possible
- Can be nearly continuous or as needed to characterize ozone events

U.S. Air Quality Index

- Good (0-50)
- Moderate (51-100)
- Unhealthy for Sensitive Groups (101-150)
- Unhealthy (151-200)
- Very Unhealthy (201-300)
- Hazardous (301+)



What are some examples of transportable TOLNet LiDARs?

NOAA TOPAZ (Tunable Optical Profiler for Aerosols and oZone)

NASA LaRC LMOL (Langley Mobile Ozone LiDAR)

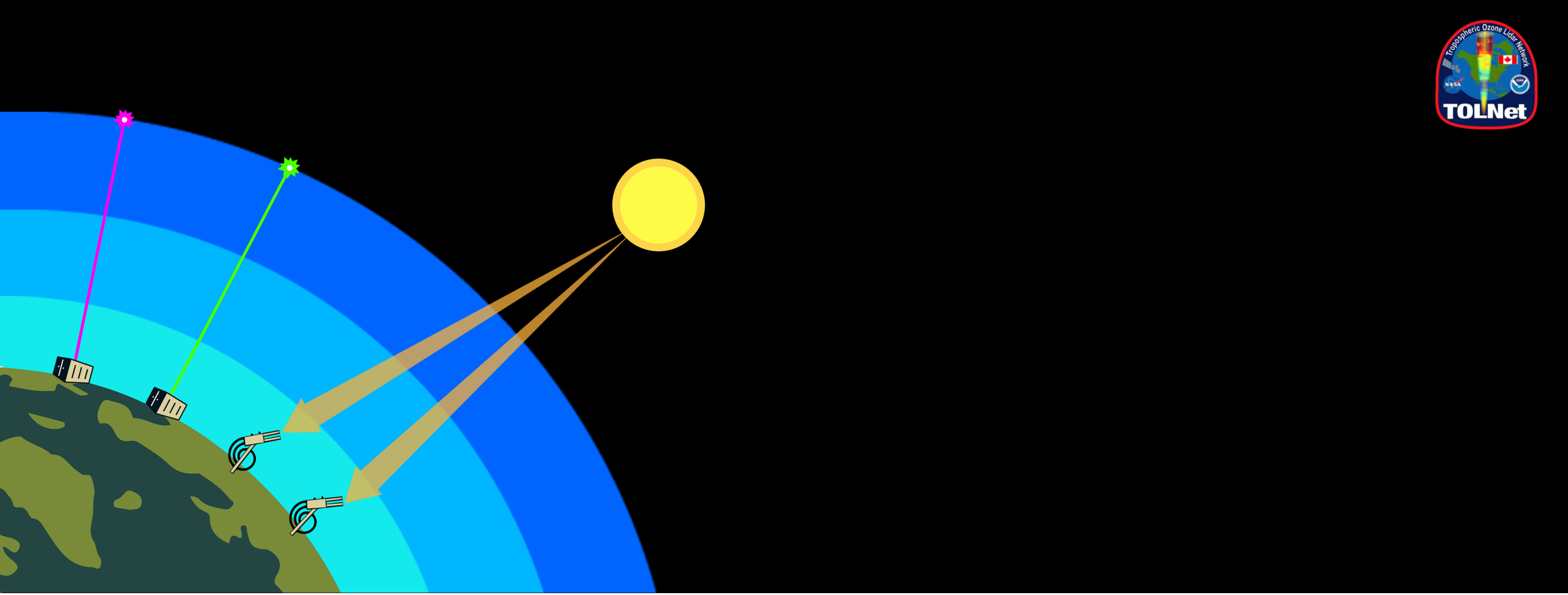
NASA GSFC TROPOZ (TROPospheric OZone LiDAR)

These larger, trailer-based, transportable systems offer an ozone chemistry 'lab on wheels.'

More info on TOLNet website!

Introducing Our New Small Ozone LiDAR (SMOL)

- These compact and portable systems (developed at NASA's JPL Table Mountain Facility) offer the ability to provide ozone profiles to the community at lower cost and with less restrictive sampling locations.



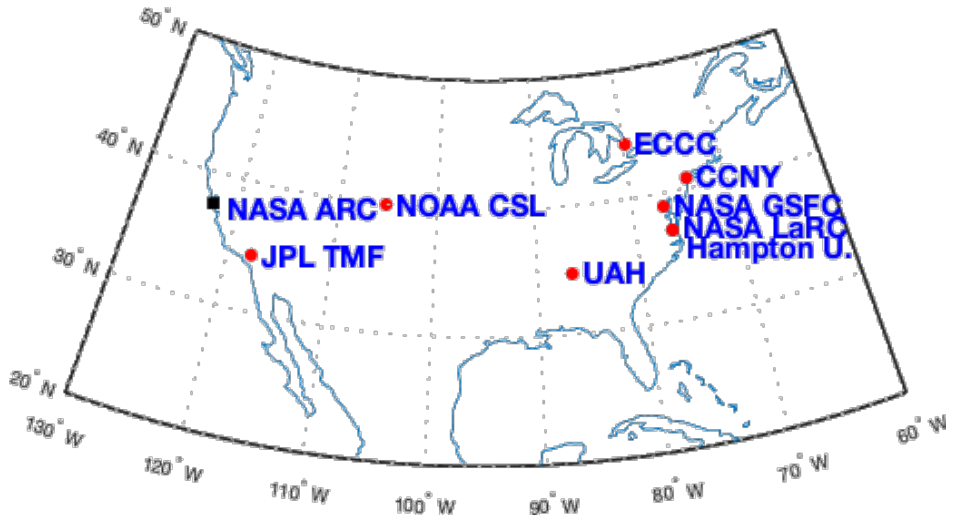
TOLNet Applications and Uses

Applications and Uses of TOLNet Data

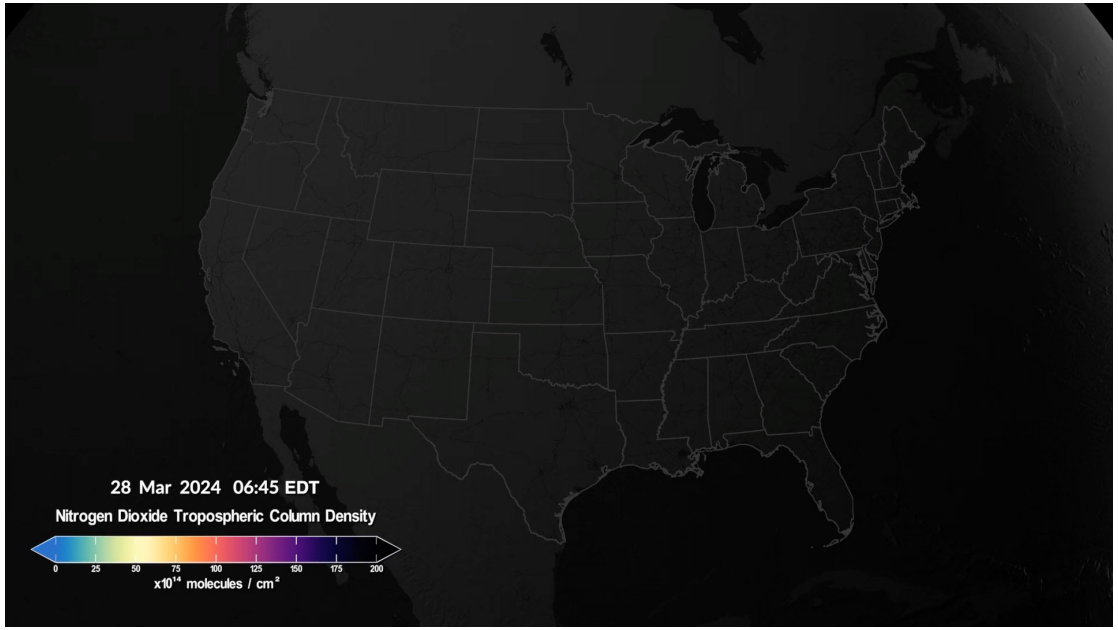
1. Observe high-resolution planetary boundary layer O_3 (**examples in the following slides**)

2. Evaluate air-quality forecast and chemical transport models

3. Study the atmospheric structure for evaluation of current and future satellites (**next steps in prep for TEMPO**)



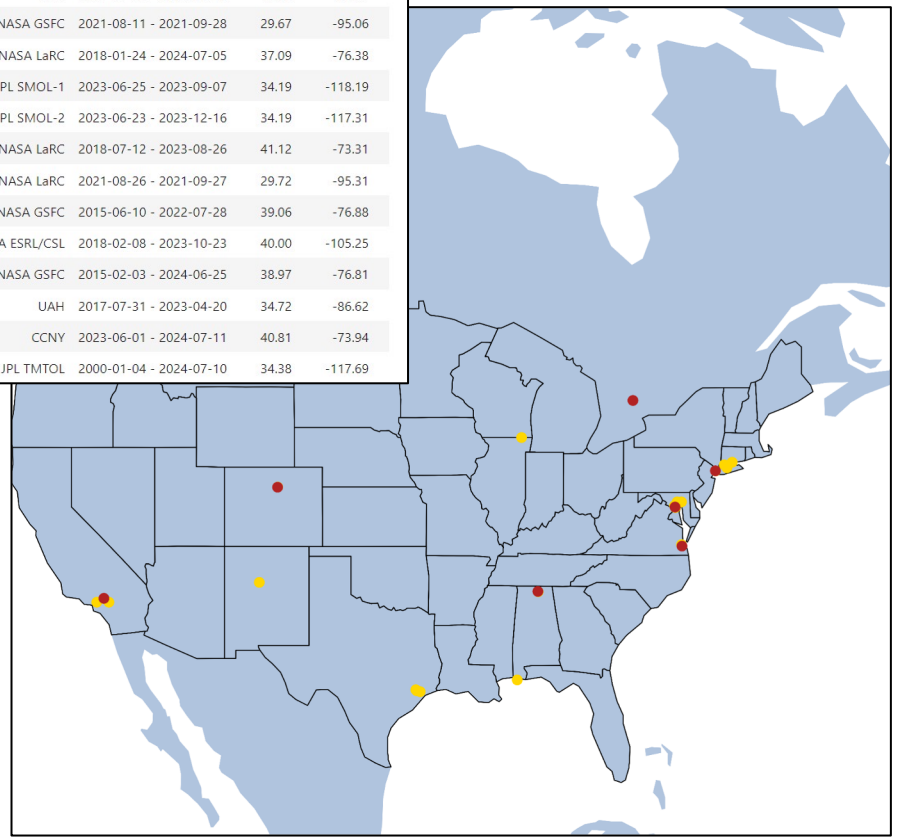
TEMPO Tropospheric NO_2 (Not Ozone!)



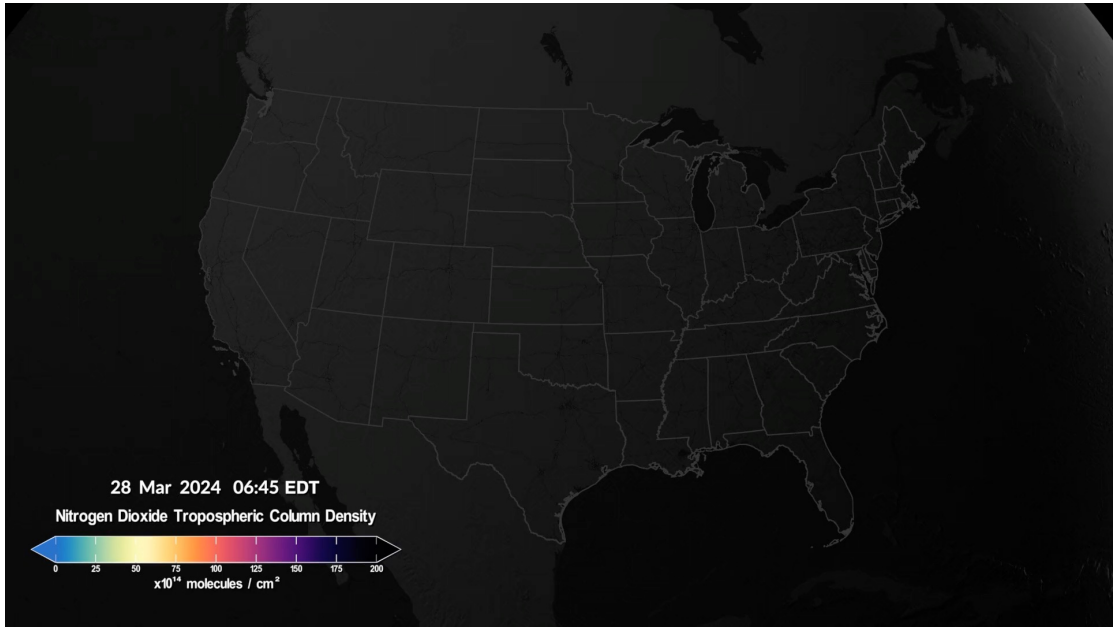
Credit: NASA GSFC Science Visualization Studio

Deployment Locations

Location	Mode	Instrument Group Name	Date Range	Latitude	Longitude
Albuquerque Fiesta Park NM	Campaign	NASA JPL SMOL-1	2023-10-11 - 2023-10-15	35.19	-106.56
Cabauw	Campaign	NASA JPL SMOL-1	2024-05-22 - 2024-06-09	51.97	4.93
Cabauw	Campaign	NASA GSFC	2019-09-12 - 2019-10-02	51.97	4.93
Fort Mackay	Campaign	ECCC	2016-11-04 - 2019-09-23	57.19	-111.62
Guilford YCFS CT	Campaign	NOAA ESRL/CSL	2023-07-04 - 2023-08-14	41.25	-72.75
Huntsville AL	Campaign	UAH	2022-07-08 - 2022-07-10	30.27	-88.12
Kenosha WI	Campaign	UAH	2023-07-18 - 2023-08-16	42.50	-87.81
La Porte TX	Campaign	NASA GSFC	2021-08-11 - 2021-09-28	29.67	-95.06
Langley Research Center VA	Campaign	NASA LaRC	2018-01-24 - 2024-07-05	37.09	-76.38
Pasadena JPL CA	Campaign	NASA JPL SMOL-1	2023-06-25 - 2023-09-07	34.19	-118.19
San Bernardino Calstate CA	Campaign	NASA JPL SMOL-2	2023-06-23 - 2023-12-16	34.19	-117.31
Sherwood Island CT	Campaign	NASA LaRC	2018-07-12 - 2023-08-26	41.12	-73.31
University Of Houston Moody Tower TX	Campaign	NASA LaRC	2021-08-26 - 2021-09-27	29.72	-95.31
Beltsville MD	Routine	NASA GSFC	2015-06-10 - 2022-07-28	39.06	-76.88
Boulder CO	Routine	NOAA ESRL/CSL	2018-02-08 - 2023-10-23	40.00	-105.25
Goddard Space Flight Center MD	Routine	NASA GSFC	2015-02-03 - 2024-06-25	38.97	-76.81
Huntsville AL	Routine	UAH	2017-07-31 - 2023-04-20	34.72	-86.62
New York NY	Routine	CCNY	2023-06-01 - 2024-07-11	40.81	-73.94
Table Mountain CA	Routine	NASA JPL TMTOL	2000-01-04 - 2024-07-10	34.38	-117.69



TEMPO Tropospheric NO_2 (Not Ozone!)



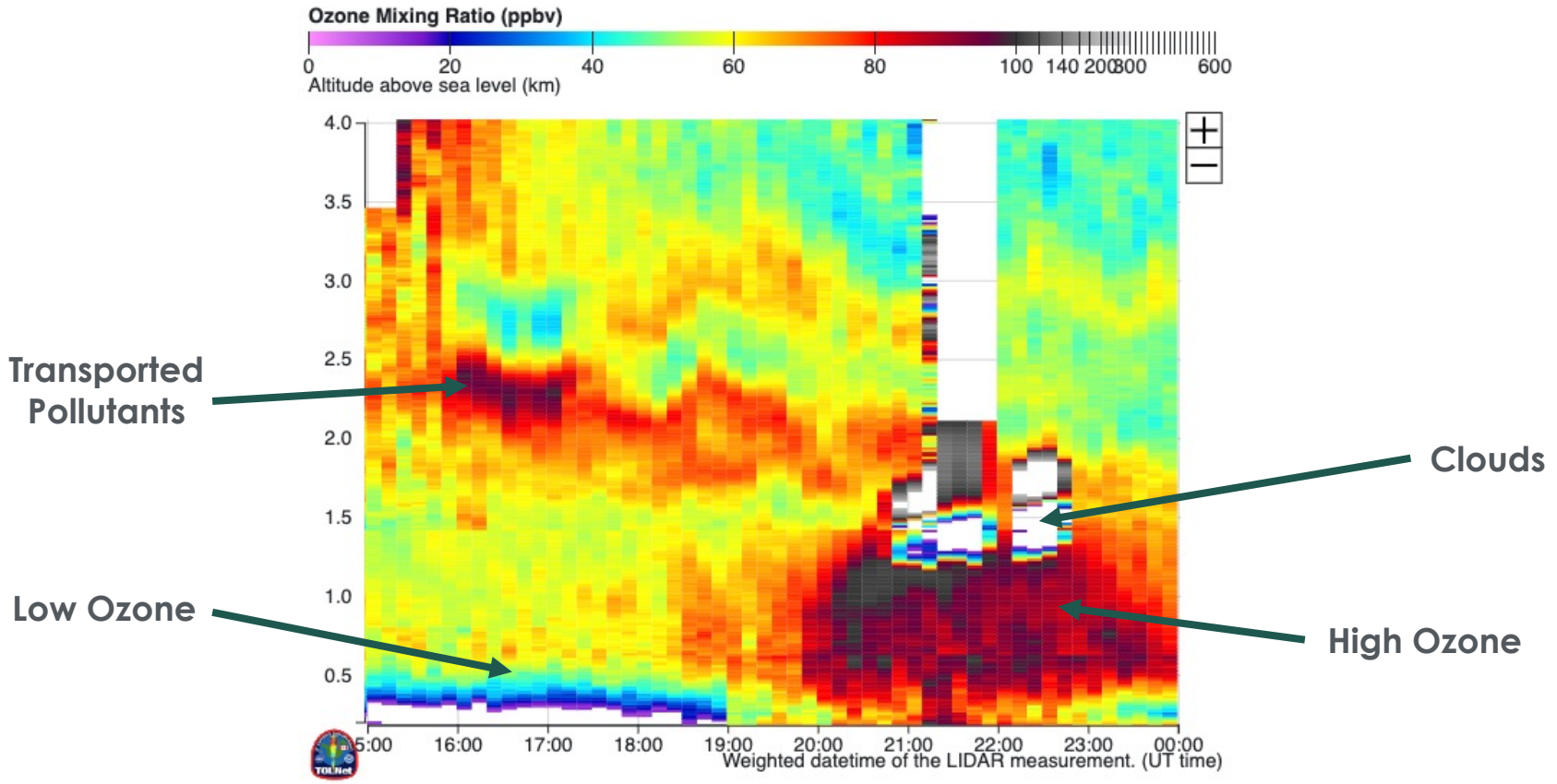
Credit: NASA GSFC Science Visualization Studio

General Benefits of TOLNet LiDAR

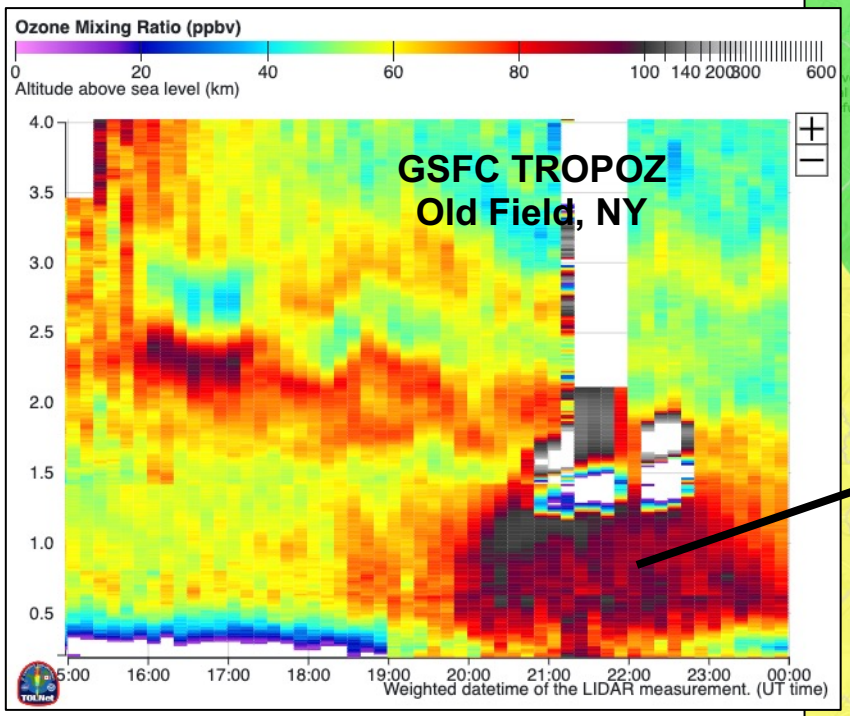
- Obtain profiles of ozone, rather than a total column amount
- Generate your own light source, so both daytime and nighttime observations are possible
- Can be nearly continuous or as needed to characterize ozone events

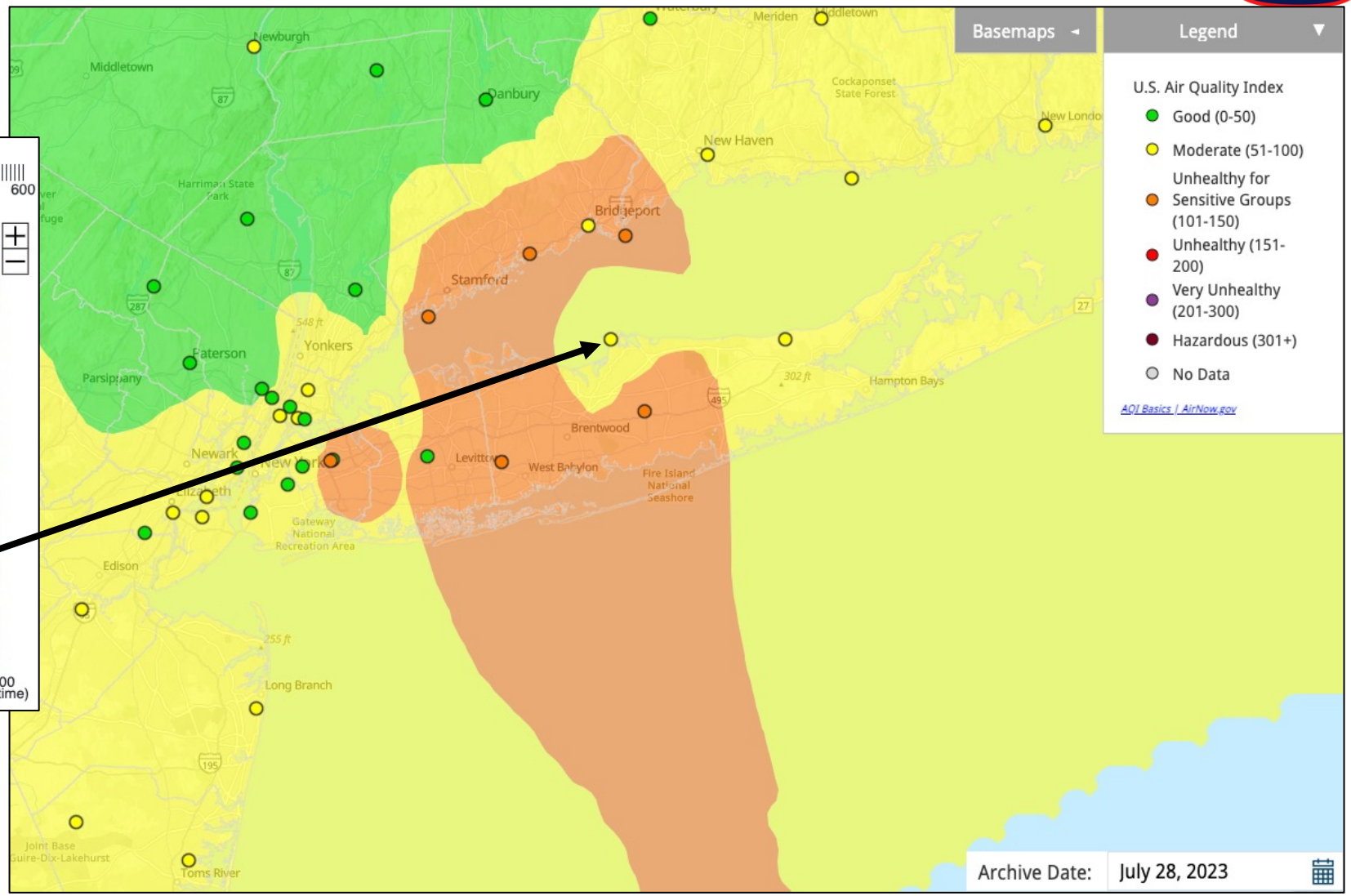
U.S. Air Quality Index

- Good (0-50)
- Moderate (51-100)
- Unhealthy for Sensitive Groups (101-150)
- Unhealthy (151-200)
- Very Unhealthy (201-300)
- Hazardous (301+)



Example Case Study: July 28, 2023

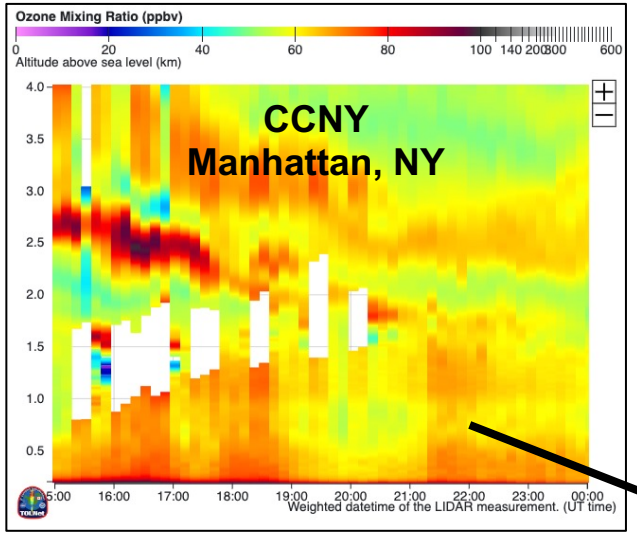


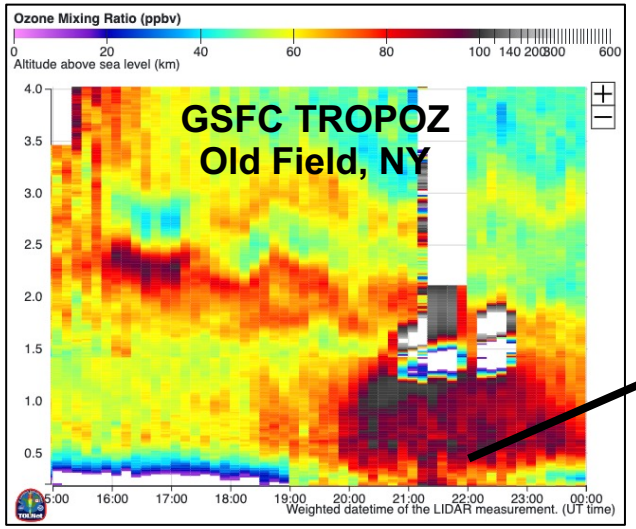


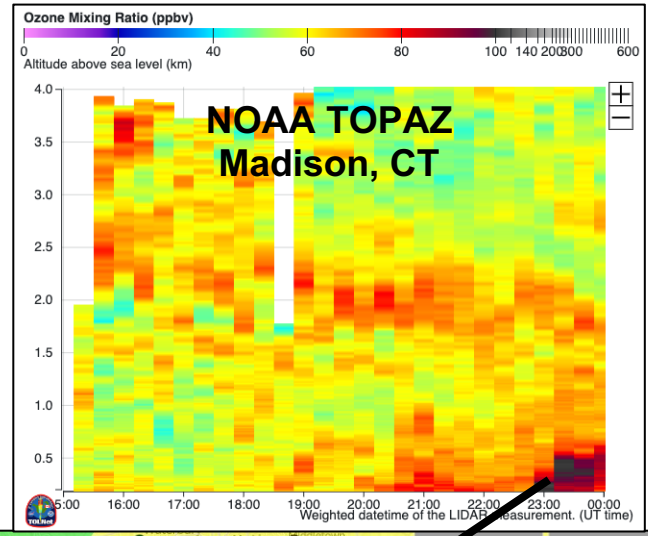
TOLNet Curtains: https://tolnet.larc.nasa.gov/

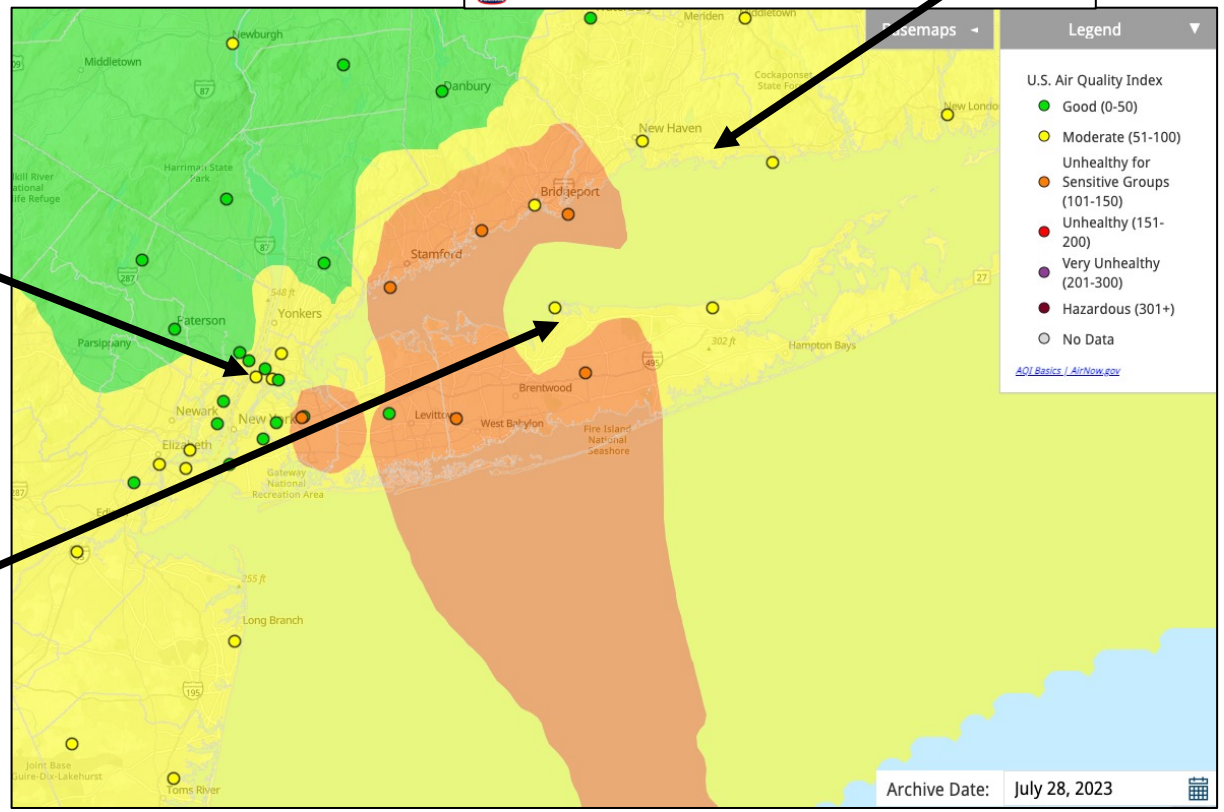
AirNow Maps: https://www.airnow.gov/

Multiple TOLNet LiDARs During Campaigns – NY



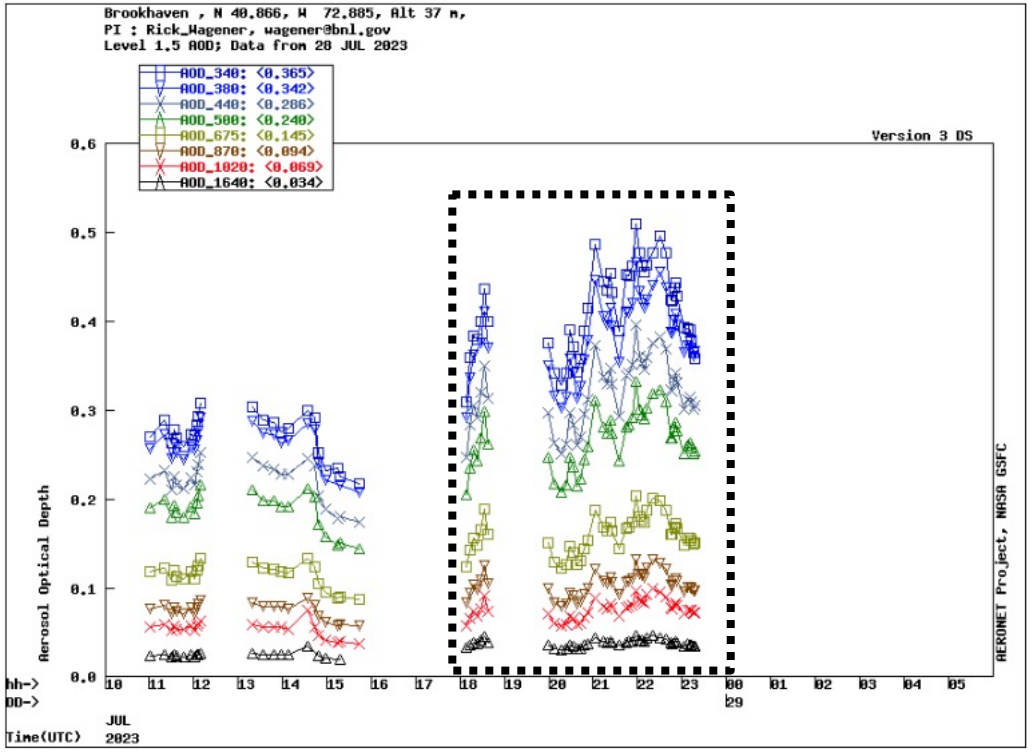


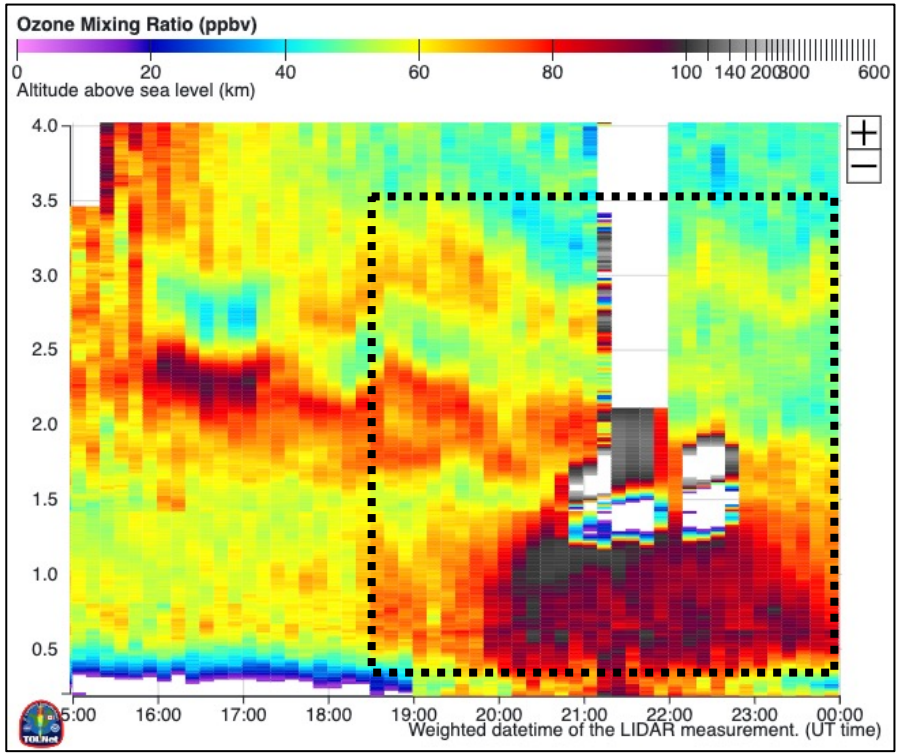




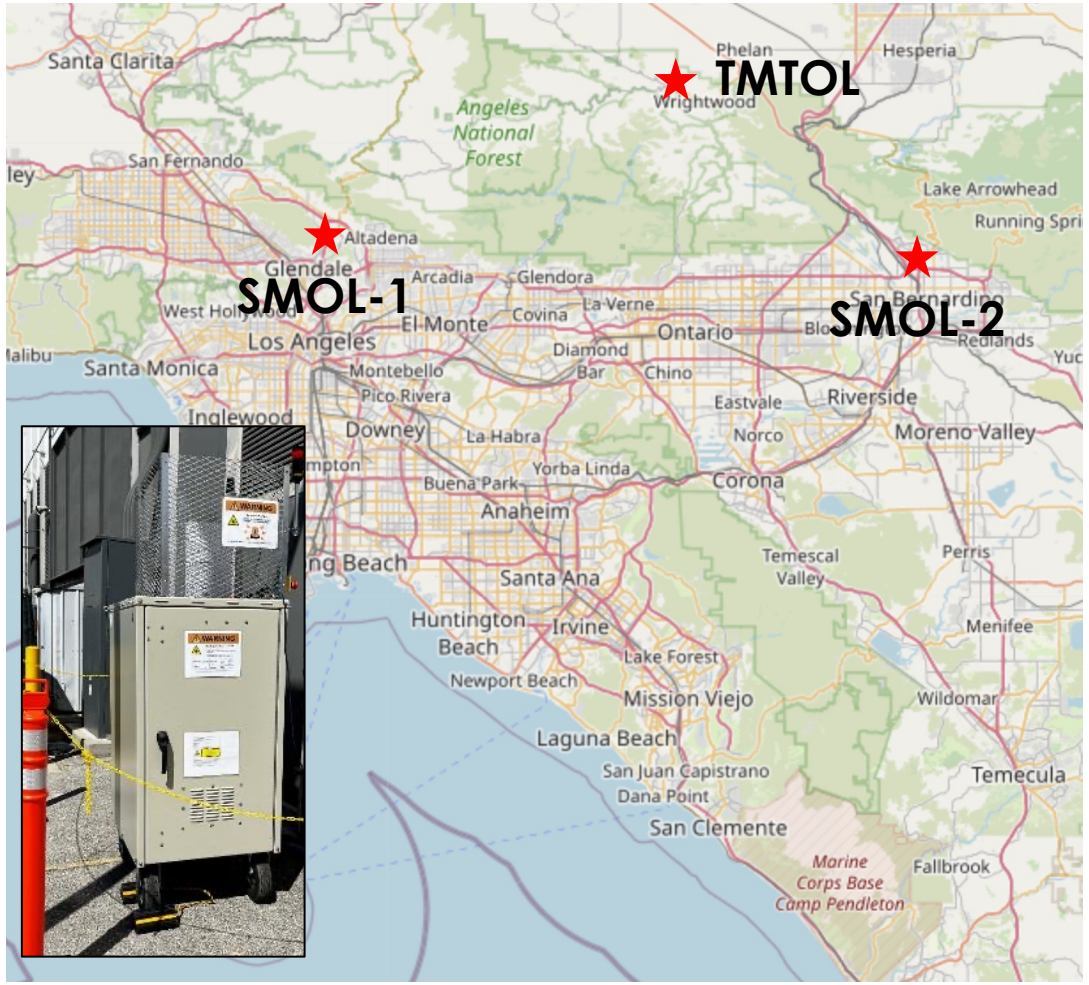
Using Multiple Ground-Based Networks to Characterize Pollution Events

- Using AERONET retrievals, we can better characterize the pollution event that occurred at the Flax Pond, NY site.
- Increases in AOD occurred during the same times as the increase in boundary layer ozone observed by TOLNet. Combining these and other NASA networks can aid in understanding transport patterns.





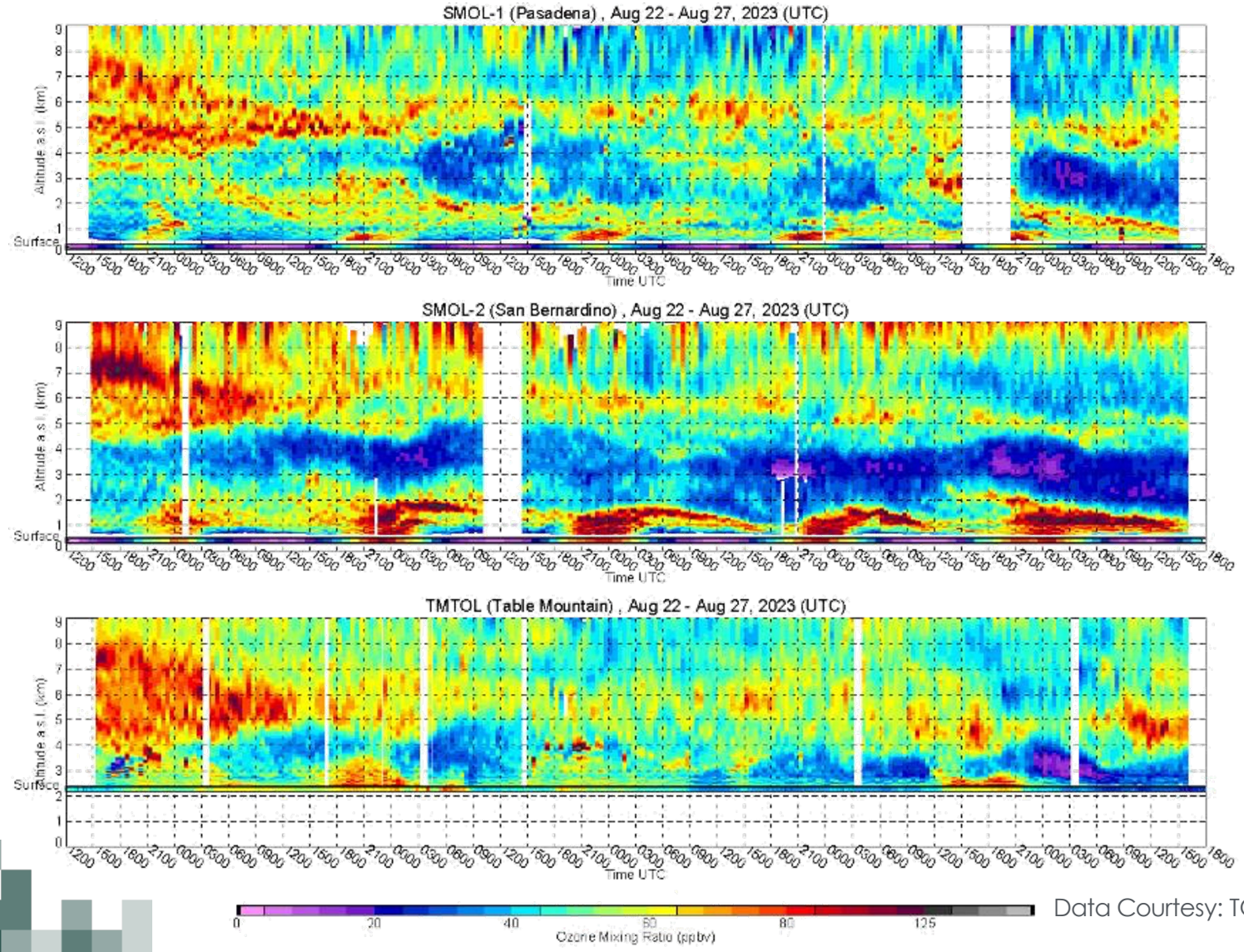
Multiple TOLNet LiDARs During Campaigns – CA



Data Courtesy: TOLNet/TMF JPL Team

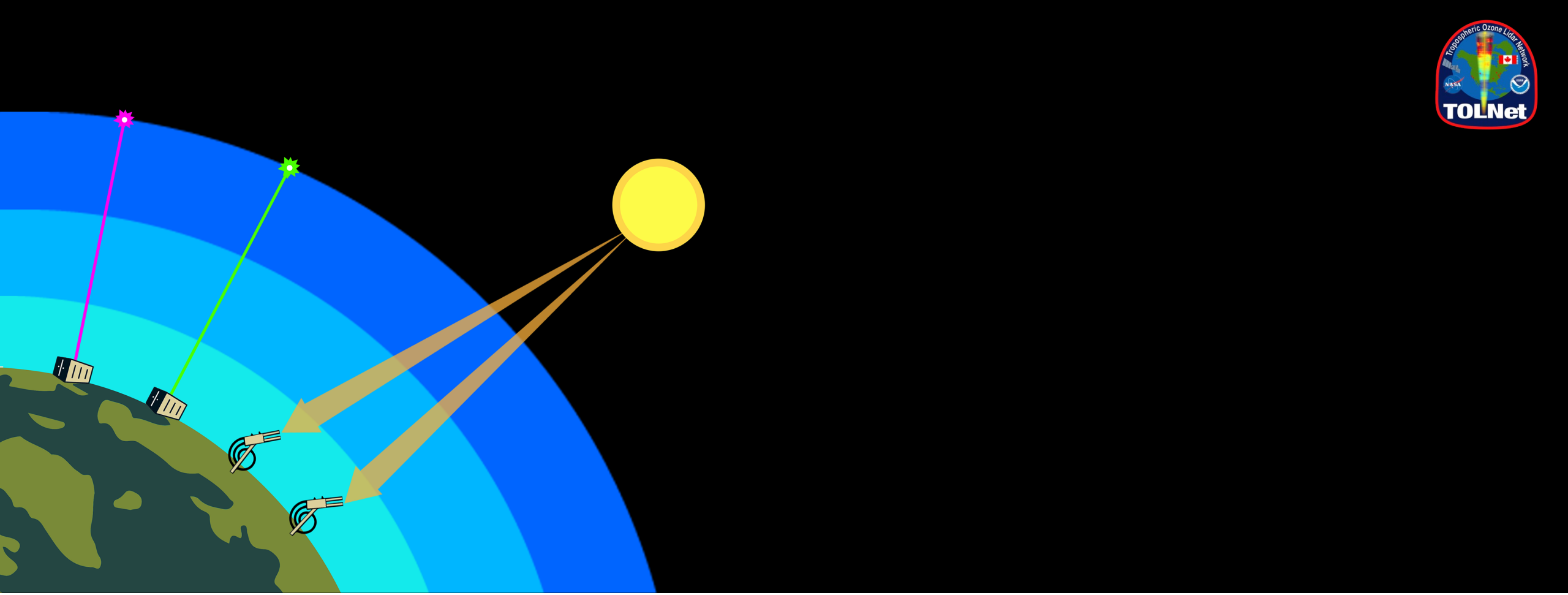
- **TMTOL** is a fixed high performance ozone LiDAR located at the JPL Table Mountain facility.
- **SMOL-1** was deployed at JPL Pasadena during AEROMMA, STAQS, and early TEMPO validation efforts. Pasadena exhibits a strong ozone diurnal cycle due to titration.
- **SMOL-2** is deployed to CSUSB. San Bernardino county has the largest number of ozone exceedances in the US.

Multiple TOLNet LiDARs During Campaigns – CA



- **TMTOL** is a fixed high performance ozone LiDAR located at the JPL Table Mountain facility.
- **SMOL-1** was deployed at JPL Pasadena during AEROMMA, STAQS, and early TEMPO validation efforts. Pasadena exhibits a strong ozone diurnal cycle due to titration.
- **SMOL-2** is deployed to CSUSB. San Bernardino county has the largest number of ozone exceedances in the US.

Data Courtesy: TOLNet/TMF JPL Team



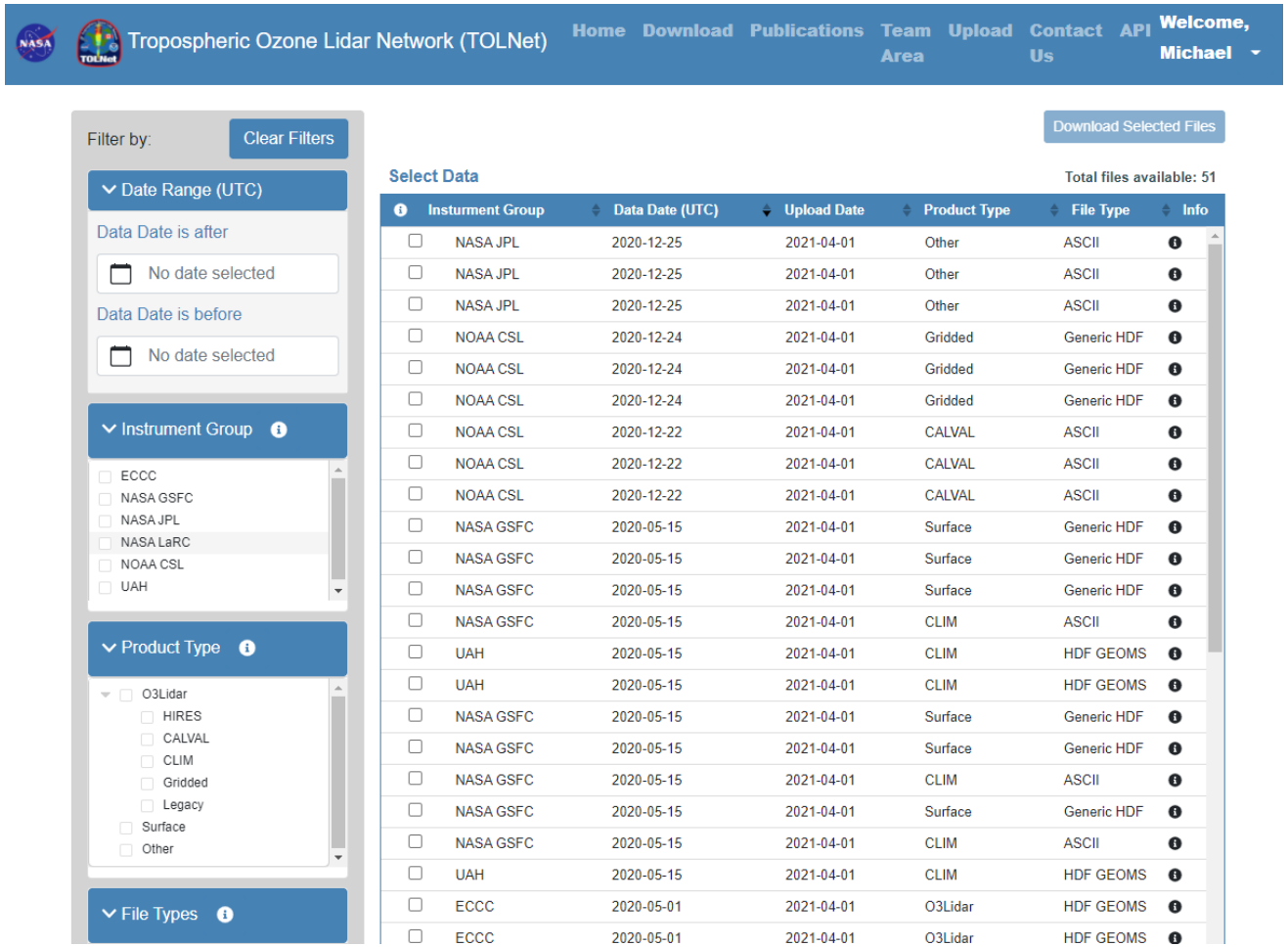
Accessing TOLNet Data:
TOLNet Website/Archive & Python Toolbox

Accessing TOLNet Data – Website

2024 Website Roll-Out Significance:

- ✓Easier data discovery and data management for end users
- ✓Graphing capability/near-real time data viewing
- ✓API for automation, future interface, and interoperability
- ✓More functional search features and data sub-setting

TOLNet Website

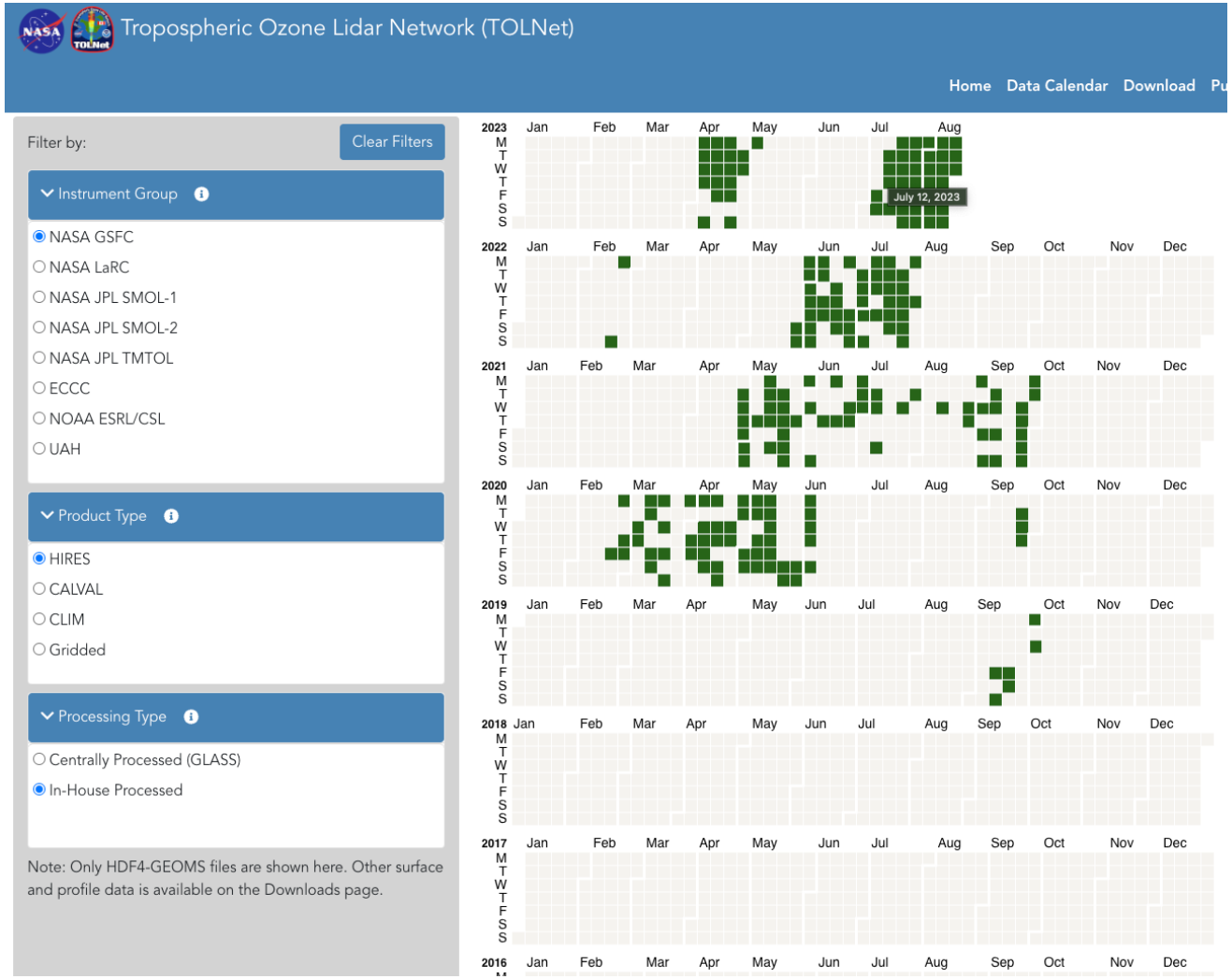


Accessing TOLNet Data – Data Calendar View

2024 Website Roll-Out Significance:

- ✓Easier data discovery and data management for end users
- ✓Graphing capability/near-real time data viewing
- ✓API for automation, future interface, and interoperability
- ✓More functional search features and data sub-setting

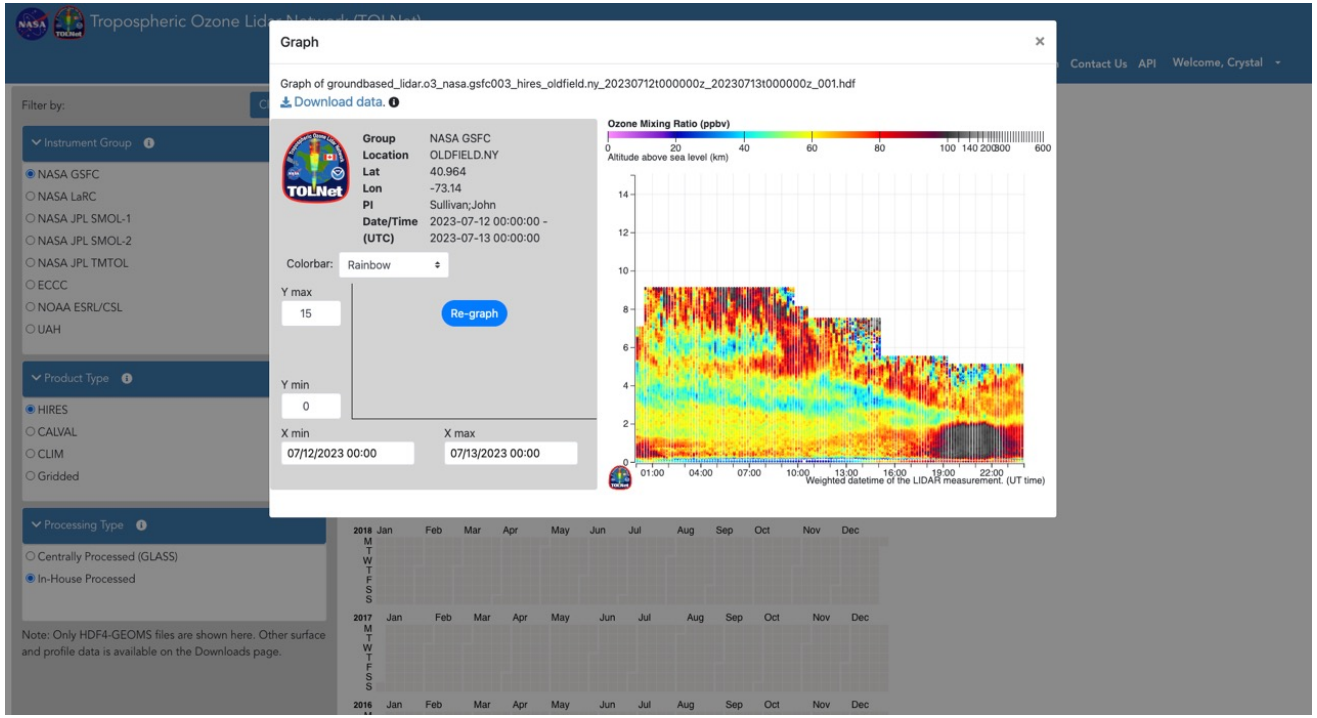
TOLNet Website



Accessing TOLNet Data – Selecting a Specific Day of Data

2024 Website Roll-Out Significance:

- ✓Easier data discovery and data management for end users
- ✓Graphing capability/near-real time data viewing
- ✓API for automation, future interface, and interoperability
- ✓More functional search features and data sub-setting



TOLNet Website

Accessing TOLNet Data – TOLNet Toolbox (Python Notebook)

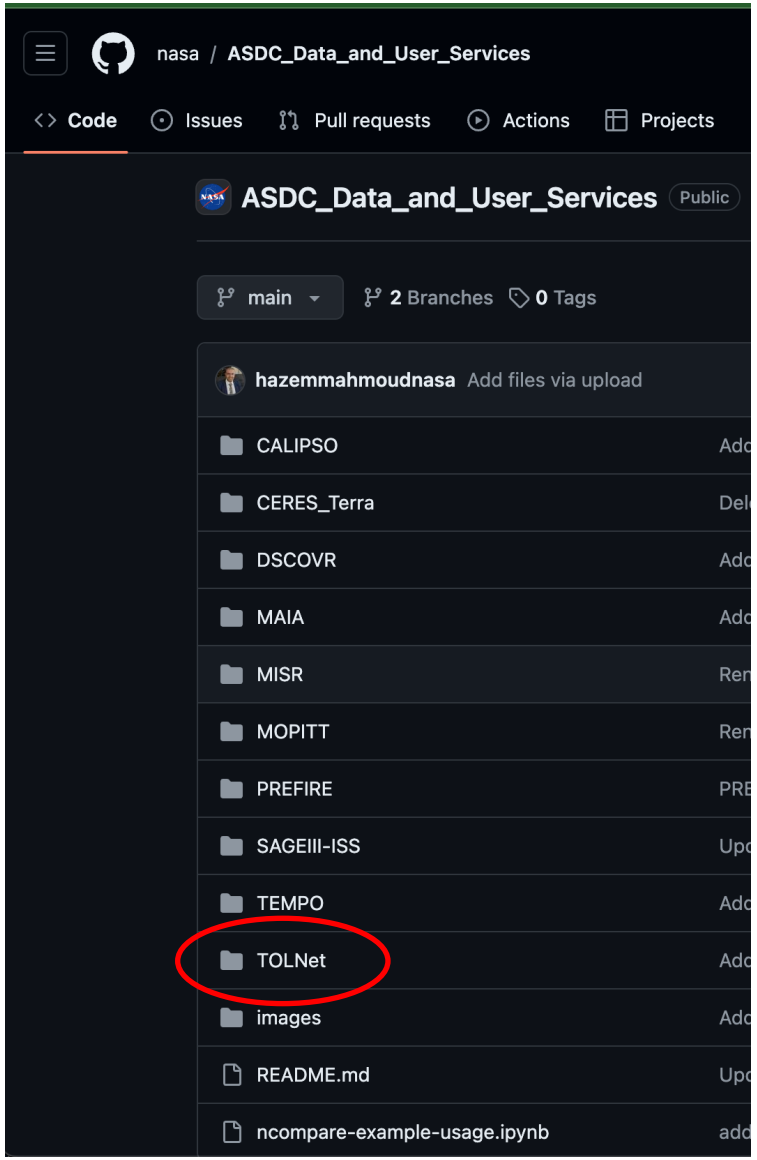
This can be accessed by going to the **ASDC Data and User Services Github**:

- https://github.com/nasa/ASDC_Data_and_User_Services/tree/main/TOLNet

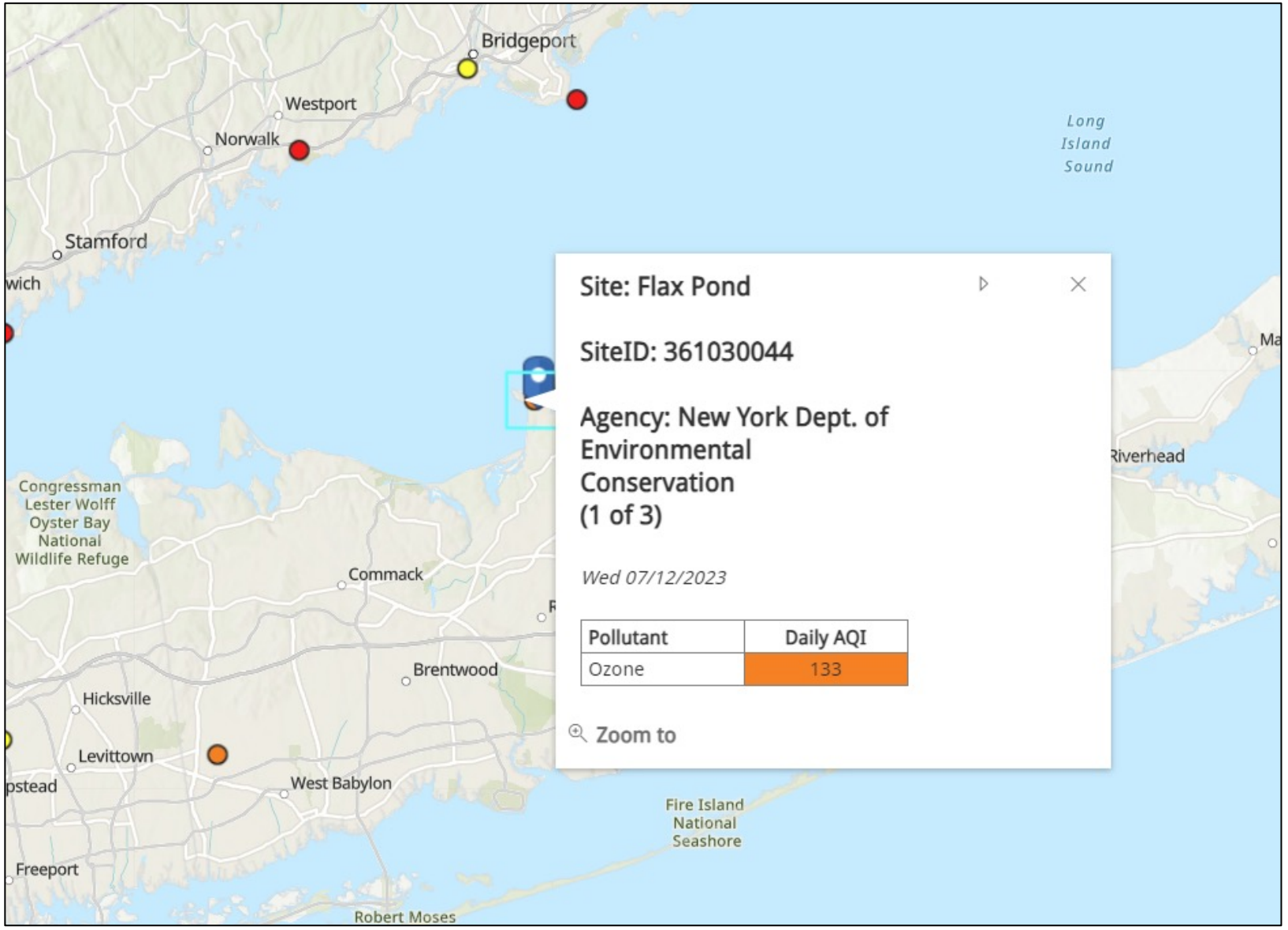
Then by opening up '**TOLNet API Examples.ipynb**':

- https://github.com/nasa/ASDC_Data_and_User_Services/blob/main/TOLNet/TOLNet_API_Examples.ipynb

This can be viewed in the native browser or downloaded to use in other environments (e.g., within Anaconda/Jupyter).



Accessing TOLNet Data – TOLNet Toolbox (Python Notebook)



Accessing TOLNet Data – Calling the API for Data

Example Case Study

On July 12th, 2023, the air quality surrounding the Goddard Space Flight Center was particularly poor, with an ozone index of about 100(Unhealthy for sensitive groups).
We will use the TOLNet API to graph the ozone data at GSFC during this time.

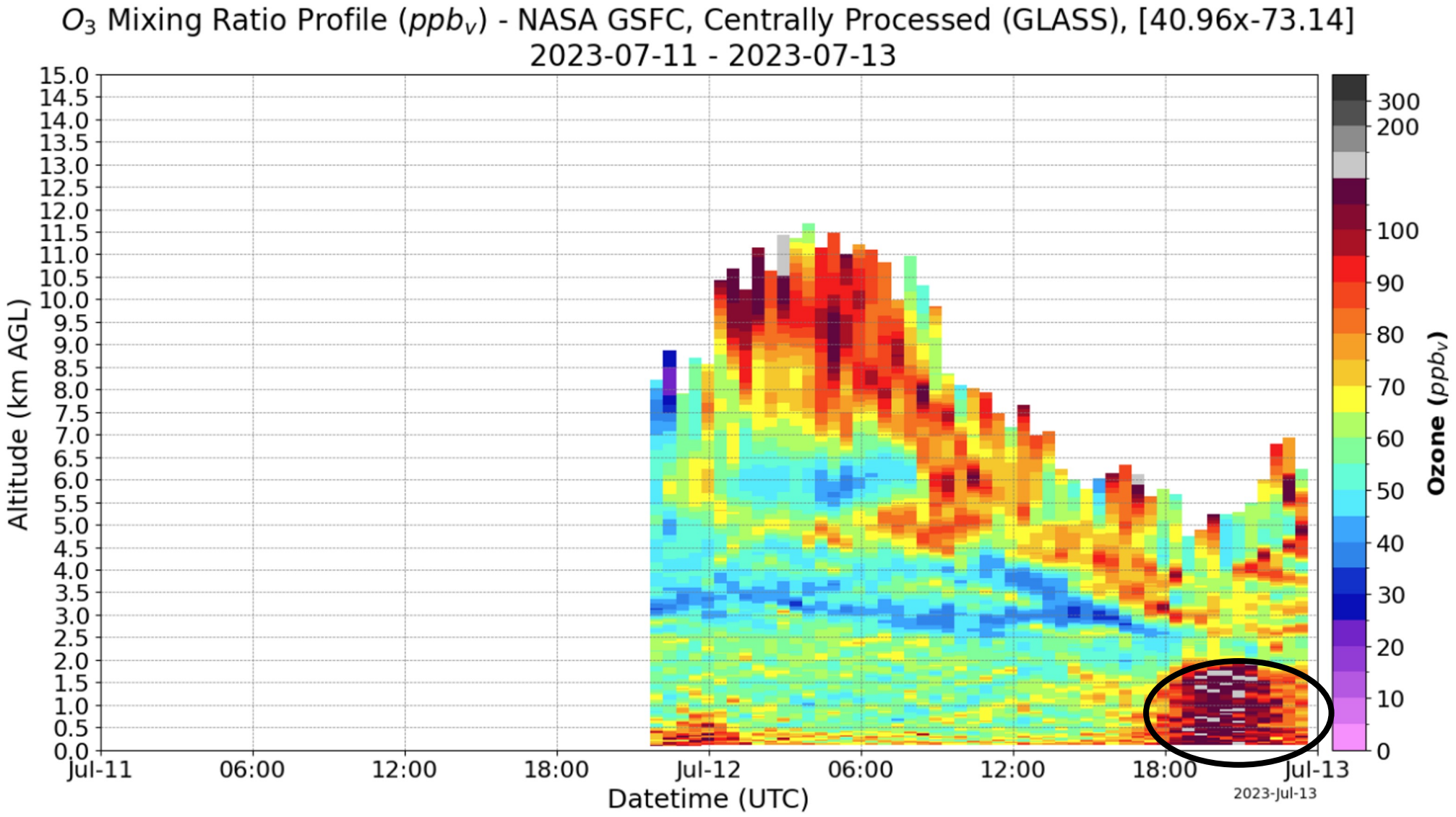
Then, we import it with python.

In [1]:
```
from tolnet import TOLNet
tolnet = TOLNet() # Creates an object that retrieves data from the API and stores it
```

We only want data from the GSFC area around June 12th. As such, we filter accordingly:

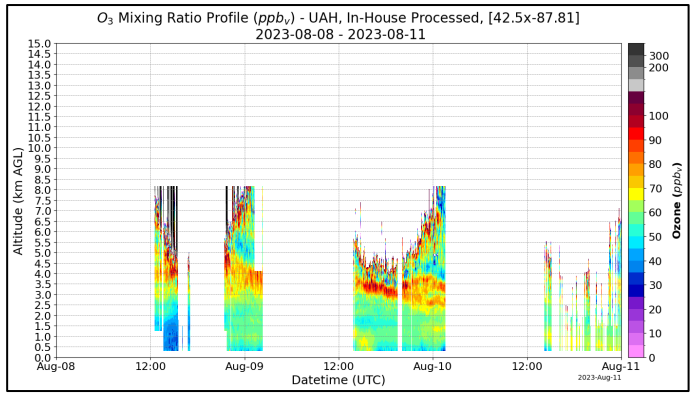
In [2]:
```
date_start = "2023-07-11"
date_end = "2023-07-13"
group = [2] # List of instrument group IDs to filter by. We only want GSFC(ID=2), so this list only contains 2.
product_ID = [4] # Filter for high-resolution files only

tolnet.import_data(min_date=date_start, max_date=date_end, instrument_group=group, product_type=product_ID)
```

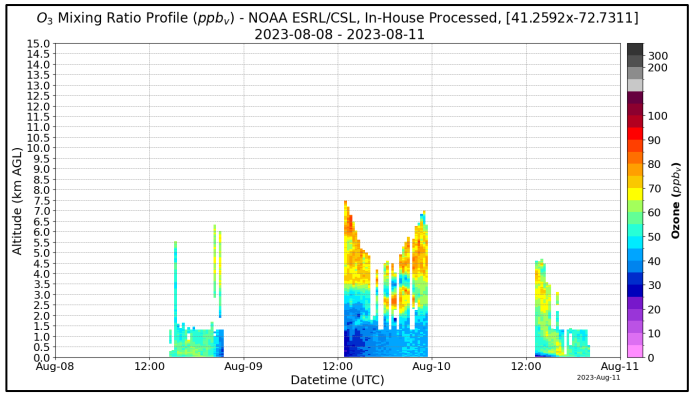
Accessing TOLNet Data – Generating a Curtain Plot

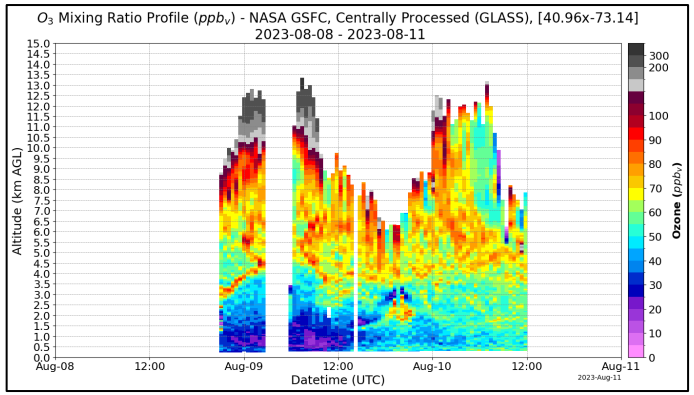


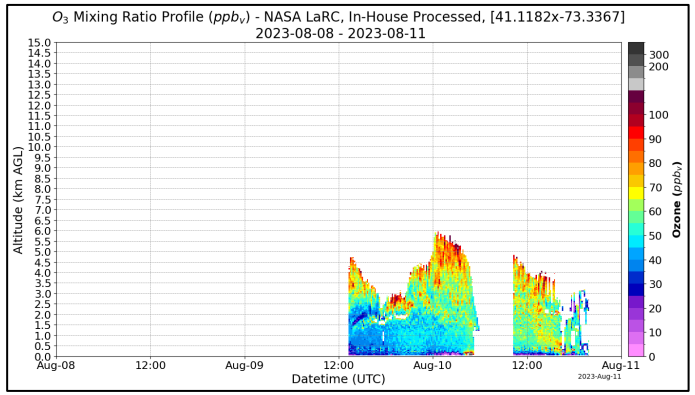
Accessing TOLNet Data – Polling All TOLNet Data Given a Date Range

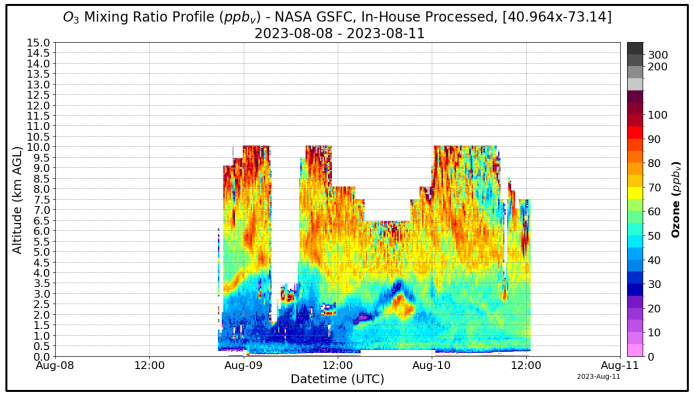
date_start = "2023-08-08" | date_end = "2023-08-11" | product_IDs = [4] # *HIRES*

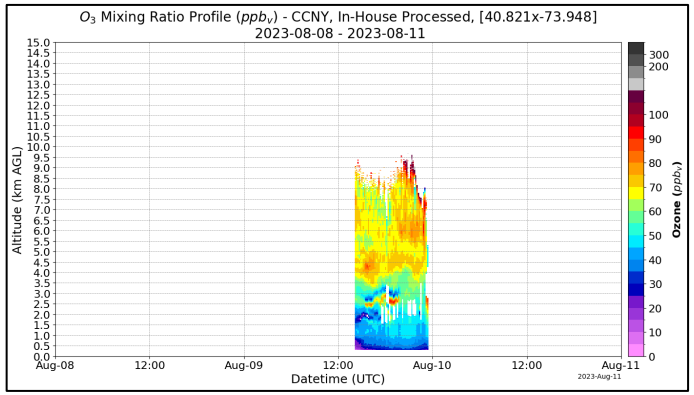












Accessing TOLNet Data – Customizing Plots

- Graph from tolnet_curtains() can be customized

```
# xlims takes a list of two dates in ISO 8601 Format(YYYY-MM-DD), like this: ['2023-08-05', '2023-08-08'].
data.tolnet_curtains(xlims=['2023-08-08', '2023-08-09'], title="Cropped Graph(X-axis)")
```

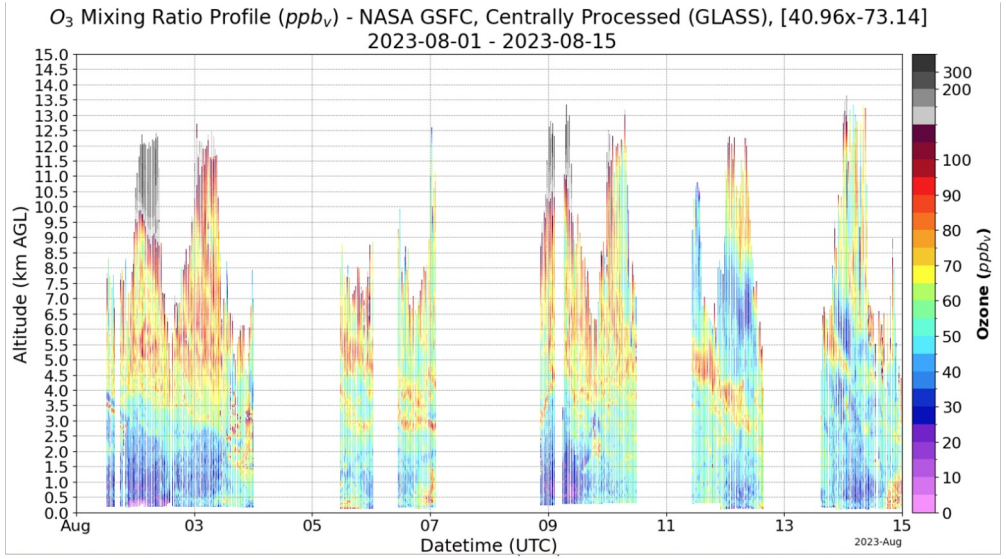
```
data.tolnet_curtains(ylims=[0, 2], title="Cropped Graph (Y-axis)")
```

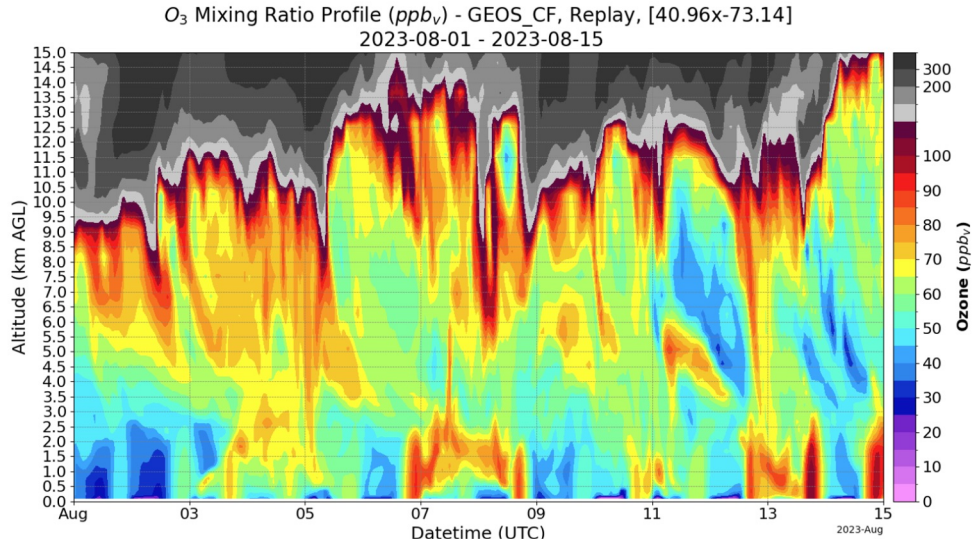
```
data.tolnet_curtains(xlabel="Sample X Label", ylabel="Sample Y Label", title="Axis labelling demo")
```

Accessing TOLNet Data – Comparing with GEOS-CF Outputs

- GEOS-CF is a global atmospheric composition model which produces ozone forecasts and replays.

[20]:
```
# Copy of previous query for sample data
from tolnet import TOLNet
tolnet = TOLNet()

params = {"min_date": "2023-08-01",
          "max_date": "2023-08-15",
          "product_type": [4],
          "instrument_group": [2],
          "processing_type": [1],
          "GEOS_CF": True
         }

data = tolnet.import_data(**params).tolnet_curtains()
```





Accessing TOLNet Data – Website or Python Toolbox

2024 Website :

- ✓Easier data discovery and data management for end users
- ✓Graphing capability/Near-Real Time data viewing
- ✓API for automation, future interface, and interoperability
- ✓More functional search features and data sub-setting

2024 TOLNet Toolbox:

- ✓Allow for multiple lidars to be quickly plotted with a simple call
- ✓Future work will be developing analysis tools to complement website
- ✓Visual comparisons to GEOS-CF and future statistics can be generated

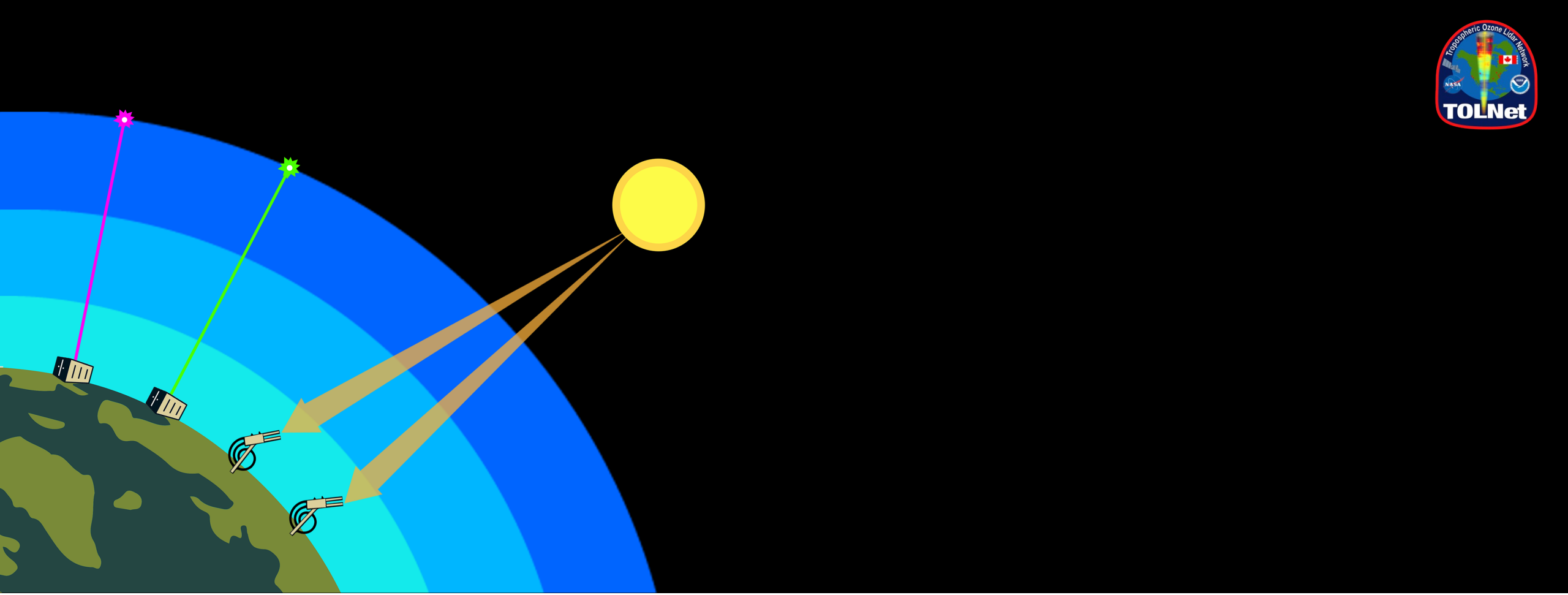
TOLNet Website

TOLNet Toolbox

Acknowledgements

7th Annual TOLNet Science Team Meeting
Silver Spring, MD 2019

- NASA HQ- Tropospheric Composition Program
- TOLNet Scientists and Station Leads
- Michael Newchurch/UAH TOLNet Chief Scientist
- NASA ASDC and Data Team



Part 4:
Summary

Summary

- Discussed the basic characteristics of the ozone in the atmosphere and available techniques to measure vertical profiles of ozone
- Simple introduction to Differential Absorption LiDAR (DIAL), which is used for ozone LiDARs with TOLNet
- Introduced a few of the major hardware components and sizes of TOLNet LiDARs
- Recognize how TOLNet supports air quality: We described a case study where TOLNet LiDARs were able to characterize high ozone in two domains (New York and California)
- Access relevant TOLNet data for a given location and application purpose by using the website and the TOLNet Toolbox Python Notebook

Summary – Ground Networks Chart

Network	Type	Primary Measurands	Number of Sites	Vertical Coverage
AERONET	Passive	Aerosols (Optical, Microphysical, Radiative)	~600 Active	Total Column
Pandora (PGN)	Passive	Trace Gases (Ozone, NO_2, Formaldehyde)	168 Official	Total Column, Near-Surface, Lower Tropospheric Profiles
TOLNet	Active	Trace Gases (Ozone Vertical Profiles)	12 (3 Fixed, 9 Transportable)	Tropospheric Profiles (0-15 km)

Looking Ahead to Part 5

- We will learn about the Micro-Pulse LiDAR Network (MPLNET).
- MPLNET is another active remote sensing network, this time focused on clouds and aerosols.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 22/08/2024
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 05/09/2024**

- **Certificate of Completion:**
  - Attend all five live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

Trainers:

- John Sullivan
  - john.t.sullivan@nasa.gov
  - Follow us on Twitter!
    - @NASA_TOLNET

- Melanie Follette-Cook
  - melanie.cook@nasa.gov

- ARSET Website
- Follow us on Twitter!
  - @NASAARSET
- ARSET YouTube

Visit our Sister Programs:

- DEVELOP
- SERVIR

Resources

- AERONET Website
  - AERONET Data Synergy Tool
  - AERONET Map Explorer
- Pandora Website
  - Pandonia Global Network
  - Pandonia Network Data
- TOLNet Website
  - Data Calendar
  - TOLNet Data API 'TOLNet Toolbox'


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!