TEMPO Product Training Overview

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Session III: TEMPO
GeoXO ACX Science Team Meeting
May 7, 2024

NOAA
National Satellite and Information Service
Center for Satellite Applications and Research

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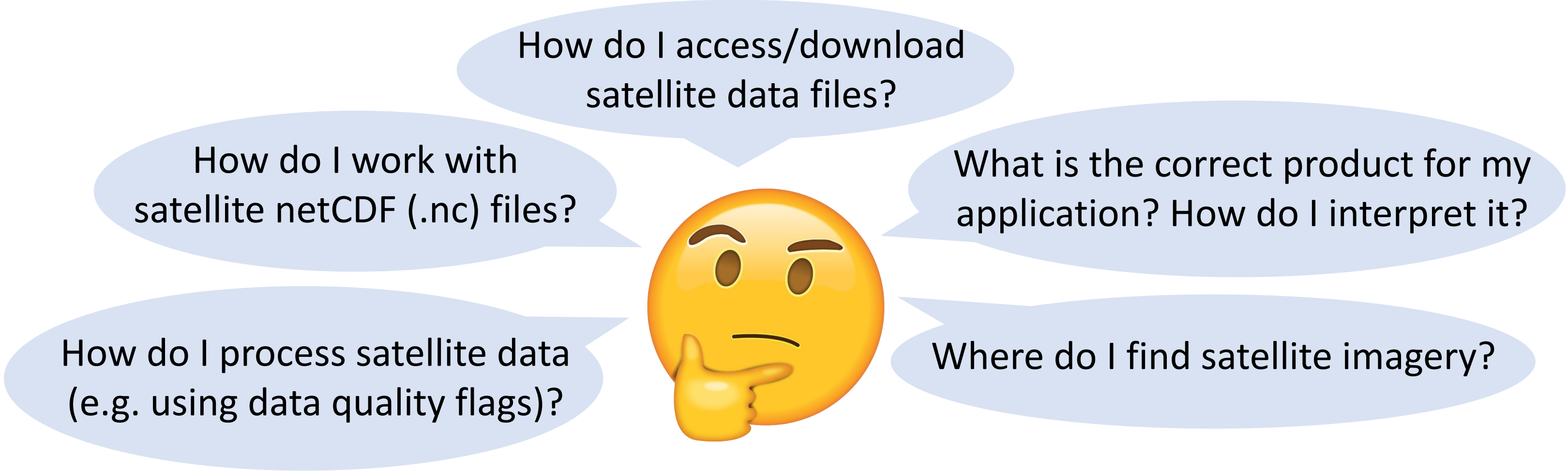
STAR Atmospheric Composition Training Program



How do I access/download satellite data files?

How do I work with satellite netCDF (.nc) files?

What is the correct product for my application? How do I interpret it?

How do I process satellite data (e.g. using data quality flags)?

Where do I find satellite imagery?

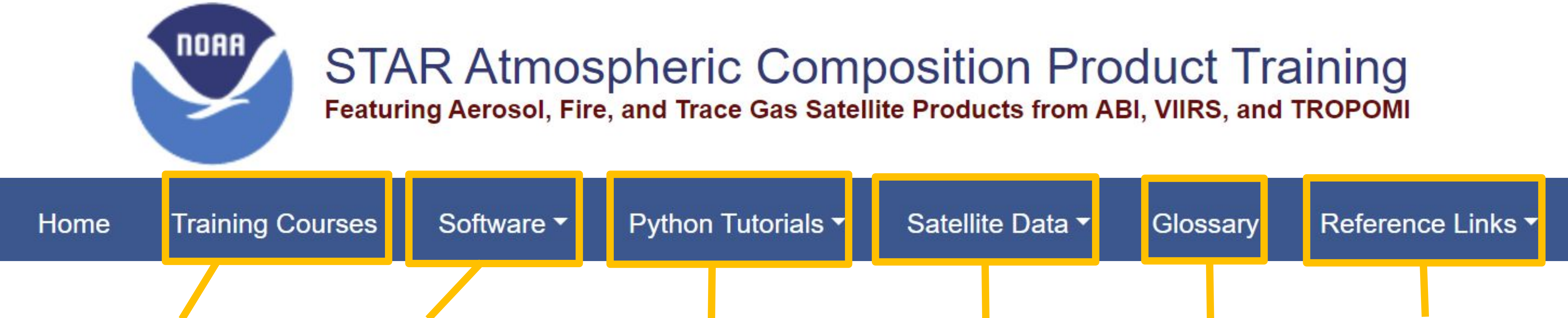
- Hands-on training program for end users; began in 2020
- Breaking down barriers preventing wider user of STAR products
- Targeted sessions for specialized user groups (e.g., air quality forecasters) and more general sessions at scientific meetings
- Focus is on **proper workflow** for satellite data using **Python**:
  - Search for/download satellite data files from online archives
  - Open/read netCDF satellite data files
  - Process/analyze/visualize satellite data

STAR Training Program Objectives

1. Increase access to STAR's aerosol, fire & trace gas satellite data
2. Promote proper use of the satellite products in operations & research

STAR Training Website: Resources for End Users

https://www.star.nesdis.noaa.gov/atmospheric-composition-training/



STAR Atmospheric Composition Product Training

Featuring Aerosol, Fire, and Trace Gas Satellite Products from ABI, VIIRS, and TROPOMI

Training Courses: Agendas & links to hands-on tutorials for specific training courses

Software: Instructions & links to install Anaconda & Python packages, set-up Jupyter Notebook

Python Tutorials: Examples of annotated Python code used in training tutorials

(additional tutorials coming soon!)

Satellite Data: Everything users need to work with satellite data files, including links to online data archives

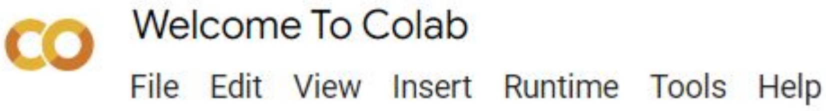
Glossary: Extensive glossary of satellite sensor and data terminology

Reference Links: Links to info on satellites, imagery, and Python resources

Thanks to Donovan Kelly, Jr. (Axiom Consulting) & Lori Brown (Axiom Consulting) for design of the website

TEMPO Product Training at the GeoXO ACX STM

- 2 opportunities to work hands-on with TEMPO data using Python
  - Tomorrow at 2:00-3:30 pm: **work flow for TEMPO NO_2 Level 2 granules & experimental AOD granules files** (parallel with the Poster Session)
  - Thursday at 1:00-2:00 pm: **TEMPO via the Python interface to the Remote Sensing Information Gateway (RSIG)** (parallel with end of lunch & beginning of Special Topics session)
- Python tutorials will be run on Google Colaboratory (Colab)
  - Google-hosted Jupyter Notebook service
  - No setup to use! **All you need is a Google (gmail) account!**
  - Free access to computing resources! Very fast & powerful!


Welcome To Colab

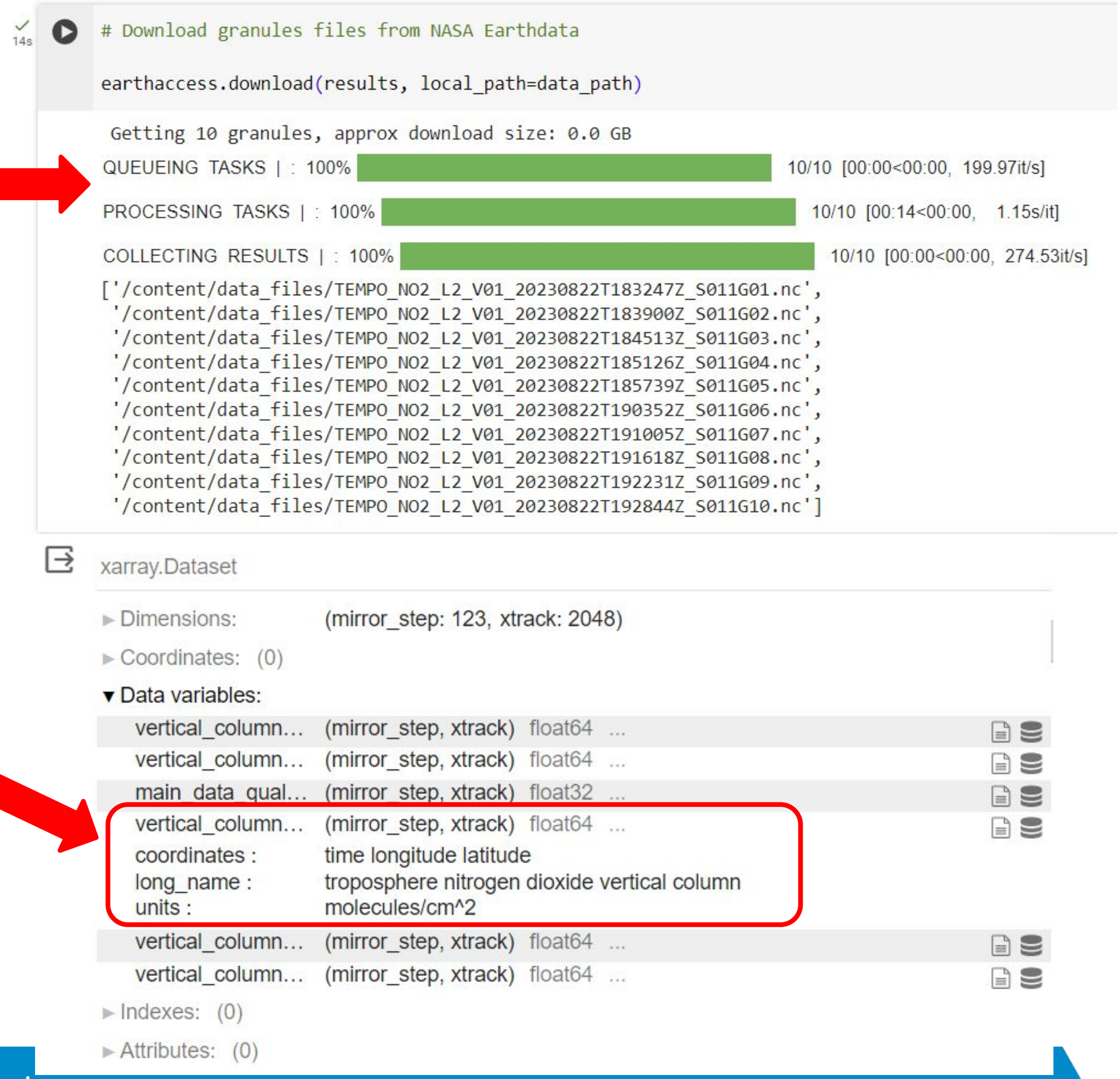
- Prior experience with Python or computer programming is NOT required
  - Come and see how easy it is to use Python!
  - Get your hands on actual TEMPO data!
  - More advanced Python programmers will find plenty to interest them!

Wednesday’s Training: Working with TEMPO Granules

- Download one full TEMPO scan (10 files) of:
  - Level 2 NO_2 granules from **NASA Earthdata**
  - Experimental aerosol granules from my STAR FTP webpage

If you don’t already have an Earthdata account, search for “Earthdata Login” and register! It’s free!

- Open & understand the contents of the TEMPO granule files
  - Find data variables; understand their valid ranges, units, data types
  - Tricks & tips for reading in data arrays
  - See the difference b/w an operational file (NO_2) & an experimental file (AOD)



```
# Download granules files from NASA Earthdata

earthaccess.download(results, local_path=data_path)
```

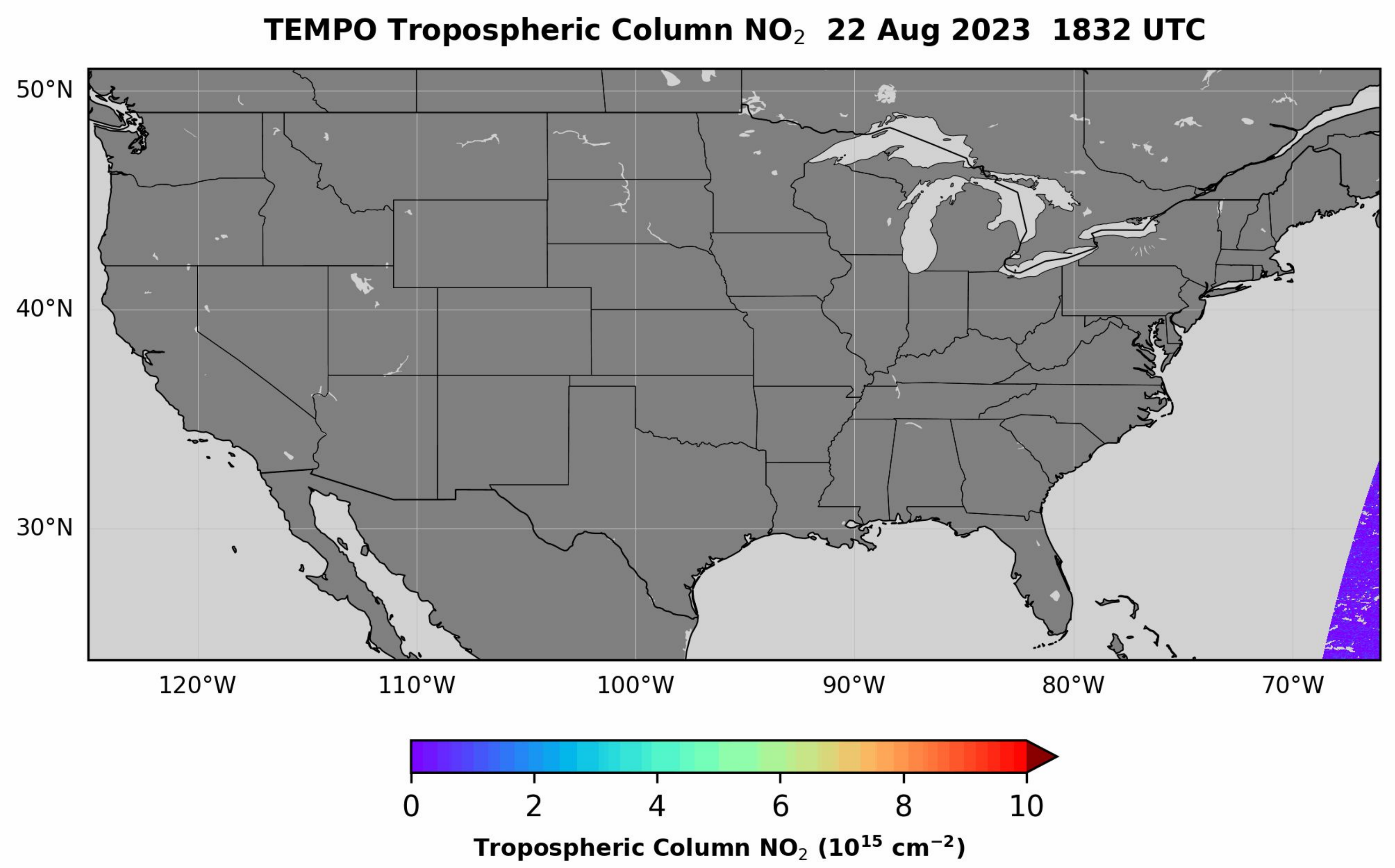
```
 Getting 10 granules, approx download size: 0.0 GB
QUEUEING TASKS | : 100%  10/10 [00:00<00:00, 199.97it/s]
PROCESSING TASKS | : 100%  10/10 [00:14<00:00,  1.15s/it]
COLLECTING RESULTS | : 100%  10/10 [00:00<00:00, 274.53it/s]
['/content/data_files/TEMPO_NO2_L2_V01_20230822T183247Z_S011G01.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T183900Z_S011G02.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T184513Z_S011G03.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T185126Z_S011G04.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T185739Z_S011G05.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T190352Z_S011G06.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T191005Z_S011G07.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T191618Z_S011G08.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T192231Z_S011G09.nc',
 '/content/data_files/TEMPO_NO2_L2_V01_20230822T192844Z_S011G10.nc']
```

```
xarray.Dataset

▸ Dimensions:        (mirror_step: 123, xtrack: 2048)
▸ Coordinates:  (0)
▾ Data variables:
    vertical_column…   (mirror_step, xtrack)  float64  …
    vertical_column…   (mirror_step, xtrack)  float64  …
    main_data_qual…    (mirror_step, xtrack)  float32  …
    vertical_column…   (mirror_step, xtrack)  float64  …
    coordinates :      time longitude latitude
    long_name :        troposphere nitrogen dioxide vertical column
    units :            molecules/cm^2
    vertical_column…   (mirror_step, xtrack)  float64  …
    vertical_column…   (mirror_step, xtrack)  float64  …
▸ Indexes:  (0)
▸ Attributes:  (0)
```

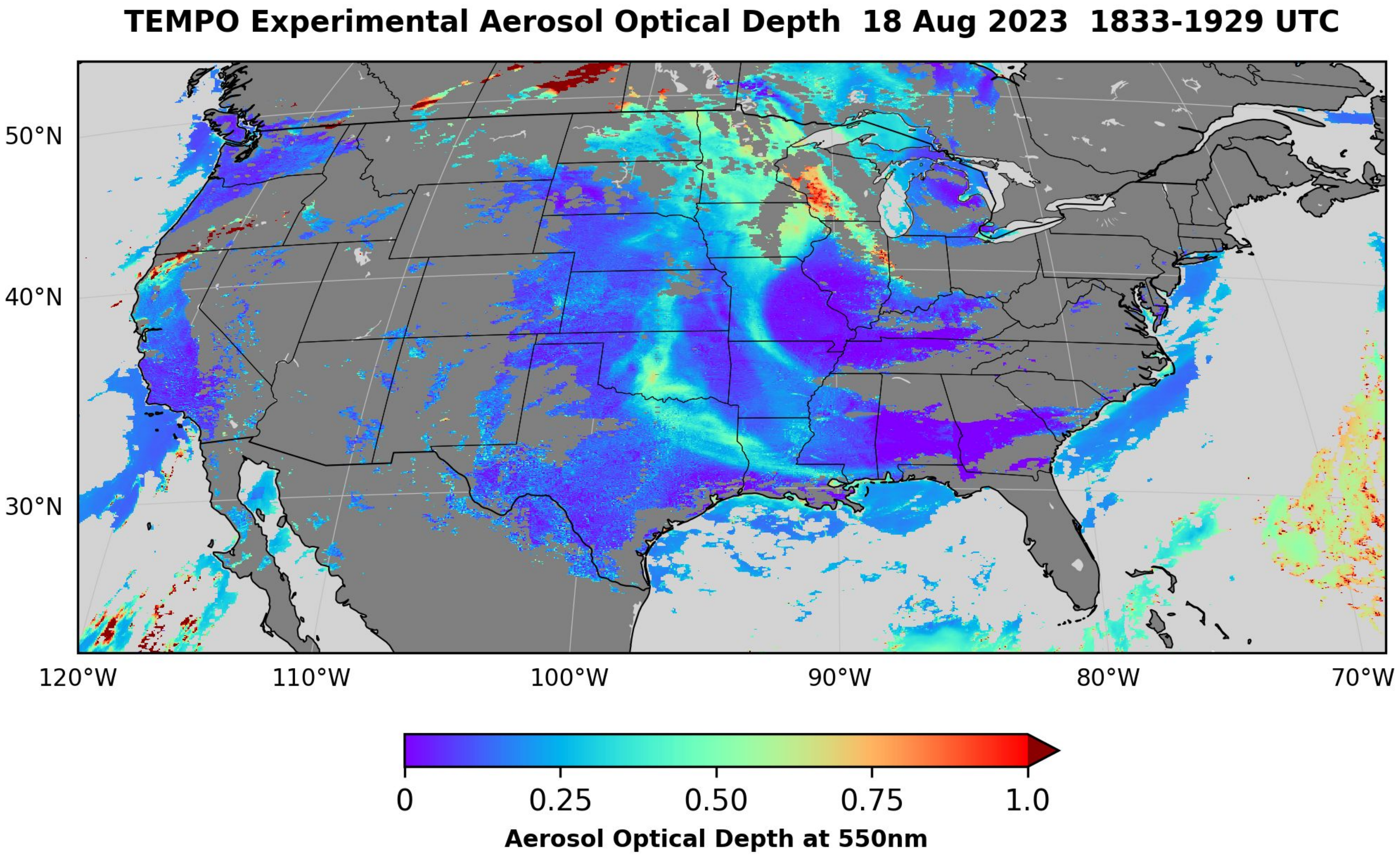
Wednesday’s Training: TEMPO NO_2 Granules

- Process tropospheric column NO_2 per TEMPO Science Team recommendations:
  - Set main_data_quality_flag = 0
  - Exclude pixels with effective_cloud_fraction > 0.3
  - Exclude pixels with solar_zenith_angle > 70
- Plot processed NO_2 from each granule on a separate map (Plate Carree equirectangular projection)
- Make a .gif animation of the individual NO_2 map plots


TEMPO Tropospheric Column NO₂ 22 Aug 2023 1832 UTC
50°N
40°N
30°N
120°W
110°W
100°W
90°W
80°W
70°W
0
2
4
6
8
10
Tropospheric Column NO₂ (10¹⁵ cm⁻²)

Wednesday's Training: TEMPO Experimental AOD Granules

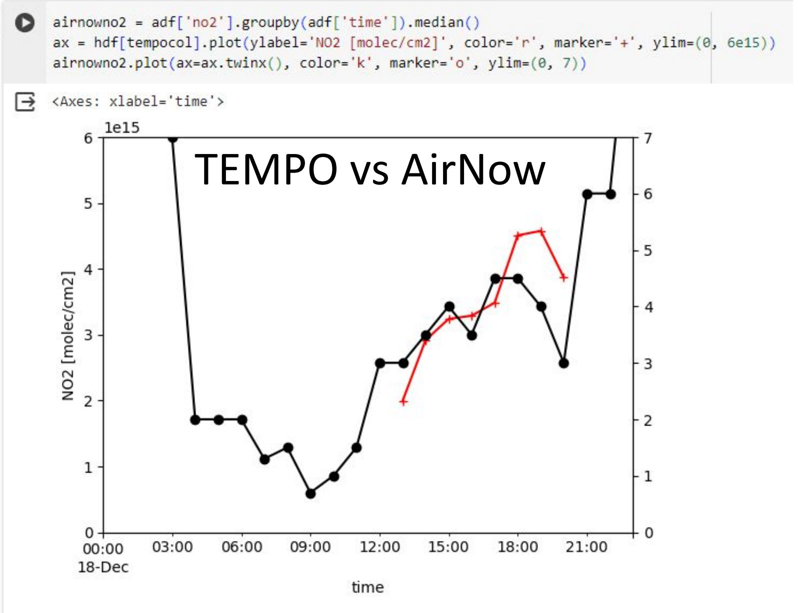
- Set up the geostationary map projection for the Intelsat-40e satellite
- Plot experimental AOD from each granule on one map (geostationary projection)
  - Thanks to Hai Zhang for providing the experimental TEMPO aerosol granules
  - Thanks to NASA and SAO for providing the TEMPO L1b data used in the aerosol retrieval algorithm


TEMPO Experimental Aerosol Optical Depth 18 Aug 2023 1833-1929 UTC
50°N
40°N
30°N
120°W
110°W
100°W
90°W
80°W
70°W
0
0.25
0.50
0.75
1.0
Aerosol Optical Depth at 550nm

Unofficial Experimental Data: Not for Public Release

Thursday’s Training: Remote Sensing Information Gateway (RSIG) Python and TEMPO

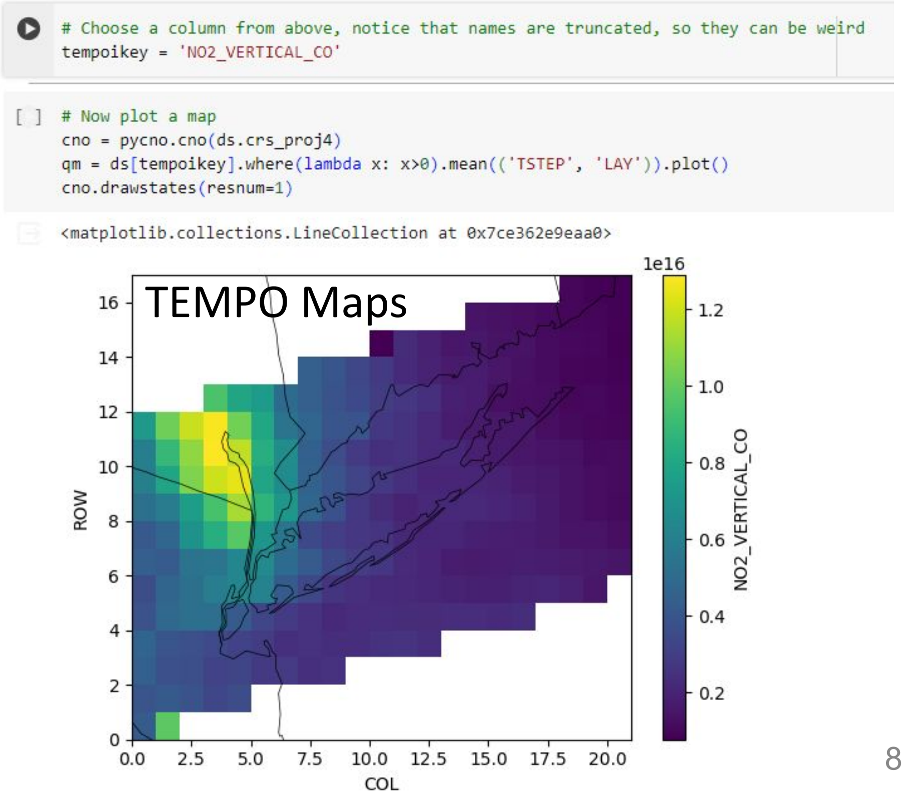
- RSIG makes satellite data easier
- RSIG connects satellite to AirNow, Pandora and many other observations
- Pyrsig uses python to script RSIG easily
- Training skills:
  - Compare TEMPO to AirNow, Pandora, TropOMI
  - Create a TEMPO NO2 map.
  - Create a TEMPO Surface NO2 estimate.
  - Adapt other tutorials.



```
airnowno2 = adf['no2'].groupby(adf['time']).median()
ax = hdf[tempocol].plot(ylabel='NO2 [molec/cm2]', color='r', marker='+', ylim=(0, 6e15))
airnowno2.plot(ax=ax.twinx(), color='k', marker='o', ylim=(0, 7))
```

```
<Axes: xlabel='time'>
```

TEMPO vs AirNow



```
# Choose a column from above, notice that names are truncated, so they can be weird
tempoikey = 'NO2_VERTICAL_CO'
```

```
# Now plot a map
cno = pycno.cno(ds.crs_proj4)
qm = ds[tempoikey].where(lambda x: x>0).mean(('TSTEP', 'LAY')).plot()
cno.drawstates(resnum=1)
```

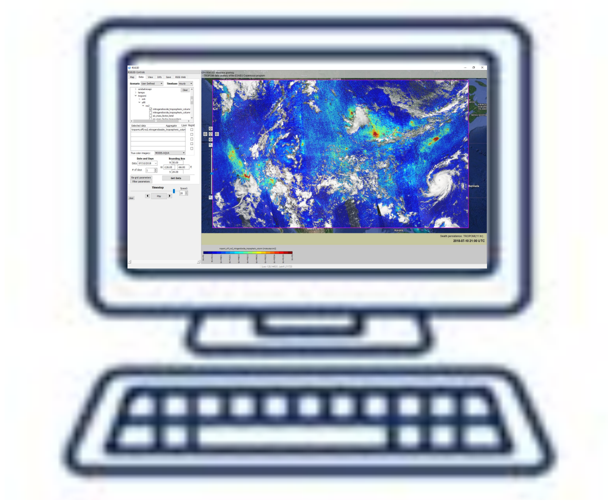
```
<matplotlib.collections.LineCollection at 0x7ce362e9eaa0>
```

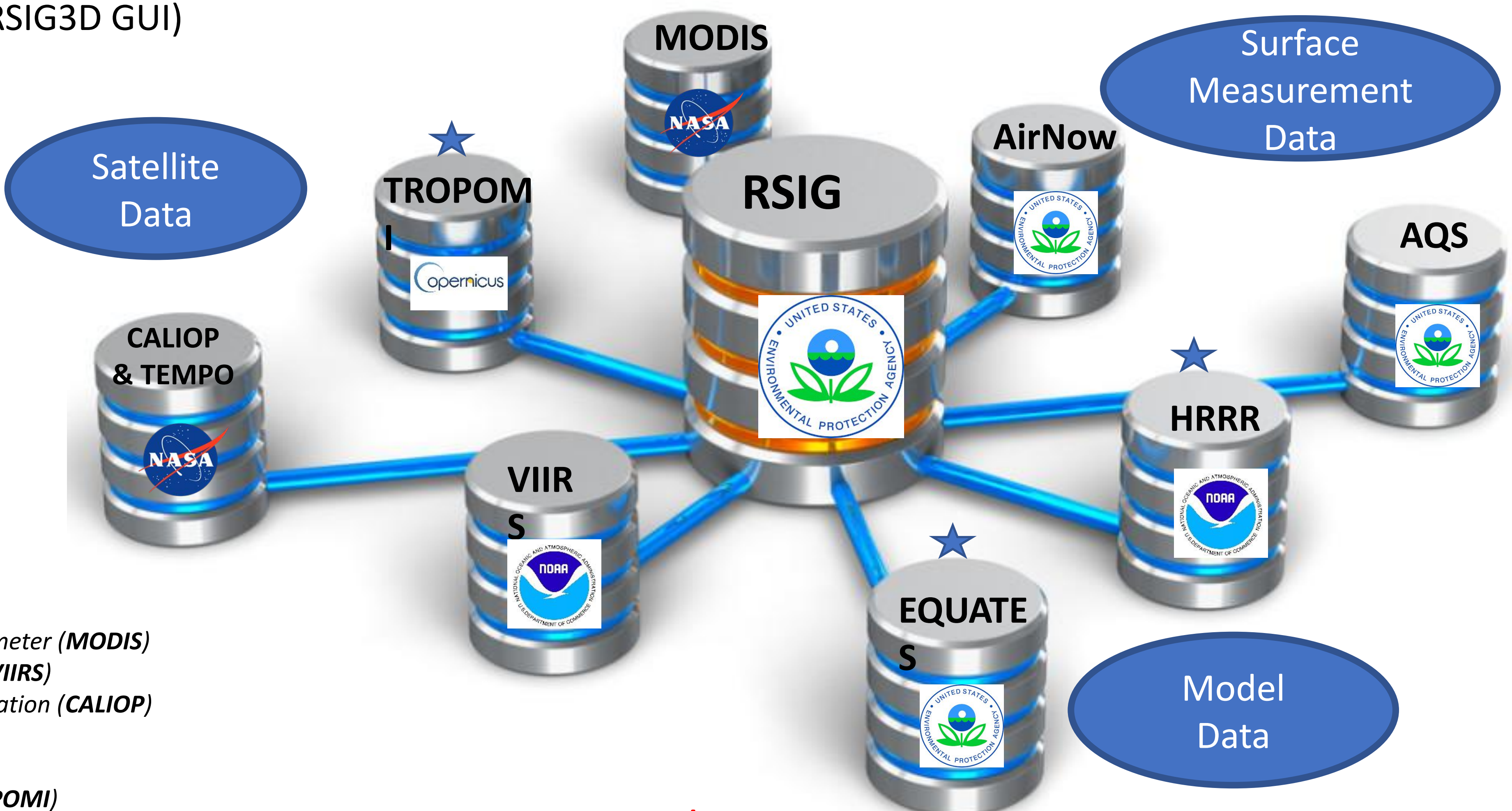
TEMPO Maps

What is the Remote Sensing Information Gateway?

- ***Free*** multi-platform, ***scriptable*** access to terabytes (TB) of air quality model, measurement, and satellite data from EPA, NOAA, NASA, ESA, etc.

- Multiple access methods
  - Graphical User Interface (RSIG3D GUI)
  - Python Interface (pyrsig)
  - Custom API shell scripts





Popular Air Quality Data Sets:

- *Moderate Resolution Imaging Spectroradiometer (**MODIS**)*
- *Visible Infrared Imaging Radiometer Suite (**VIIRS**)*
- *Cloud-Aerosol Lidar with Orthogonal Polarization (**CALIOP**)*
- *Air Quality System (**AQS**)*
- *EPA's Air QUAlity TimE Series (**EQUATES**)*
- *TROPOspheric Monitoring Instrument (**TROPOMI**)*
- *Tropospheric Emissions: Monitoring of POllution (**TEMPO**)*
- *High-Resolution Rapid Refresh (**HRRR**)*

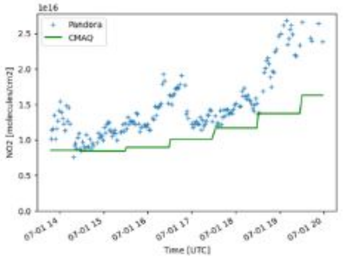
Training Focus : ***pyrsig/TEMPO***

Download Python source code: plot_elpaso.py

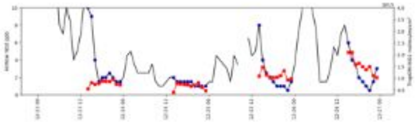
Download Jupyter notebook: plot_elpaso.ipynb

Python scripting examples in public gallery

https://barronh.github.io/pyrsig/

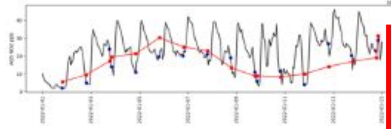


CMAQ vs Pandora

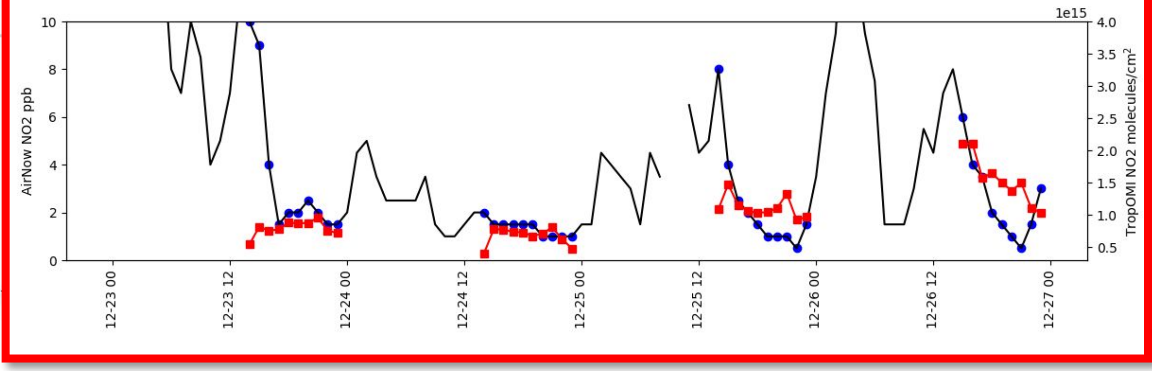


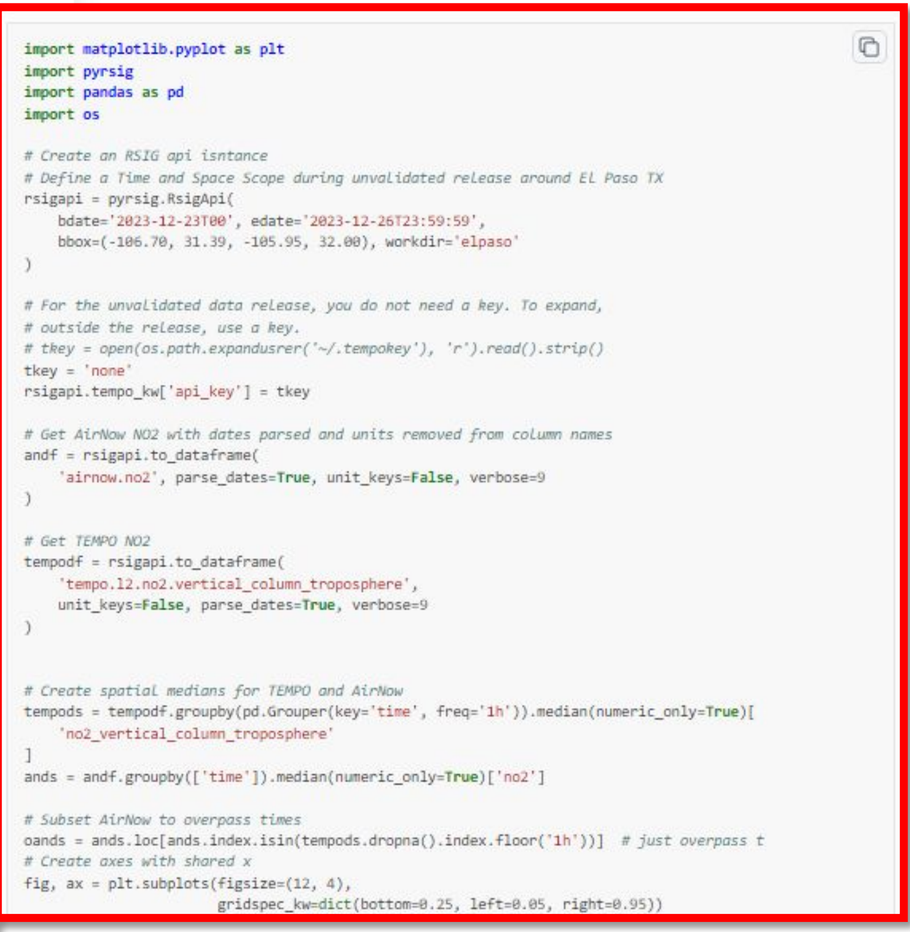
El Paso AirNow vs TEMPO

NYC VIIRS AOD vs TropOMI NO2



Phoenix AQS vs TropOMI





```
import matplotlib.pyplot as plt
import pyrsig
import pandas as pd
import os

# Create an RSIG api isntance
# Define a Time and Space Scope during unvalidated release around El Paso TX
rsigapi = pyrsig.RsigApi(
    bdate='2023-12-23T00', edate='2023-12-26T23:59:59',
    bbox=(-106.70, 31.39, -105.95, 32.00), workdir='elpaso'
)

# For the unvalidated data release, you do not need a key. To expand,
# outside the release, use a key.
# tkey = open(os.path.expanduser('~/.tempokey'), 'r').read().strip()
tkey = 'none'
rsigapi.tempo_kw['api_key'] = tkey

# Get AirNow NO2 with dates parsed and units removed from column names
andf = rsigapi.to_dataframe(
    'airnow.no2', parse_dates=True, unit_keys=False, verbose=9
)

# Get TEMPO NO2
tempodf = rsigapi.to_dataframe(
    'tempo.l2.no2.vertical_column_troposphere',
    unit_keys=False, parse_dates=True, verbose=9
)


# Create spatial medians for TEMPO and AirNow
tempods = tempodf.groupby(pd.Grouper(key='time', freq='1h')).median(numeric_only=True)[
    'no2_vertical_column_troposphere'
]
ands = andf.groupby(['time']).median(numeric_only=True)['no2']

# Subset AirNow to overpass times
oands = ands.loc[ands.index.isin(tempods.dropna().index.floor('1h'))]  # just overpass t
# Create axes with shared x
fig, ax = plt.subplots(figsize=(12, 4),
                       gridspec_kw=dict(bottom=0.25, left=0.05, right=0.95))
```

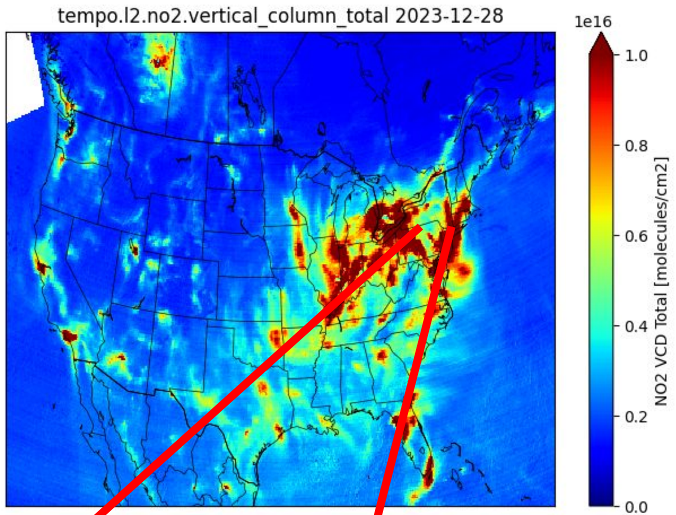
Pyrsig: Connecting TEMPO, TropOMI, and Pandora

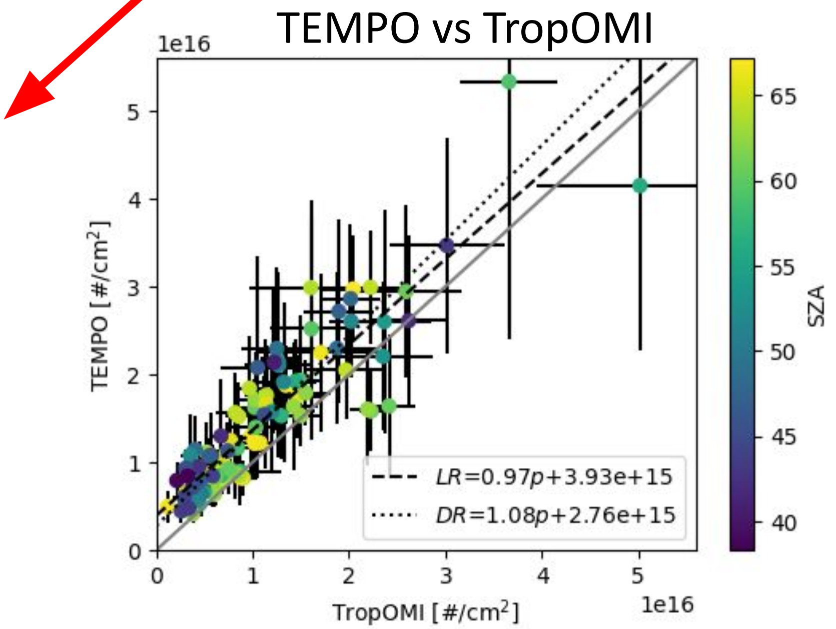
- pyrsig connects you to the same data ***and*** allows you to perform custom analyses.

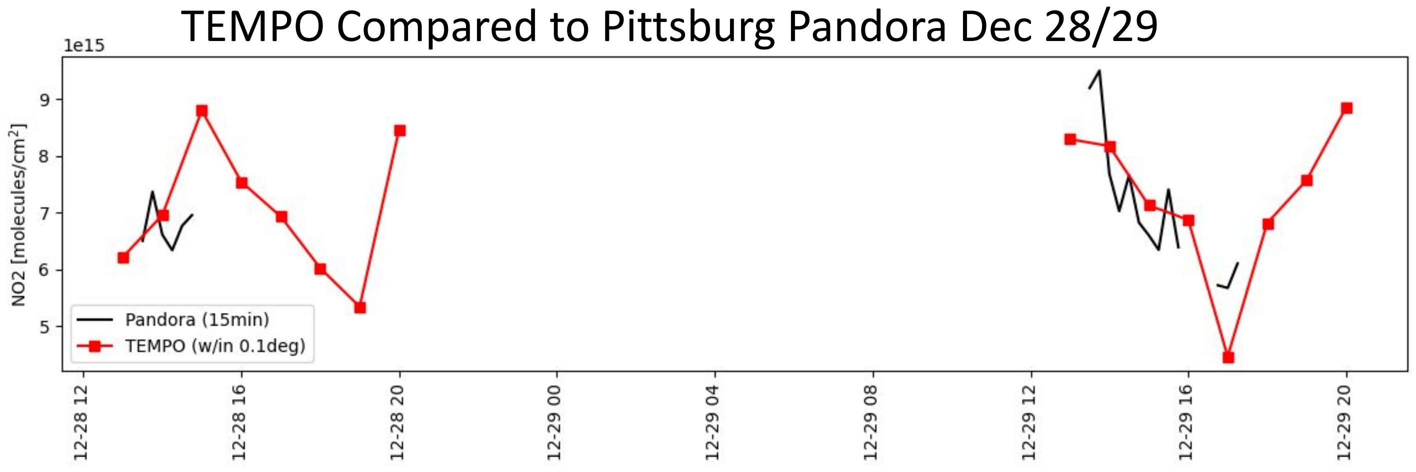
- Map uses TEMPO data that is already public (Dec 1-29)

- Scatterplot for long-term comparison between TEMPO and TropOMI.

- Time series on the bottom-right shows comparison to a Pandora ground-based remote sensor to evaluate TEMPO.


tempo.l2.no2.vertical_column_total 2023-12-28
1e16
1.0
0.8
0.6
0.4
0.2
0.0
NO2 VCD Total [molecules/cm2]


TEMPO vs TropOMI


TEMPO Compared to Pittsburg Pandora Dec 28/29

What You’ll Need for the TEMPO Training Sessions

- **Computer with access to the internet**
- **Google account (to use Google Colab)**
- Wednesday session only: NASA Earthdata account (to download TEMPO granules data files)
  - If you don’t have an account and don’t want one, it’s ok
  - Amy will provide a link to download the TEMPO NO_2 Level 2 data as a .zip file

In-person and virtual STM attendees are all welcome!