U.S. EPA Remote Sensing Information Gateway (RSIG)

Western States Air Resources Council Training Workshop on use of Satellite Data for Air Quality

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Jim Szykman, US EPA ORD

Matt Freeman, US EPA EMVL – Applied Research Associates

Barron Henderson, US EPA ORD

***Disclaimer**: The views expressed in this presentation are those of the authors and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.*

Overview

- Intro to RSIG suite
- Selected dataset overview
- TEMPO Products and Validation with RSIG
- Introduction to RSIG3D Desktop App
- Hands-on Example

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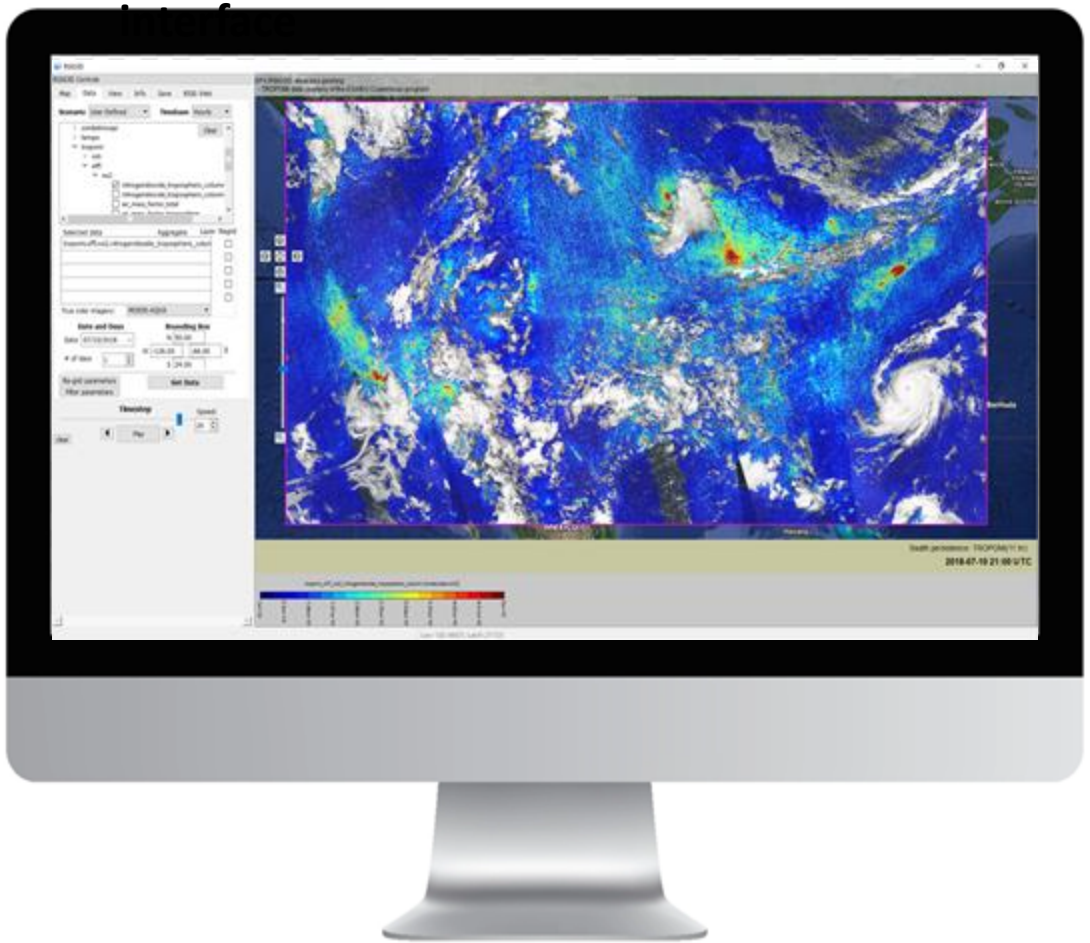
What is the Remote Sensing Information Gateway?

- Easy access to 100's of terabytes of high value air quality datasets
  - Free, multi-platform (windows/mac/linux), graphical or scriptable software.
  - 5000+ curated products including remote sensing, model, and in-situ datasets selected for Air Quality Manager staff.
  - Datasets selected through collaboration of EPA Air Quality Staff, SLT Air Quality Agencies, and other federal partners.

- Retrieve, visualize and save geospatial atmospheric datasets
  - Use RSIG3D desktop application to point and click to make maps and save as images or CSV files.
  - Use Excel, R, or python to make custom visualizations from saved outputs.
  - Python scriptable interface (pyrsig). pyrsig has example analyses by experienced EPA Air Quality Researchers that you can reuse.

- Compliant with EPA Quality Assurance Policies with multiple relevant QAPPs and supports several requirements under the CAA:
  - -Research Program, Cooperative Research, Monitoring and Studies (Sections 103)
  - -Enhanced Monitoring for Ozone and Associated Precursors (PAMS- Section 182)
  - -Air quality monitoring (AQI reporting and Exceptional Events)

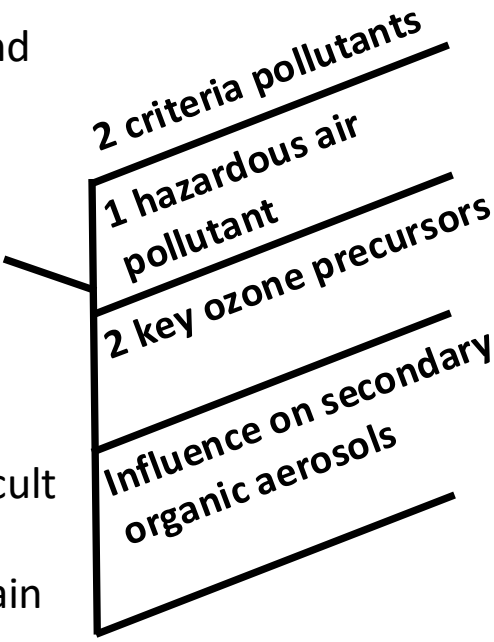
RSIG3D is the client graphical user



https://www.epa.gov/rsig

RSIG meets needs identified US Govt Accountability Office (GAO-21-38, 2020 under the 1st Trump Administration)

- RSIG delivers real-time, near-realtime monitor, PurpleAir, and satellite data
  - Because "Information needs are (1) local-scale, real-time air quality; (2) air toxics; (3) persistent and complex pollution; and (4) using low-cost sensors and satellites."
  - "low-cost sensors measure criteria pollutants, such [**$PM_{2.5}$**] and ozone", and
  - "satellites currently provide information related to … **ozone**, **particulate matter**, **nitrogen dioxide**, sulfur dioxide, and **formaldehyde**" (and carbon monoxide and methane)



- RSIG gives easy access to satellite product from TEMPO, TropOMI, OMI, MODIS, and VIIRS because
  - "Satellites can provide information on air pollutants over large areas, including areas that are difficult or impossible to monitor with traditional monitoring methods."
  - "Air quality managers, researchers… are increasingly using [satellites and low-cost sensors] to obtain information on air quality."

- RSIG facilitates comparison to traditional observations and model results because:
  - Air Quality staff "need more information on the reliability and accepted uses of … remote sensors on satellites operated by NOAA and NASA."
  - "Satellite-based sensor data can be difficult to interpret, especially for pollution at ground level."

Report can be found at: https://www.gao.gov/products/gao-21-38

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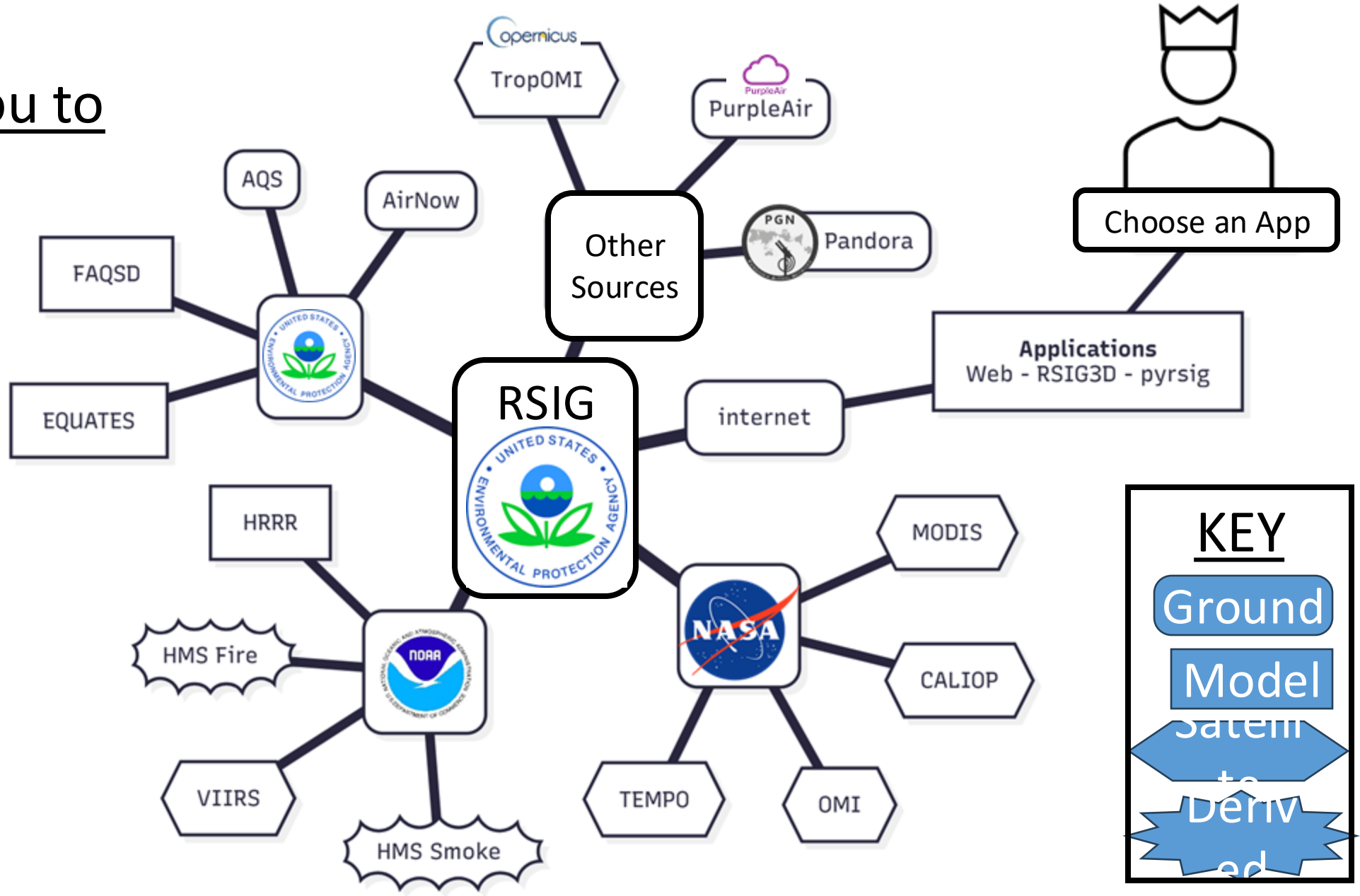
RSIG connects you to popular datasets

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



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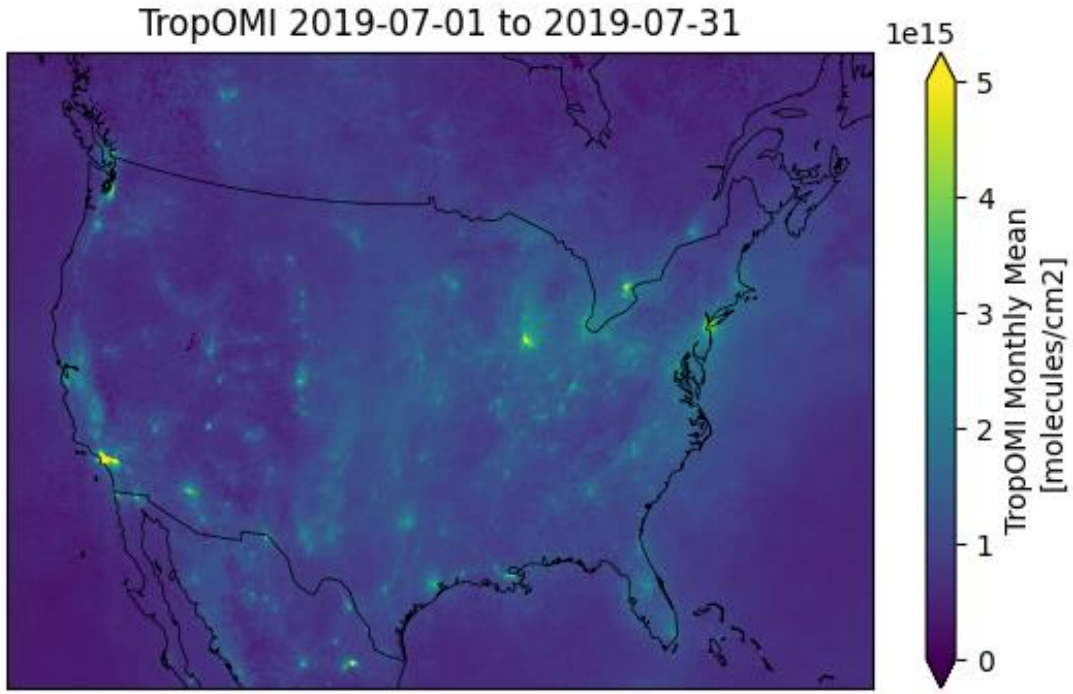
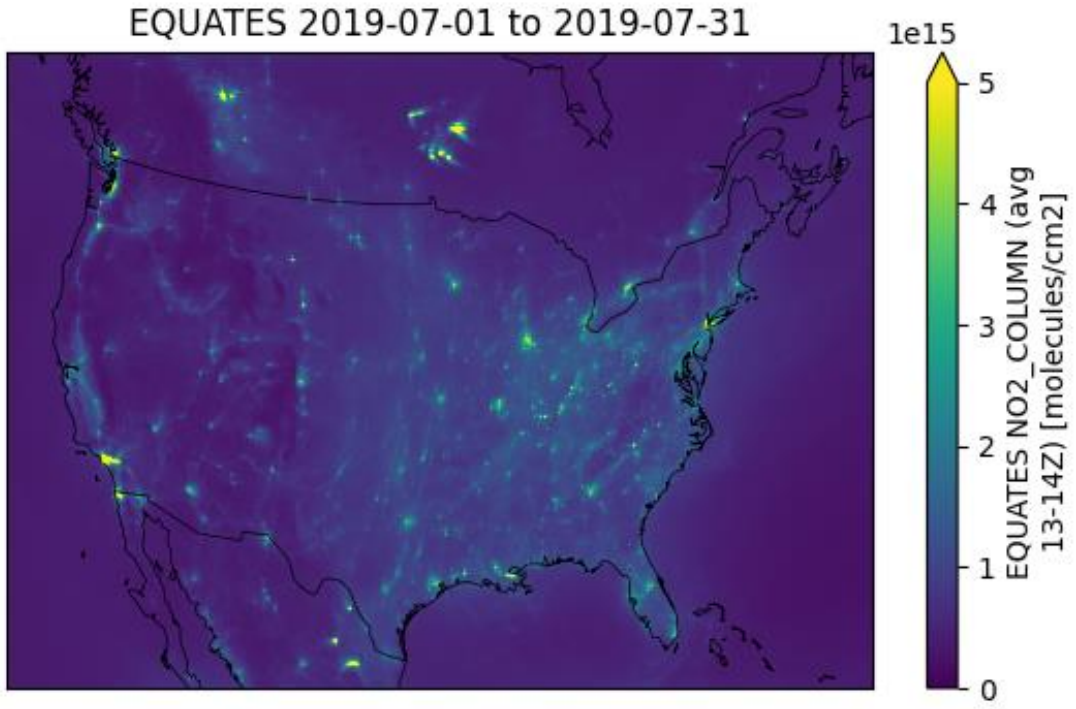
RSIG Inventory: TropOMI and EPA's EQUATES CMAQ

pyrsig-based comparison of TropOMI vs EQUATES Column NO_2

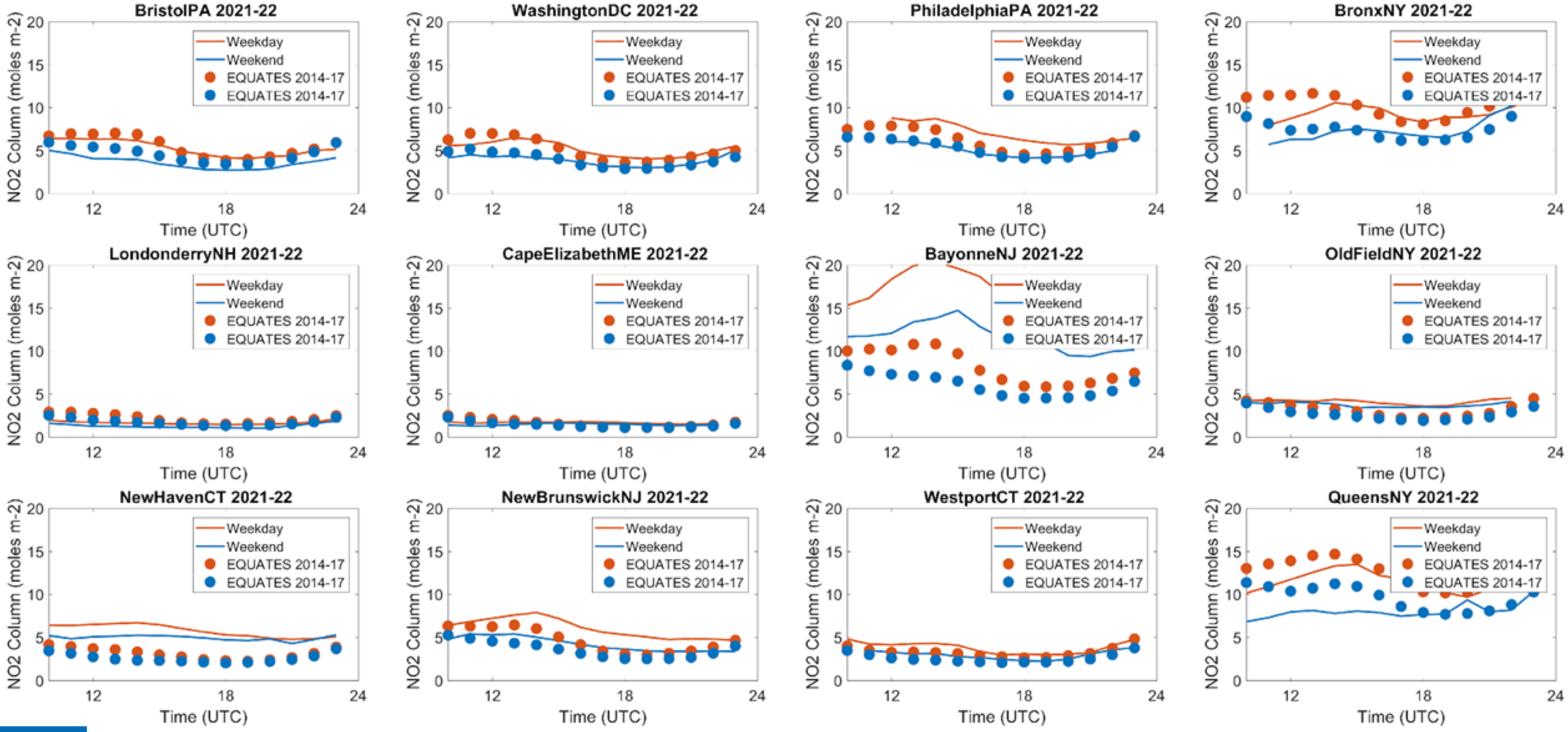




- pyrsig used to query and subset
- EQUATES is filtered for only valid TropOMI Overpass times
- Scripted analysis will work for CMAQ or CAMx for any simulation

Source: B. Henderson, USEPA

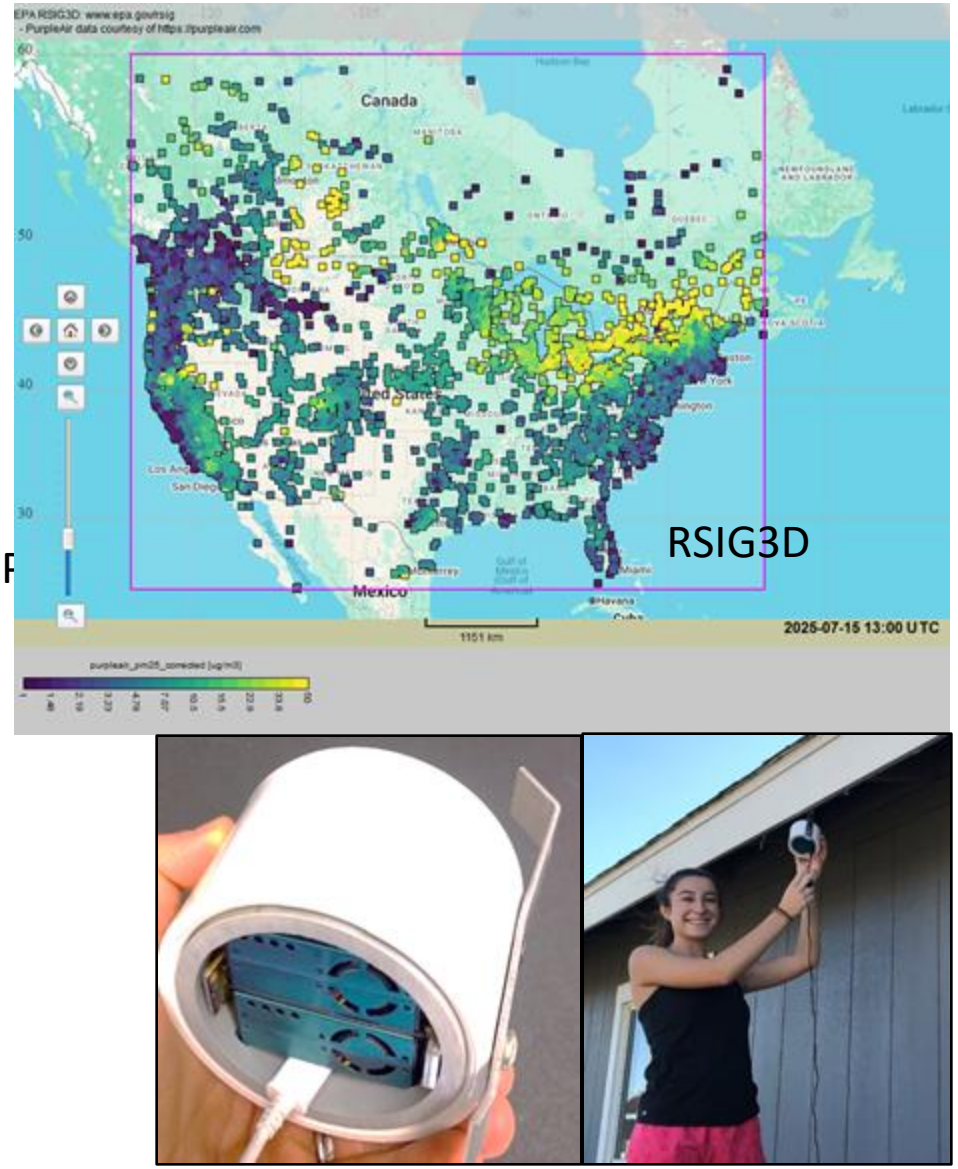
RSIG Inventory: Pandonia Global Network
Web Interface-based comparison of Pandora and Model



Source: L. Valin, USEPA

RSIG Inventory: Crowdsourced PurpleAir $PM_{2.5}$ Air Sensor

- **Data Set Type:** Global, ground-based, publicly reporting crowdsourced $PM_{2.5}$ data from a commercial network of air sensors. Data secured to reduce access costs for both EPA and the company. Use governed by Materials Transfer Agreement (requires research in collaboration with ORD).
- **Dates:** Network started ~2016; currently, 27,000+ indoor (~20%) and outdoor (80%) sensors operating globally
- **Variables:** Primarily measures $PM_{2.5}$ (T, RH, PM_1, etc. also available); available in raw form but also as a quality assured and corrected data stream using EPA's U.S.-wide correction; available at various time averages; updated every minute.
- **Applications:** Public real-time air quality communication (e.g., AirNow Fire and Smoke Map), available as comparison data in data tools (e.g., RETIGO, ASNAT), research applications continue to grow (e.g., data fusion, model validation, more local air quality data, characterizing the impact of events and/or interventions)

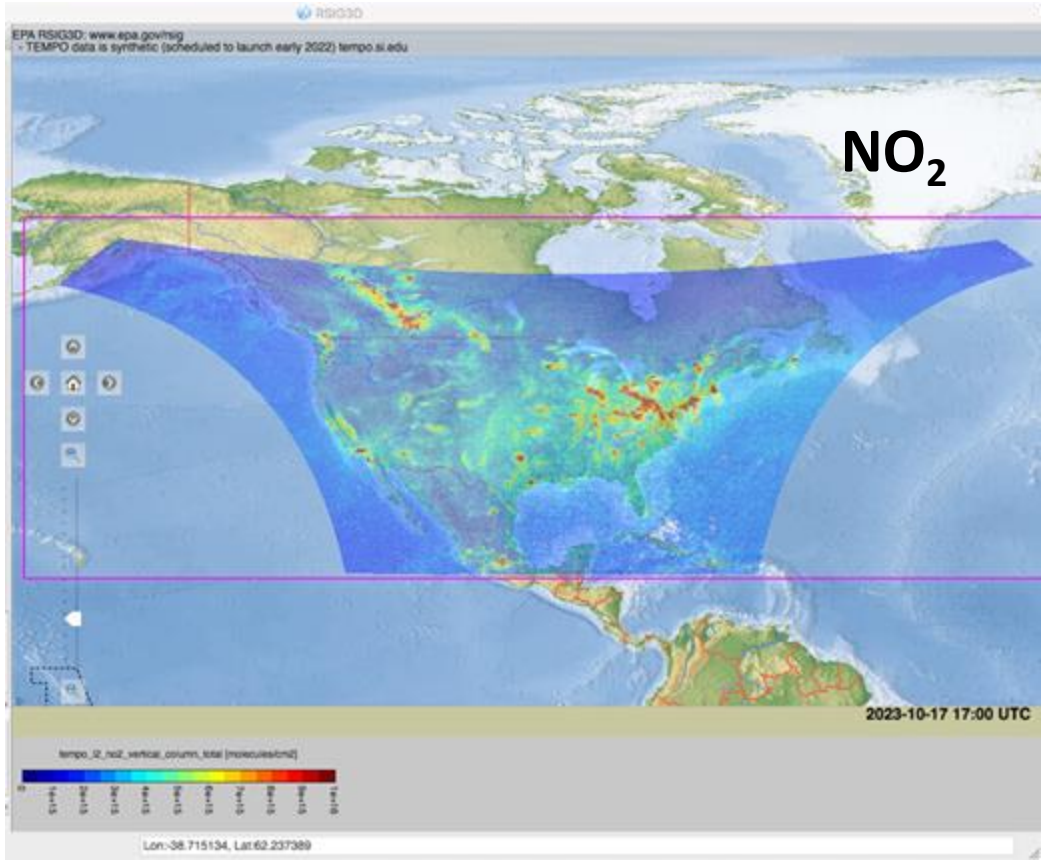


Top: AirNow Fire and Smoke Map showing sensor locations each displaying the current NowCast AQI (accessed 7/15/25). **Bottom left:** PurpleAir PA-II-SD outdoor sensor. **Bottom Right:** Intern installing a sensor at a Nez Perce library.

Tropospheric Emissions: Monitoring of Pollution (TEMPO)

- Satellite dataset from NASA Earth Venture Instrument Program with daylight hourly scans (geostationary) over greater North America at urban scales
  - Dates: August 2023-present
  - Species: Nitrogen dioxide, Formaldehyde, ozone and ozone profiles
  - Total, tropospheric, and near surface (ozone) column abundances
  - Predetermined QA metrics
- Typical Application Uses: model evaluation, air quality event and trends analysis, pollutant emissions research, air pollutant exposure studies
- Data Latency:
  - Near-real-time: a few hours
  - Offline processing: less than a day

RSIG3D GUI Map example.

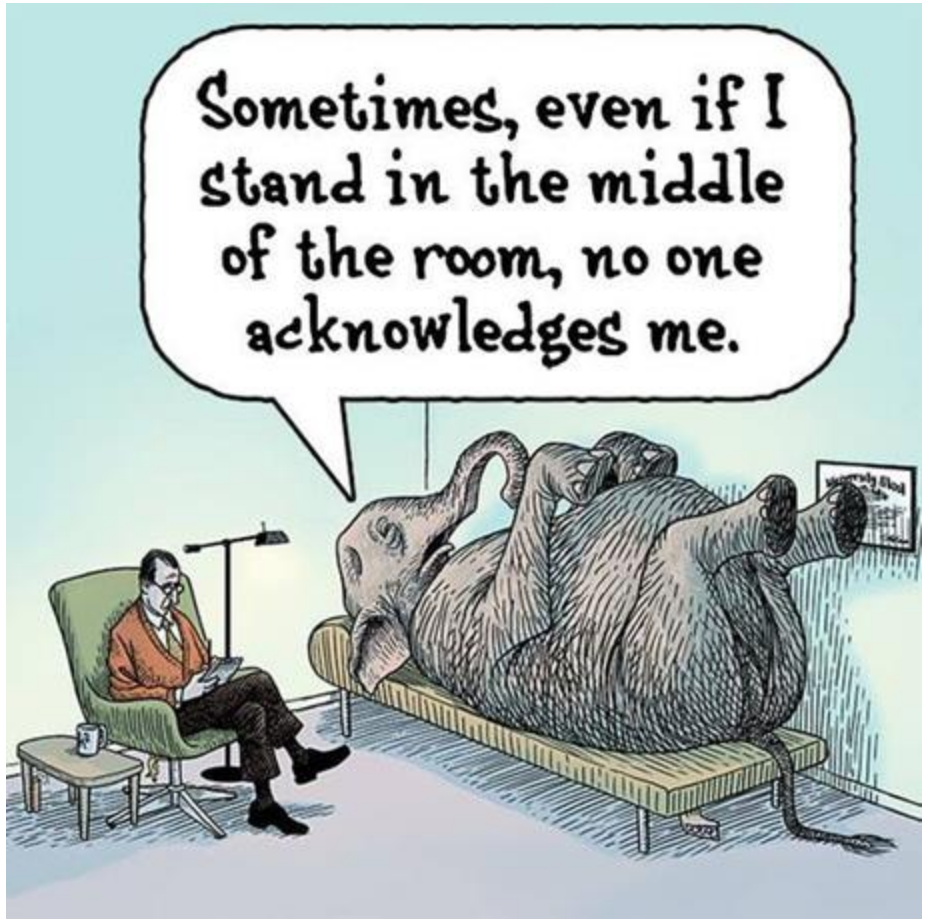


Satellite Data Product Validation

- Quantifying the quality of these products by decomposing the inherent uncertainty components is often a very challenging task and limited by appropriate independent geophysical measurements with appropriate levels of traceability.

- Historically validation for non-operational satellite science missions such as TEMPO have relied on episodic field campaigns and research measurements to assess data quality.

- Use of satellite data for air quality applications often lack the appropriate validation metrics to inform fitness for purpose, a more routine and systematic approach can help fill this void.



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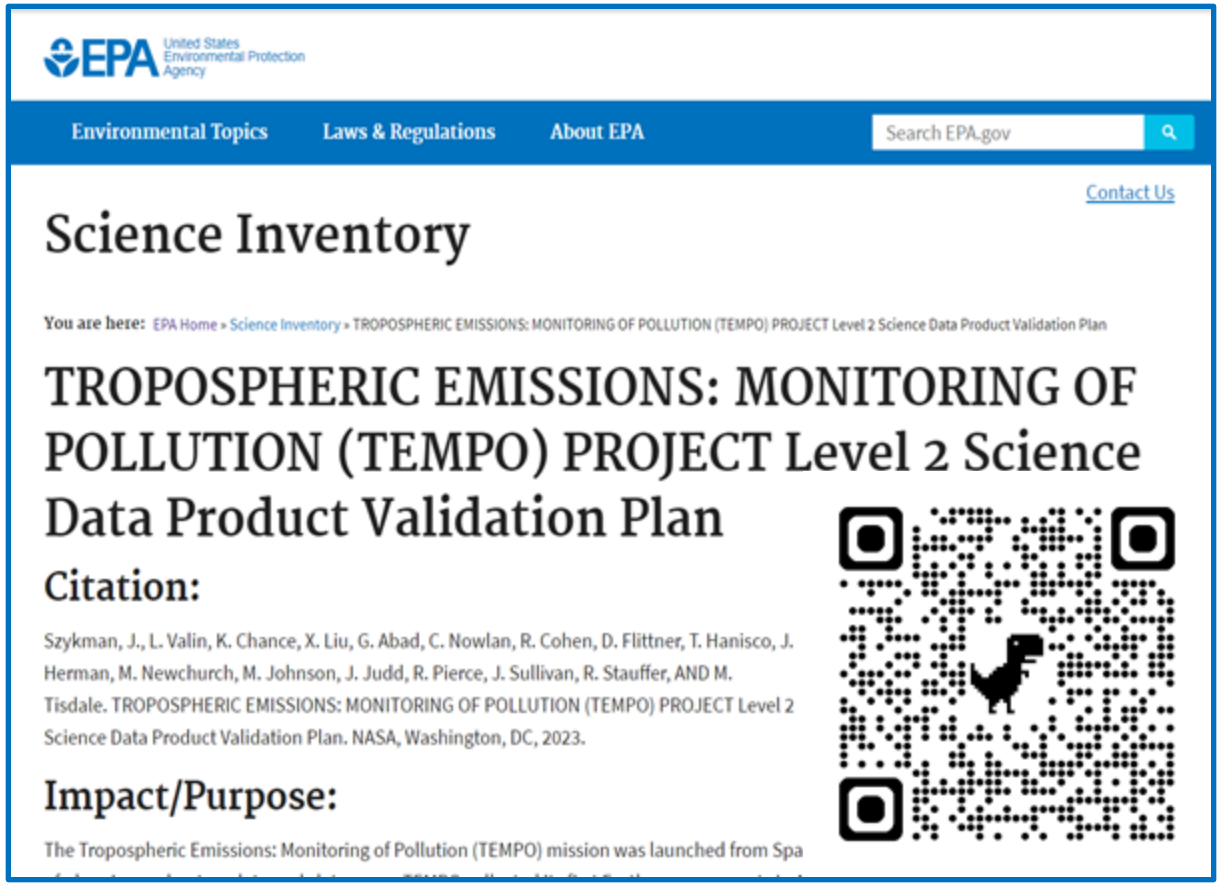
EPA Validation Efforts to Advance TEMPO



EPA Science Inventory: 362165 or https://tempo.si.edu under documents

EPA ORD Air, Climate and Energy Research Program filled a critical gap through expansion and network ops of pandora spectrometers across the U.S. aided by State and Local agencies monitoring staff

- Plan and execution led by US EPA with input from the TEMPO Validation Team and a large group of scientist from NASA, NOAA, NCAR, ECCC, and Universities.
  - Developed Level 2 Data Validated Plan for baseline L2 data products: ozone, nitrogen dioxide, and formaldehyde, ozone profiles not included.
  - Plan centered around Product Specific Performance Indicators (PSPIs) for Beta, Provisional, and Full validation stages, providing a structured approach for the geophysical data product maturity progression and with specific metrics to be generated to provide a ‘fit for purpose’ applications framework.
  - **Helps address EPA, State, Local, and Tribal agency needs of assuring the suitability of this information for new applications, consistent with OMB and EPA Information Quality Guidelines.**
  - Analyses leverages a comprehensive set of existing measurements (ground-based and satellite) for routine validation enhanced by STAQS, AEROMMA, and CUPIDS field missions and modeling efforts.

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TEMPO L2 Total and Tropospheric NO_2

Product Maturity Levels & Product Specific Performance Indicators

Product Validation Level	Product-Specific Performance Indicators (PSPIs)
Beta Validation: the product is minimally validated but may still contain significant errors; based on product quick looks using the initial calibration parameters. Publication of research based on Beta maturity products is not recommended and highly discouraged.	**NO2-01**: Distinguish high NO2 urban areas from nearby rural areas for three select urban-rural scene combinations.
	NO2-02: Assess bias and precision for at least one month of retrievals in comparison to independent correlative measurements to convey an initial characterization to the user community. The assessment should evaluate TEMPO's capability to observe diurnal variations.
	NO2-03: Identify two radiatively homogenous, cloud-clear, low tropospheric NO_2 background scenes over a dark surface (e.g., water) and over a bright surface (e.g., snow, desert) under different solar zenith angles and compute point-to-point variability (1-σ) as an empirical estimate for fitting uncertainty. Compare and communicate empirical estimates with those derived from the spectral fitting process.
Provisional Validation: product performance has been demonstrated through a large, but still (seasonally or otherwise) limited number of independent measurements. The analysis is sufficient for limited qualitative determinations of product fitness-for-purpose, and the product is potentially ready for testing by operational users and may be suitable for scientific publication.	NO2-04: Assess performance metrics (bias/precision/uncertainty) of the tropospheric NO_2 product across the CONUS for 1 month period in two seasons, preferably summer and winter, that includes a range of column densities.
	NO2-05: Conduct deep-dive analyses for an episode with relatively poor product performance, identify the root cause and recommend algorithm improvements.
Full Validation: product performance has been demonstrated over a large and wide range of representative conditions, with comprehensive documentation of product performance, including known anomalies and their remediation strategies. Products are ready for systematic use and covering the full range of scientific and application use and publication.	NO2-06: Assess bias, precision, and uncertainty of the tropospheric NO_2 product across the CONUS for a wide range of representative conditions over a period of at least one year.
	NO2-07: Assess bias, precision, and uncertainty of the tropospheric NO_2 product over areas of interest using data gathered during targeted field campaigns.

Validation PSPI Analysis/Metric(s) contributed voluntarily by many PIs/Research Organizations

TEMPO L2 Total and Tropospheric NO_2

Product Maturity Levels & Product Specific Performance Indicators

The PSPI's are like the EPA Data Quality Objectives Process and with flows from Information Quality Guidelines. Helps communicate if data are of sufficient quality and quantity to support the use of the data.

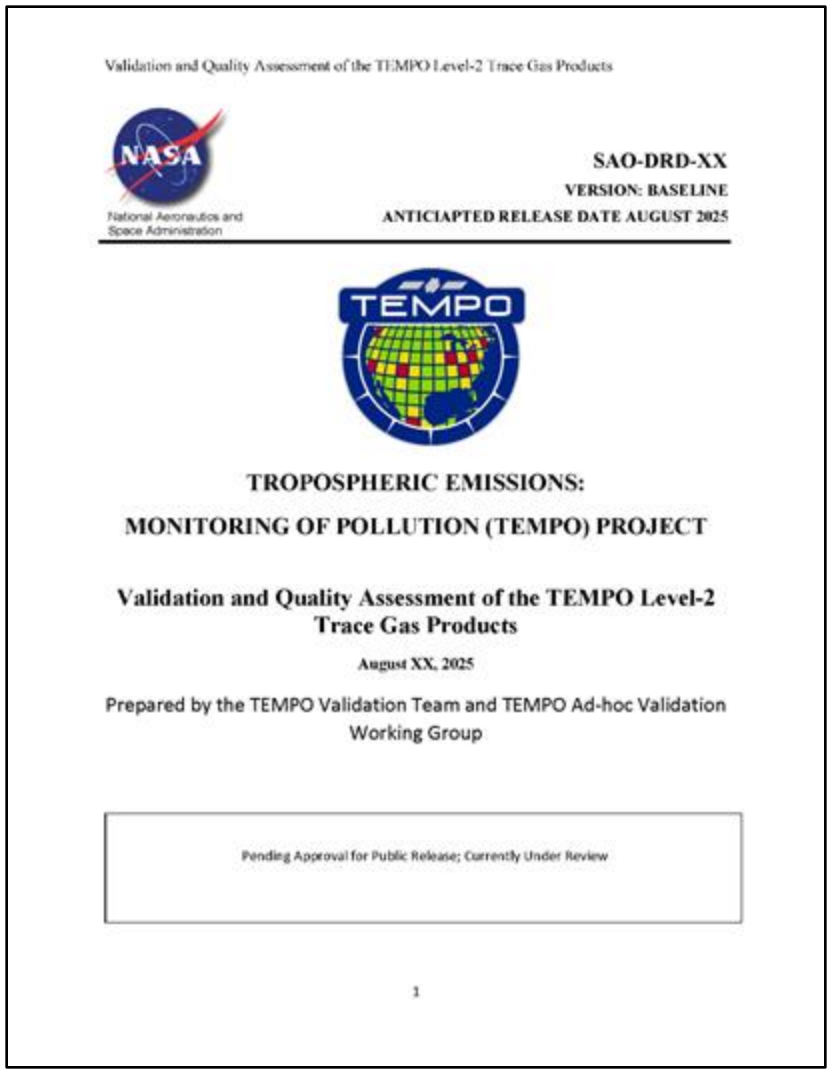
NO2-01: Distinguish high NO2 urban areas from nearby rural areas for three select urban-rural scene combinations.

PSPI included use of ground-based and airborne spectrometers which can capture such gradients and provide independent similar geophysical measurements.

Product Validati	
Beta Validation: still contain signifi using the initial ca based on Beta ma highly discourage	as for three select evals in an initial evaluate TEMPO's
	NO2-03: Identify two radiatively homogenous, cloud-clear, low tropospheric NO2 background scenes over a dark surface (e.g., water) and over a bright surface (e.g., snow, desert) under different solar zenith angles and compute point-to-point variability (1-σ) as an empirical estimate for fitting uncertainty. Compare and ctral fitting
Provisional Valid demonstrated thro otherwise) limited number of independent measurements. The analysis is sufficient for limited qualitative determinations of product fitness-fo for testing by oper scientific publicati	of the tropospheric ns, preferably summer and winter, that includes a range of column densities. y poor product provements.
Full Validation: p over a large and v comprehensive do including known anomalies and their remediation strategies. Products are ready for systematic use and covering the full range of scientific and application use and publication.	ric NO2 product over a period of at
	NO2-07: Assess bias, precision, and uncertainty of the tropospheric NO2 product over areas of interest using data gathered during targeted field campaigns.

Validation PSPI Analysis/Metric(s) contributed voluntarily by many PIs/Research Organizations

EPA Validation Efforts to Advance TEMPO



Validation and Quality Assessment of the TEMPO Level-2 Trace Gas Products

National Aeronautics and Space Administration

SAO-DRD-XX
VERSION: BASELINE
ANTICIAPTED RELEASE DATE AUGUST 2025

TROPOSPHERIC EMISSIONS:
MONITORING OF POLLUTION (TEMPO) PROJECT

Validation and Quality Assessment of the TEMPO Level-2 Trace Gas Products

August XX, 2025

Prepared by the TEMPO Validation Team and TEMPO Ad-hoc Validation Working Group

Pending Approval for Public Release; Currently Under Review

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- Validation results were discussed in bi-weekly telecons from Fall 2023-Winter 2024.
- Draft report submitted for review December 2024
- TEMPO L2 TropNO2, TotHCHO, and TotO3 V3 reached provisional status in December 2024 through the internal review by the validation team of the report
- Report publication expected August 2025
- Validation effort provided real-time feedback to TEMPO algorithm developers and science team.
  - Early results identified a priori profile issues.
  - Early results identified unrealistic AMF spatial variation.
  - Development team updated algorithm to V2 and V3
- ***RSIG used to support EPA's Automated Analysis System for validation***
  - Nitrogen dioxide correlating well with Pandora and TropOMI.
  - Formaldehyde correlating well with Pandora
  - Comparison to surface monitors useful for air quality managers

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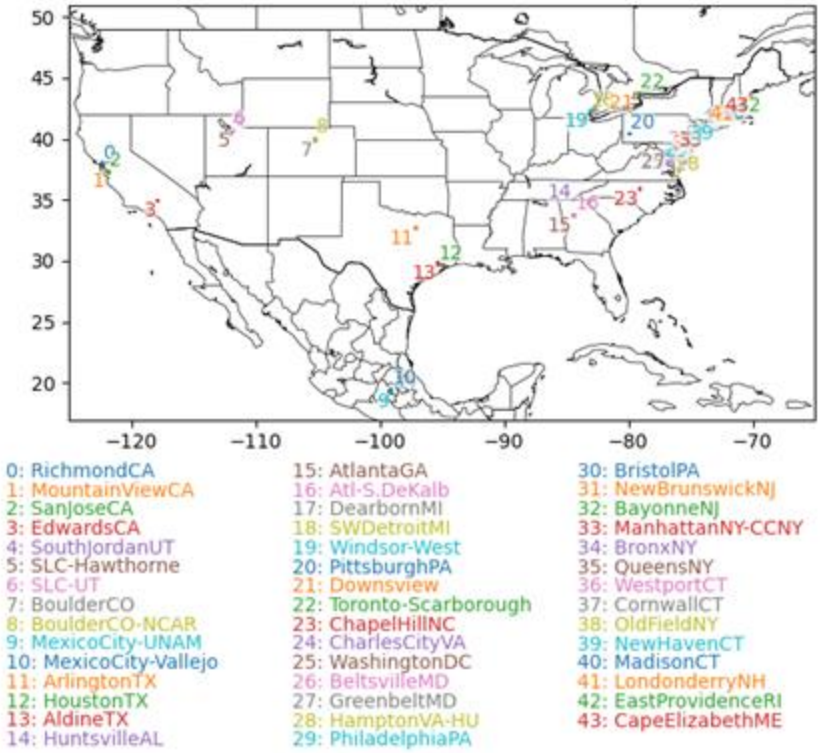
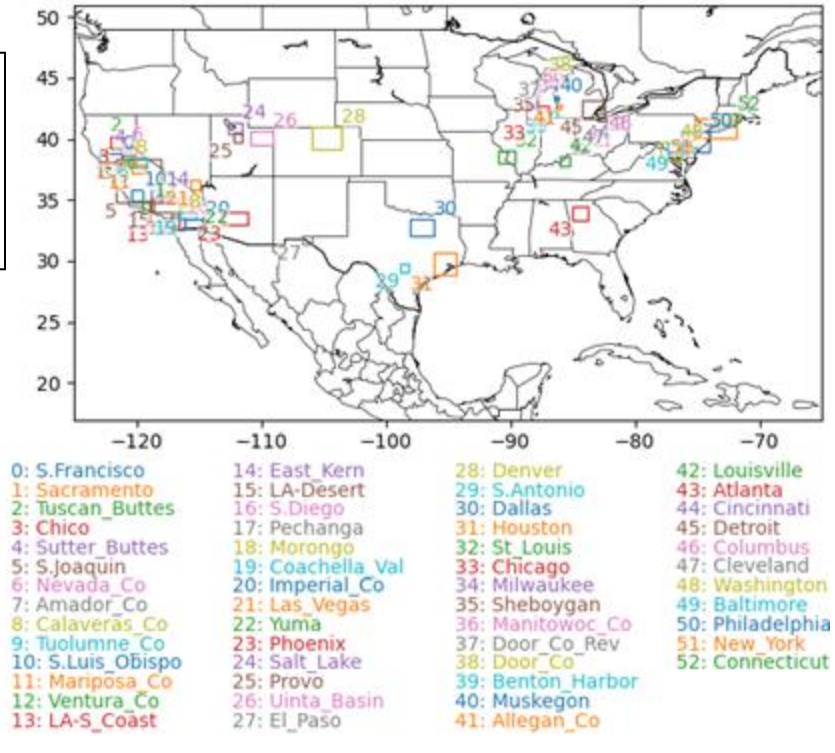
TEMPO Validation with pyrsig

- Correlative measurements : TropOMI and Pandora Spectrometers
  - Pandora stations: best ground-based validation dataset available for total vertical columns.
  - TropOMI: state-of-the-art satellite retrievals at similar spatial resolution.
- 96 Analysis Regions: Pandonia Global Network and Ozone Nonattainment Areas.



- 44 **Pandora** stations
- Most stations in the east

- 52 **Nonattainment Areas**
- Better spatial coverage
- Of special interest for emissions control



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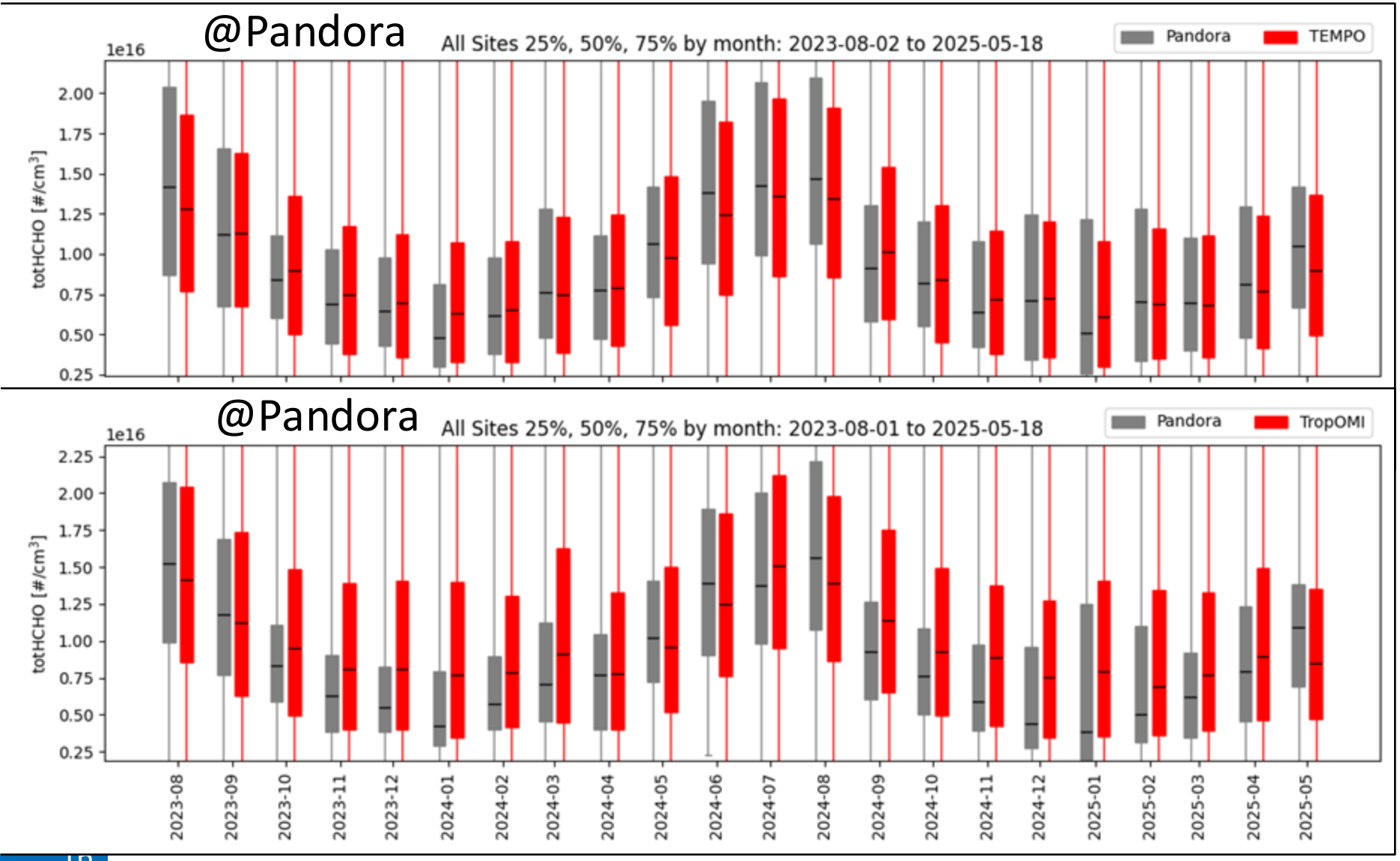
Pandora totHCHO Validation
Aug 2023 to May 2025



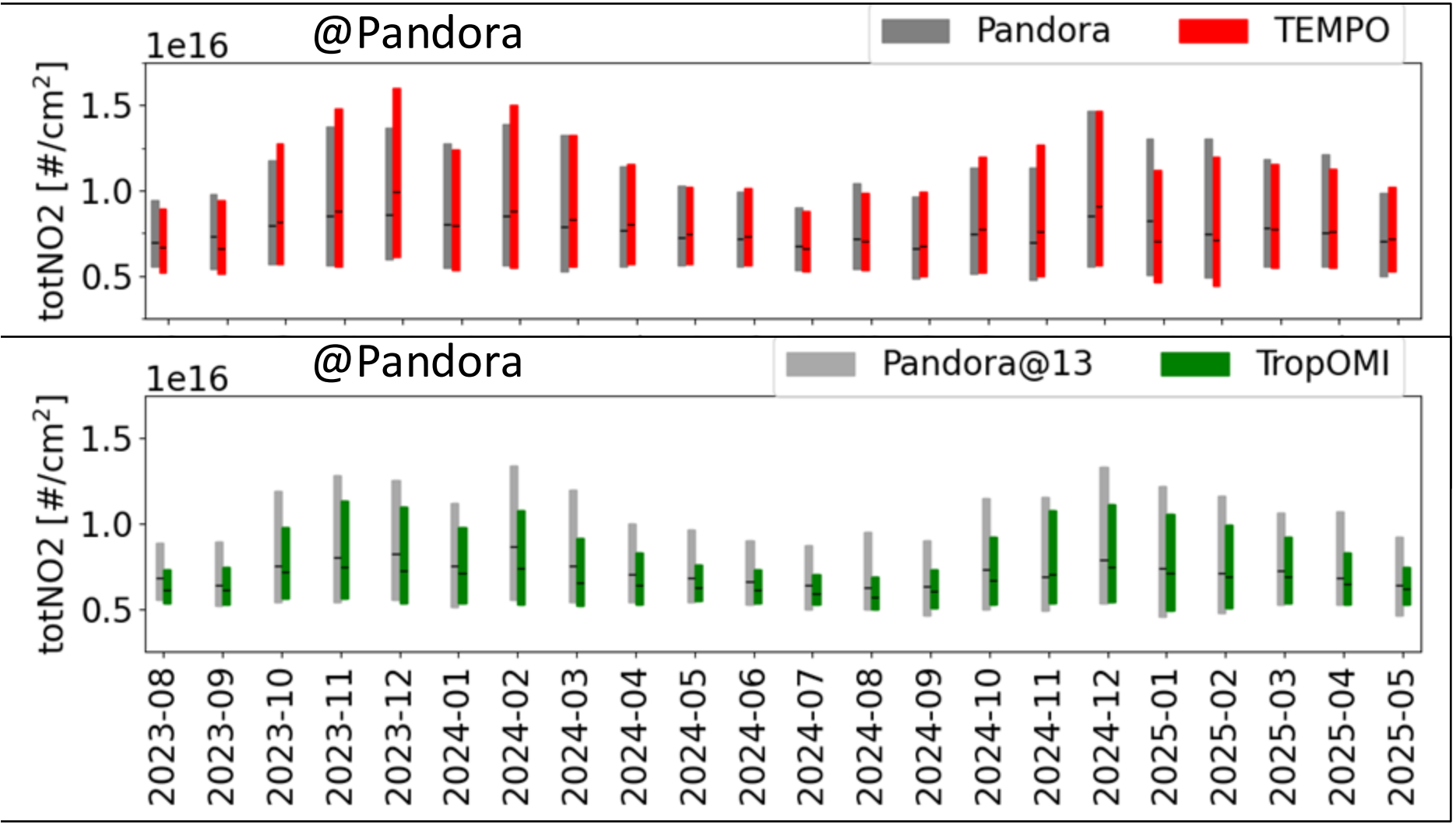
line: 50% boxes: 25%-75%
Solid Boxes: Mon-Fri

TEMPO captures seasonal pattern (r=0.98) with good bias (NMB=-3%)

TropOMI captures seasonal pattern (r=0.91), but high in winter (NMB=+12%)

- **Smaller variability in TropOMI**
- **TropOMI high-biased for low HCHO?**

Pandora totNO$_2$ Validation Aug 2023 to May 2025



line: 50% boxes: 25%-75%
Solid Boxes: Mon-Fri

TEMPO captures seasonal pattern (r=0.82) with good bias (NMB=3%)

TropOMI captures seasonal pattern (r=0.88), but low (NMB=-14%)

- **Smaller variability in TropOMI**
- **TropOMI low-biased for high NO2?**

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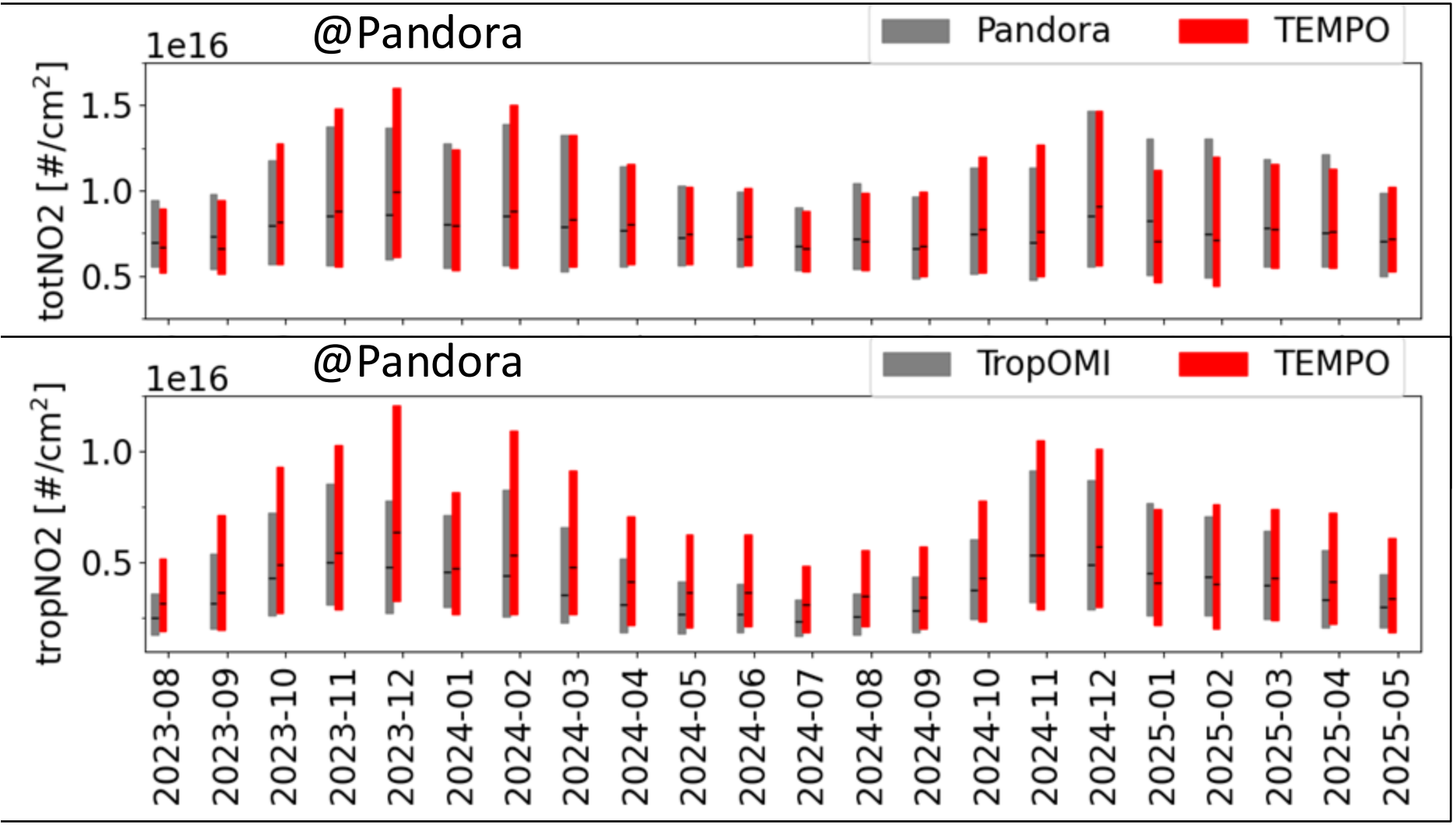
TropOMI $totNO_2$ and $tropNO_2$ Eval ***@Pandora*** Aug 2023 to May 2025



line: 50% boxes: 25%-75%
Solid Boxes: Mon-Fri

TEMPO captures Pandora seasonal pattern (r=0.82) with good bias (NMB=3%)

<u>Using TropOMI as a reference</u>

As expected, TEMPO is higher than TropOMI (NMB=+19%)

So, you might expect TEMPO to be high biased over Nonattainment Areas (NAA)

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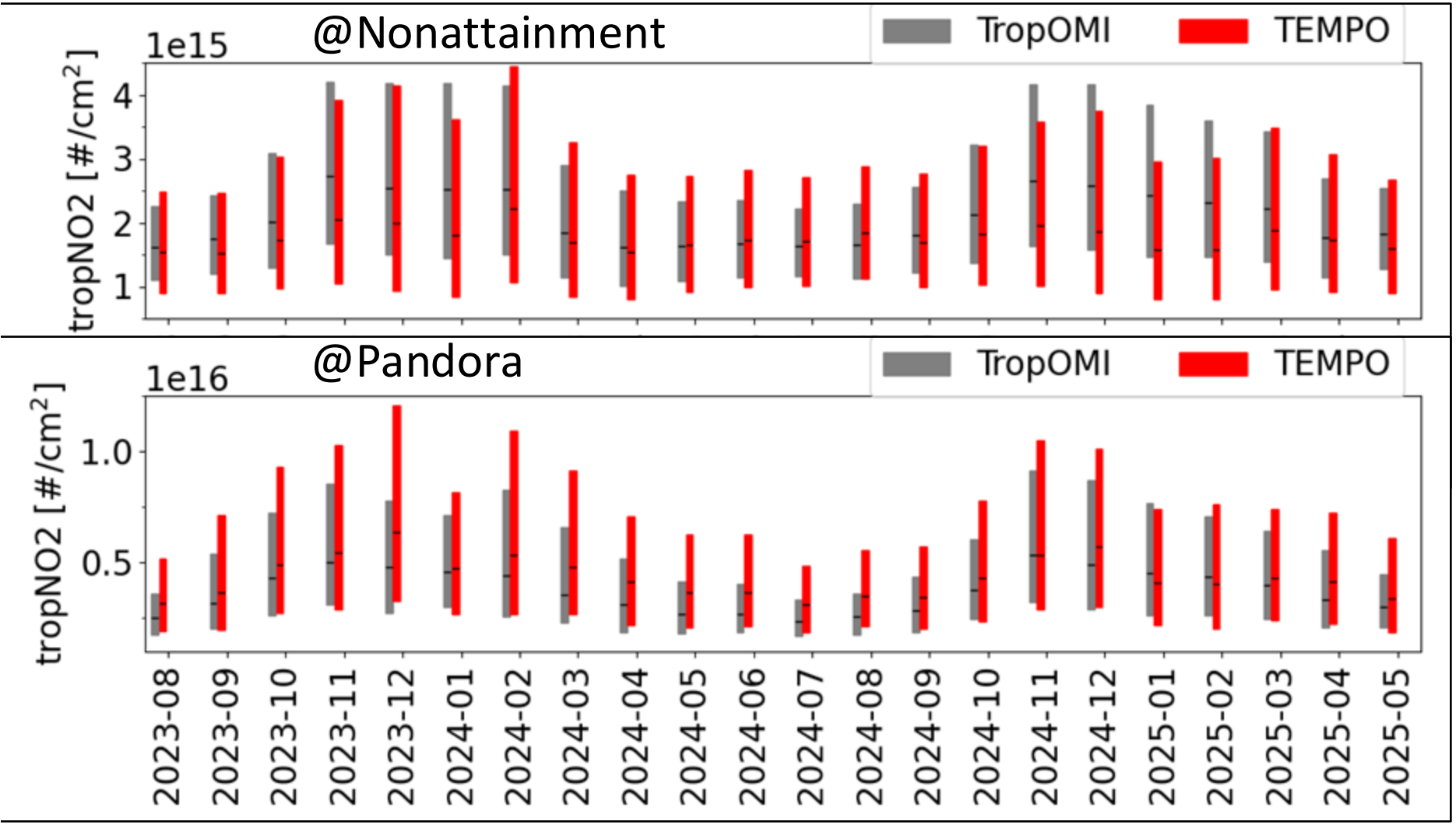
TropOMI totNO$_2$ and tropNO$_2$ Eval
@All Intersections Aug 2023 to May 2025



line: 50% boxes: 25%-75%
Solid Boxes: Mon-Fri

Unexpectedly TEMPO has lower NAA values (NMB=-11%)

- **Pandora sites are typically in urban areas, mostly in the west**
- **NAA cover urban, but area dominated by suburbs/rural and area-wise are in the west (California).**
- **TropOMI may have a high-bias at low NO2?**

Need Pandoras at strategic suburban ad rural locations to provide ground truth.

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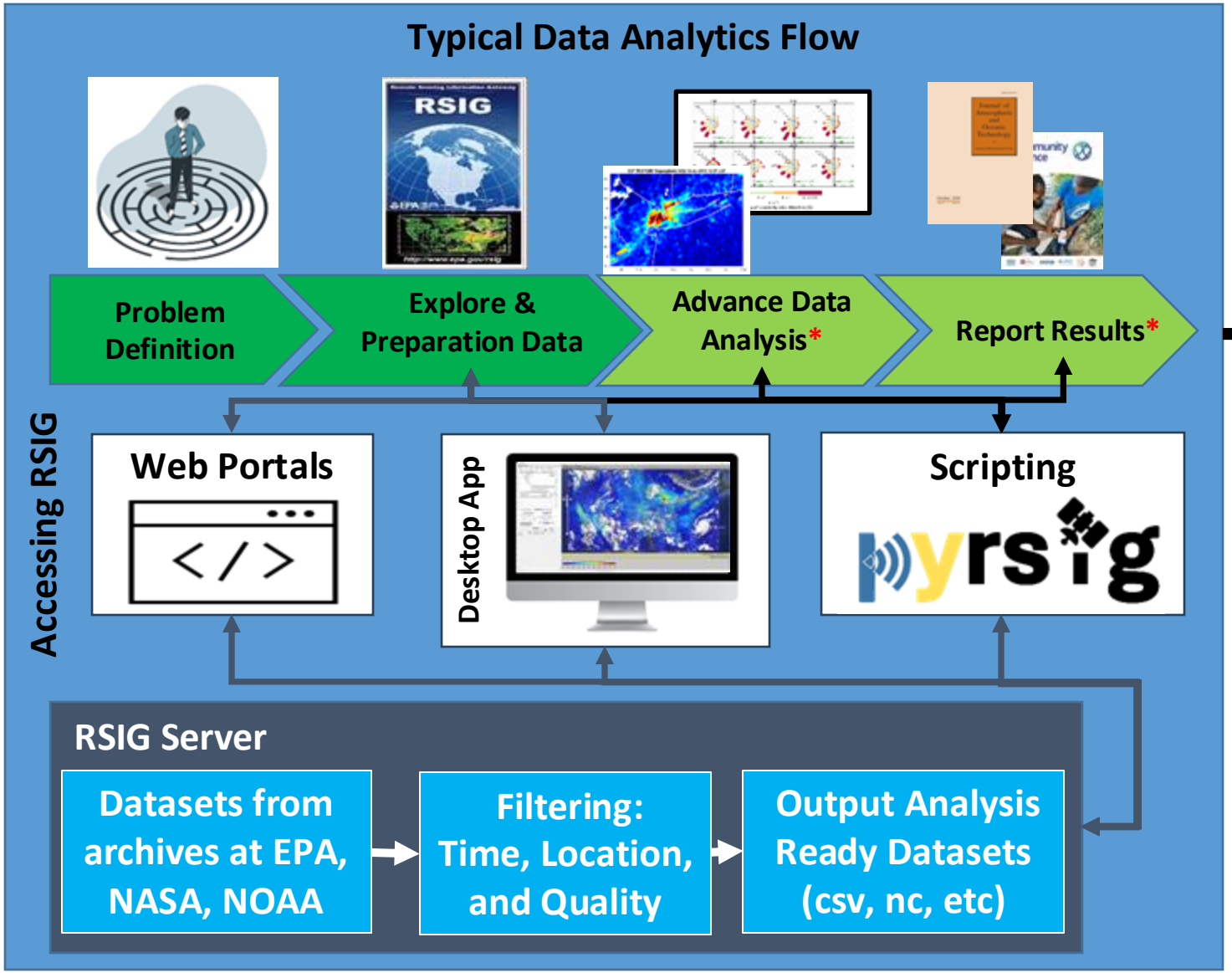
RSIG Provides Several Access Pathways



RSIG Desktop Support and Web

Air Quality Modelers
- Model Evaluation
- Case Study Analysis

Air Quality Forecasters
- Retrospective Analysis

Scientists & Researchers
- Exposure studies
- Inverse modeling studies
- Improving air quality models

Students
- Thesis/Dissertation Research

pyrsig extends capabilities
- Custom analyses including GIS
- Runs on laptop, server, or cloud
- Cloud apps even run on phones!

RSIG3D Desktop User Interface Orientation

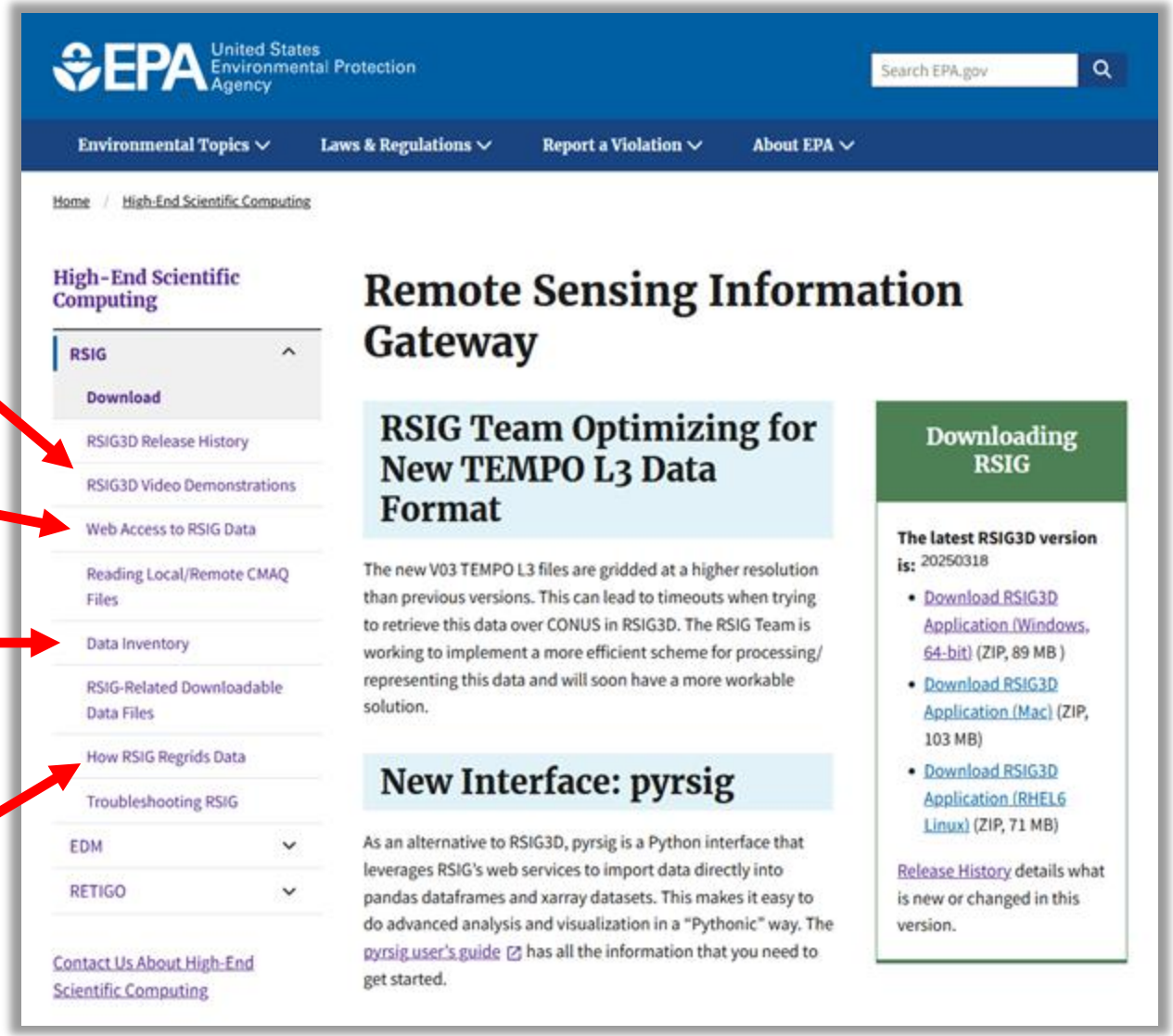
www.epa.gov/rsig

"Getting started" video tutorials

Web access to RSIG data

Data Inventory

How RSIG regrids data

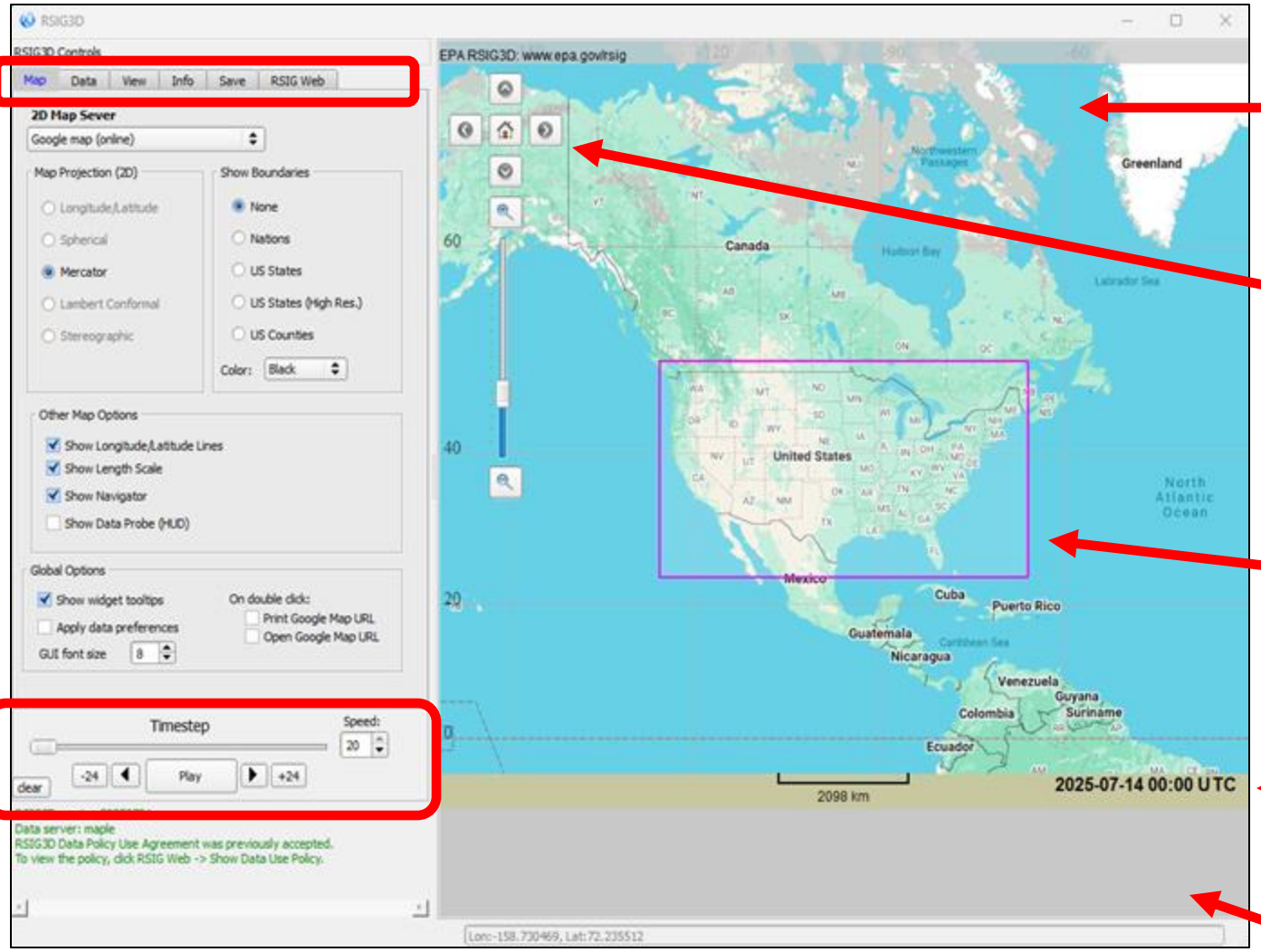


RSIG3D application download

- Windows
- Mac
- Linux (RHEL7)

Detail and Hands-on later

RSIG3D User Interface Orientation



Control tabs

Tab specific controls

Animation controls

Useful info including full WCS URL string

Map / data display

Map controls

Bounding box for data retrievals

Time and date

Colorbar area

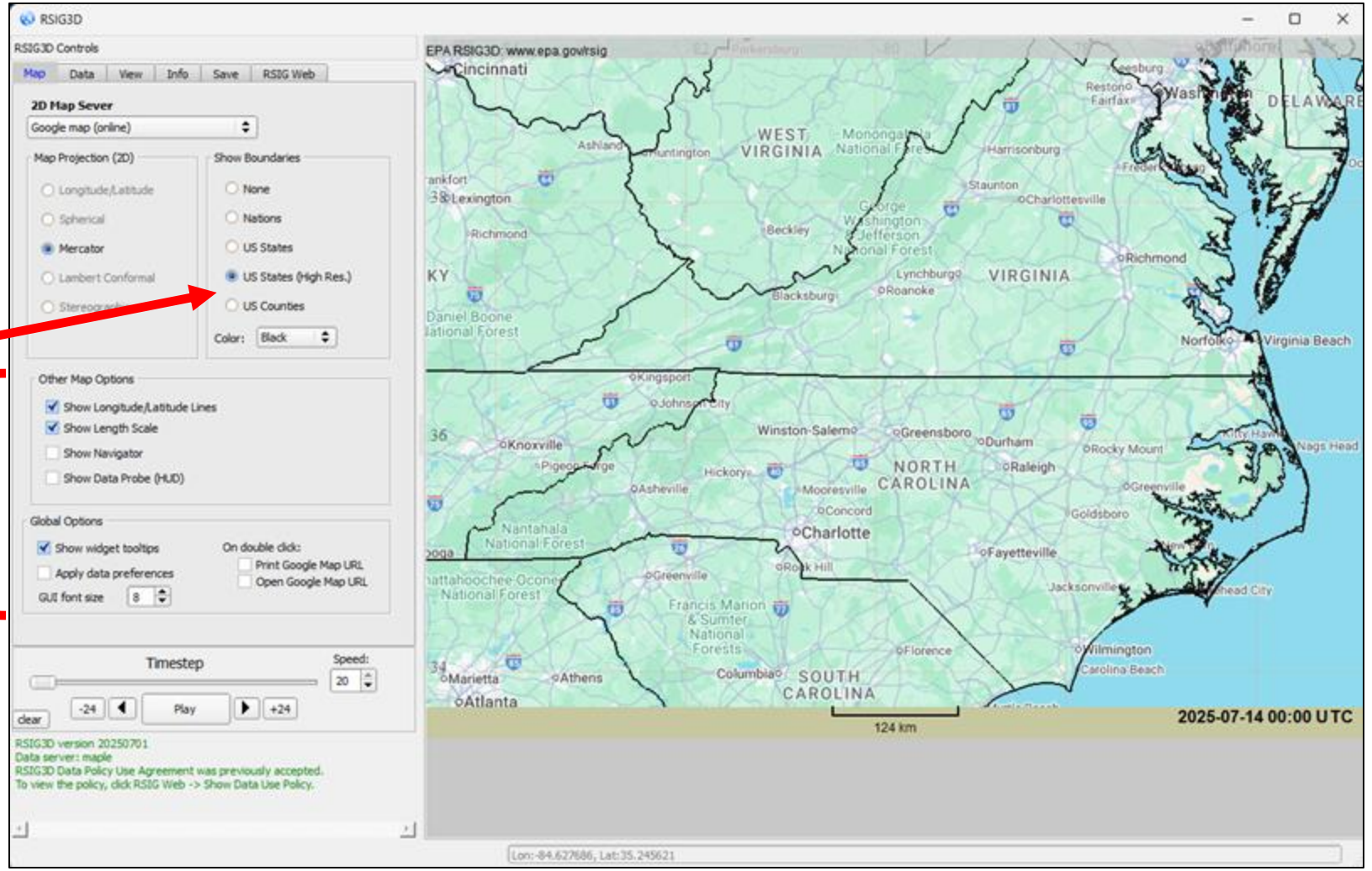
RSIG3D User Interface – Map Tab

Basemap

Map projection

Political boundaries

Other options
- Grid lines
- Map navigator
- Data probe
- Tooltips



RSIG3D User Interface – Data Tab

Time base (hourly, daily, or monthly)

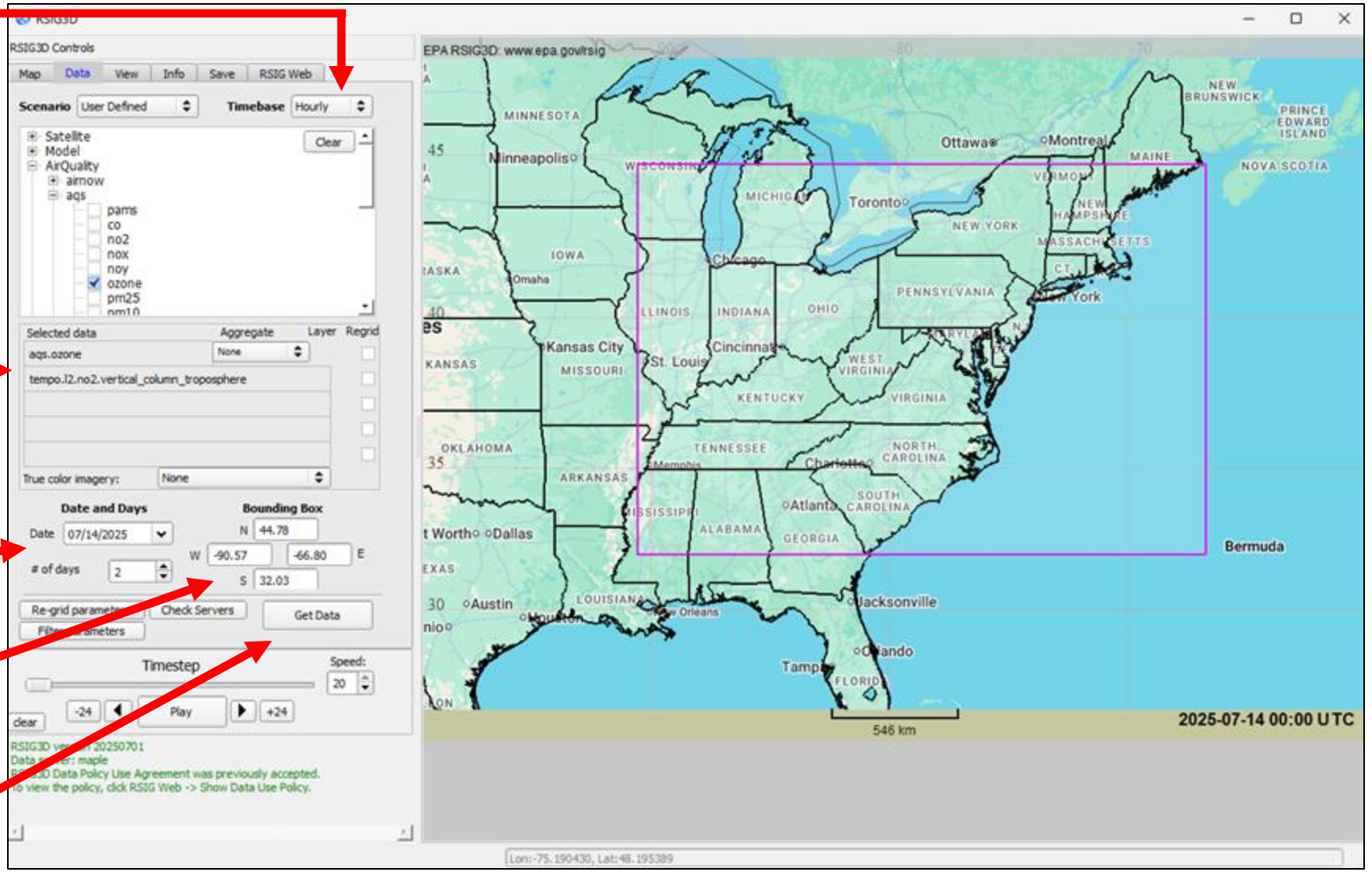
Data selection tree
- 27 sources
- 4148 variables

Selected variables appear here (up to five)

Date and number of days to process

Bounding box (or draw with mouse)

Get Data!



RSIG3D User Interface – Data Tab

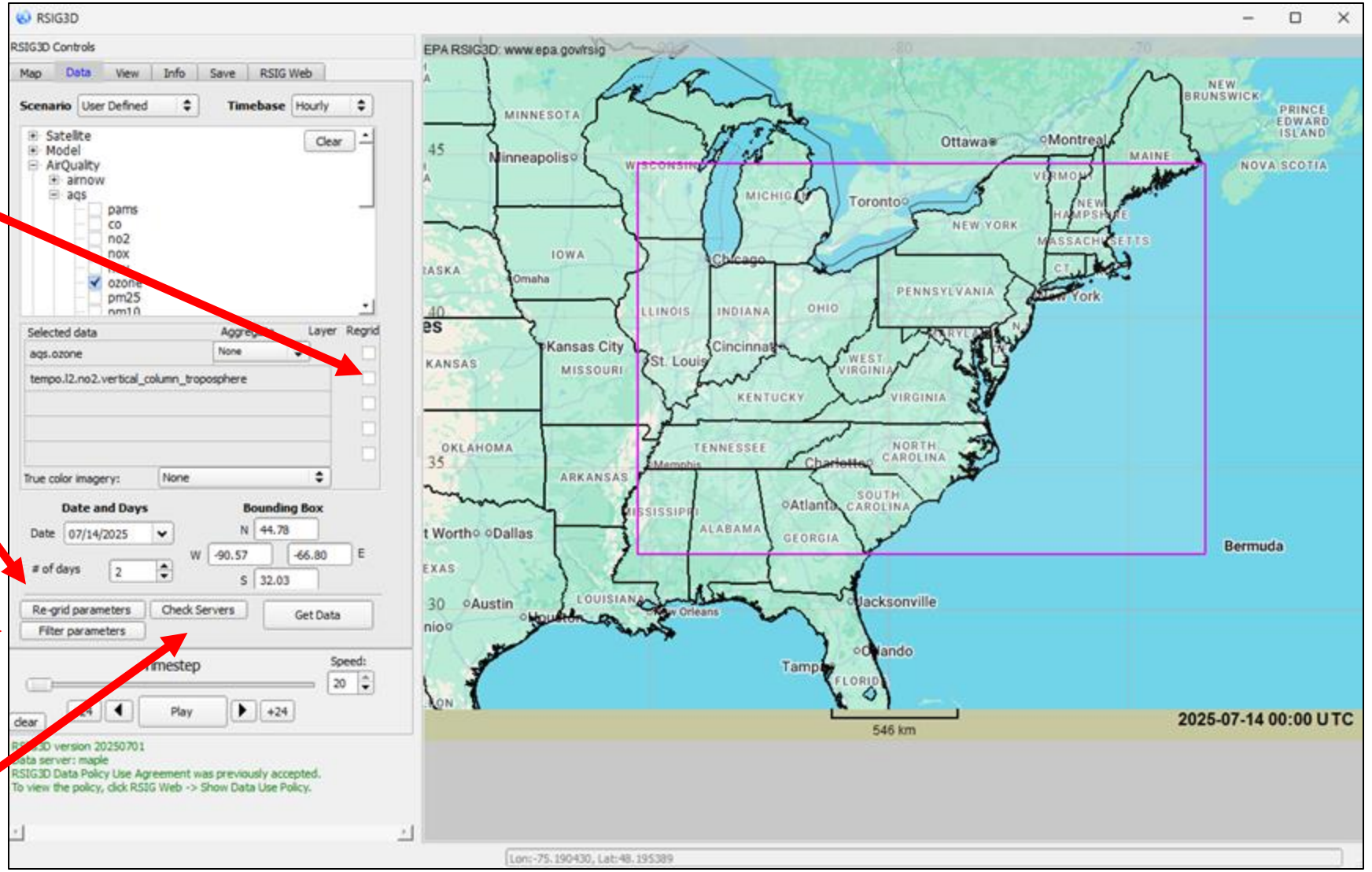
Advanced options

Each data type can optionally be interpolated (regridded) to CMAQ or other grids

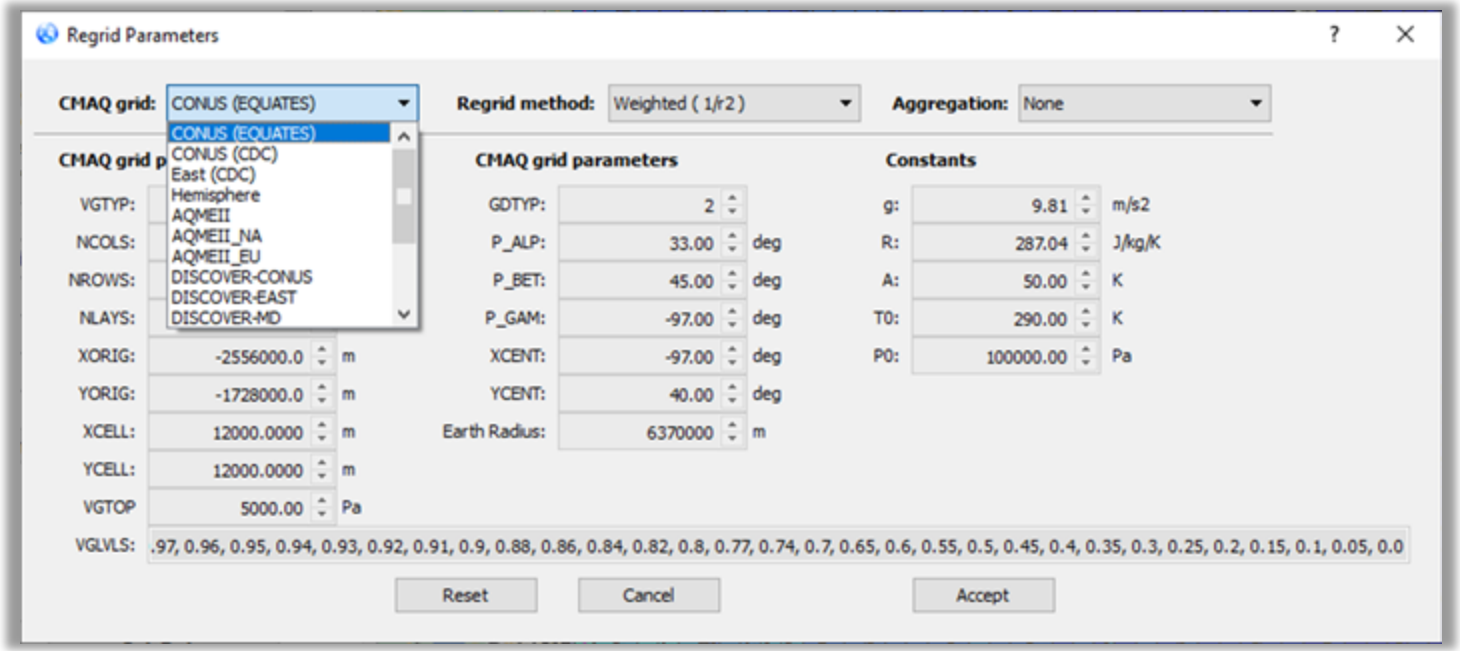
Regridding parameters can be specified here

Some data sources have filter or quality control parameters that can be changed

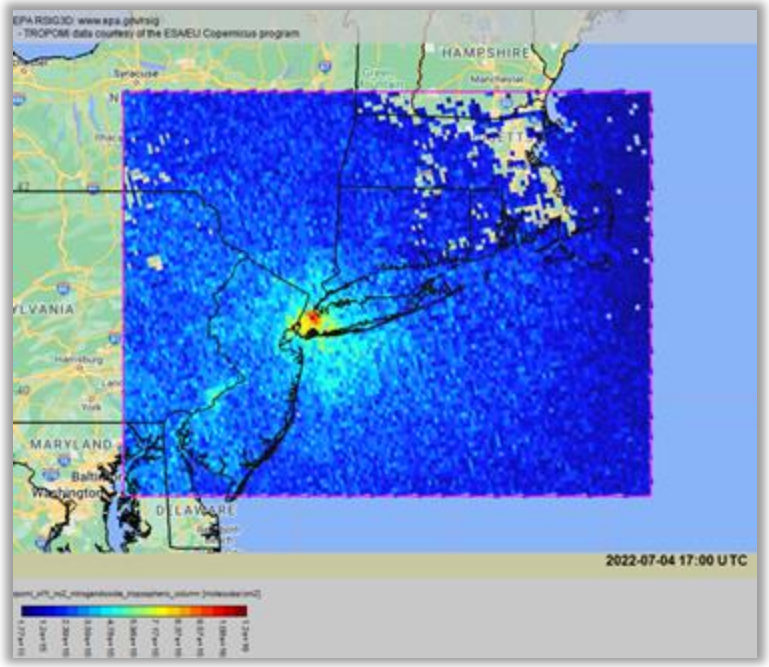
Check to see if servers are responding

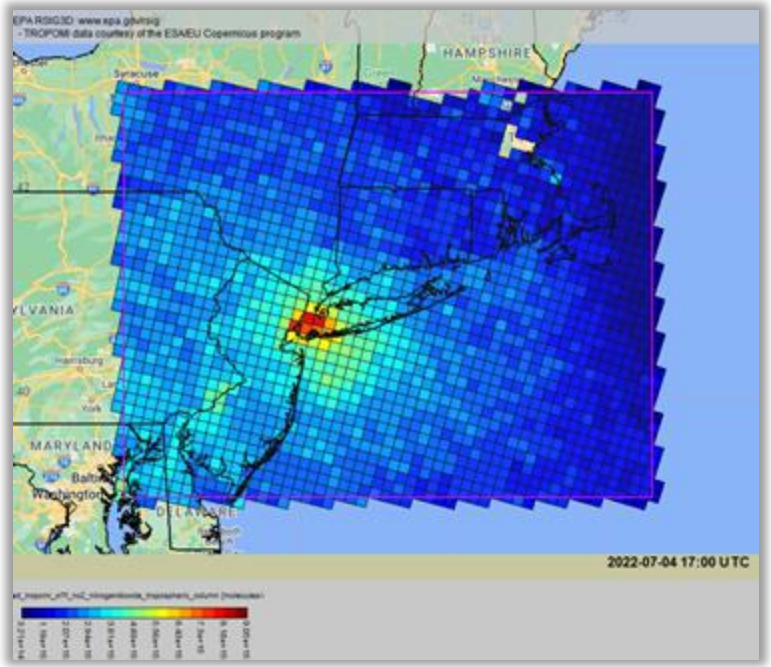


Regridding parameters



TROPOMI NO_2, native resolution





TROPOMI NO_2, regridded to CMAQ EQUATES 12km CONUS grid

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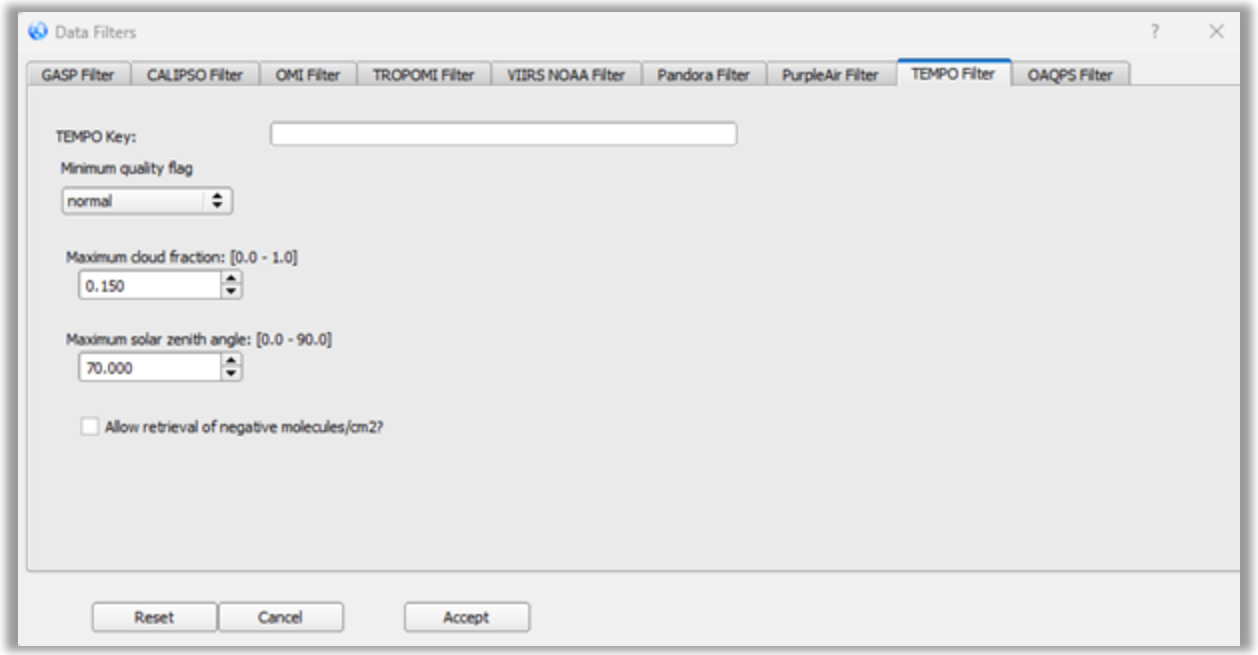
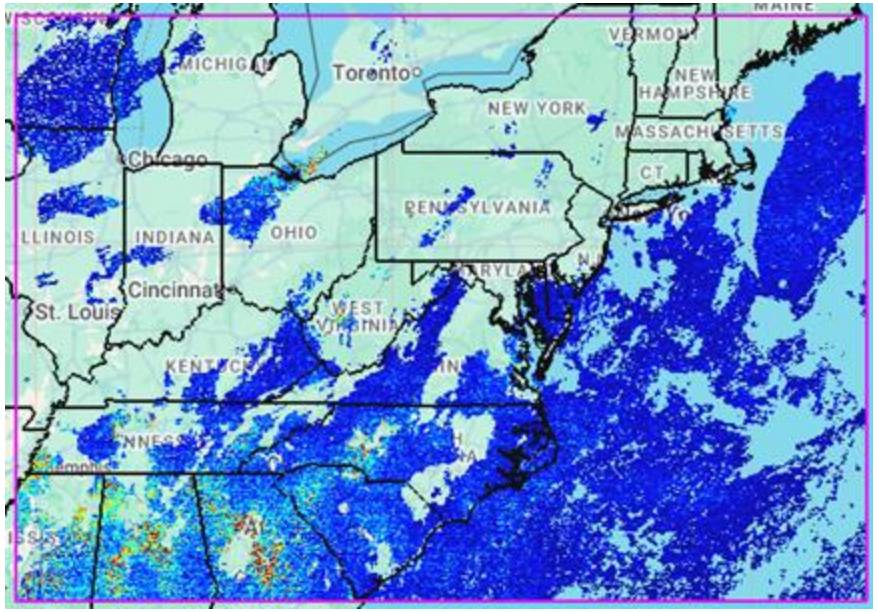
Filter parameters

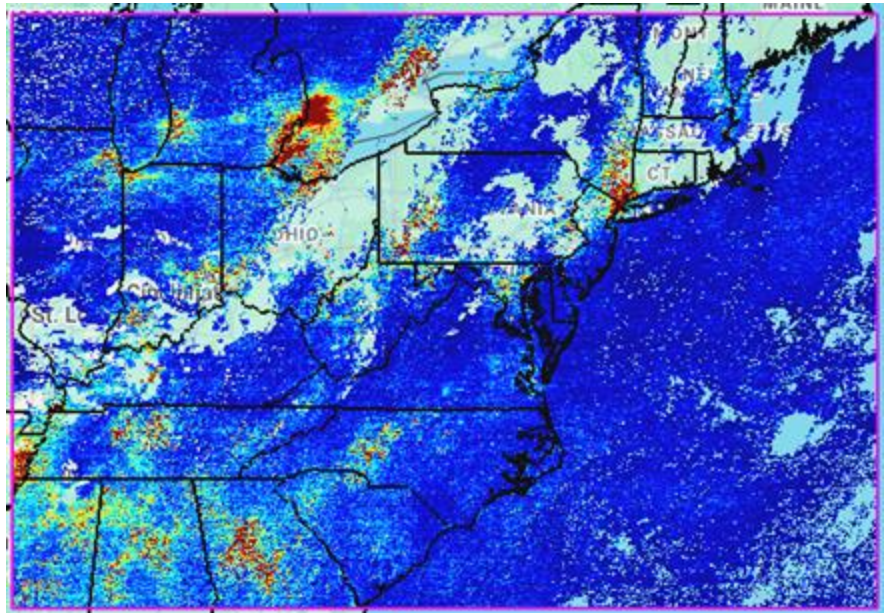
- Settings are by source.
- Defaults settings recommended by science teams.
- Filtering can result in no returned data.



TEMPO Max cloud fraction 15%



TEMPO max cloud fraction 75%



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RSIG3D User Interface – View Tab

Select the variable on which to operate

Visibility toggle

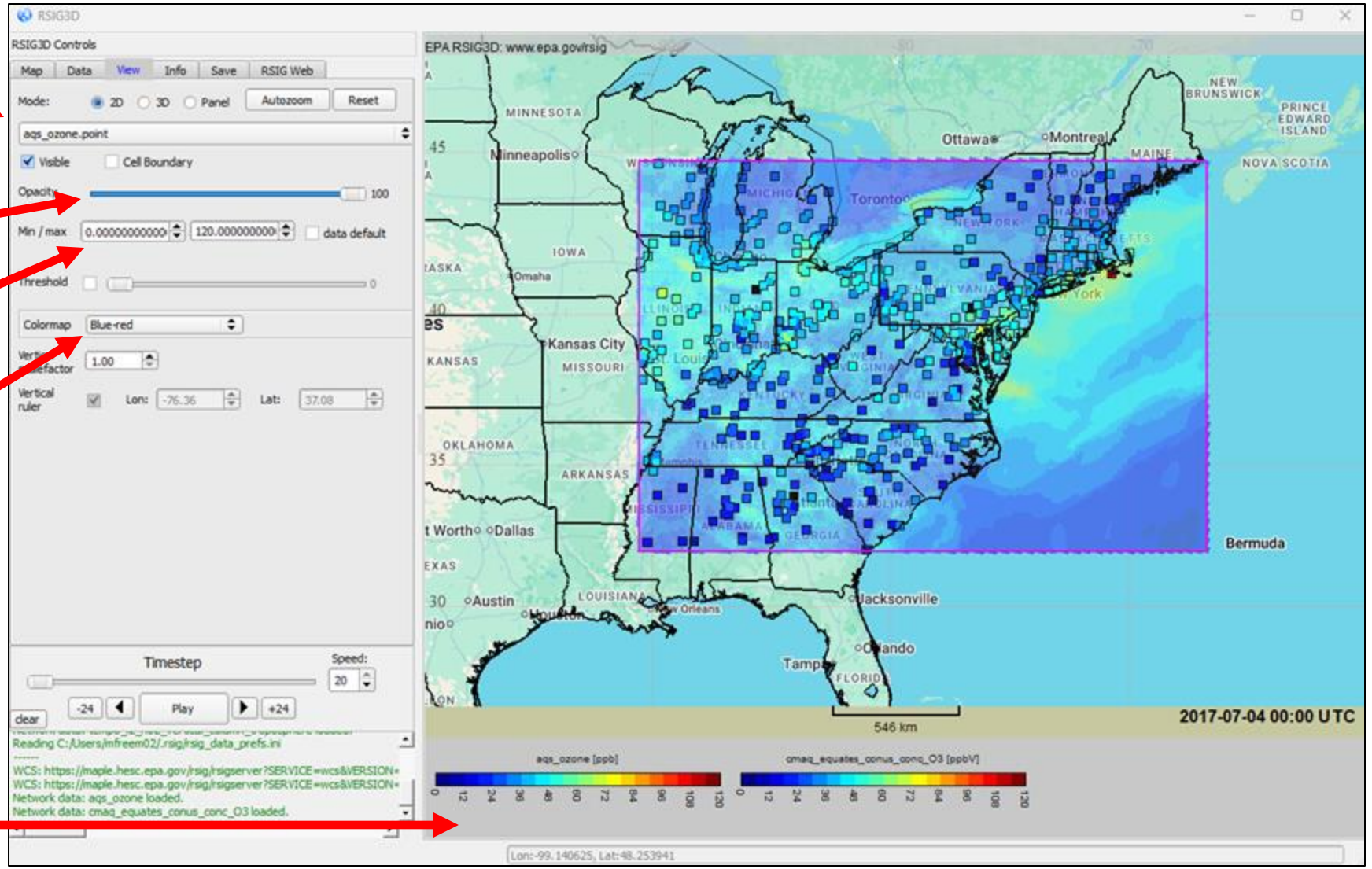
Opacity

Data range to display

Color map

Animation controls

Color bars for each variable shown here

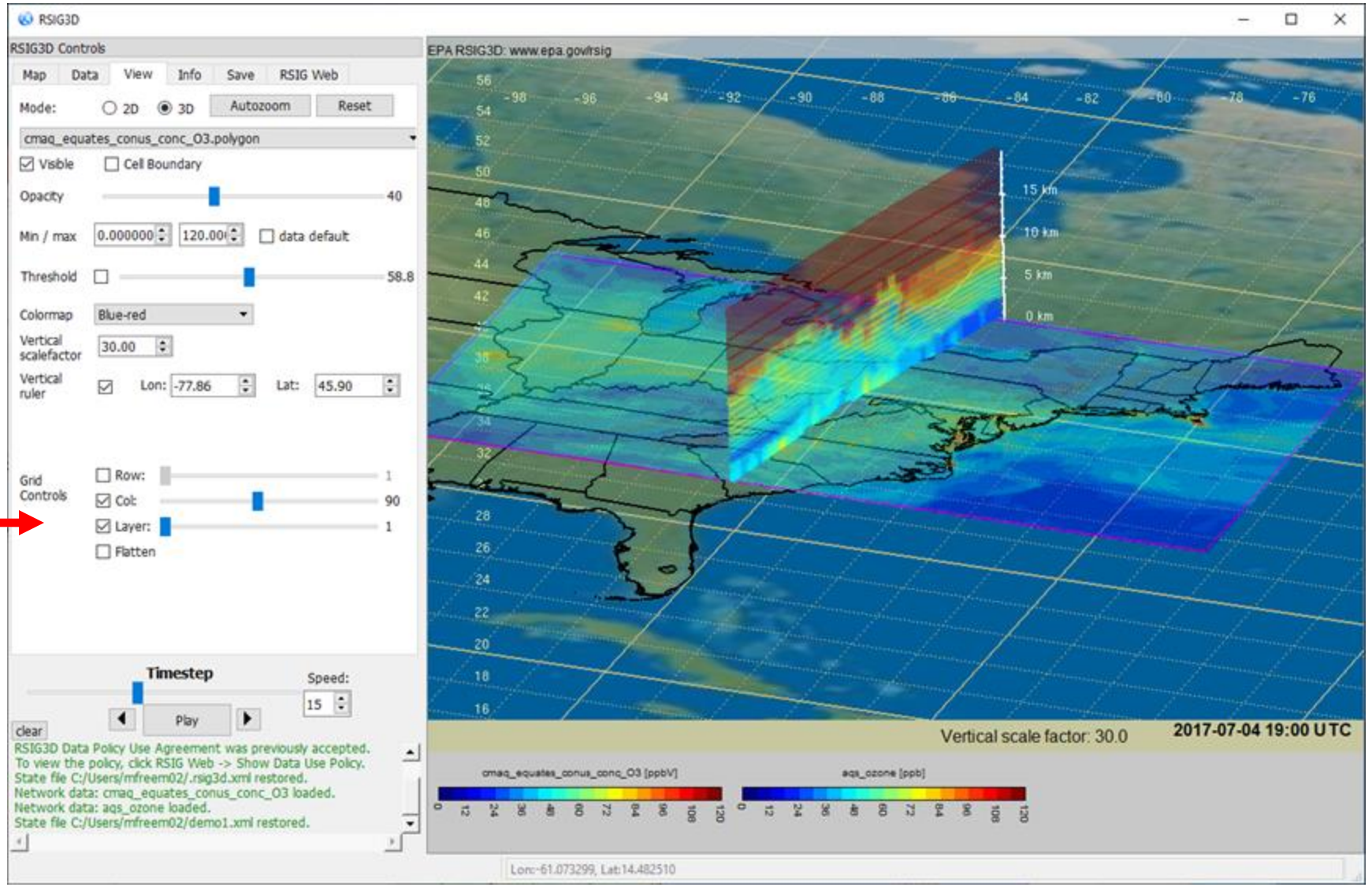


RSIG3D User Interface – View Tab

Advanced options

Visualization mode (2D or 3D)

Data specific controls (here to manipulate CMAQ “slice planes”)

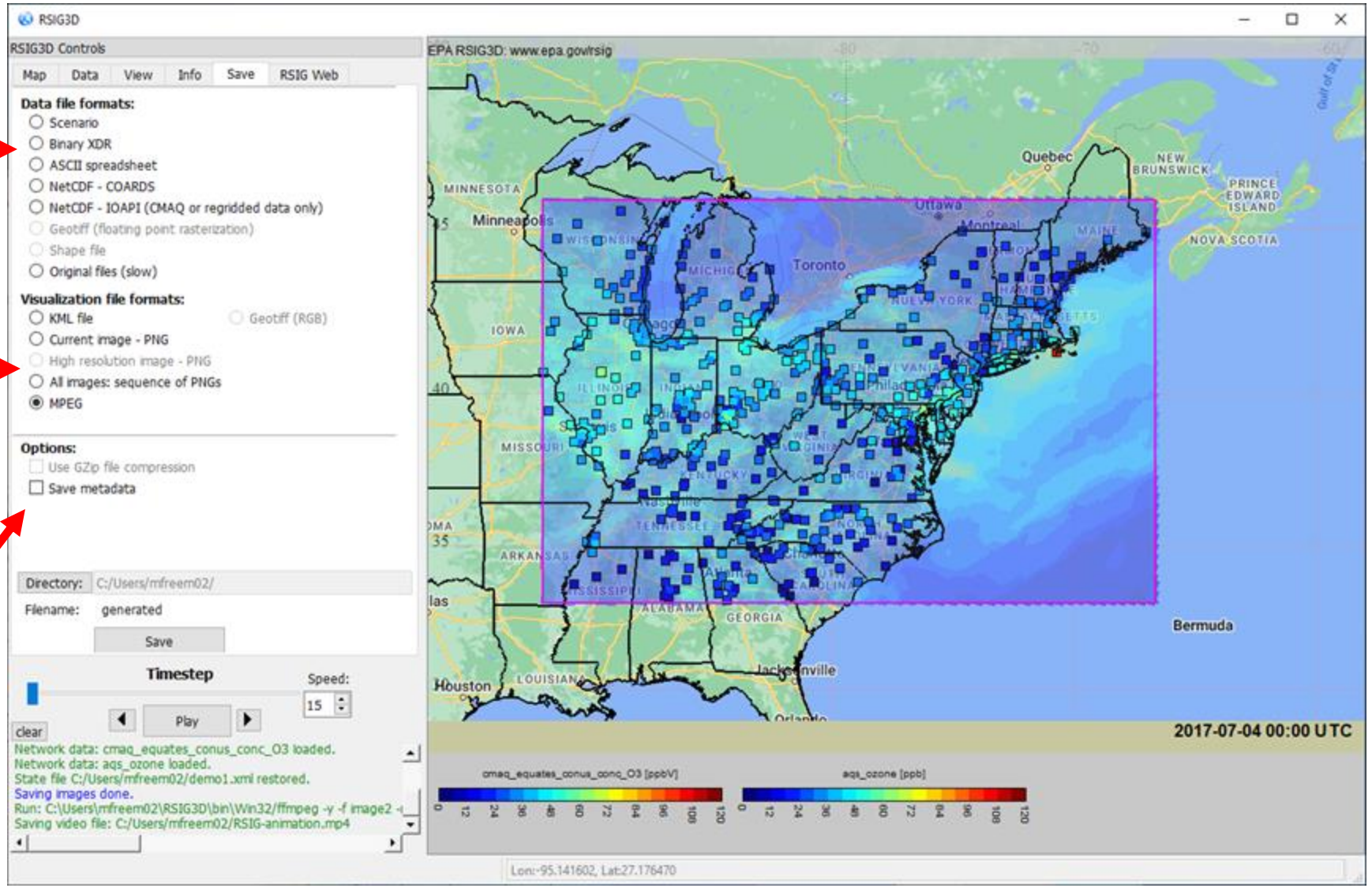


RSIG3D User Interface – Save Tab

Data formats
- Scenario
- Binary or ASCII
- NetCDF (2 kinds)

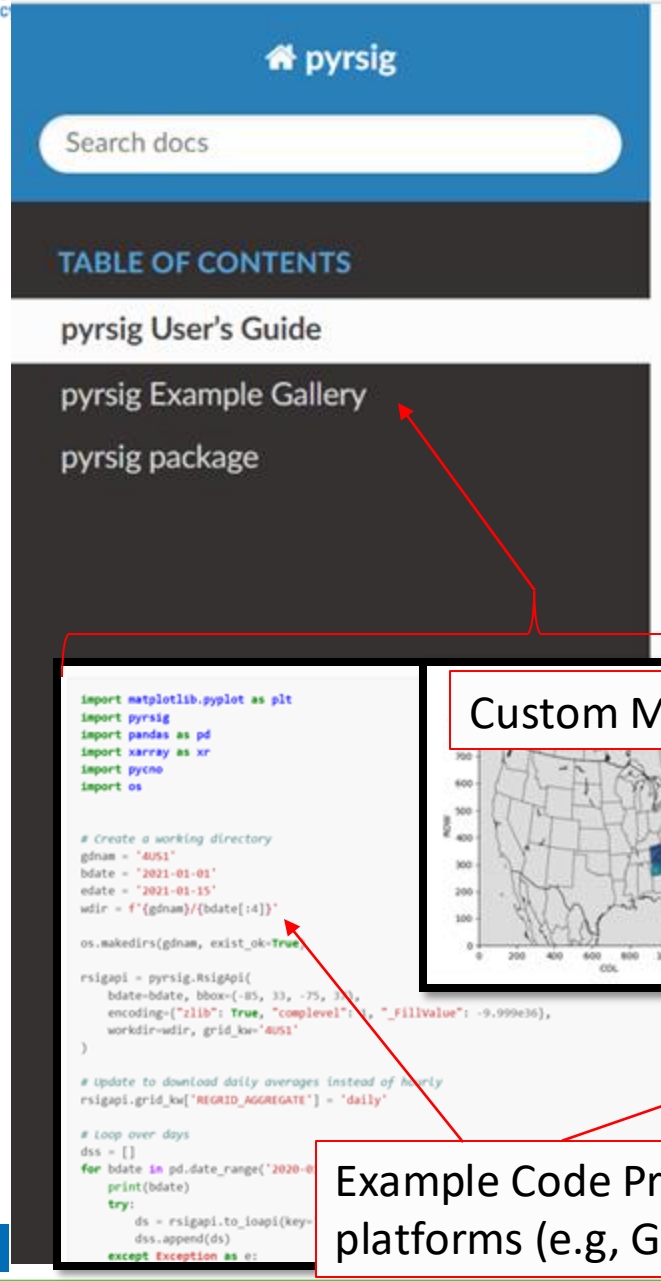
Visualization formats
- KML
- PNG
- Sequence on PNGs
- MP4

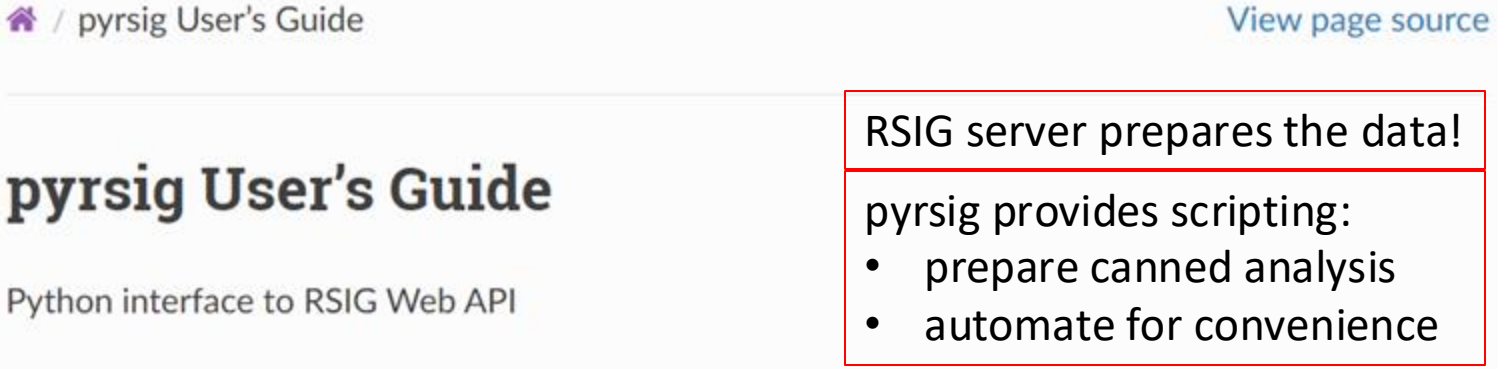
Options
- File compression
- Metadata



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

Source: B. Henderson, USEPA



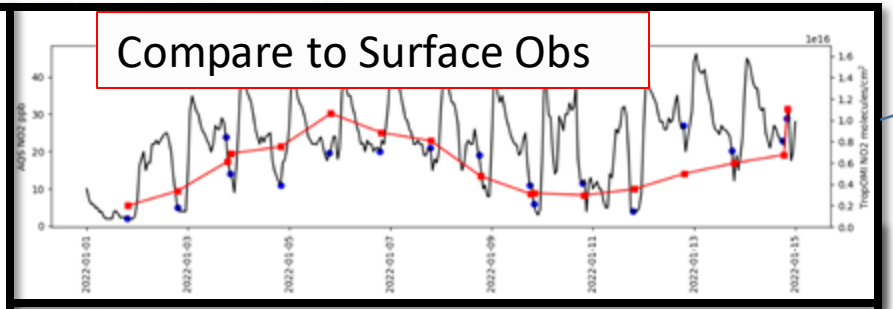


RSIG server prepares the data!

pyrsig provides scripting:
- prepare canned analysis
- automate for convenience

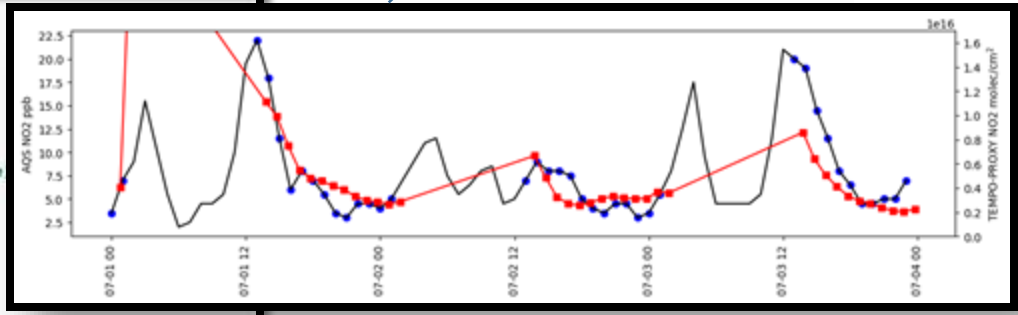
Custom Maps

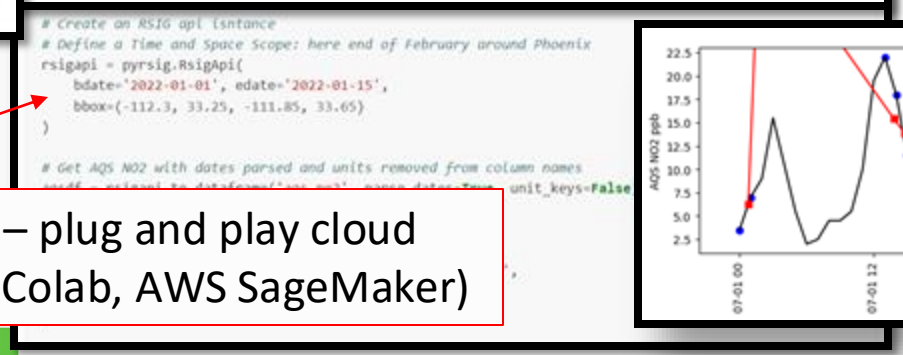
Compare to Surface Obs



TropOMI

TEMPO





Example Code Provide – plug and play cloud platforms (e.g, Google Colab, AWS SageMaker)

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

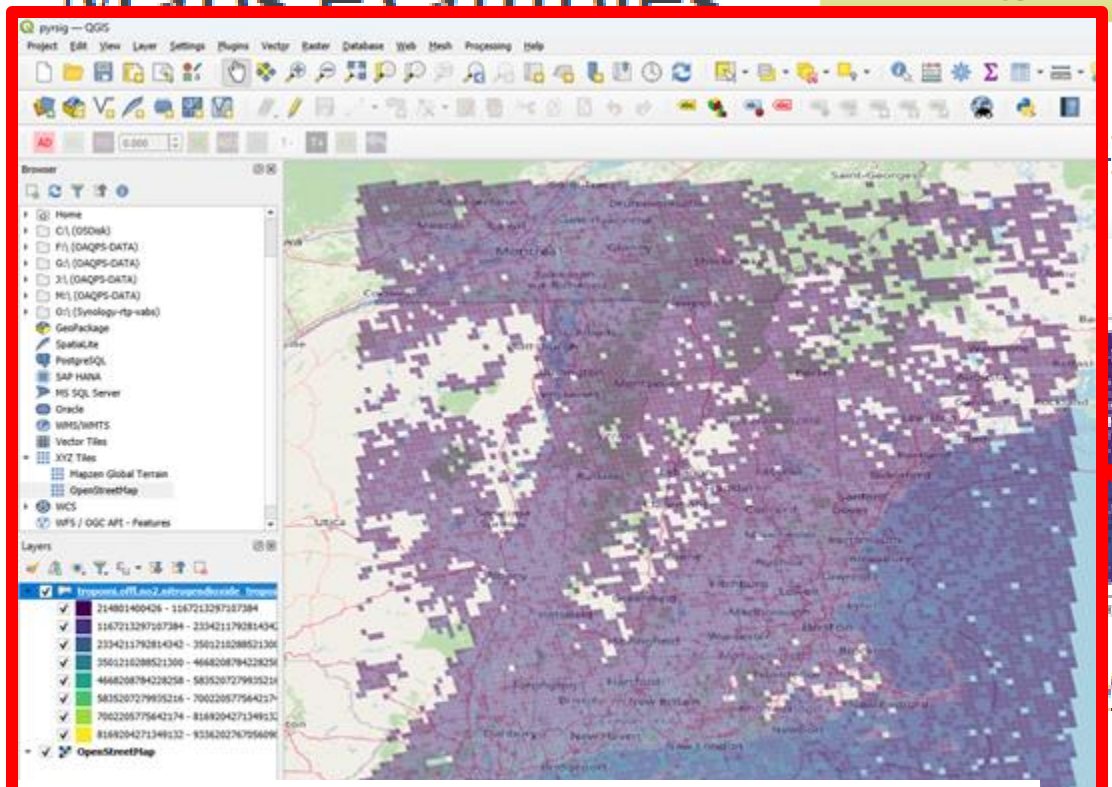
pyrsig connects satellite data to GIS

Download Python source code: plot_shapefile.py

Download Jupyter notebook: plot_shapefile.ipynb

Maps examples

...ps.



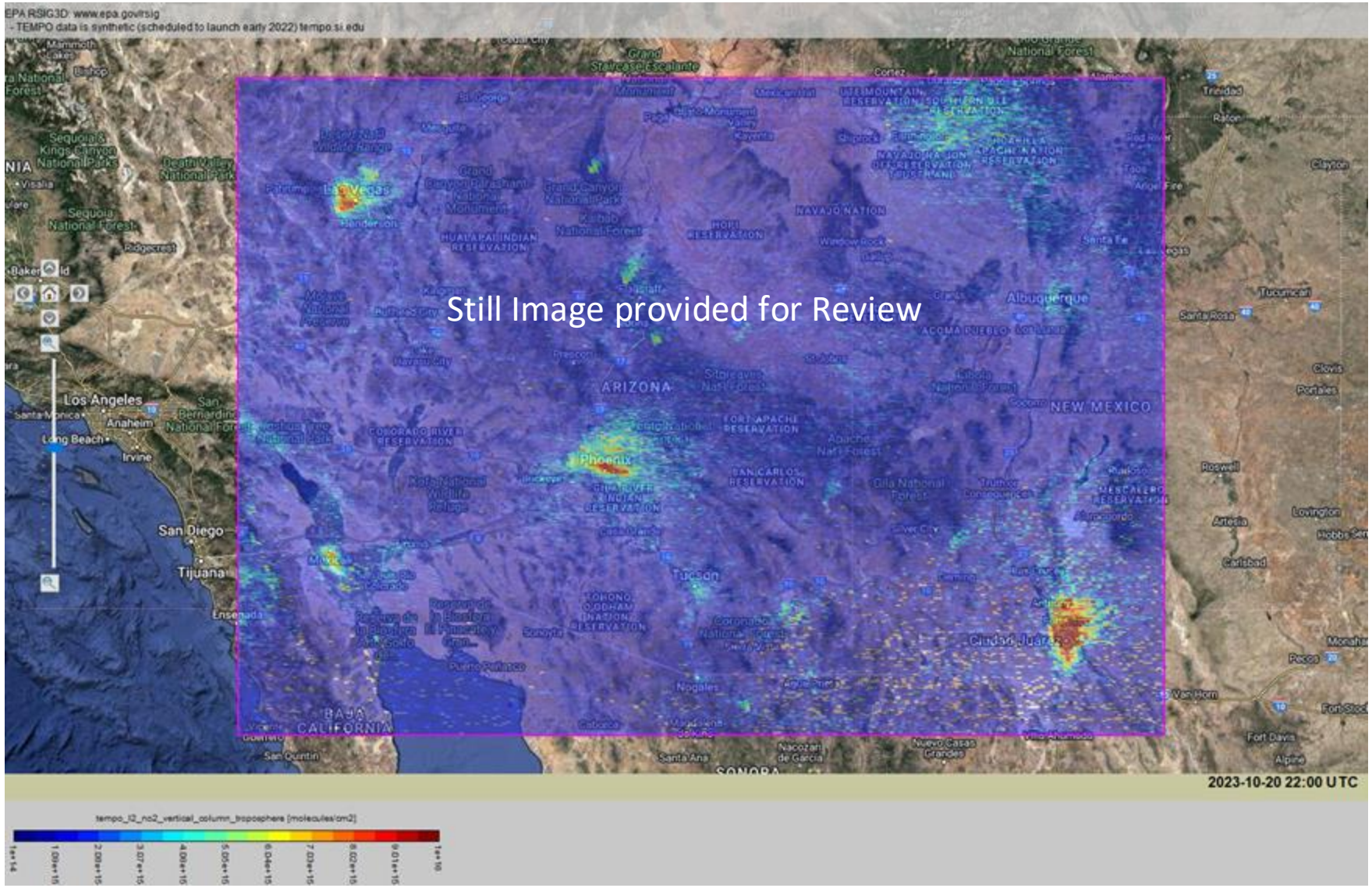
In QGIS w/ OpenStreetMap

Convert GIS-Compatible Vector Files

```
import matplotlib.pyplot as plt
import geopandas as gpd
from shapely import polygons
import pyrsig
import pycno


coordkeys = [
    'Longitude_SW(deg)', 'Latitude_SW(deg)',
    'Longitude_SE(deg)', 'Latitude_SE(deg)',
    'Longitude_NE(deg)', 'Latitude_NE(deg)',
    'Longitude_NW(deg)', 'Latitude_NW(deg)',
    'Longitude_SW(deg)', 'Latitude_SW(deg)',
]

cno = pycno.cno()

# Retrieve data from RSIG (or cache)
datakey = "tropomi.offl.no2.nitrogendioxide_tropospheric_column"
bdate = "2023-07-23"
bbox = (-75, 40, -69, 46)
api = pyrsig.RsigApi(bbox=bbox)
# Either ascii or xdr backend works, xdr is faster
```

```
# Save as a GIS Format
gtropdf.to_file(f'{datakey}_{bdate}.geojson')
# Shapefiles prefer short names
gtropdf.rename(columns={
    'Timestamp(UTC)': 'time_utc',
    'LATITUDE(deg)': 'lat_center',
    'LONGITUDE(deg)': 'lon_center',
    col: 'no2_trop',
}).to_file(f'{datakey}_{bdate}.shp')
```

Live demonstration of TEMPO Column NO_2 data within RSIG over SW U.S.



RSIG Summary

- Designed to assist users in obtaining complex datasets relevant to the air quality research and application community.
- Critical access to TropOMI, TEMPO, Pandora, AirNow, etc
- Significantly reduce data processing time associated with air quality relevant high value data sets.
- Provides data access via the RSIG3D user interface, web browser, cURL (client URL) scripts, or via pyrsig scripting.
- Visualization capabilities can be used to explore episode case studies and provide high quality graphics for reports and presentations.

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Contacts

Jim Szykman
Senior Research Engineer
Center for Environmental Measurements and Modeling
US EPA Office of Research and Development
Szykman.Jim@epa.gov

Barron Henderson
Research Physical Scientist
Center for Environmental Measurements and Modeling
US EPA Office of Research and Development
Henderson.Barron@epa.gov

Matt Freeman
Senior Scientific Applications Developer
Applied Research Associates
contractor to US EPA Office of Mission Support
Freeman.Matt@epa.gov

Remote Sensing Information Gateway:
https://www.epa.gov/rsig

Thank You!

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