EPA United States Environmental Protection Agency

Using Satellite Data: Overview of Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission and data product validation plans

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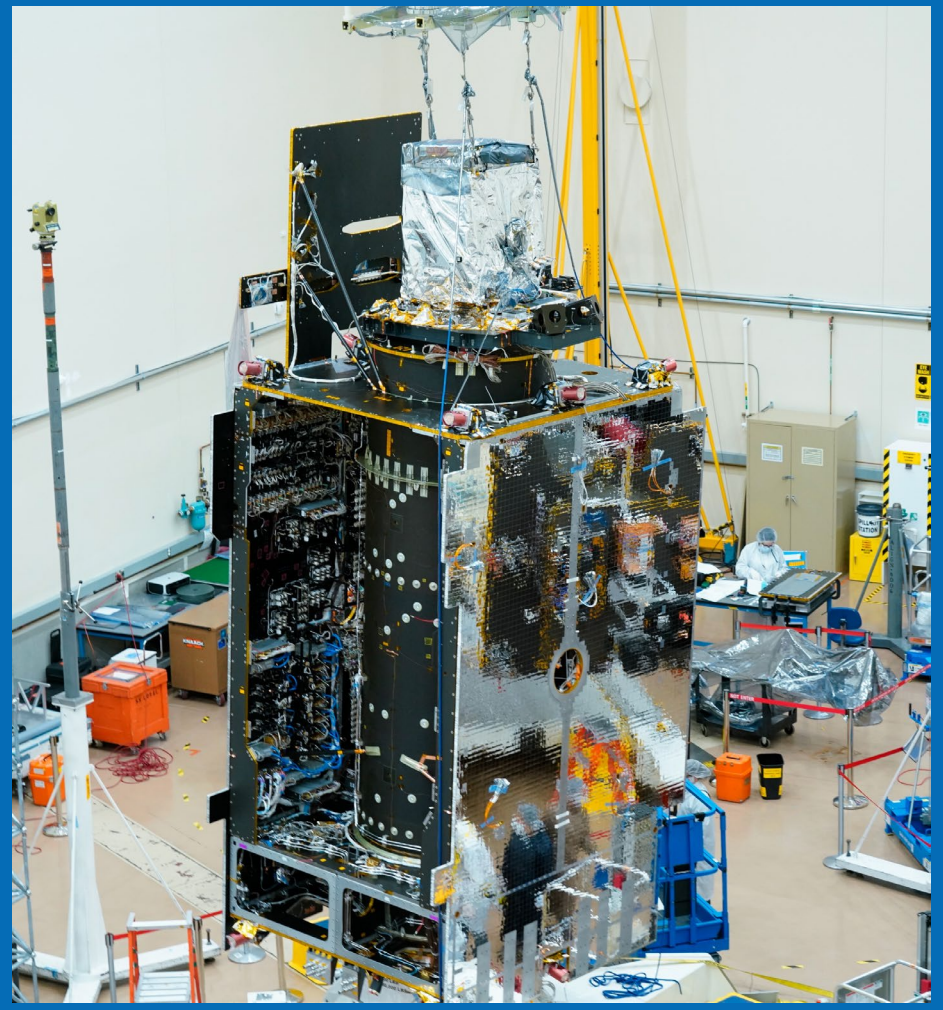
U.S. EPA Office of Research and Development

w/ contributions from others, including Kelly Chance (TEMPO PI, SAO), Xiong Liu (TEMPO D-PI, SAO), Alexander Cede & Martin Tiefengraber, Luftblick, Laura Judd & Jim Crawford (NASA-LaRC), Tom Hanisco, John Sullivan, & Nader Abuhassan (NASA-GSFC), etc.

TEMPO Instrument Integration onto Intelsat 40e



Outline

- GAO reports and areas of relevance
  1) *Opportunities to Better Sustain and Modernize the National Air Quality Monitoring System, 2020*
  2) *Science & Tech Spotlight: Air Quality Sensors*, Dec 2020
- Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission
- Ground Remote Sensing Observations – Improving Validation Resources for Routine and Systematic Use
- Emerging Validation Paradigm for TEMPO data products
- Wrap-up

GAO Report Modernize the National Air Quality Monitoring System: Excerpts relevant to Satellite Data

- The 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.

- Air quality managers, researchers…are increasingly using emerging technologies to obtain information on air quality, but many…(of) these users need more information on the reliability and accepted uses of these technologies. These technologies include remote sensors on satellites operated by NOAA and NASA.

- Satellites can provide information on air pollutants over large areas, including areas that are difficult or impossible to monitor with traditional monitoring methods.

- Satellite-based sensor data can be difficult to interpret, especially for pollution at ground level. In addition, deployed satellite-based sensor technologies currently only measure a few pollutants, including particulate matter, **ozone**, sulfur dioxide, **nitrogen dioxide**, **formaldehyde**, and carbon monoxide.

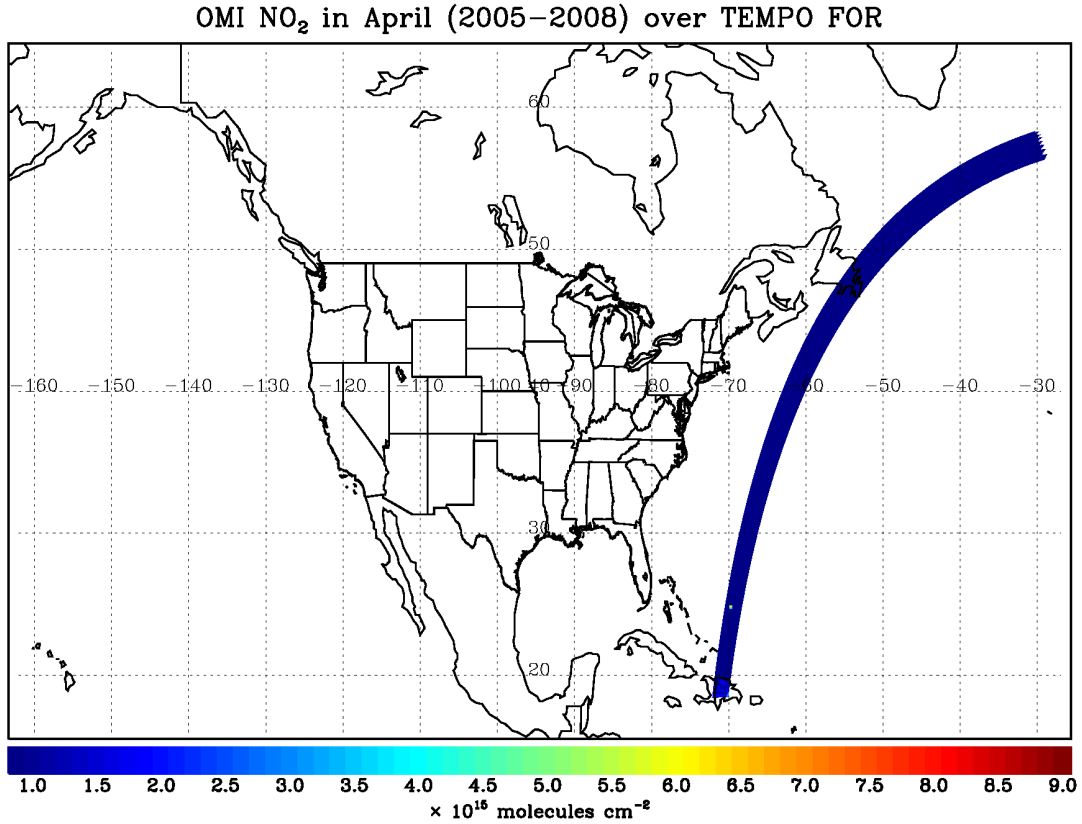
- State and local agencies use information from satellites to supplement air quality monitoring for limited purposes but said that they would likely increase their use of satellite data if they had more information on appropriate applications.

Tropospheric Emissions: Monitoring of Pollution –TEMPO
Moving to Time Resolved Observations at Neighborhood Scales

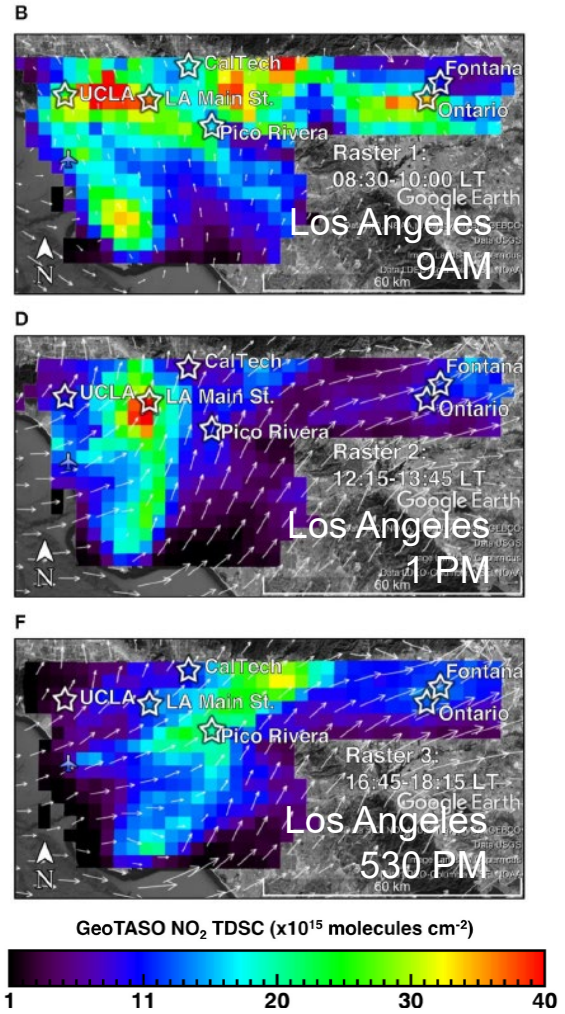
PI: **Kelly Chance, Smithsonian Astrophysical Observatory**

Current other Institutions: **EPA, NASA LaRC, NASA GSFC, NOAA, NCAR, Harvard, UC Berkeley, St. Louis U, U Alabama Huntsville, U Iowa**

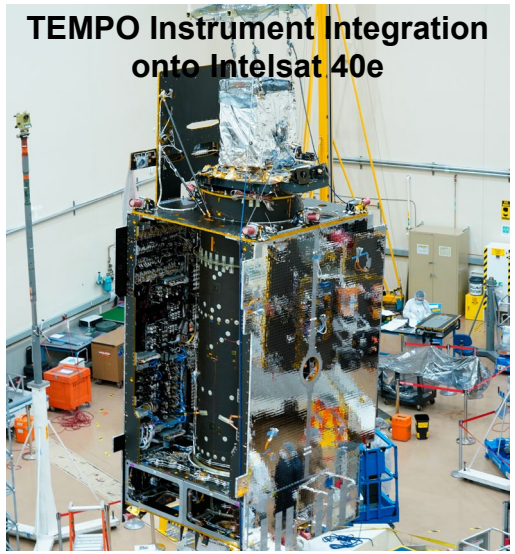
International collaboration: **Korea, Mexico, Canada, Europe**



NO2 Columns from Airborne TEMPO Risk Reduction Mission



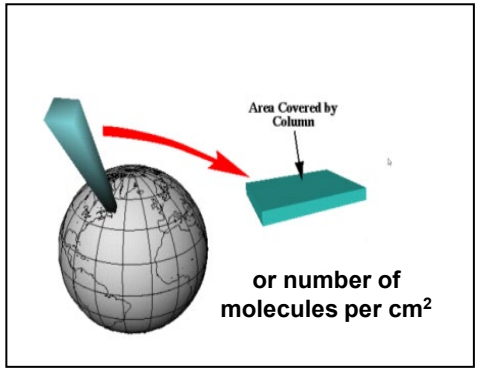
CONUS + parts of Canada and Mexico every hour at ~2.1 km × 4.6 km!



TEMPO Products and Requirements

Species/Products (geophysical product)	Required Precision	AQ relevance (All in surface- 1 km)	Temporal Revisit
0-2 km O_3 (Selected Scenes) Baseline only	10 ppbv	10 ppb	2 hour
Tropospheric O_3	10 ppbv	10 ppb	1 hour
Total O_3	3%		1 hour
Tropospheric NO_2	1.0 × 10^{15} molecules cm^{-2}	0.4 ppb	1 hour
Tropospheric H_2CO	1.0 × 10^{16} molecules cm^{-2}	4 ppb	3 hour
Tropospheric SO_2	**1.0 × 10^{16} molecules cm^{-2}**	**4 ppb**	**3 hour**
Tropospheric $C_2H_2O_2$	**4.0 × 10^{14} molecules cm^{-2}**	**0.16 ppb**	**3 hour**
Aerosol Optical Depth	**0.10**		**1 hour**

TEMPO observes vertical column densities

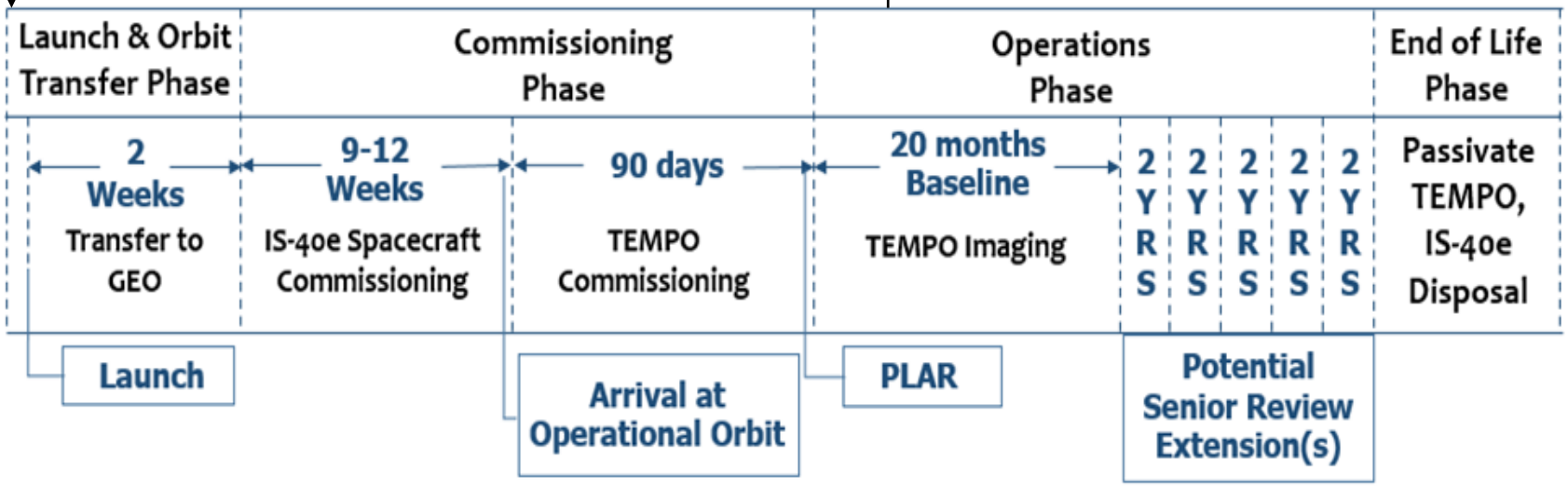


- **Spatial resolution of ~2 km × 4.75 km; coarse (O3 profile) 8 km x 9.5 km – 12 km x 14.25 km**
- **Up to 25% of observing time can be devoted to non-standard operational scans**
  - **Two types envisioned:**
    - **Events (e.g., eruptions, fires, dust storms, etc.)**
    - **Experiments (non-standard scan patterns to explore phenomena, e.g. lightening NOx, mobile NOx emissions**
- **Aerosols (AOD, SSA, AAI), SO2, C2H2O2 were removed from baseline products during project implementation. Funding via the Federal Satellite Needs Working Group will allow for products to be developed, timing is TBD.**

Tropospheric Emissions: Monitoring of Pollution –TEMPO
Project Schedule

Current Launch Schedule March 2023

Public Data Release Required 6 months after Commissioning Phase ~March 2024

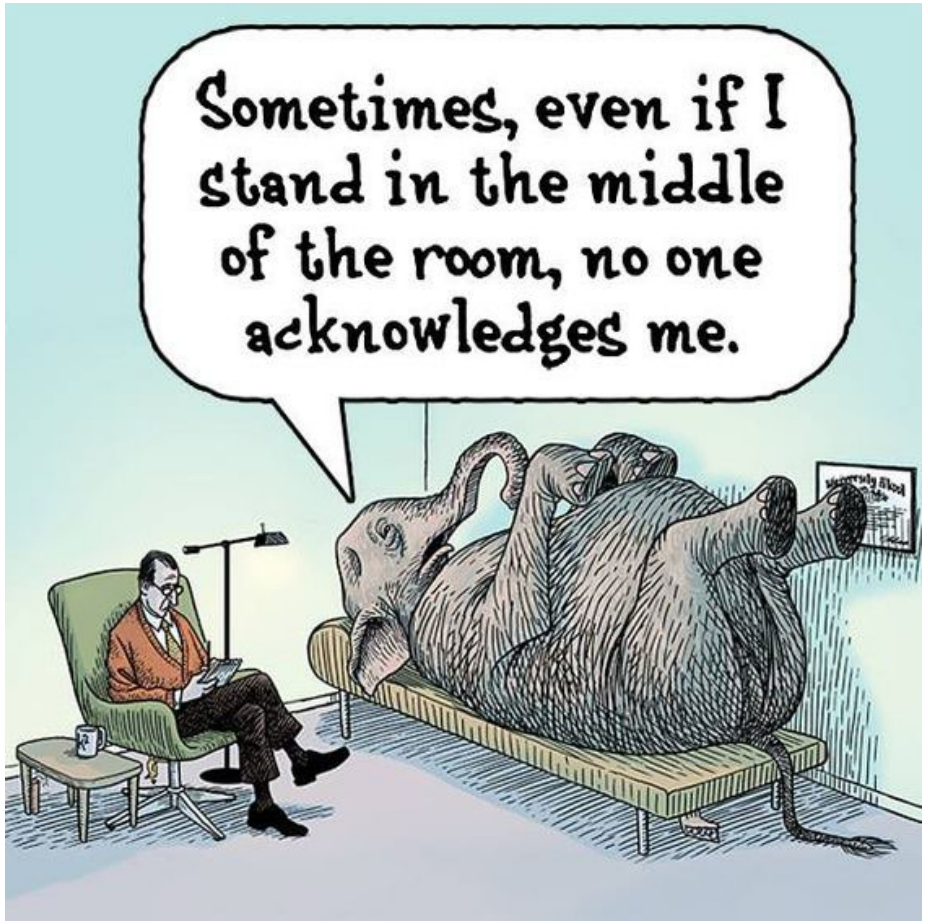


Satellite Data Product Validation

- *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.



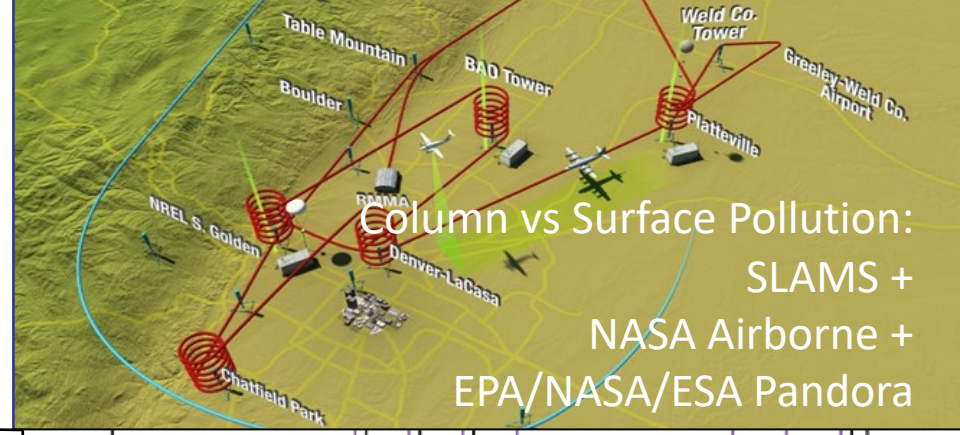
Two primary goals

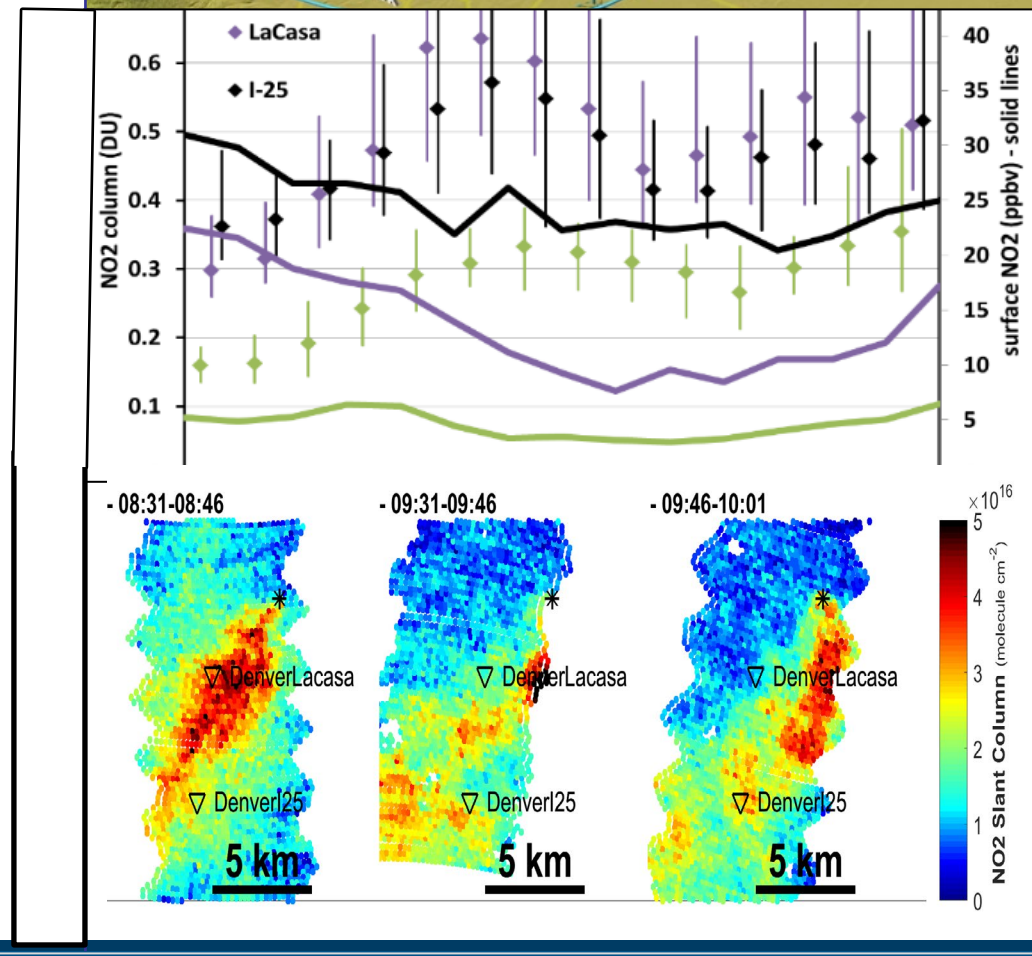
Systematically and routinely validate TEMPO data products over a variety of air quality and geographical regimes, covering scales relevant to neighborhood-scale air quality applications

Utilize remote sensing products as novel and highly valuable tools to better characterize air quality and meteorology within the conventional AQ management framework (e.g., trends analyses, process studies, chemical transport model evaluation)

Key Capacity Building Efforts associated (TEMPO) Satellite Validation

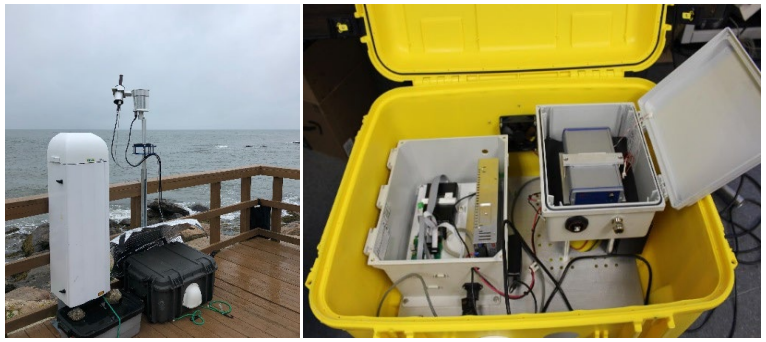
- **NASA DISCOVER-AQ mission 2011-2014 kick-started a new paradigm on measurement strategies** to connect satellite and surface observations, along with a decade+ effort to improve on emerging remote sensing technologies.
- **Field Campaigns such as KORUS-AQ, LMOS, LISTOS, MOOSE, TRACER-AQ have been a key driver in continued maturity** of remote sensing measurements and algorithms for the development of independent geophysical measurement for satellite validation:
  - Pandora Spectrometer
  - NASA airborne spectrometers (GCAS/GEOTASO)
  - Tropospheric Ozone Lidar Network
  - Associated retrieval algorithms including Planetary Boundary Layer Heights now being used by the Unified Ceilometer Network
- **EPA-ORD has played a key role in assisting NASA and ESA mature the pandora ground-based spectrometer** which now serves as the primary validation instrument for satellite data and adoption as a Fiducial Reference Measurement by EU Copernicus Program.



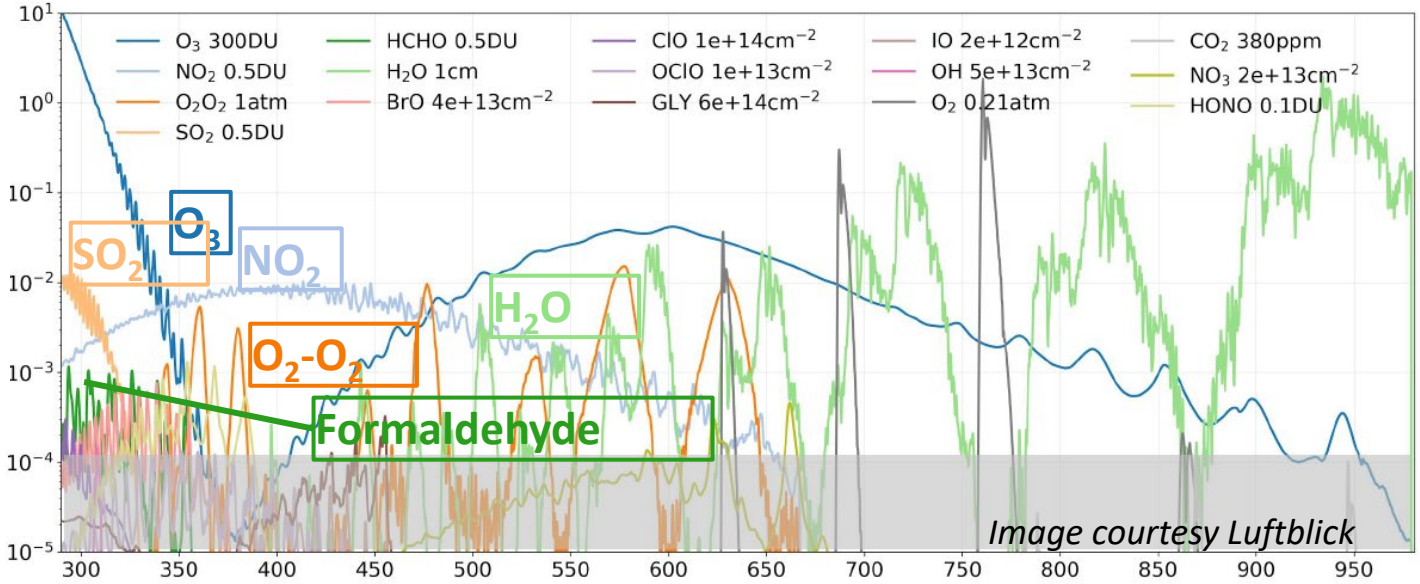


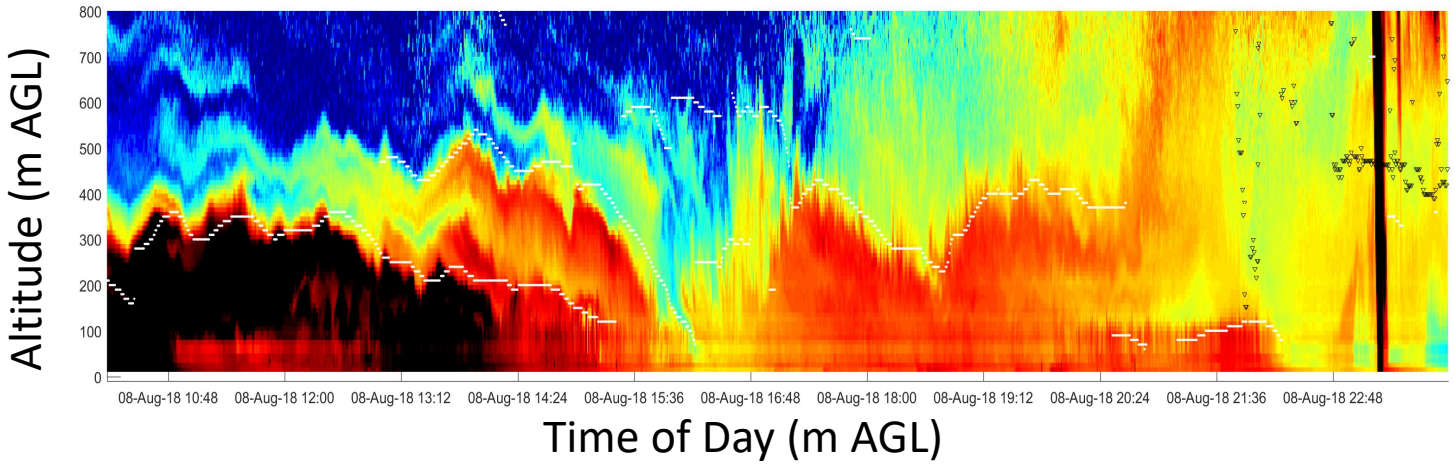
Fundamental Measurements for Atmospheric Remote Sensing Supporting ORD ACE Research related to Satellite Validation

Path-integrated gas absorption from spectrally resolved solar radiance measurements in the ultraviolet, visible or near infrared



LiDAR backscatter from aerosol and clouds provide information to infer atmospheric layering

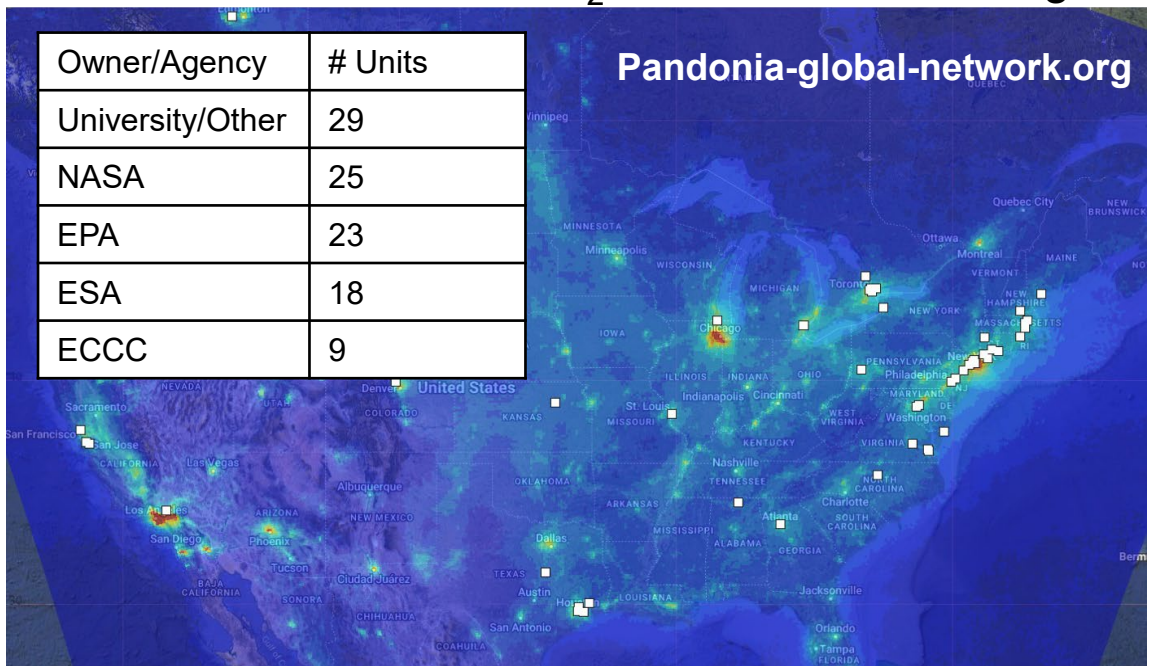




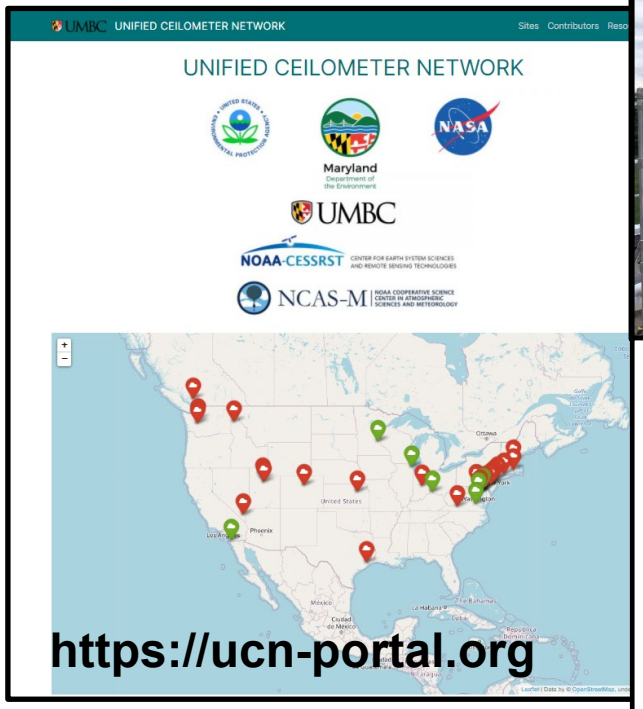
EPA is a key partners in transitioning remote sensing research measurements into operational networks in USA for use in TEMPO validation

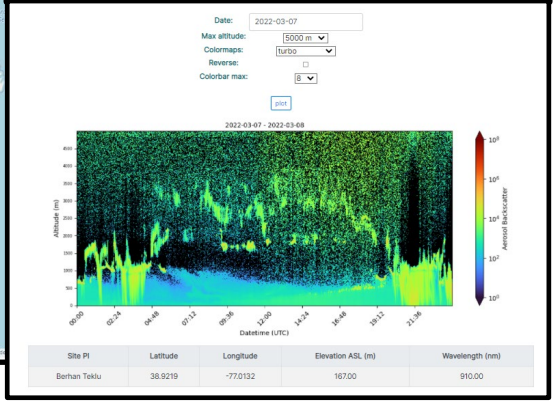
TROPOMI Column NO_2 2021 summer average

Owner/Agency	# Units
University/Other	29
NASA	25
EPA	23
ESA	18
ECCC	9



In North America both EPA and Environment and Climate Change Canada (ECCC) are collaborating with NASA the European Space Agency in building out ground-based Pandora spectrometer validation measurements.



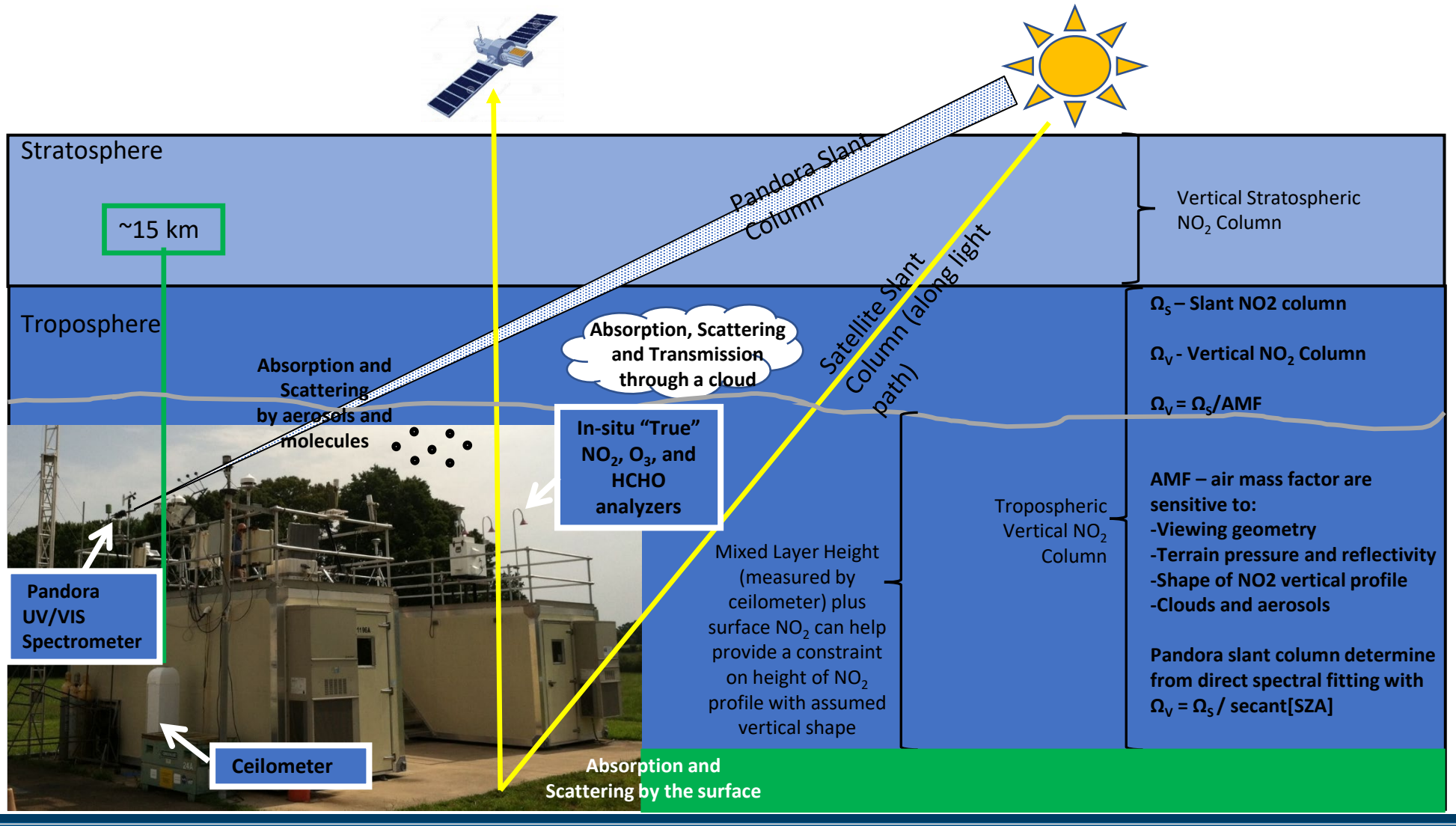


EPA/ORD led collaboration to systematize collection and analysis of Ceilometer aerosol backscatter profiles for planetary boundary layer heights and aerosol height determinations (Caicedo et al. 2020).

The combination of Pandoras, ceilometers and surface AQ measurements provide validation and evaluation data to understand satellite retrieval biases

VA Department of Environmental Quality, Hampton, VA Air Quality Site

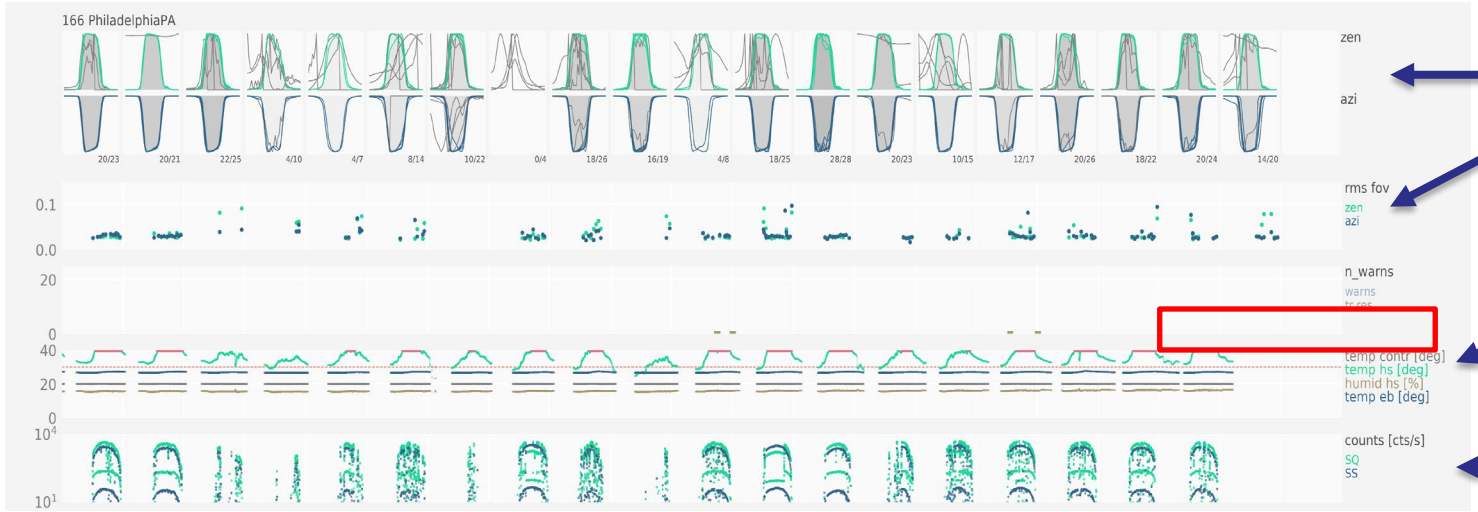
Graphical illustration of depicting how ground based remote sensing measurements can aid in satellite validation/.



Building QA Routine and Systematic Data Sets for TEMPO Validation (1)

Pandora/PGN Quality Assurance

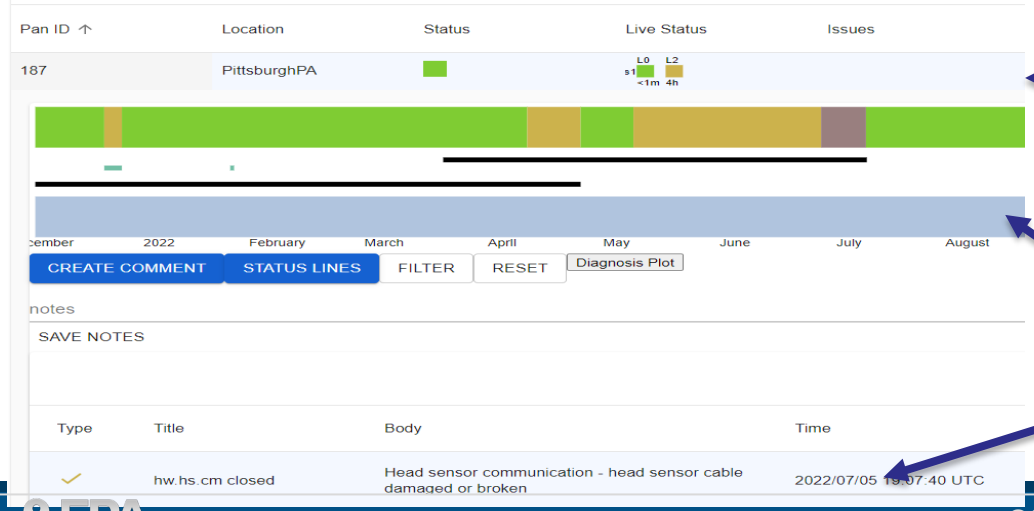
Ensuring High Quality Data involves Daily Checks. These checks ensure the Pandora is operating at full capacity with zero issues.



Ensures the FOV is unobstructed

Monitors the diagnosis are within tolerable levels

Signifies amount of light reaching spectrometer



Current Status

Operation History

Status of Issues

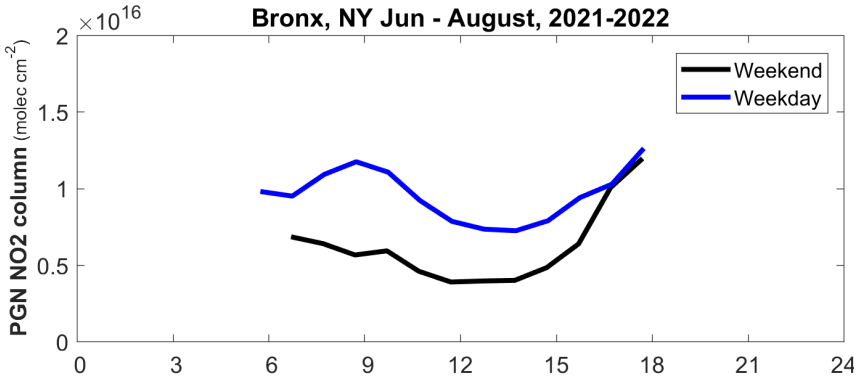
If a Daily Check sparks any concerns about the data, a detailed check is initiated.

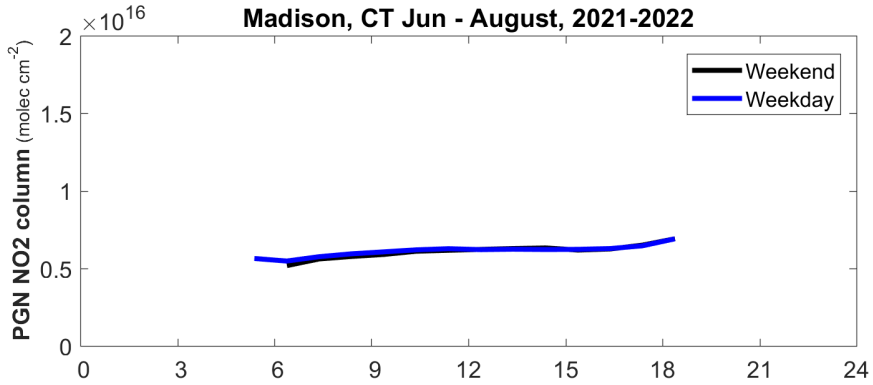
For example, the Red Box in the diagnosis section indicated high Temperature Levels. This requires a more detailed investigation.

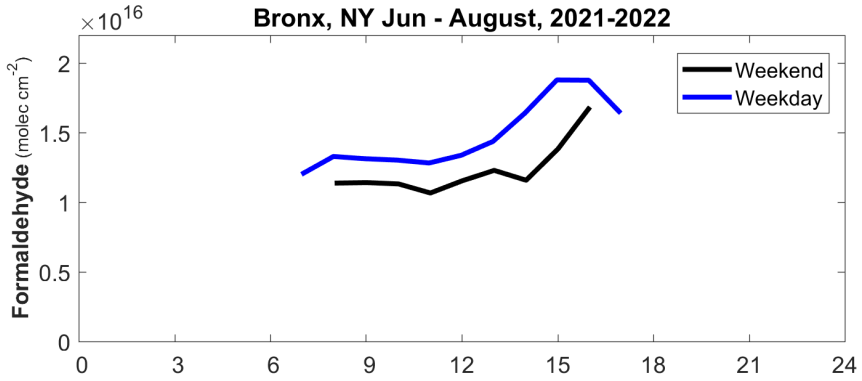
PGN/Pandora: A key TEMPO validation resource

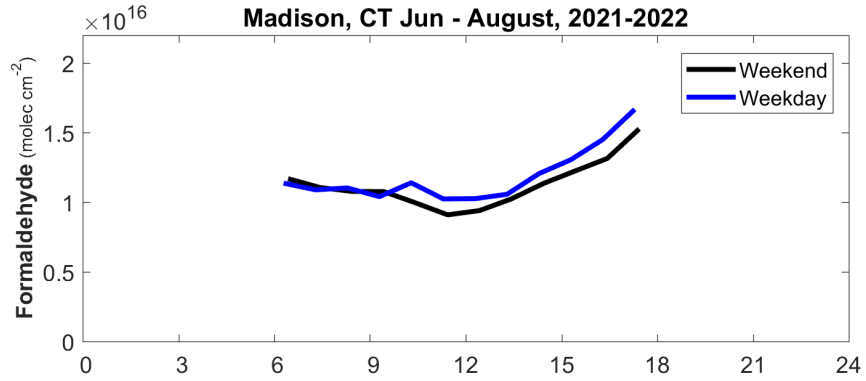
Preliminary data

- The PGN via Pandora spectrometers are making measurements of a geophysical variable never measured in an operational research network.
- Development of appropriate QA metrics is an on-going process.
- Preliminary data products are very promising and providing the first reveal of key trace gas column at high temporal frequencies.

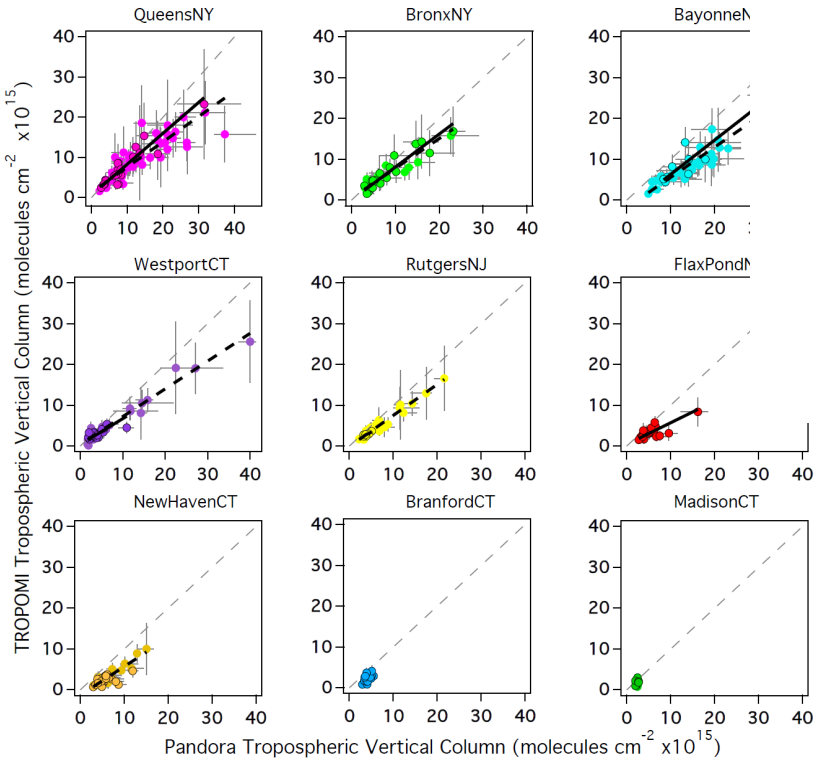




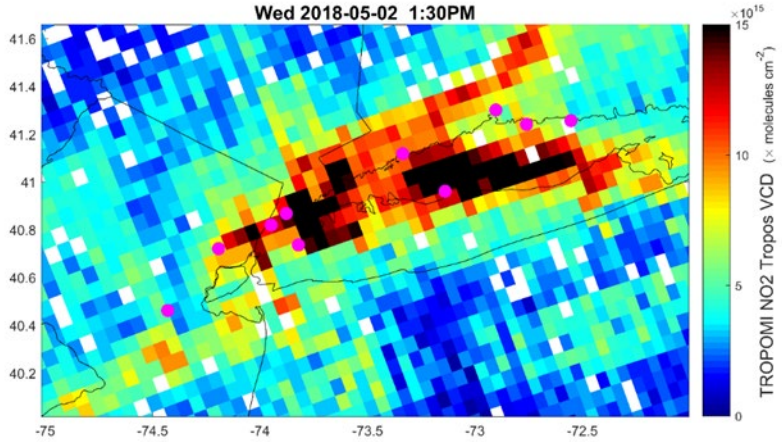




Examples: Pandora Long-Term Deployments provide a more Routine and Systematic Evaluation of Satellite NO_2 data



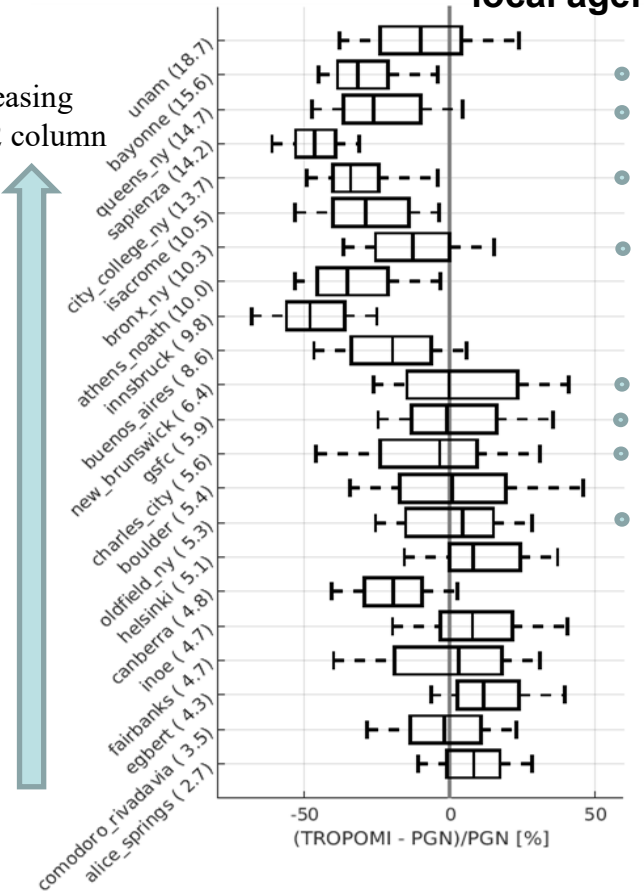
TROPOMI NO_2 – May 2, 2018



data sets from around the world to compare with TROPOMI **(Pandoras in the OTR)**

These types of comparisons can be used to refine TEMPO retrievals

EPA pandoras hosted by state and local agencies



Judd et al, Evaluating Sentinel-5P TROPOMI tropospheric NO2 column densities with airborne and Pandora spectrometers near New York City and Long Island Sound, *AMT,* 2020.

Verhoelst et al, : Ground-based validation of the Copernicus Sentinel-5p TROPOMI NO_2 measurements with the NDACC ZSL-DOAS, MAX-DOAS and Pandonia global networks, *AMT,* 2021.

TEMPO Validation - Geophysical Data Products

Product Validation Maturity level are likely to be adopted from the NOAA GOES-R program for the aerosol products:

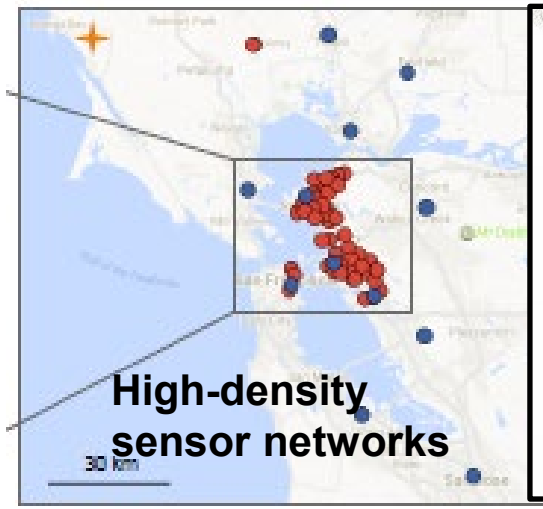
- Beta: the product is minimally validated and may still contain significant errors; based on product quick looks using the initial calibration parameters.

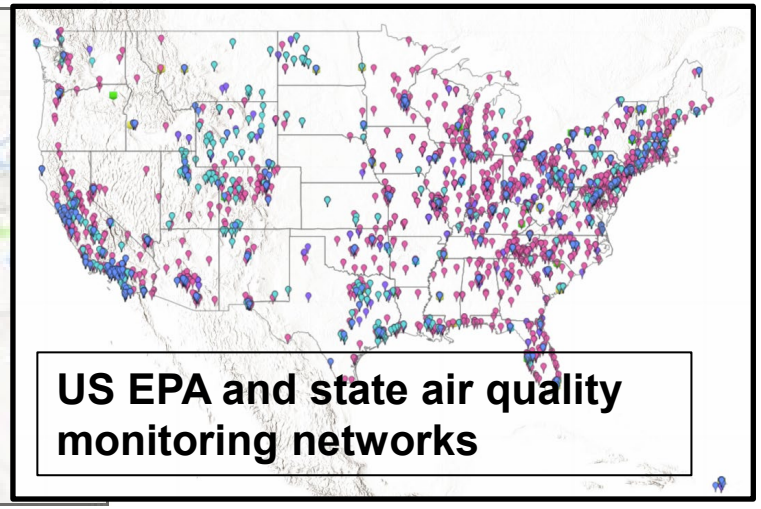
- Provisional: product performance has been demonstrated through a large, but still (seasonally or otherwise) limited, number of independent measurements. The analysis is sufficient for limited qualitative determinations of product fitness-for-purpose, and the product is potentially ready for testing operational use.

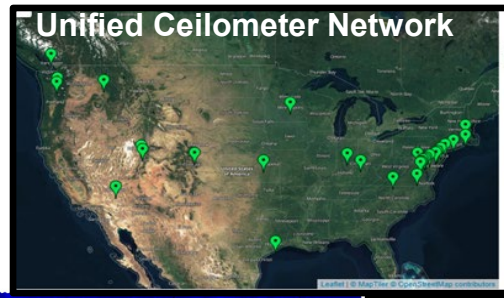
- Full: product performance has been demonstrated over a large and wide range of representative conditions, with comprehensive documentation of product performance, including known anomalies and their remediation strategies. Products are ready for operational use.

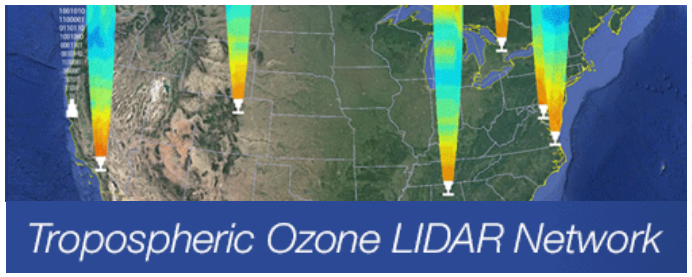
Wrap-Up

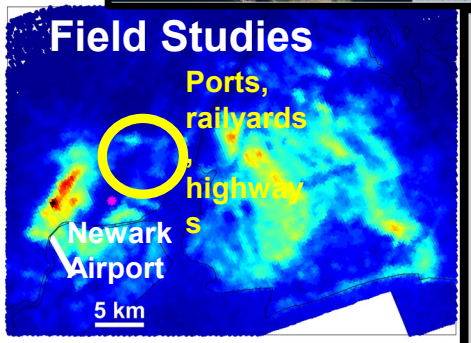
- A concerted effort is developing for validation of TEMPO data products which is based on leveraging both operational and research air quality monitoring systems.
- TEMPO validation efforts will provide routine and systematic(on-going) validation through the PGN and more complex (episodic) validation via planned science campaigns with focus on satellite data and local air quality.
- For the first time, validation measurements for a satellite mission are being integrated within the existing air quality network.
- While the GAO report did not highlight validation as a key step in facilitating greater use of satellite data products, the emerging TEMPO validation paradigm is focused on providing information on the reliability and accepted uses of data products.

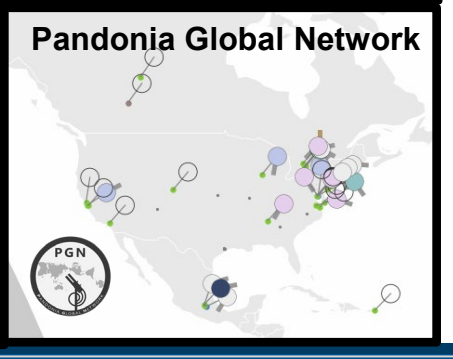












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Thank You!