

weather.msfc.nasa.gov/tempo/



Tropospheric Emissions:
Monitoring of Pollution
Hourly Measurement of Pollution



Smithsonian Astrophysical
Observatory



<http://tempo.si.edu/>



TEMPO Mission Update

HAQ Applications Program Review

Jackson, WY

April 24, 2024

Aaron Naeger

& TEMPO Team

TEMPO Mission Applications Lead
NASA Marshall Space Flight Center

U.S. Government sponsorship acknowledged.



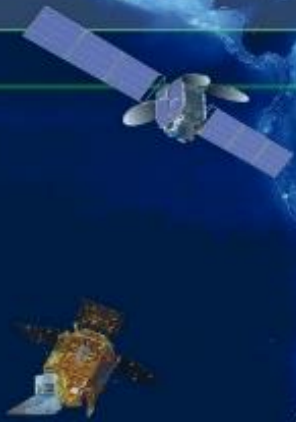


TEMPO Quick Facts



Launched April 2023

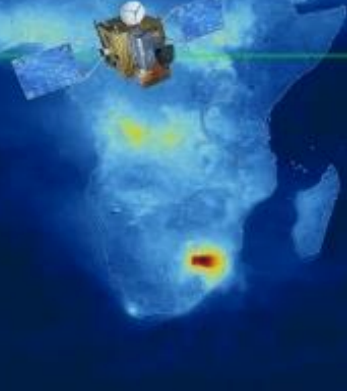
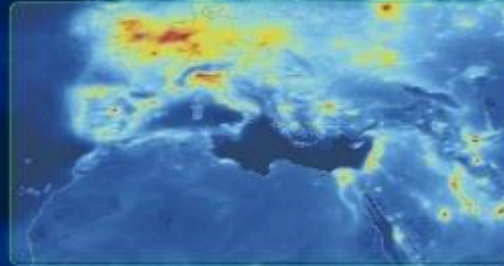
TEMPO (hourly)
Tropospheric Emissions:
Monitoring of Pollution



Sentinel-5P (once per day)

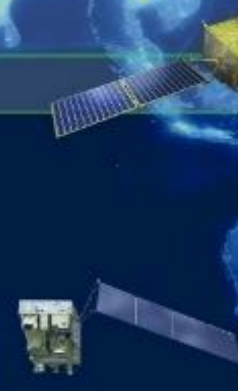
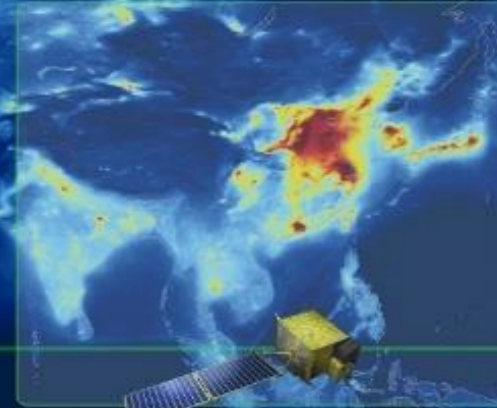
Launch 2025

Sentinel-4 (hourly)



Launched Feb 2020

GEMS (hourly)
Geostationary Environmental
Monitoring Spectrometer



GaoFen-5 (once per day)

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erosols.

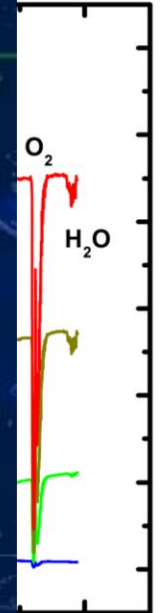


Image Credit: NASA LaRC

Wavelength (nm)

- Cap
- tropo
- Lau
- Intel
- Part
- hour

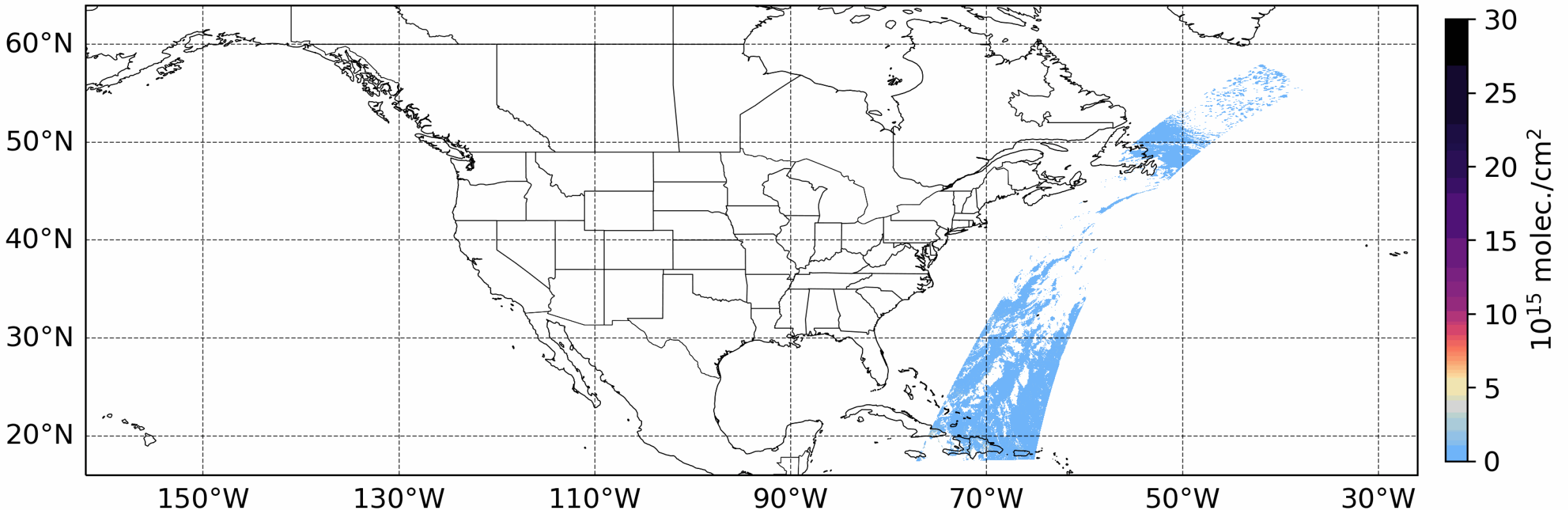


TEMPO Nominal Operations - Nov 1, 2023



Provisional Data!

TEMPO Tropospheric NO₂ 20231101 1141 UTC



TEMPO performs **standard (nominal)** East-West hourly daytime scans across the Field of Regard (FoR) over North America and **optimized (sub-hourly)** scans over daylight portions of the FoR during the early morning and late afternoon.



Mission Phases & Operational Timeline

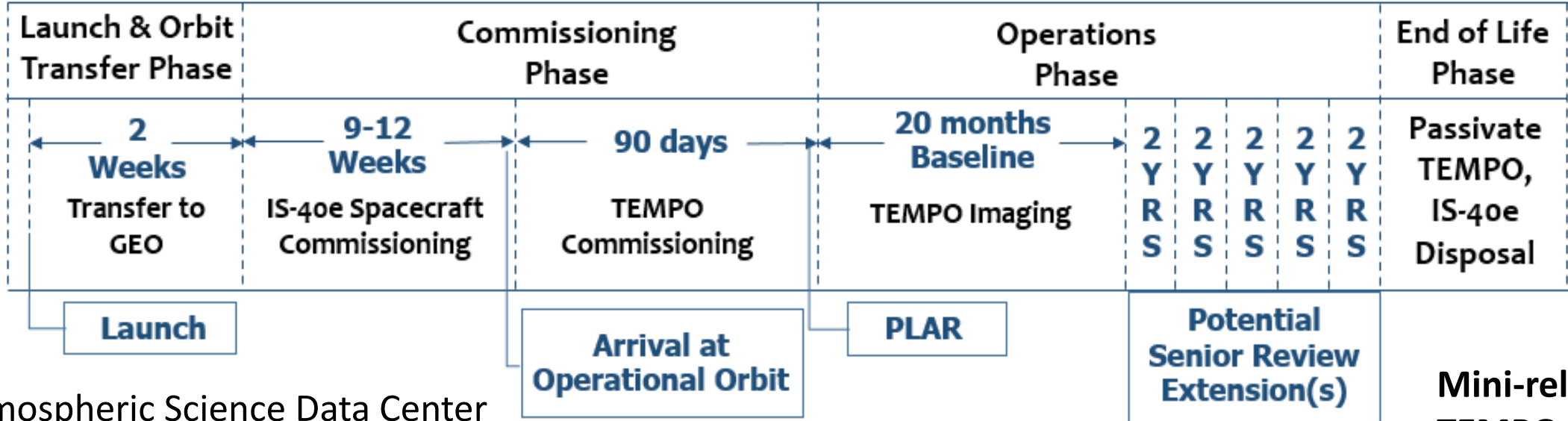


Launched:
April 7, 2023

Powered On:
June 7

Commissioning:
June 7 – Oct. 18

Nominal Operations:
Oct. 19 – June 2025



Mini-release of TEMPO data



- ❑ **First light:** July 31 – August 2 with first Earth imaging on August 2
- ❑ Passed Post Launch Acceptance Review (PLAR), **started nominal operations October 19**
- ❑ Preliminary, limited release of TEMPO data products in early February
- ❑ Public release of baseline level 2 & 3 products at ASDC: **May 6 (tentative)**
- ❑ Archive of baseline “offline” products will start from commissioning phase in Aug 2023
- ❑ **Initial public release of NRT products at ASDC ~March 2025**
- ❑ Baseline mission length: 20 months (Oct 2023 – June 2025) w/ extension via NASA’s Senior Review



TEMPO L2+ Products: Baseline + SNWG TEMPO NRT



Level	Product	Key Variables	Resolution (km ²) **	Frequency/ Size
L2 *	Cloud	Cloud Fraction, Cloud Pressure	2.0 x 4.75	Per granule, ~ 6 min 40 sec 9 granules makeup the hourly TEMPO FoR SNWG: Satellite Needs Working Group
*	O ₃ (Ozone) profile	O₃ profile, Tropospheric O₃ column, Total O₃ column, Stratosphere O₃ column, Cloud Fraction, O₃ a priori, O₃ Averaging Kernel	>= 8.0 x 4.75	
*	Total O ₃	Total column O₃, Cloud Fraction, Aerosol Index	2.0 x 4.75	
*	NO₂ (Nitrogen Dioxide) NRT	Tropospheric Vertical Column Density (VCD), Total VCD, Slant Column Density (SCD), Cloud Fraction, Air Mass Factor (AMF), Data Quality Flag	2.0 x 4.75	
*	HCHO (Formaldehyde) NRT	Total VCD, SCD, Cloud Fraction, AMF, Data Quality Flag	2.0 x 4.75	
	Aerosol NRT	UV & VIS Aerosol Optical Depth (AOD), Aerosol Optical Centroid Height (AOCH), Aerosol Absorption Index (AAI)	8.0 x 4.75 (TBD)	
L3 *	Same as L2 (Gridded)	Same as L2	0.02° x 0.02°	Per scan, hourly & sub-hourly

**
Center of Field of Regard
33.7°N
91.7°W

Baseline products: Latency 3 - 6 hours (except O₃ profile ~24 hours) – **Public release date May 6* (tentative)**
Near real-time (NRT) products: Latency 2 - 3 hours – **Public release date March 2025**



TEMPO L2+ Products: **SNWG NRT / Enhanced**



* List of products with no formal release date yet, but are being planned for TEMPO

Level	Product	Key Variables	Resolution (km ²) **	Frequency/ Size
L2	C ₂ H ₂ O ₂ (Glyoxal)	Total VCD, SCD, Cloud Fraction, AMF, Data Quality Flag	2.0 x 4.75	Per granule, ~ 6 min 40 sec
	H ₂ O (Water Vapor)		2.0 x 4.75	
	BrO (Bromine)		2.0 x 4.75	
	SO₂ (Sulfur Dioxide) NRT	VCD (Total, Planetary Boundary Layer, & Lower / Middle / Upper Tropospheric, Lower Stratospheric), SCD	2.0 x 4.75	9 granules makeup the hourly TEMPO FoR
	TEMPO/GOES-R Synergistic	Aerosol, Fire / Hotspot, Cloud & Mask, Lightning, Snow / Ice, Precipitable Water, etc.	2.0 x 4.75	
	UVB	UV irradiance, erythemal irradiance, UVI	2.0 x 4.75	Hourly, scan
L3	Same as L2 (Gridded)	Same as L2	0.02° x 0.02°	Hourly, scan

**
Center of Field of Regard
33.7°N
91.7°W

List of products **being considered** for TEMPO NRT/Enhanced Productions starting in 2025



Data Access and Visualization Tools

Langley ASDC (Atmospheric Science Data Center) is the DAAC (Distributed Active Archive Center) for TEMPO

Baseline TEMPO data format: NetCDF

TEMPO data will be publicly available via Earthdata Search

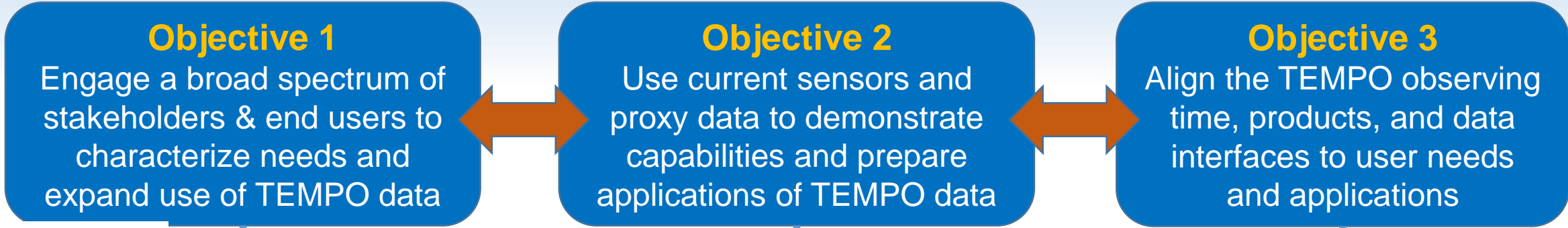
TEMPO imagery will be available in Worldview

TEMPO data in ArcGIS including development of **dashboard at SPoRT**

EPA RSIG3D Gateway



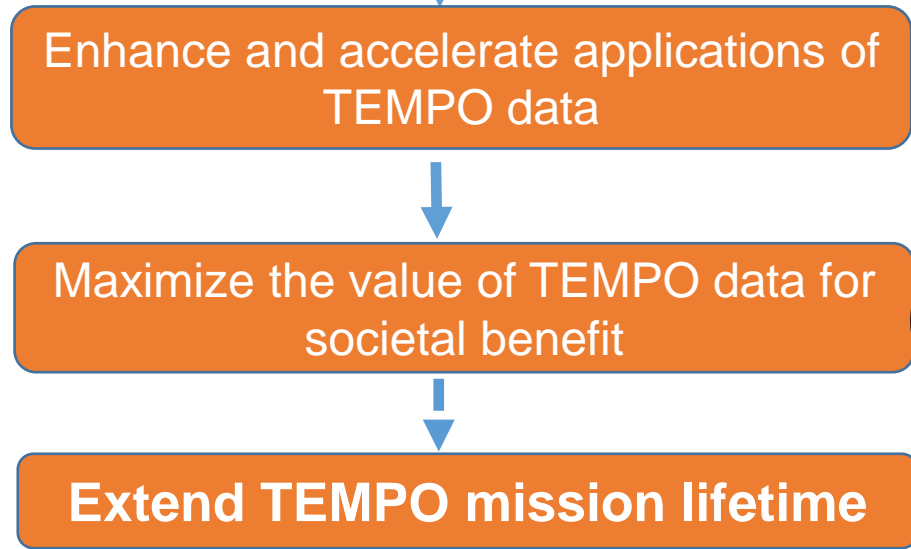
TEMPO Early Adopters to Community of Practice



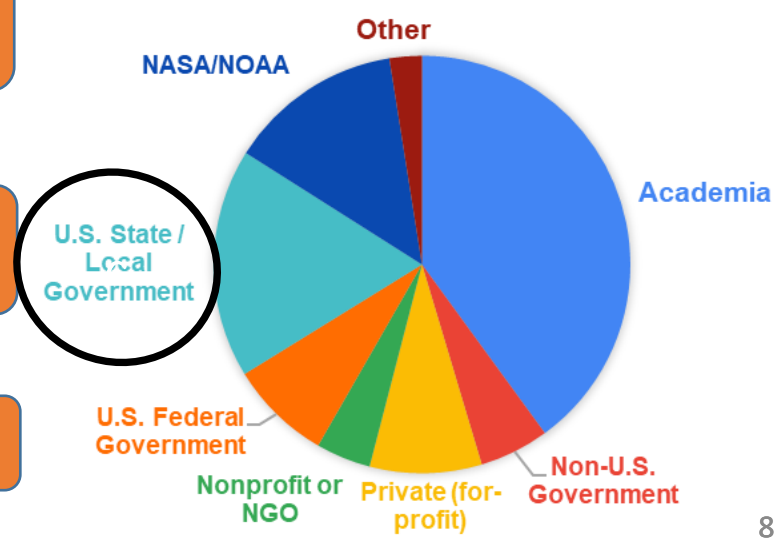
~ 620 Early Adopters (as of April 2024), including 100+ federal (EPA), state, local, & tribal air agencies

Major outcomes from program:

- (1) Facilitated inclusion of TEMPO NRT products into pipeline
- (2) Expanded breadth of application concepts



EARLY ADOPTERS BY AFFILIATION





TEMPO Applications & Special Operations



- ❑ Up to 25% of TEMPO's observing time can be devoted to **special operations** over a slice of the FoR (e.g., ≤ 10 min frequency)
- ❑ Focus areas include **air quality hazards** (e.g., wildfires, volcanoes), **chemistry studies** (e.g., lightning NO_x), & field campaigns
- ❑ **Special operations on hold until re-evaluation of TEMPO instrument in May**

Subset of special experiments

- ❖ **2023 Coastal Texas Air Quality Observations**
- ❖ **Formation of ozone along Colorado Front Range**
- ❖ High Resolution Scanning over the New York City area
- ❖ Sub-city scale AQ forecasting system from data fusion
- ❖ **AQ Impacts from Oil & Gas Activities in West U.S.**
- ❖ Monitoring volcano emissions and plume transport
- ❖ **Observing wildland fires and air quality impacts**
- ❖ **Lightning NO_x**



Green Paper!



Monitoring Tropospheric Ozone

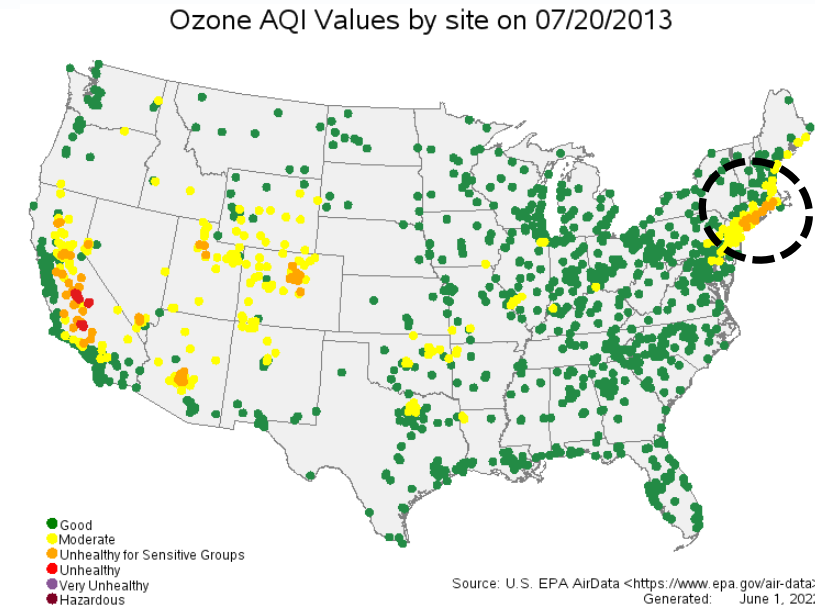
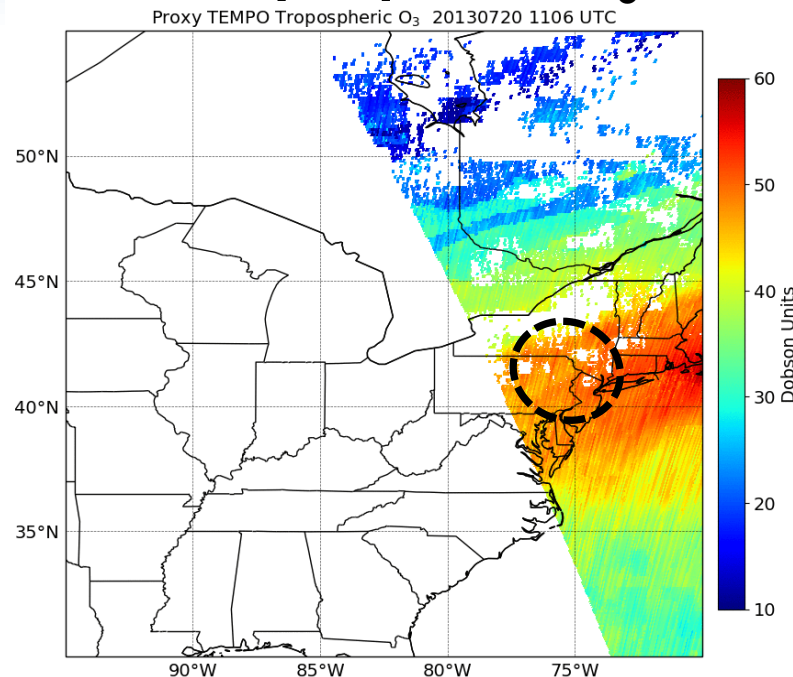
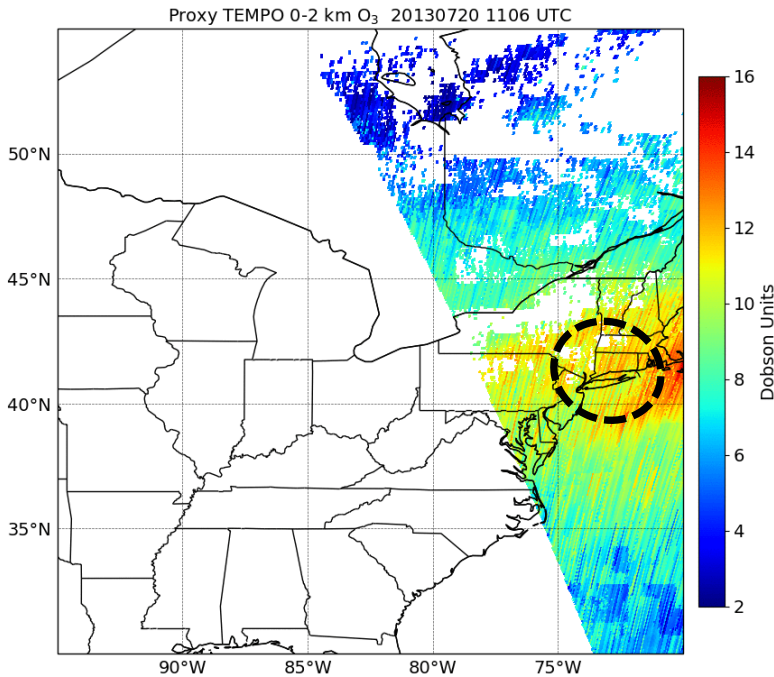


Proxy Simulated Data

20 July 2013

0-2 km (PBL) O₃

Tropospheric O₃



- ❑ TEMPO instrument has sensitivity to O₃ in the lower troposphere
- ❑ O₃ profile will offer new capabilities to track and predict (assimilation) O₃ concentrations and transport from the stratosphere to the planetary boundary layer (PBL)
- ❑ Unprecedented monitoring of **O₃ pollution within the layer of air where people live and breathe**
- ❑ **TEMPO O₃ data will help fill the gaps in surface monitor coverage, large gaps in west region**

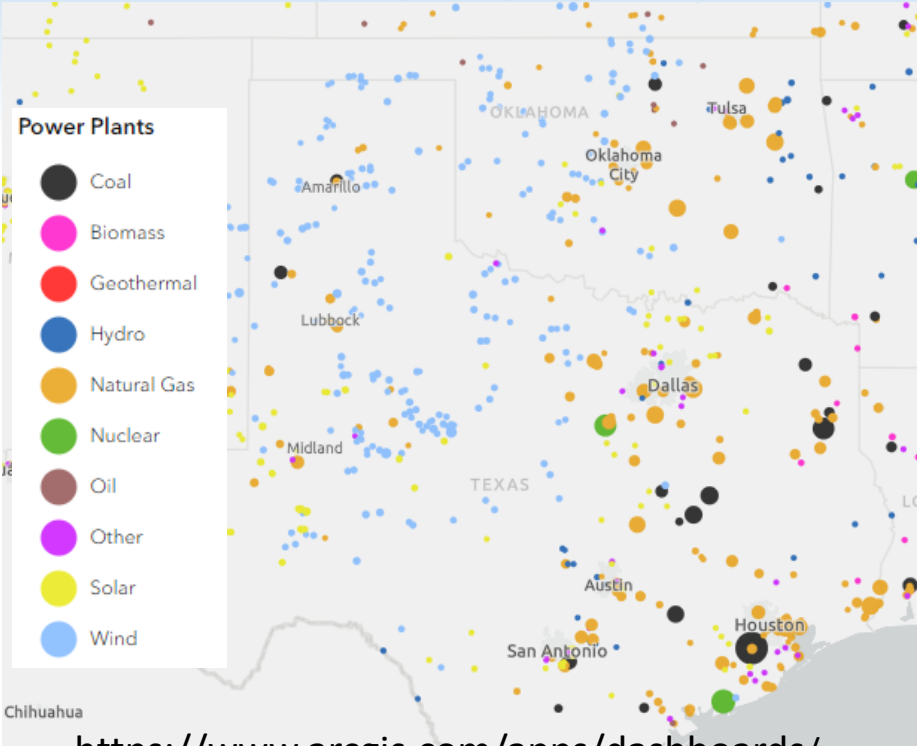


Texas Zoom on Nov 1, 2023

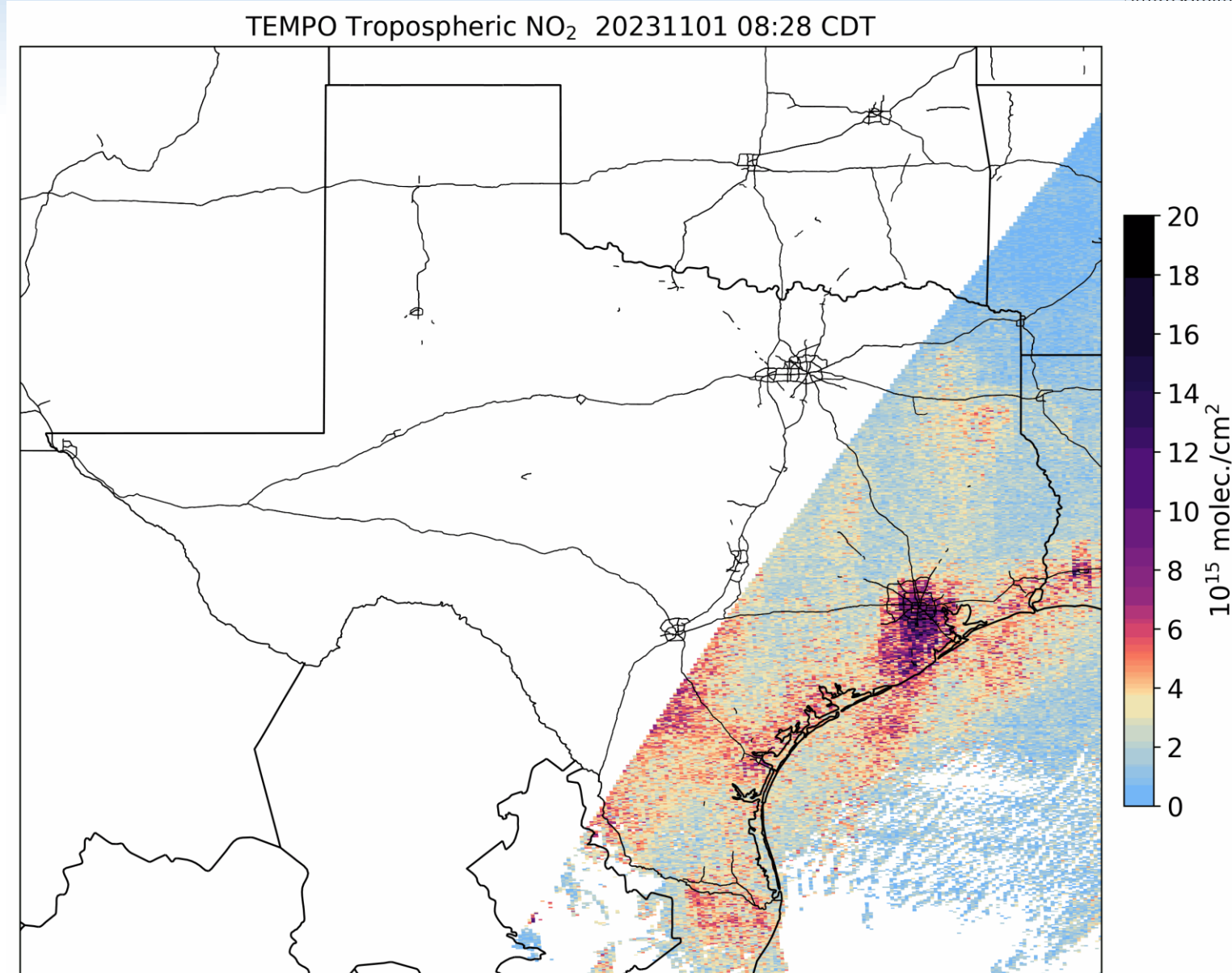
Provisional Data!



Power Plants



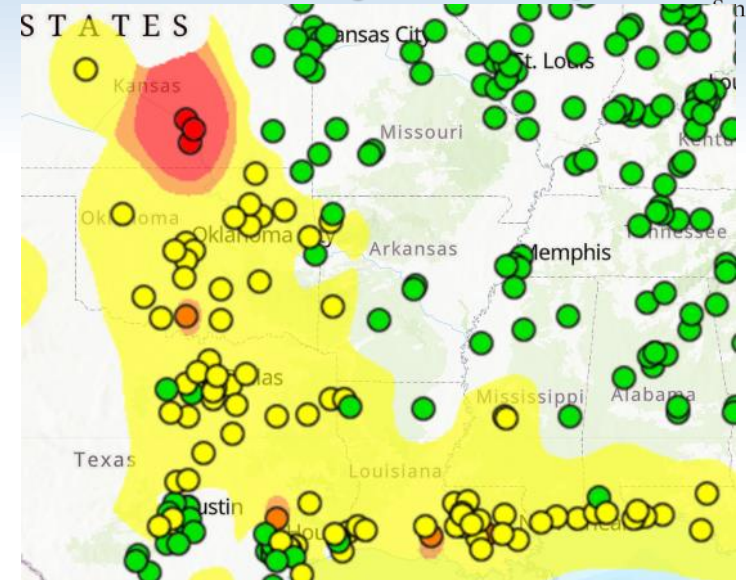
<https://www.arcgis.com/apps/dashboards/>



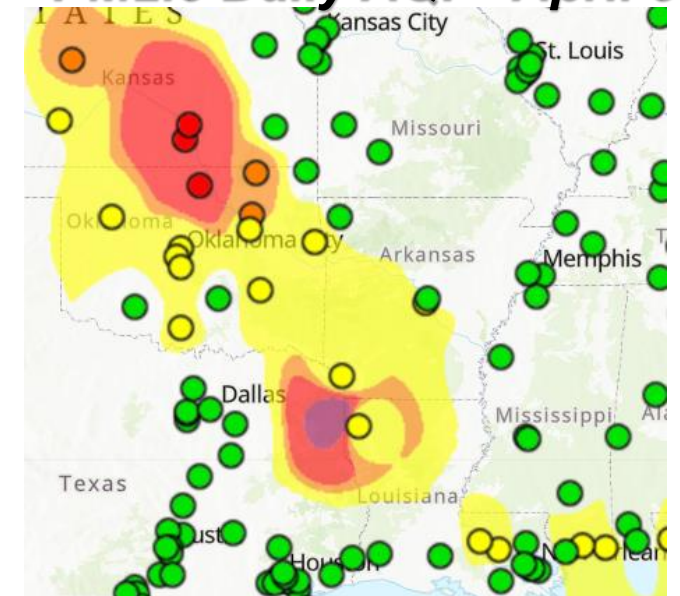
- A mostly clear day across Texas
- TEMPO captured high NO₂ from cities, traffic corridors, power plants, oil and gas fields, and fires

Prescribed burns - April 2024

Ozone Daily AQI - April 5



PM2.5 Daily AQI - April 5



April 4

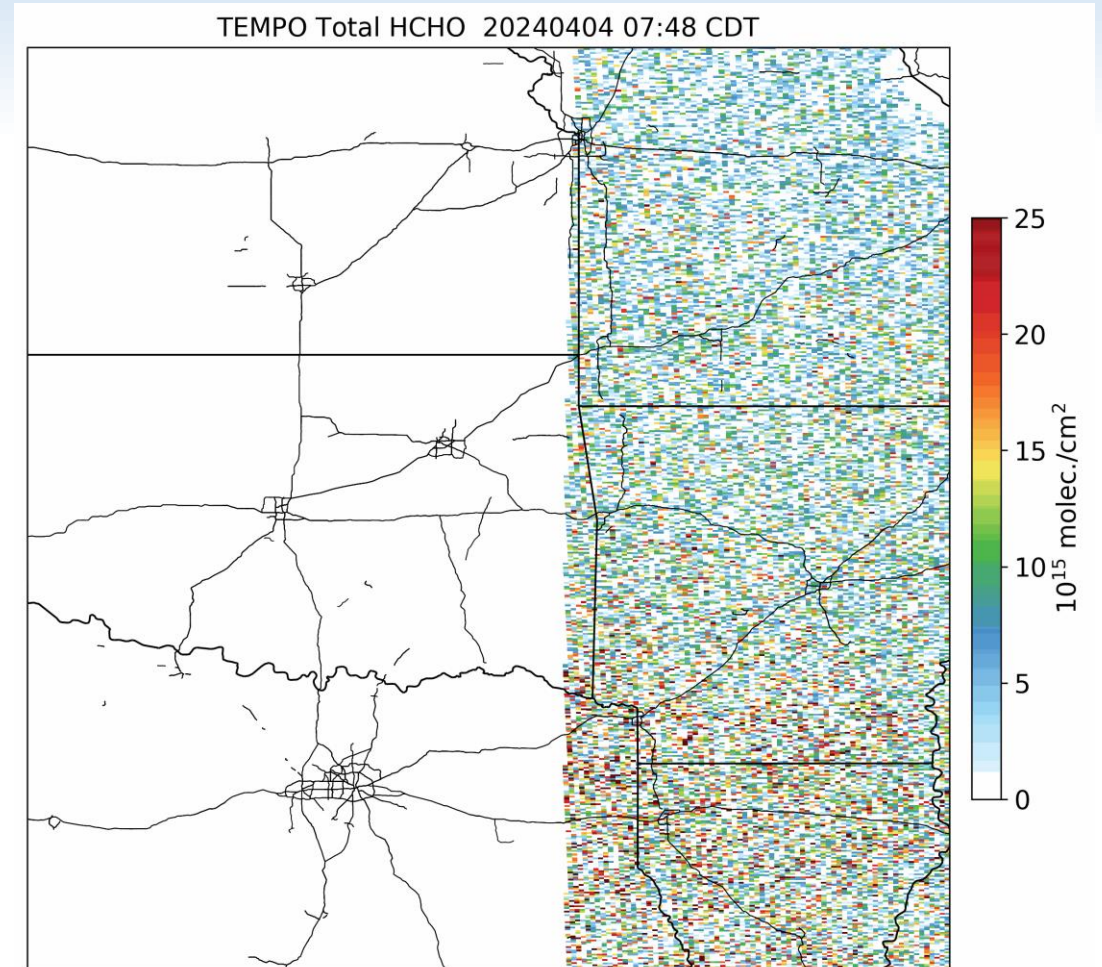
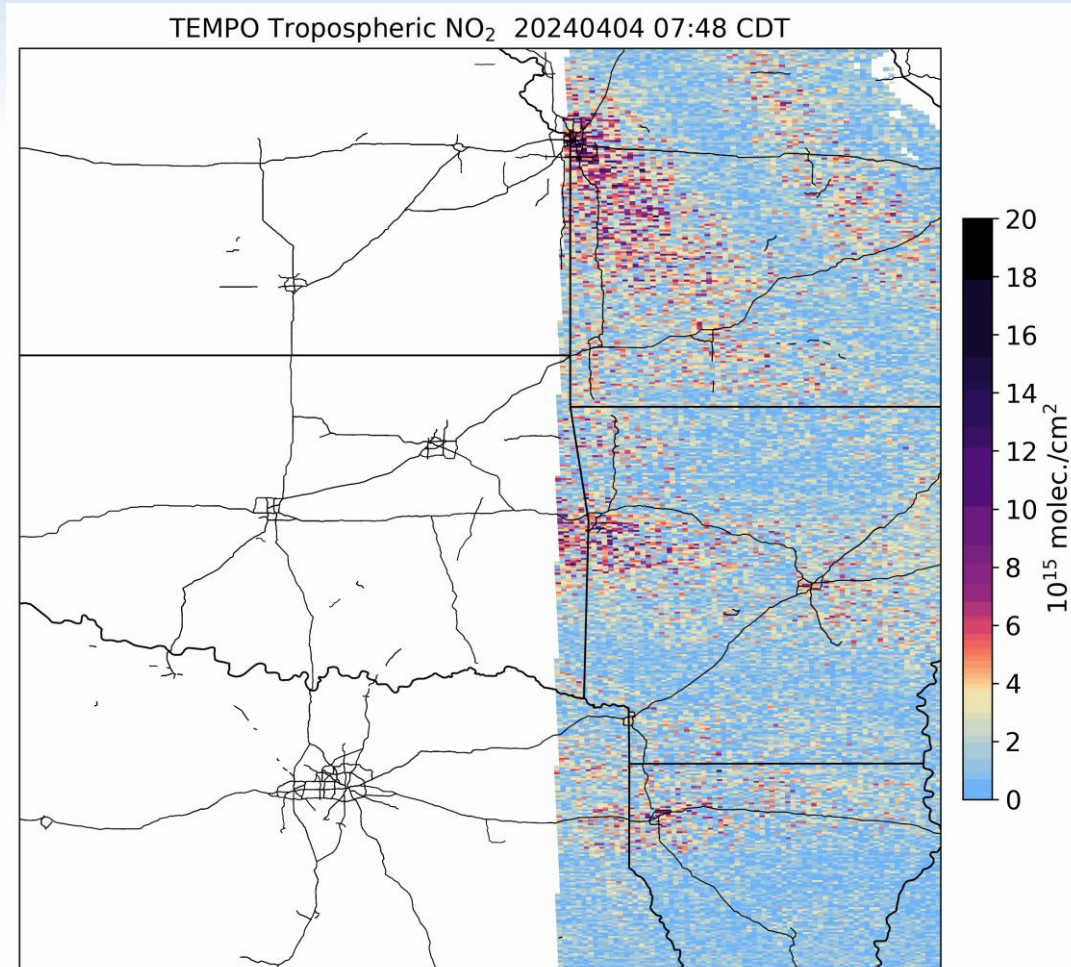
MODIS Terra

MODIS Aqua

- ❑ Controlled burns done across midwestern and southern U.S.
- ❑ Largest burns occurred across Kansas on April 4 and continued to impact the state for several days
- ❑ Both ozone and PM2.5 reached unhealthy levels during the event, especially on April 5

Prescribed burns - April 2024

Provisional Data!



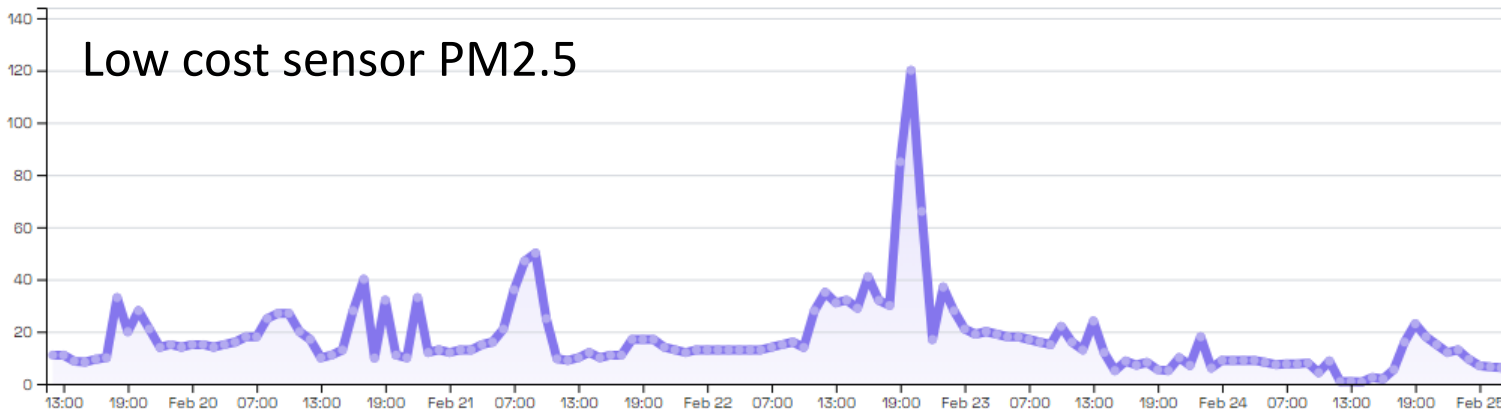
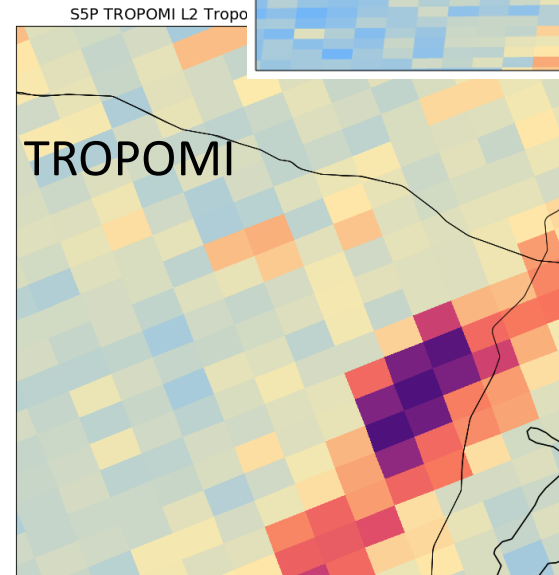
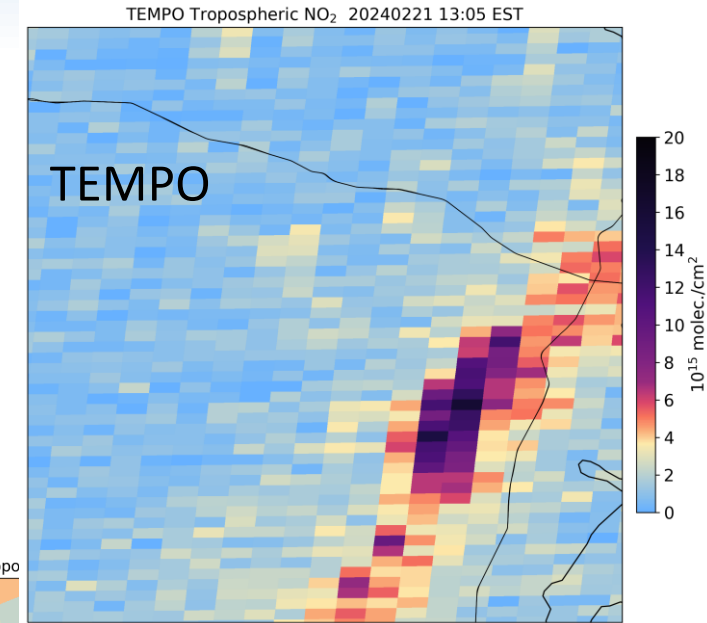
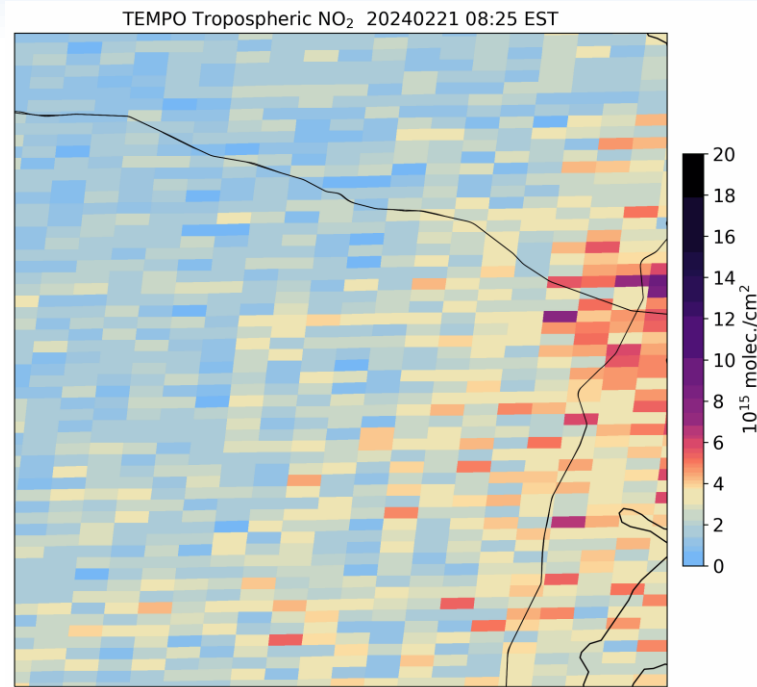
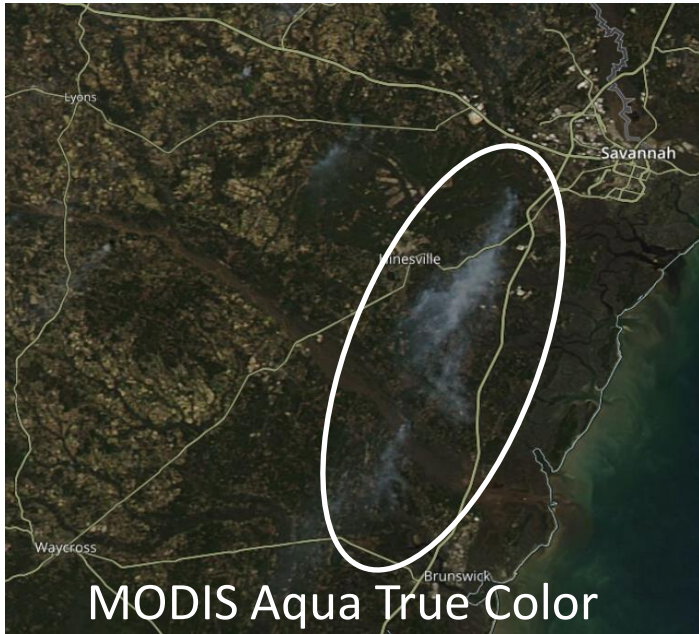
- ❑ TEMPO observed large NO₂ plumes associated with the smoke transport on April 4
- ❑ Distinct HCHO signals within the smoke plumes also observed



Fort Stewart Prescribed Burn



MSFC and TEMPO coordinated with Forest Service on a prescribed burn in Fort Stewart, GA.





Wyoming Zoom

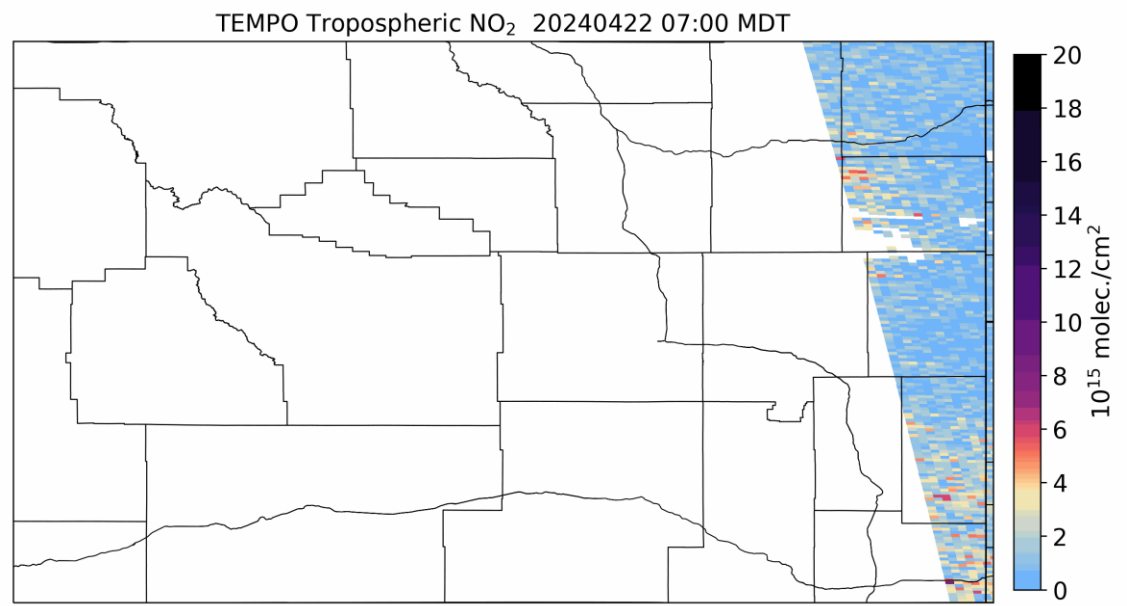
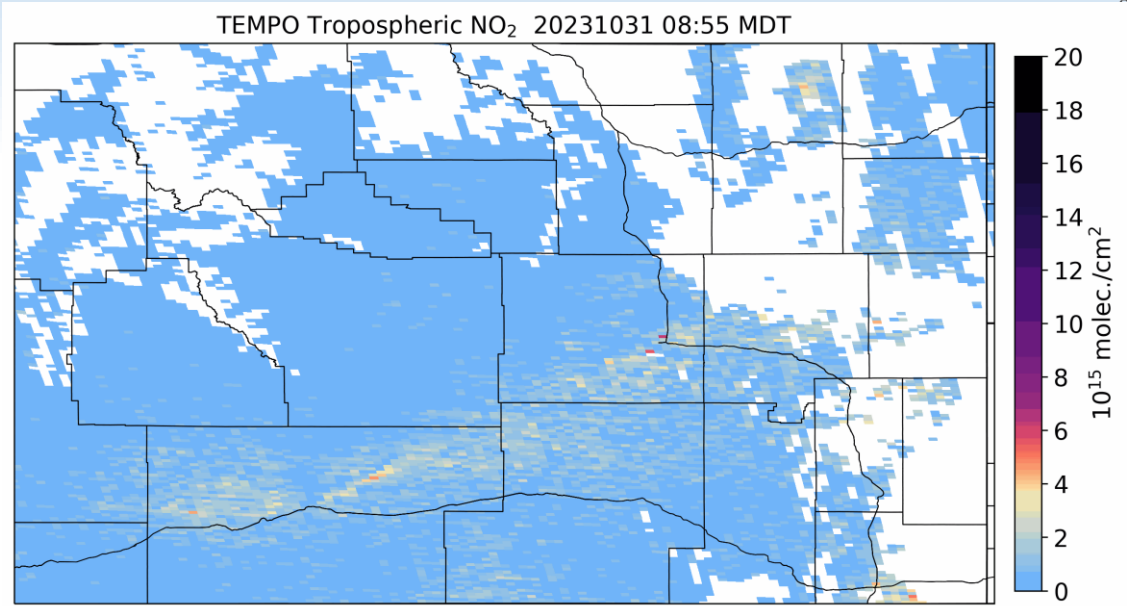
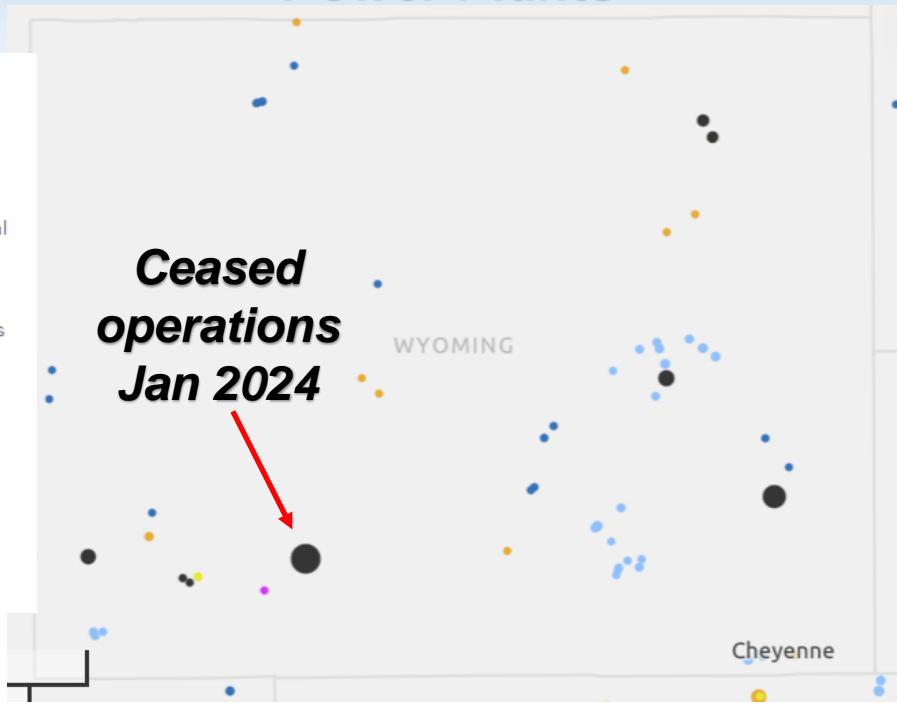
Provisional Data!



Power Plants

Power Plants

- Coal
- Biomass
- Geothermal
- Hydro
- Natural Gas
- Nuclear
- Oil
- Other
- Solar
- Wind



- Wyoming is the top coal producing state
- NO₂ plumes from power plants and oil and gas fields observed by TEMPO
- TEMPO observed NO₂ plumes from coal-fired power plant in southern WY
- NO₂ plumes from plant no longer apparent after ceasing operations in January 2024



TEMPO Data Coming Soon!



@NaegerAaron

aaron.naeger@nasa.gov



- ❑ TEMPO level 2 and 3 NO₂, HCHO, total O₃, and O₃ profile products are targeted for public release on May 6 (tentative)
 - NO₂, HCHO, and total O₃ products are currently Version 2 status which will be upgraded to Version 3 for public release date
 - O₃ profile will be a degraded UV-only retrieval version of the baseline product (UV-VIS retrieval version will be released later)
- ❑ The TEMPO team is working hard to validate and further refine the TEMPO products prior to public release
- ❑ Planning a training event for TEMPO data this summer or fall
- ❑ TEMPO-GEMS Joint Science Team Workshop from Aug 26-30 in Hawaii

Delivering Revolutionary Satellite Data with NASA's Tropospheric Emissions: **Monitoring of Pollution (TEMPO) Mission**

By Aaron R. Naeger, Laura Judd, Xiong Liu, Kelly Chance, Caroline R. Nowlan, and Gonzalo González Abad

This article introduces the revolutionary TEMPO—Tropospheric Emissions: Monitoring of Pollution—instrument, including the latest mission updates, data products, early results, and air quality management applications.

