

weather.msfc.nasa.gov/tempo/



Tropospheric Emissions:  
Monitoring of Pollution  
*Hourly Measurement of Pollution*



Smithsonian Astrophysical  
Observatory



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



# The NASA TEMPO Mission: Hourly Daytime Air Pollution Observations for Enhanced Health & Air Quality Applications

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& TEMPO Team

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U.S. Government sponsorship acknowledged.

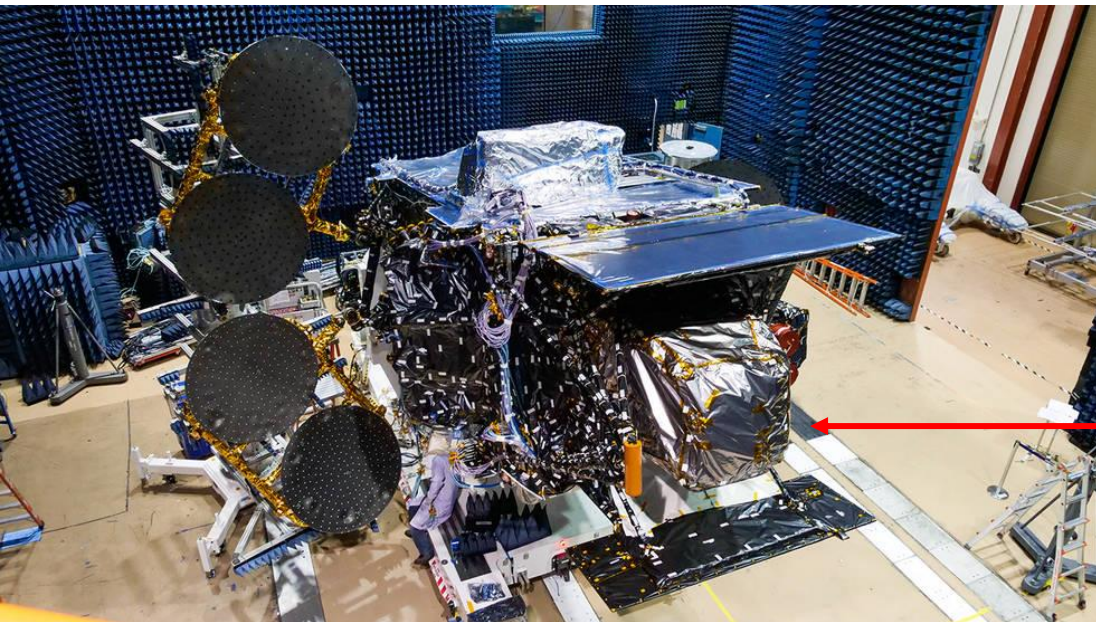


AMERICAN METEOROLOGICAL SOCIETY

104TH ANNUAL MEETING  
28 JANUARY-1 FEBRUARY 2024  
BALTIMORE, MD & ONLINE



# TEMPO Mission Status, Timeline, & Products



Intelsat 40E satellite carrying  
TEMPO instrument

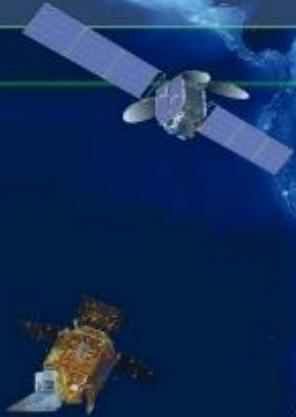


# TEMPO Quick Facts



Launched April 2023

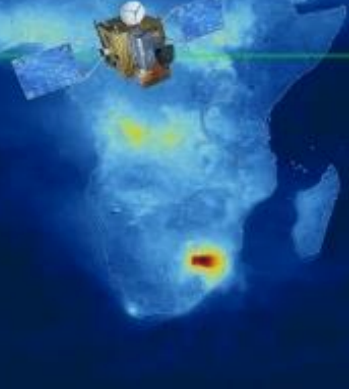
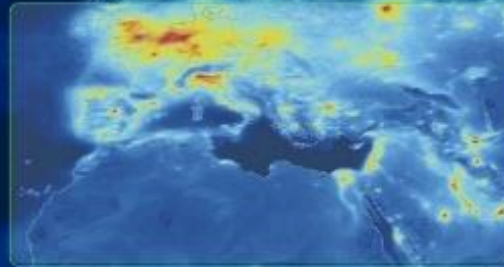
**TEMPO** (hourly)  
Tropospheric Emissions:  
Monitoring of Pollution



**Sentinel-5P** (once per day)

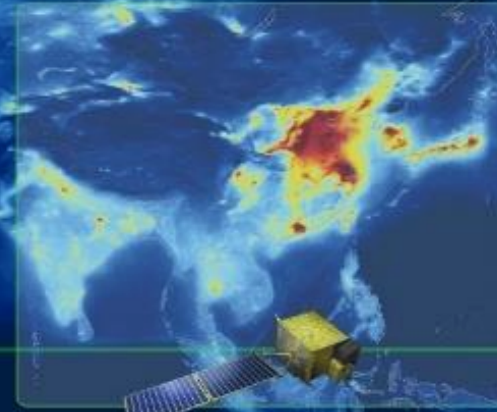
Launch 2024

**Sentinel-4** (hourly)



Launched Feb 2020

**GEMS** (hourly)  
Geostationary Environmental  
Monitoring Spectrometer



**GaoFen-5** (once per day)

Equator



Image Credit: NASA LaRC

Averaging Kernels (Norm. to 1 km)    Averaging Kernels (Norm. to 1 km)

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# TEMPO L2+ Products: Baseline + SNWG TEMPO NRT



Level	Product	Key Variables	Resolution (km <sup>2</sup> ) **	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
	O <sub>3</sub> (Ozone) profile	<b>O<sub>3</sub> profile, Tropospheric O<sub>3</sub> column, Total O<sub>3</sub> column, Stratosphere O<sub>3</sub> column, Cloud Fraction, O<sub>3</sub> a priori, O<sub>3</sub> Averaging Kernel</b>	>= 8.0 x 4.75	
	Total O <sub>3</sub>	<b>Total column O<sub>3</sub>, Cloud Fraction, Aerosol Index</b>	2.0 x 4.75	
	<b>NO<sub>2</sub> (Nitrogen Dioxide) NRT</b>	<b>Tropospheric Vertical Column Density (VCD), Total VCD, Slant Column Density (SCD), Cloud Fraction, Air Mass Factor (AMF), Data Quality Flag</b>	2.0 x 4.75	
	<b>HCHO NRT (Formaldehyde)</b>	<b>Total VCD, SCD, Cloud Fraction, AMF, Data Quality Flag</b>	2.0 x 4.75	
	<b>Aerosol NRT</b>	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°	

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

**Near real-time (NRT) products: Latency 2 - 3 hours**

**Baseline (Offline) products: Latency 3 - 6 hours (except O<sub>3</sub> profile ~24 hours)**

SNWG: Satellite

Needs Working Group



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



Level	Product	Key Variables	Resolution (km <sup>2</sup> ) **	Frequency/ Size
L2	C <sub>2</sub> H <sub>2</sub> O <sub>2</sub> (Glyoxal)	<b>Total VCD</b> , SCD, Cloud Fraction, AMF, Data Quality Flag	2.0 x 4.75	Hourly, granule
	H <sub>2</sub> O (Water Vapor)		2.0 x 4.75	
	BrO (Bromine)		2.0 x 4.75	
	<b>SO<sub>2</sub> (Sulfur Dioxide) NRT</b>	<b>VCD</b> (Total, Planetary Boundary Layer, & Lower / Middle / Upper Tropospheric, Lower Stratospheric), SCD	2.0 x 4.75	Hourly, granule
	TEMPO/GOES-R Synergistic	<b>Aerosol</b> , Fire / Hotspot, Cloud & Mask, Lightning, Snow / Ice, Precipitable Water, etc.	2.0 x 4.75	Hourly, granule
	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



# Mission Phases & Operational Timeline

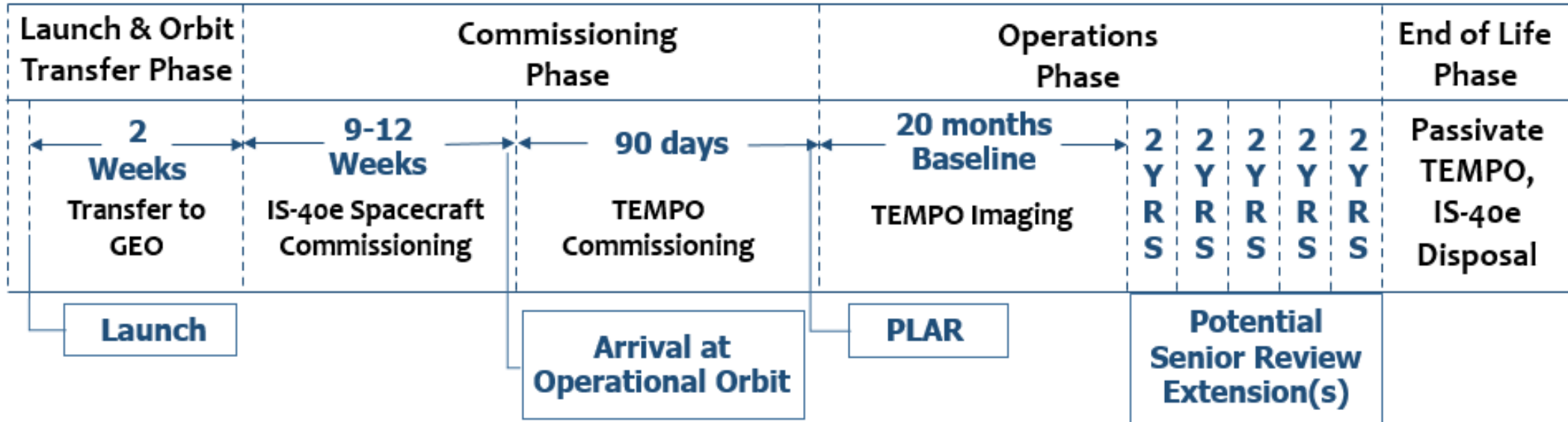


**Launched:**  
April 7, 2023

**Powered On:**  
June 7

**Commissioning:**  
June 7 – Oct. 18

**Nominal Operations:**  
Oct. 19 – May 2025



- ❑ **First light:** July 31 – August 2 with first Earth imaging on August 2
  - ❑ Successfully passed Post Launch Acceptance Review (PLAR)
  - ❑ **Started nominal operations on October 19**
  - ❑ Baseline mission length: 20 months (Oct 2023 – May 2025) **w/ extension through NASA’s Senior Review**
  - ❑ Public release of Baseline products at ASDC: Level 1b data in Feb 2024, **Level 2 & 3 data in April 2024**
  - ❑ Archive of baseline “offline” products will start from commissioning phase ~Aug 2023
  - ❑ **Initial public release of NRT products at ASDC ~Jan 2025**
- ASDC: Atmospheric Science Data Center  
Baseline TEMPO data format: **NetCDF**



# Data Distribution, Visualization, Analysis Tools



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

**TEMPO data will be publicly available via Earthdata Search**

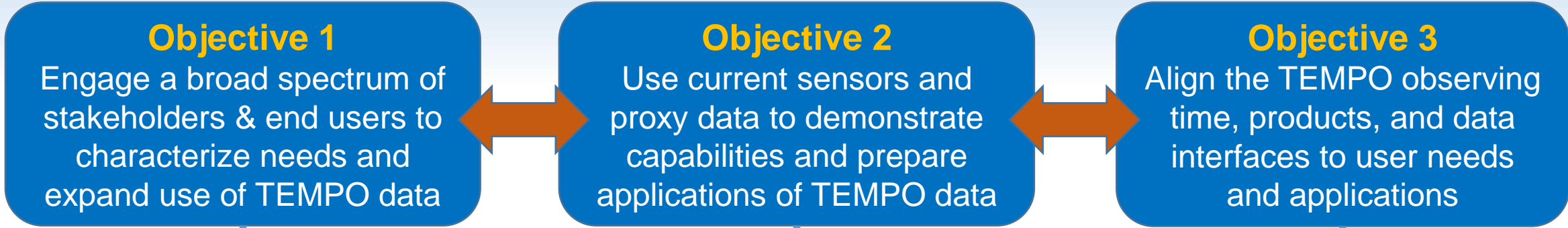
**TEMPO imagery will be available in Worldview**

**TEMPO visualization and analysis capabilities in ArcGIS**

**EPA RSIG3D Gateway**



# TEMPO Early Adopters (EA) Program



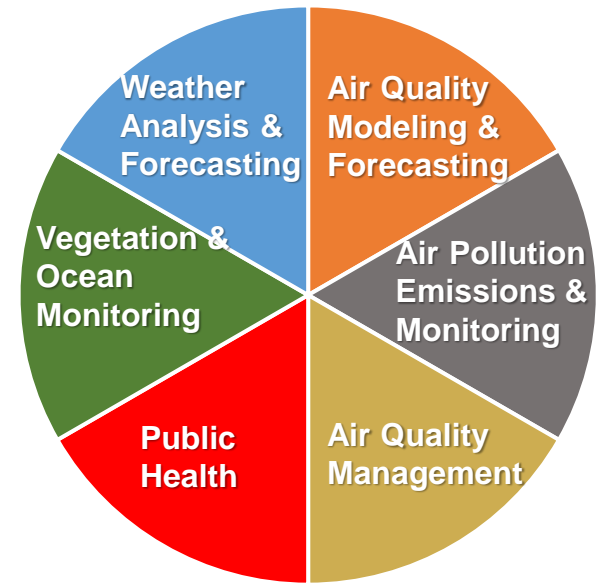
**Join EA Program**

**EAs are individuals or groups who:**

- Have an interest or need for using TEMPO data
- Have an existing or new application for TEMPO data
- Work with end-users and understand their decision-making process

**~580 EAs (as of Jan 2024)**

## Application Focus Areas

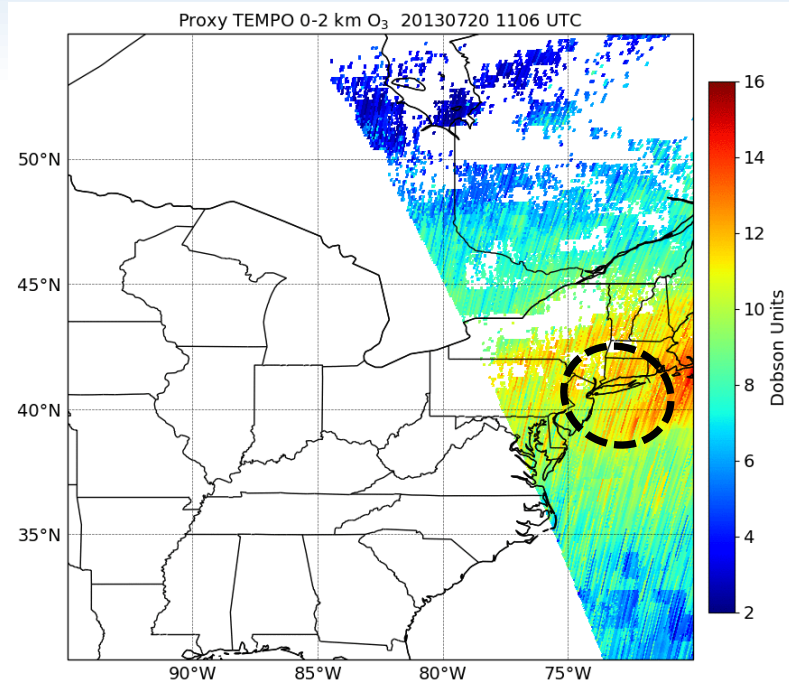




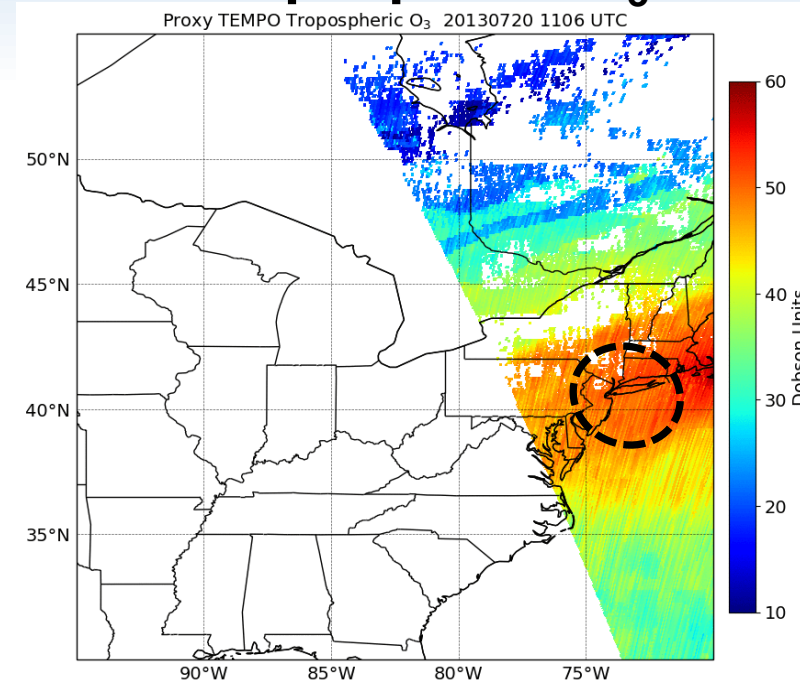
# Monitoring Tropospheric Ozone – PROXY DATA



## 0-2 km (PBL) O<sub>3</sub>

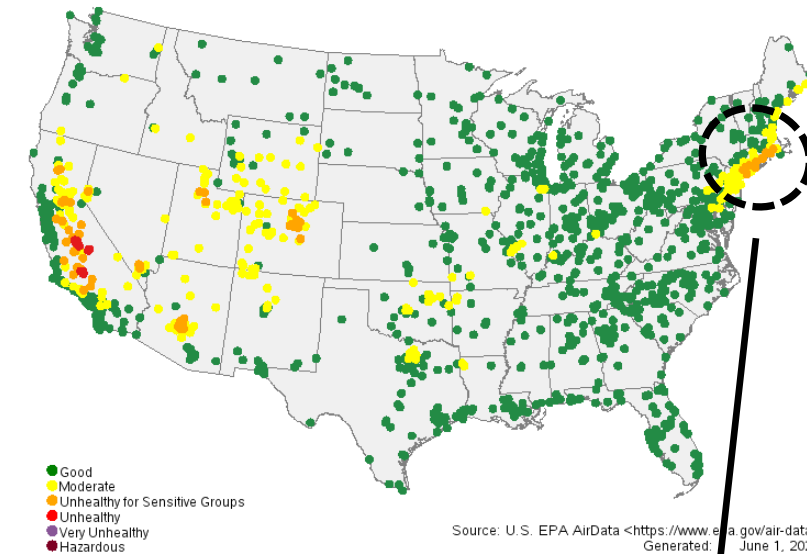


## Tropospheric O<sub>3</sub>

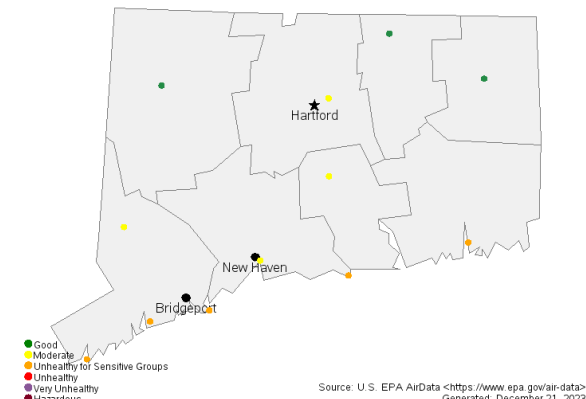


## 20 July 2013 Use Case

Ozone AQI Values by site on 07/20/2013



Ozone AQI Values by site on 07/20/2013



- ❑ O<sub>3</sub> profile will offer new capabilities to track and predict (assimilation) O<sub>3</sub> concentrations and transport in the troposphere
- ❑ Unprecedented monitoring of **O<sub>3</sub> within the layer of air where people live and breathe**
- ❑ **TEMPO O<sub>3</sub> data will help fill the gaps in surface monitor coverage, especially the large gaps in the western region**



# TEMPO Preliminary Data & Use Cases

*TEMPO data products are at beta level, meaning little is known on the data quality*

**First Light!**

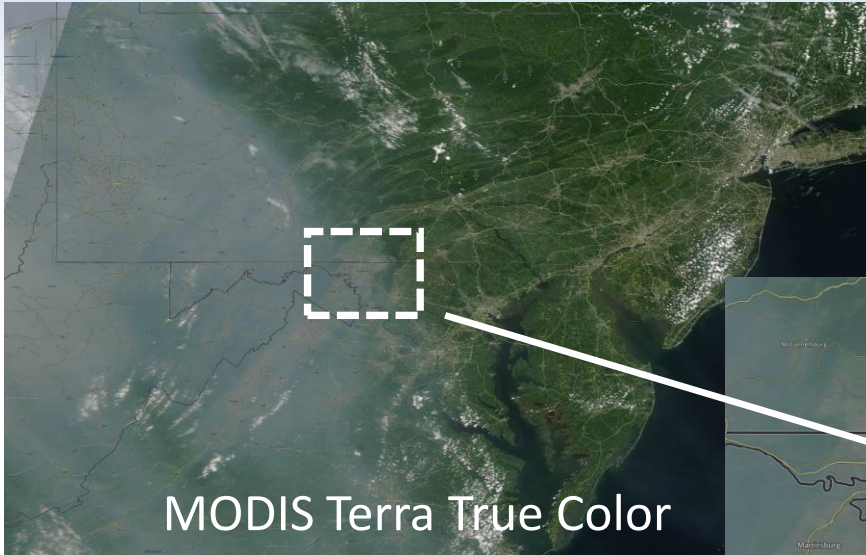


<https://svs.gsfc.nasa.gov/5175/>

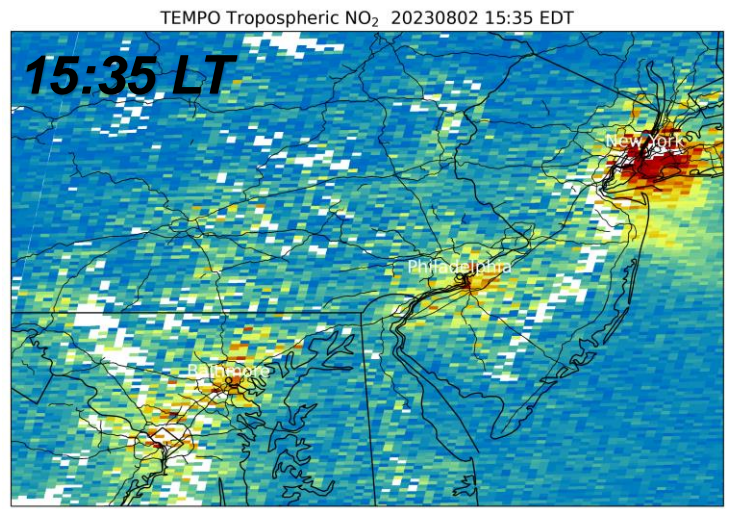
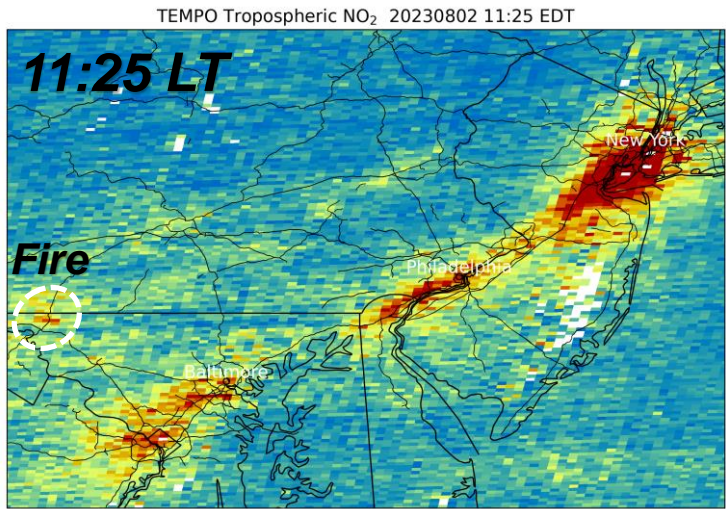
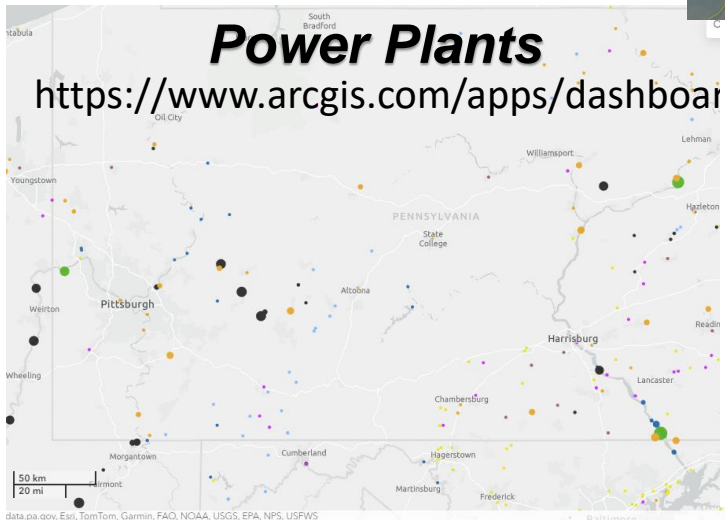
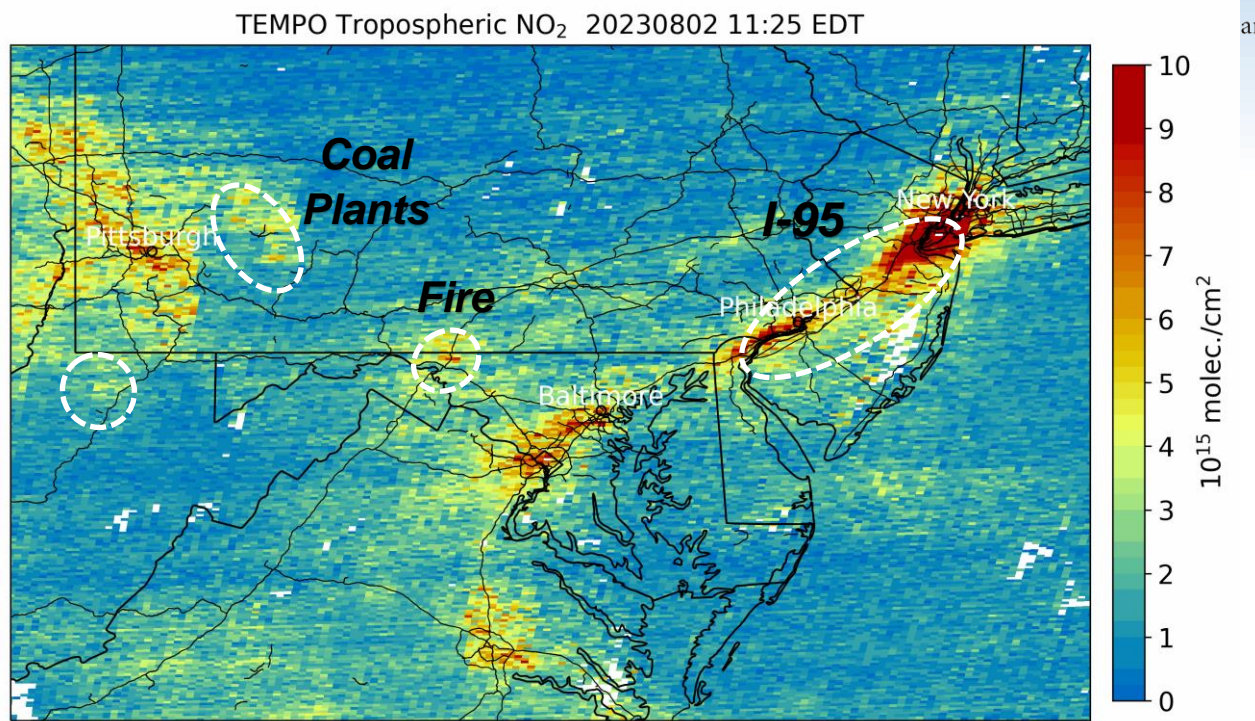


# First Light – Mid-Atlantic Zoom

Preliminary NO<sub>2</sub> Data!

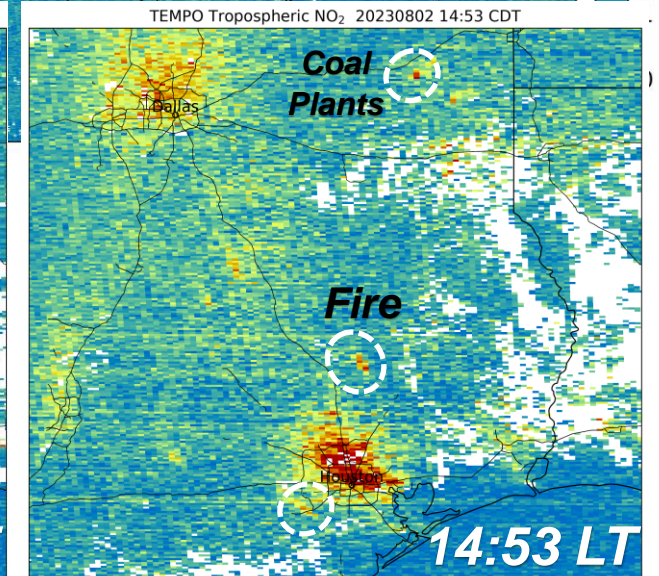
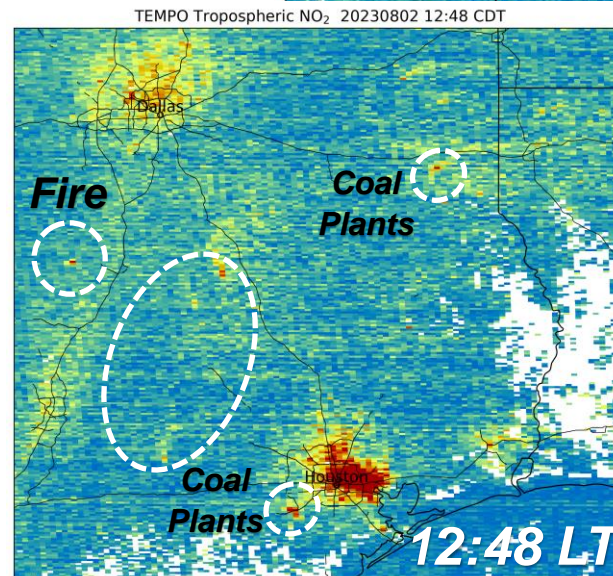
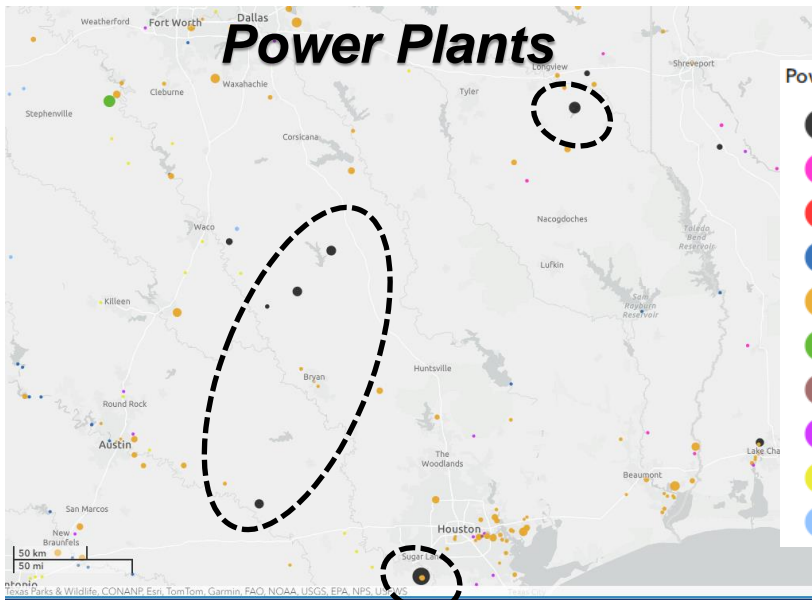
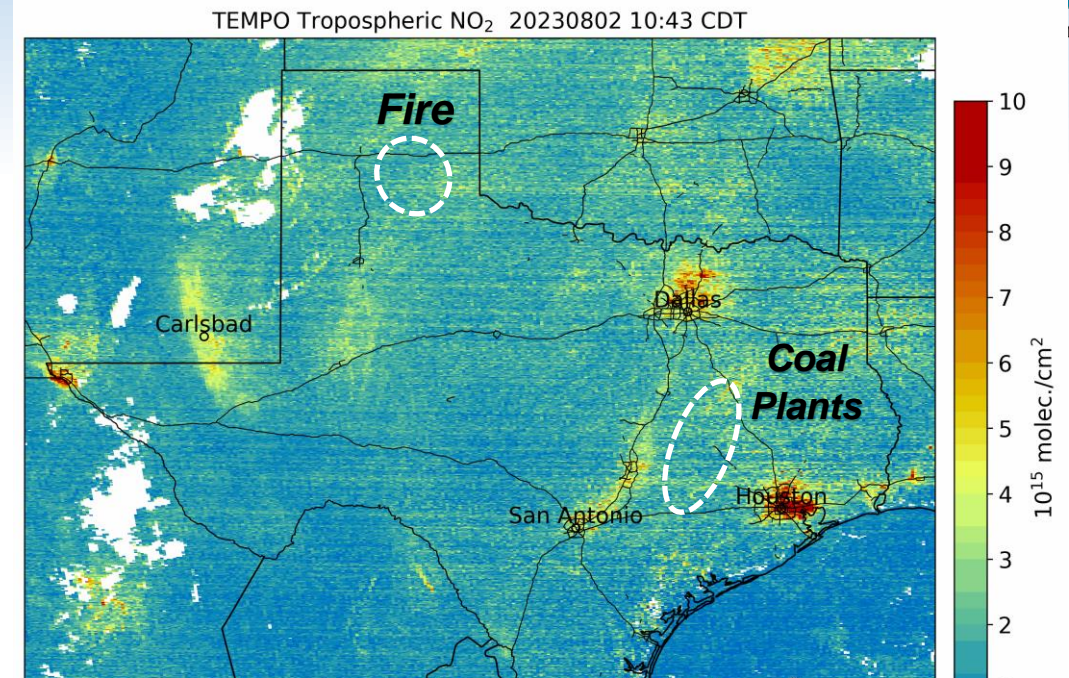
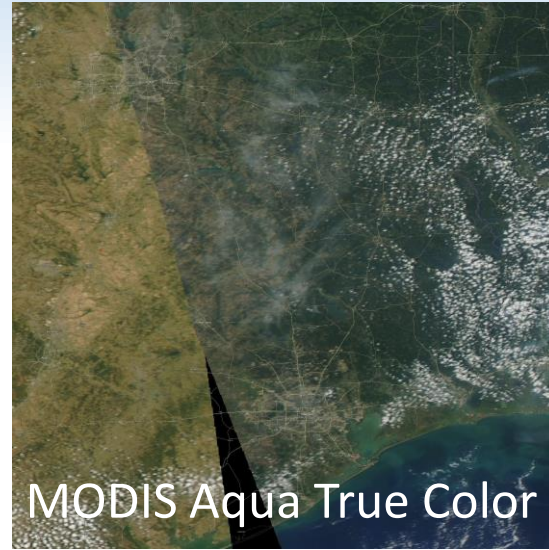
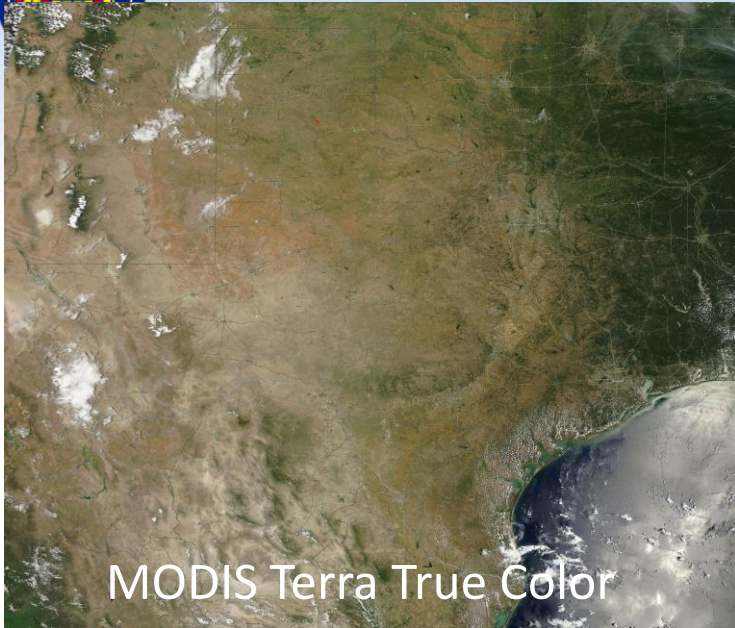


MODIS Terra True Color





# First Light – Texas Zoom



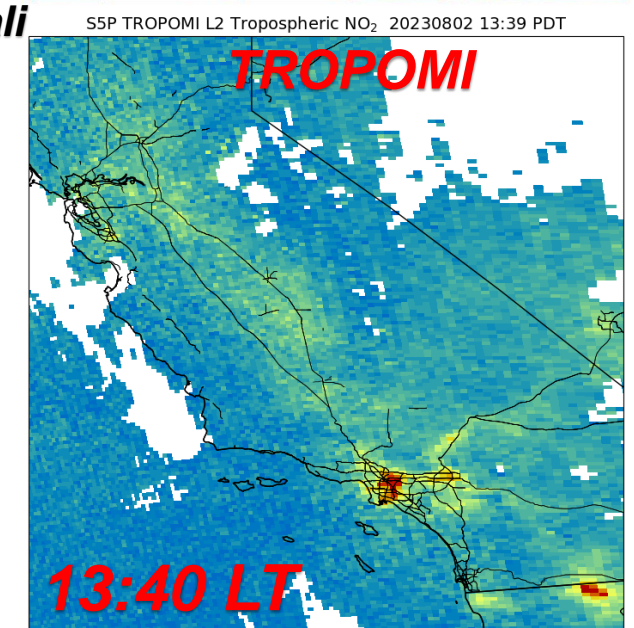
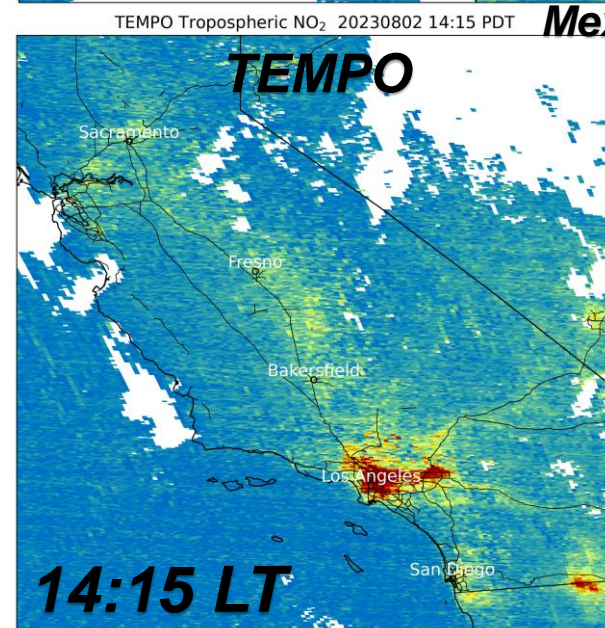
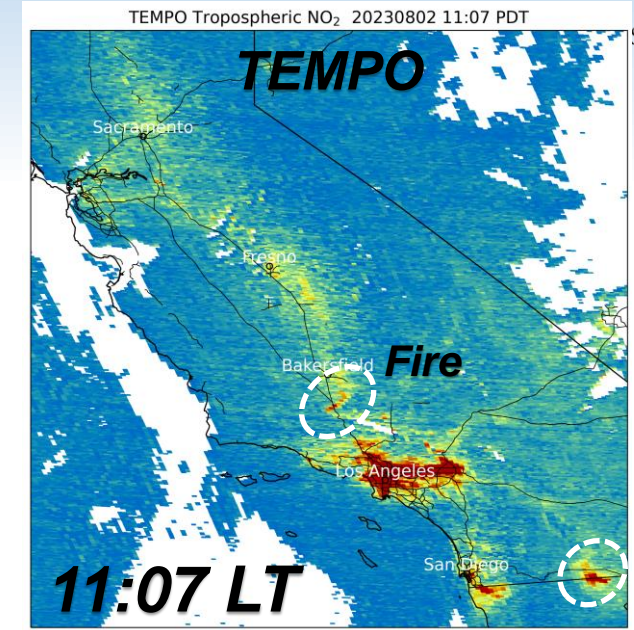
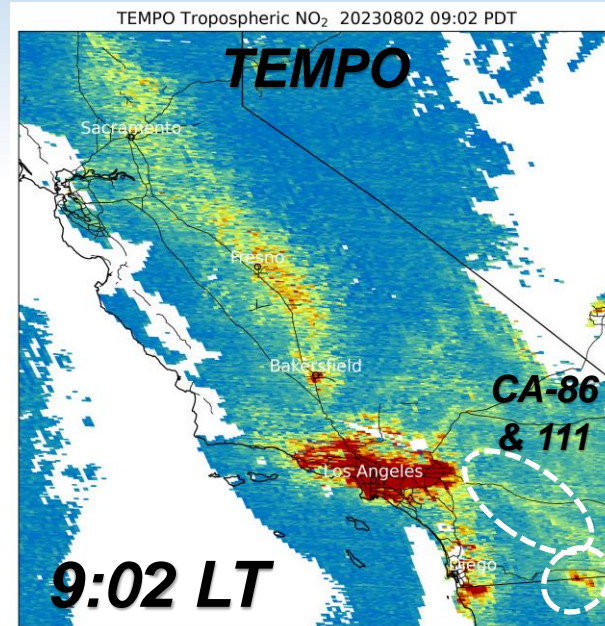
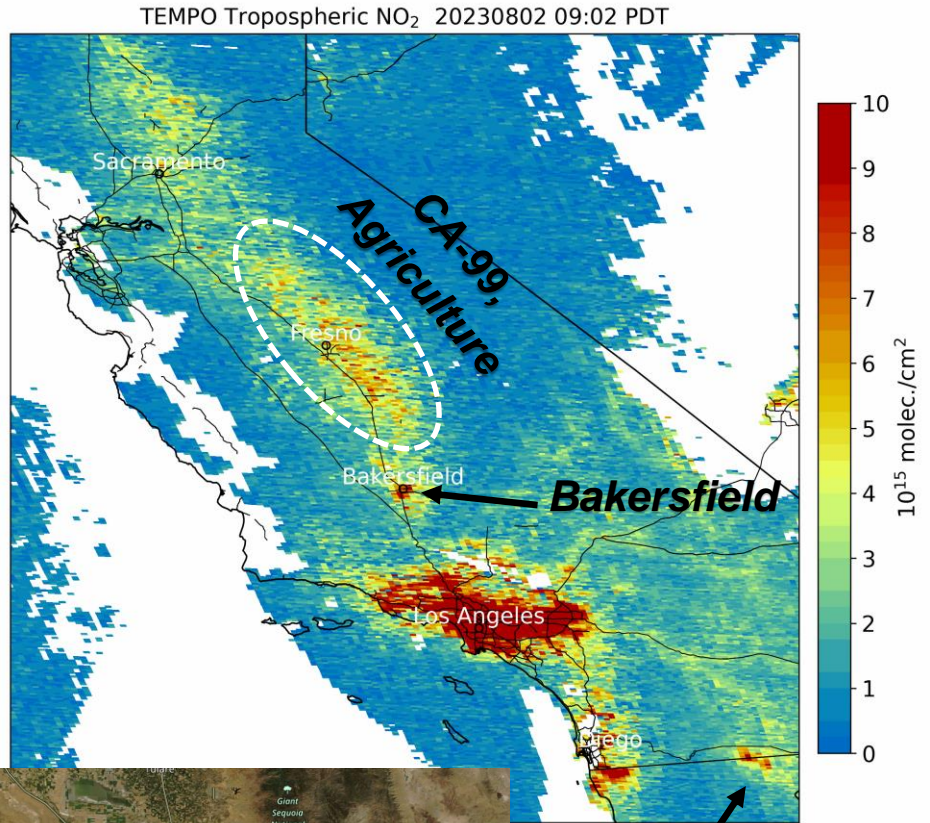


# First Light – California Zoom

Preliminary NO<sub>2</sub> Data!



Smithsonian



Mexicali



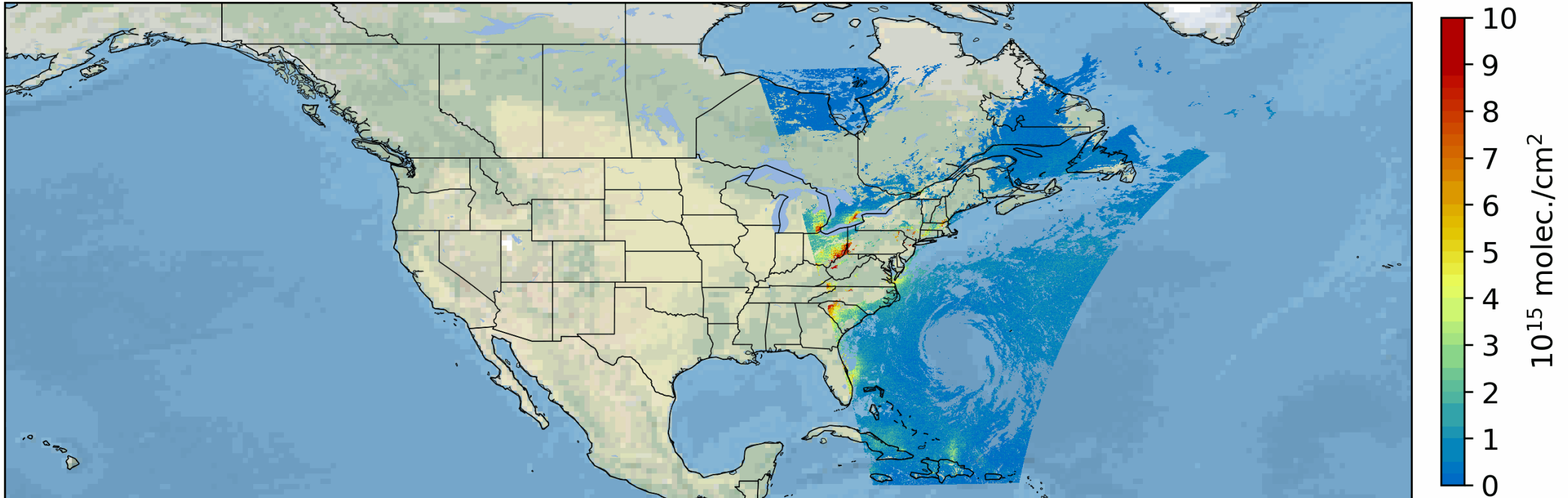


# TEMPO Scan Operations – Aug 29, 2023



**Commissioning phase scans! Additional optimized scans were performed on this day**  
**More irregular scan patterns were done compared to TEMPO's nominal operation scans**

TEMPO Tropospheric NO<sub>2</sub> 20230829 1107 UTC



Nominal operations consist of the following scan types:

- TEMPO performs standard (nominal) East-West hourly daytime scans consisting of 1181 mirror steps across the Field of Regard (FoR) over North America. **Nine different Level 2 granule files across full FoR.**
- Optimized (sub-hourly) scans over daylight portions of the FoR during the early morning and late afternoon



# Summary of TEMPO Strengths (Non-Exhaustive)



- ❑ **O<sub>3</sub> profile will offer new capabilities to monitor and distinguish ozone concentrations from the stratosphere to the planetary boundary layer (PBL)**
- ❑ TEMPO will **observe small-scale emission sources** that have not been adequately resolved by current satellite missions, **capability to quantify sub-urban emissions and pollutant gradients**
- ❑ TEMPO will **monitor rapidly evolving pollutants from episodic events such as wildland fires**
- ❑ Tracking criteria air pollutants associated with interstate and international transport
- ❑ **Diurnal information on HCHO / NO<sub>2</sub> ratios for new understanding of sensitivity of local O<sub>3</sub> production and assessments of O<sub>3</sub> production regimes**
- ❑ **Supporting surface monitor site analysis and selection of new site locations**
- ❑ **Robust monitoring of industrial operations, regulatory monitors may miss peak emissions!**
- ❑ Hourly scans for observing gaps in cloud cover, mitigate impact of clouds on monitoring air quality using satellite data
- ❑ Aerosol optical depth and aerosol layer height for aerosol plume monitoring and PM<sub>2.5</sub> estimates
- ❑ **Near real-time NO<sub>2</sub>, HCHO, and aerosol products for air quality monitoring & forecasting!**

***Preliminary data has provided early insight into advanced TEMPO capabilities***



# Current & Upcoming Work



- ❑ Article on TEMPO to be published in February in A&WMA EM Plus magazine
- ❑ Continue to engage users and stakeholders on TEMPO products and applications
  - Identify and produce value-added products and tools tailored to stakeholder needs
  - Development of codes, user guides, and training items to enable effective use of TEMPO data
- ❑ Early evaluation / validation of TEMPO data
  - Coordinate between different projects and initiatives to most effectively evaluate TEMPO data in areas throughout the Field of Regard
  - Provide feedback to TEMPO retrieval team to improve future versions of data products
- ❑ Coordination of TEMPO special operations
  - Align TEMPO special operations with important initiatives between projects



**Join EA  
Program  
here!**

**TEMPO Mission  
Applications Lead  
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**X @NaegerAaron**

**TEMPO  
Green Paper!**

