weather.msfc.nasa.gov/tempo/

TEMPO

Tropospheric Emissions: Monitoring of Pollution

Hourly Measurement of Pollution

NASA   Smithsonian Astrophysical Observatory   Ball

http://tempo.si.edu/

Tropospheric Emissions: Monitoring of POllution (TEMPO) Mission
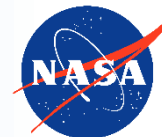
NASA HAQ Team Meeting 2023

March 29 – 30, 2023

Aaron Naeger

TEMPO Deputy Program Applications Lead

NASA / University of Alabama in Huntsville

U.S. Government sponsorship acknowledged.

NASA   SPORT   THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

TEMPO Mission Status, Products, & Operations

TEMPO Quick Facts

Launched Feb 2020

Launch 2023
TEMPO *(hourly)*
Tropospheric Emissions:
Monitoring of Pollution

Launch 2024
Sentinel-4 *(hourly)*
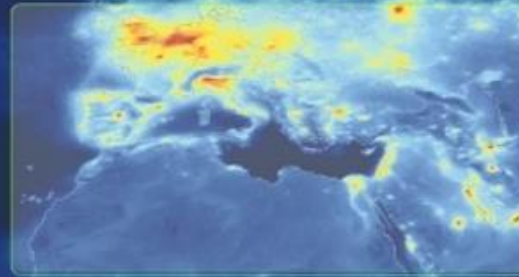
GEMS *(hourly)*
Geostationary Environmental
Monitoring Spectrometer

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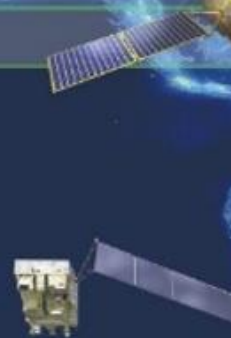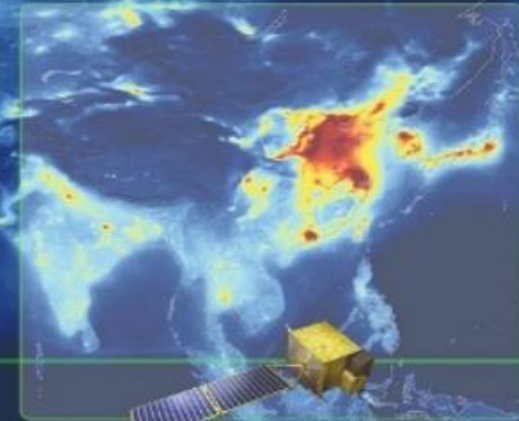
GaoFen-5 *(once per day)*

Equator

Image Credit: NASA LaRC
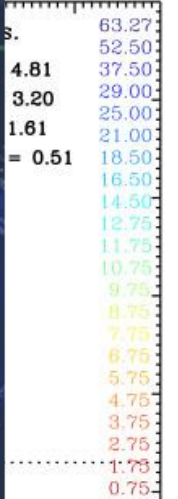
- ❑ UV/... **rele**...
- ❑ Cap... trop...
- ❑ **Lau**... Inte...
- ❑ Part... hou...

TEMPO Data Products

Level	Product	Key Variables	Resolution ** (km²)	Frequency/ SIze
L1b	Radiance	Geolocated, calibrated, geolocation & quality flags	2.0 x 4.75	Hourly, granule
L2 ⭐	**Cloud**	Cloud fraction, cloud pressure	2.0 x 4.75	Hourly, granule
	O_3 (Ozone) profile	O_3 profile, Tropospheric O_3 column, 0-2 km O_3 column, Errors	**8.0 x 4.75 OR 8.0 x 9.5**	Hourly, granule
	Total O_3	Total column O_3	2.0 x 4.75	Hourly, granule
⭐	**NO_2 (Nitrogen Dioxide)**	Slant Column Density (SCD) Tropospheric Vertical Column Density (VCD) Errors	2.0 x 4.75	Hourly, granule
⭐	**HCHO (Formaldehyde)**	SCD	2.0 x 4.75	Hourly, granule
	$C_2H_2O_2$ (Glyoxal)	Total VCD	2.0 x 4.75	
	H_2O (Water Vapor)	Errors	2.0 x 4.75	
	BrO (Bromine)		2.0 x 4.75	
⭐	**SO_2 (Sulfur Dioxide)**	SCD VCD (Total, Planetary Boundary Layer, & Lower / Middle / Upper Tropospheric, Lower Stratospheric)	2.0 x 4.75	Hourly, granule
⭐	**Aerosol**	Ultraviolet & Visible Aerosol Optical Depth (AOD) Aerosol Optical Centroid Height (AOCH) Aerosol Absorption Index (AAI)	**8.0 x 4.75**	Hourly, granule
	TEMPO/GOES-R Synergistic	Aerosol (see above), Fire / Hotspot, Lightning, snow/ice, etc.	2.0 x 4.75	Hourly, granule
L3	**Gridded L2**	Same as L2	~5 x 5 (TBD)	Hourly, scan
L4	**UVB**	UV irradiance, erythemal irradiance, UVI	TBD	Hourly, scan

** Center of Field of Regard

⭐ Proposed Near Real-Time products (latency 2-3 hours)

Black text: Baseline products

Orange text: Additional / proposed products

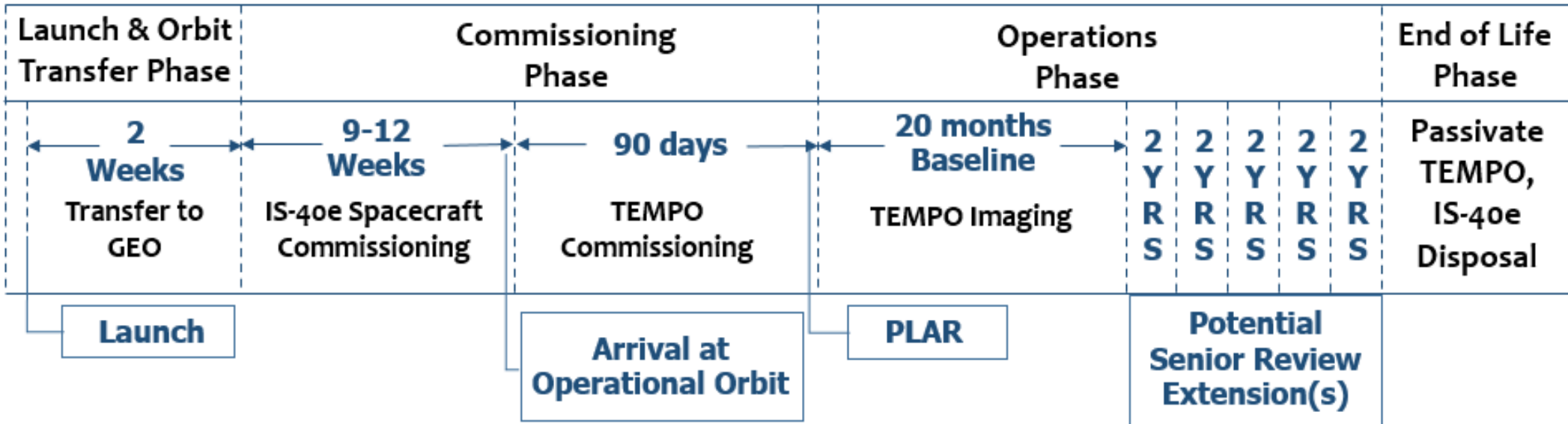Level 3 product composed of 10 granules of Level 2 files for complete TEMPO FoR scans

Mission Phases & Operational Timeline

Launch:
April 2023

Commissioning:
July – Oct 2023

- ❑ TEMPO commissioning phase from July – Oct 2023
- ❑ Nominal operation: ~6 months after launch (Oct 2023)
- ❑ Baseline mission length is 20 months with possible 10+ year lifetime depending on senior review extensions
- ❑ Plan to release level 1b data ~4 months after commissioning phase (Feb 2024) and **level 2 and 3 data ~6 months after commissioning phase (April 2024)**
- ❑ Data will be **publicly available** via NASA Earthdata Search in netCDF4/HDF5 format.

TEMPO Scan Operations

Proxy TEMPO Tropospheric NO_2 20130809 1000 UTC

- ❑ TEMPO will perform standard (nominal) East-West hourly daytime scans consisting of ~1226 mirror steps across the Field of Regard (FoR) over Greater North America.

- ❑ Sub-hourly scans will also be performed:

  1) Optimized scans across the East and West during sunrise and sunset periods, respectively, when SZA is too high (> 80°) over portions of the FoR for collecting measurements of pollutants

  2) **Special operations for dedicated experiments (e.g., wildland fires, industrial accidents, dust storms, volcanoes) over a portion or slice of the TEMPO FoR (e.g., <= 10 minutes)**
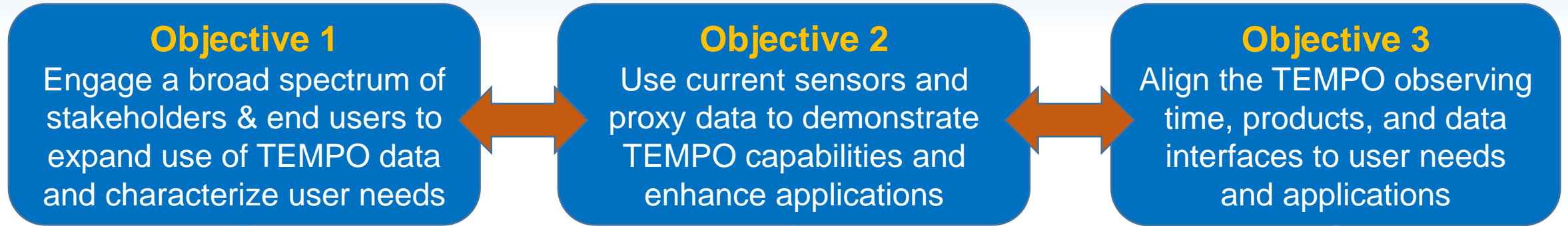
TEMPO Early Adopters Program & Applications

TEMPO Early Adopters (EA) Program

User-centric program focused on broadening and enhancing applications of TEMPO data

Objective 1
Engage a broad spectrum of stakeholders & end users to expand use of TEMPO data and characterize user needs

Objective 2
Use current sensors and proxy data to demonstrate TEMPO capabilities and enhance applications

Objective 3
Align the TEMPO observing time, products, and data interfaces to user needs and applications

Prepare users for operational TEMPO data

TEMPO Launch

Overarching Goal
Maximize and accelerate the value of TEMPO data for societal benefit

Extend TEMPO mission lifetime

Early Adopters by Affiliation & Area

*Last updated June 2022

EARLY ADOPTERS BY AFFILIATION

Legend:
- 0
- 1
- 2 - 3
- 4 - 5
- 6 - 10
- 11 - 25
- 26 - 36
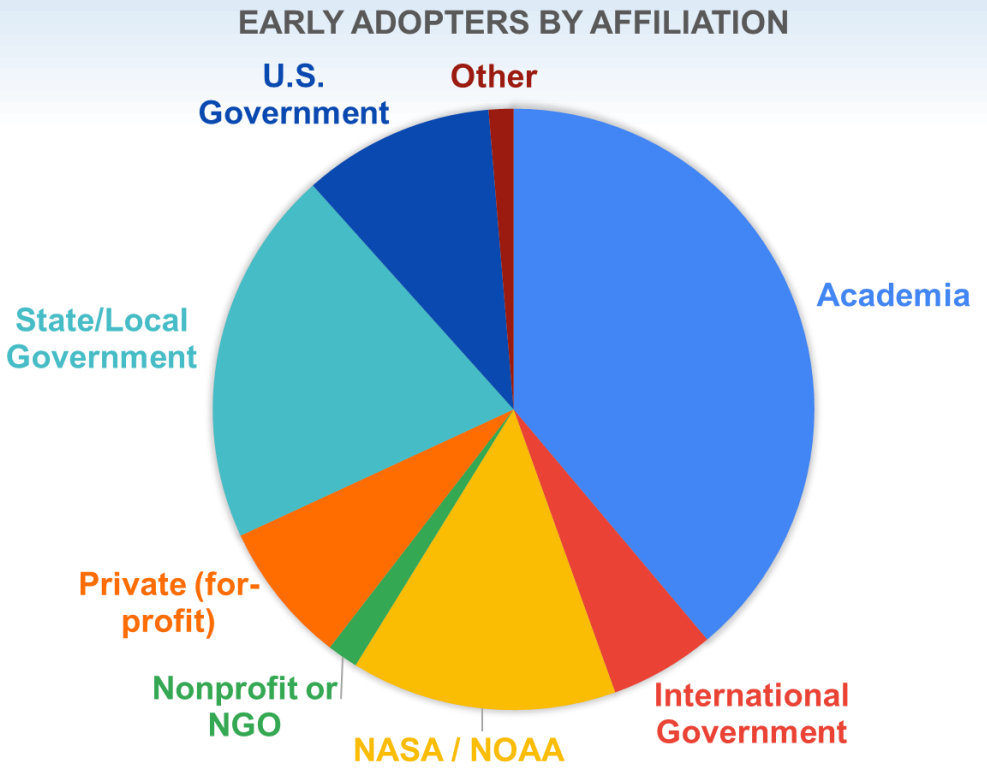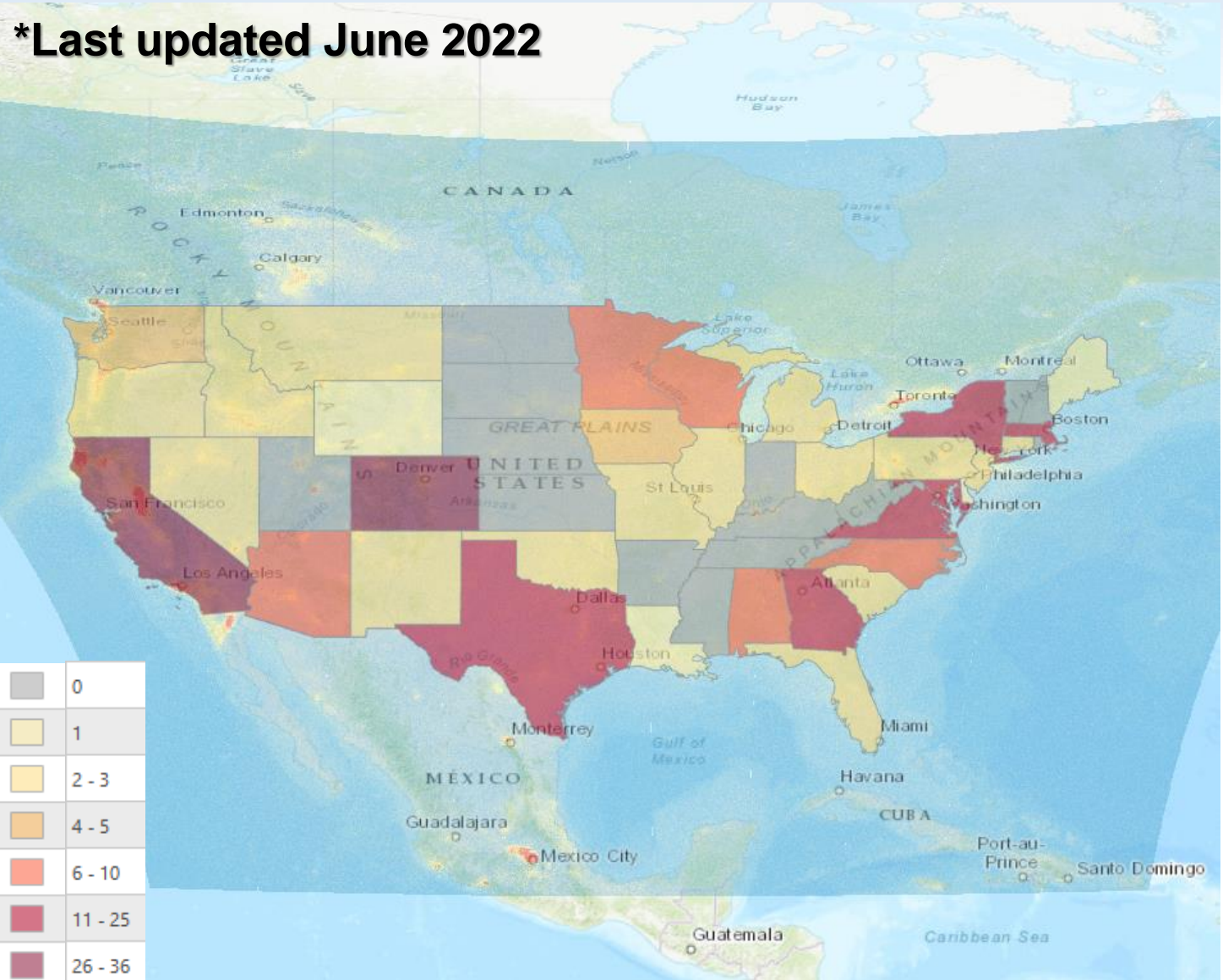
❑ Participation includes state, local, and tribal air agencies, federal agencies, health organizations, and NGOs

❑ International participation within FoR from Canada, Mexico, Puerto Rico

TEMPO Early Adopter Studies

☐ **Observing NO$_2$ pollution inequality**

- TEMPO will provide new insight into emission sources and drivers of pollution inequality at intra-urban scales.

☐ **Dust storm monitoring**

- Dust storms in U.S. are mostly short-lived, occurring a few hours before sunset. TEMPO will provide new monitoring capabilities of active dust storms.

☐ **Short-term public health outcomes**

- Hourly gaseous pollutants from TEMPO will enable acute exposure assessments.

☐ **Assimilation of TEMPO in regional air quality forecasting system**

- Apply WRF-Chem/DART for NRT forecasting with meteorological/chemical data assimilation

TEMPO data will enable new and enhanced health and air quality applications
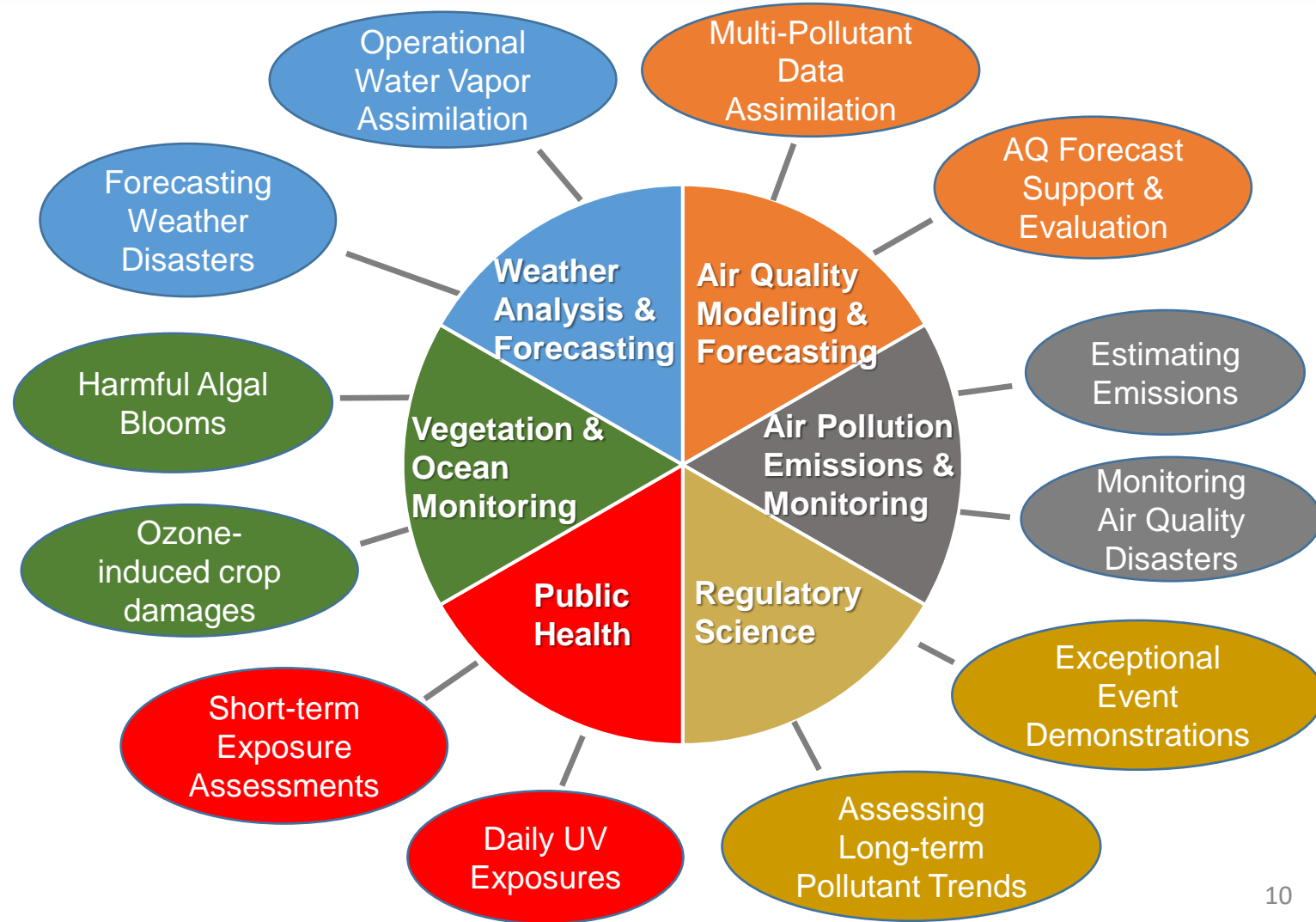
TEMPO EA Program – Objective #1

Engage a broad spectrum of stakeholders & end users to expand use of TEMPO data and characterize user needs

- ❑ TEMPO-MAIA Environmental Justice Workshop
- ❑ Joint TEMPO-HAQAST science meeting with TEMPO Early Adopter panels
- ❑ Presentations / discussions on TEMPO at conferences (AMS, AGU) and technical meetings (MARAMA, NTAA-EPA) along with TEMPO outreach in publications and science articles
- ❑ Very successful NASA Airathon Crowdsourcing Competition (TEMPO-MAIA collaborative activity) drew over 1000 participants from across the globe
- ❑ TEMPO contribution to air quality applications panel at PACE workshop
- ❑ TEMPO presentation and discussion at two VAAC workshops
- ❑ TEMPO presentation at ARSET Air Quality-Focused Remote Sensing for EPA Applications

Major outcomes:

1) Growth in EA program from ~200 to ~400 members between 2021 and 2023 including ~60 advanced (Tier 2) members
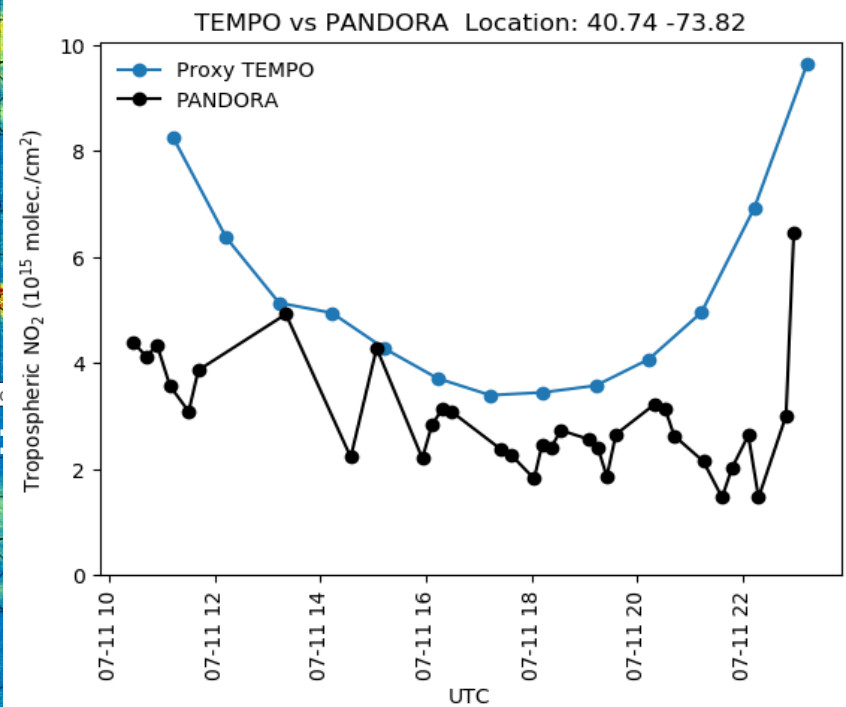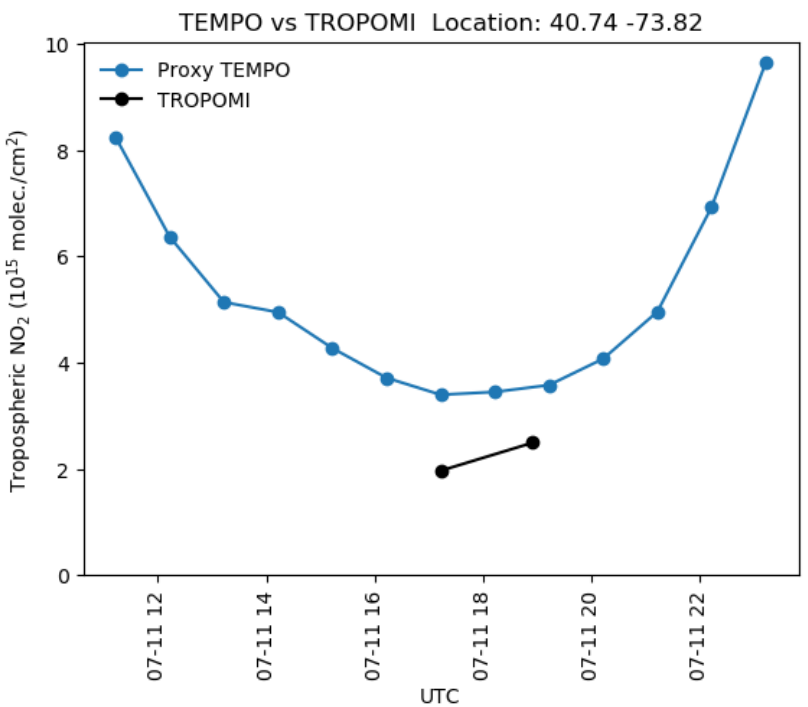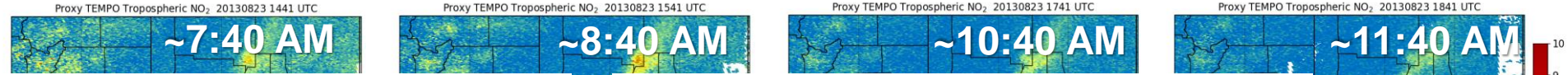2) Identified needs for TEMPO NRT products, files, data interfaces & value-added tools, and scan operations
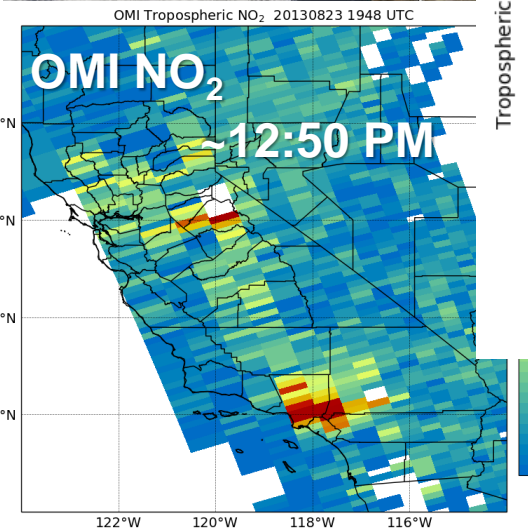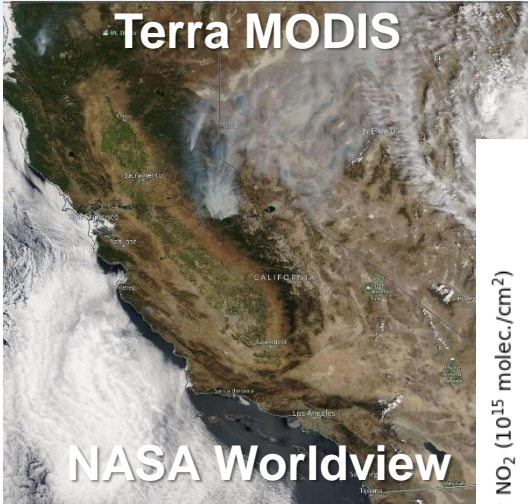
TEMPO EA Program – Objective #2

Use current sensors & proxy data to demonstrate TEMPO capabilities & applications

TEMPO Proxy Level 2 NO$_2$ data
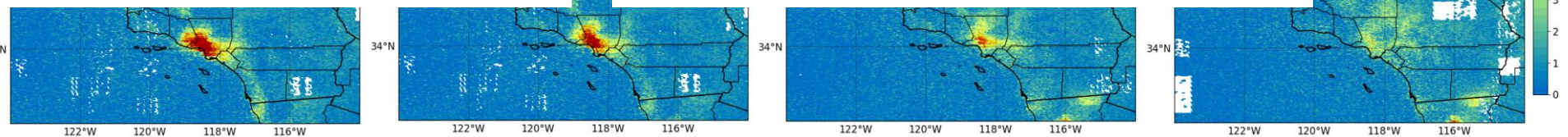
☐ TEMPO will observe rapidly varying NO$_2$ columns within wildfire smoke plumes and across urban areas and traffic corridors.
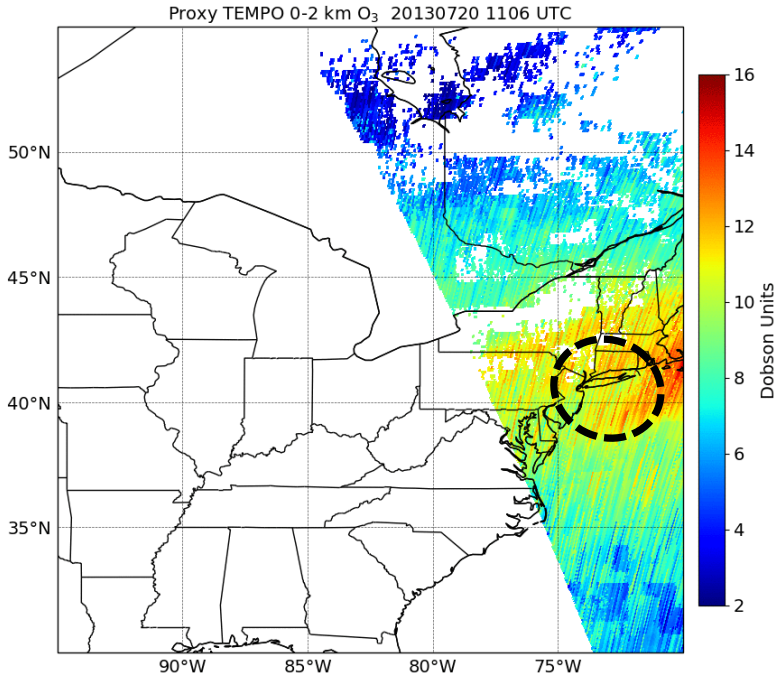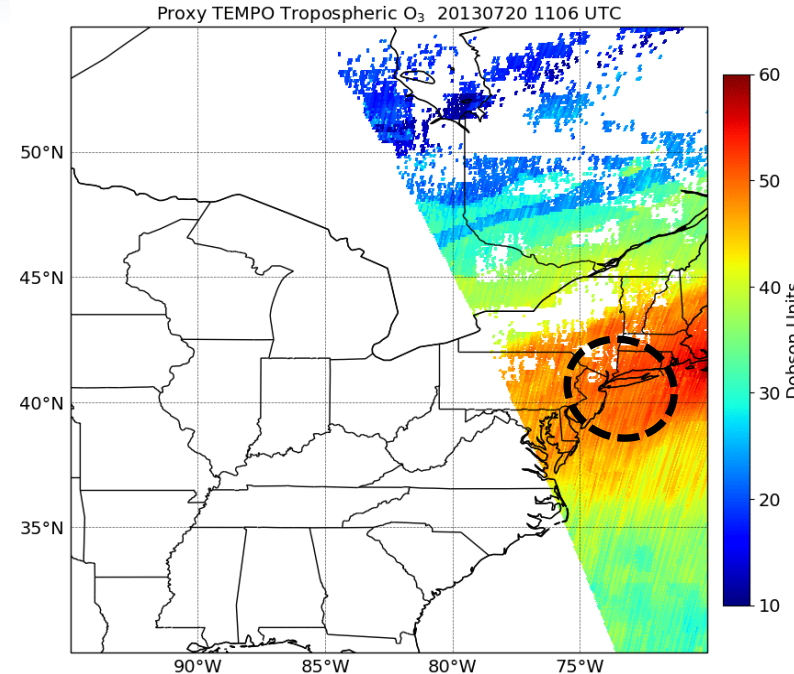
Aug. 23, 2013

Use current sensors & proxy data to demonstrate TEMPO capabilities & applications
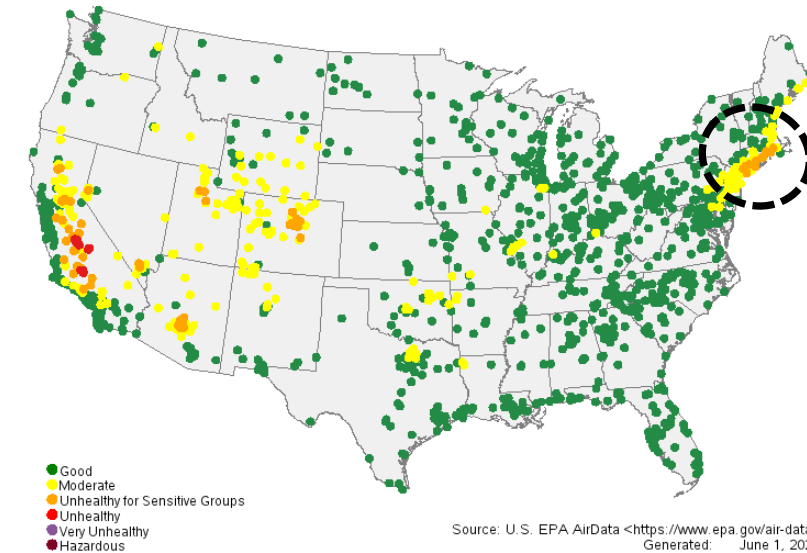
0-2 km (PBL) O_3

Proxy TEMPO 0-2 km O_3 20130720 1106 UTC

Tropospheric O_3

Proxy TEMPO Tropospheric O_3 20130720 1106 UTC

20 July 2013 Use Case

Ozone AQI Values by site on 07/20/2013

- Good
- Moderate
- Unhealthy for Sensitive Groups
- Unhealthy
- Very Unhealthy
- Hazardous

Source: U.S. EPA AirData <https://www.epa.gov/air-data>
Generated: June 1, 2022

- ❑ TEMPO instrument will be sensitive to O_3 in the lower troposphere as shown by the proxy data

- ❑ O_3 profile will offer new capabilities to track and predict (assimilation) O_3 concentrations and transport from the stratosphere to the planetary boundary layer (PBL)

- ❑ Unprecedented monitoring of **O_3 pollution within the layer of air where people live and breathe**

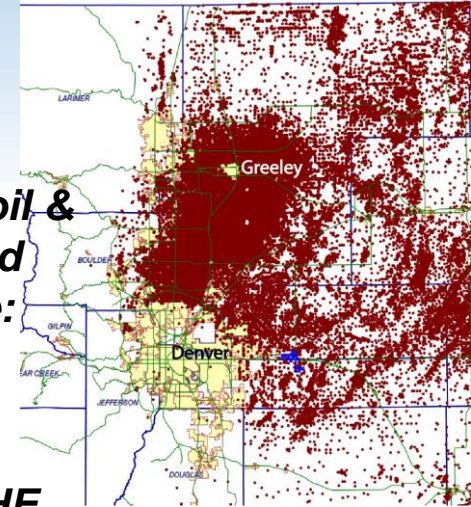- ❑ TEMPO O_3 data will help fill the gaps in surface monitor coverage, especially the large gaps in the western region
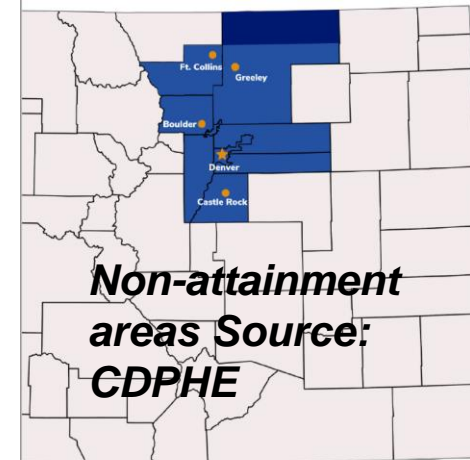
13

Align the TEMPO observing time, products, and data interfaces to user needs and applications

☐ Up to 25% of TEMPO's observing time will be devoted to special operations over a slice of the FoR (e.g., ≤ 10 min frequency), which can commence during the commissioning phase

☐ Early adopters have submitted experiment requests focused on **air quality disasters** (*e.g., wildfires, dust storms, volcanoes*), episodic events, and **research studies** (*e.g., agriculture, lightning NO$_x$*)

Selection of special experiments in **TEMPO Green Paper**

☐ **Formation of ozone along the Colorado Front Range**

☐ High Resolution Scanning over the New York City area

☐ Study of Winter Air Pollution in Toronto

☐ Air Quality Impacts from Oil and Gas Activities Across Multiple Basins in the Western U.S.

☐ Monitoring Volcanic Activity, Emissions, and Air quality Impacts from Mexican Volcanoes

☐ Lightning NOx

☐ Agricultural soil NOx emissions and air quality in California

Location of oil & gas wells (red dots) Source: COGCC

Credit: CDPHE

Non-attainment areas Source: CDPHE

'Severe' Ozone Non-Attainment (Partial List of Communities)

- Arvada
- Aurora
- Boulder
- Brighton
- Broomfield
- Castle Rock
- Centennial
- Commerce City
- Denver
- Englewood
- Estes Park
- Evergreen
- Ft. Collins
- Golden
- Greeley
- Highlands Ranch
- Lakewood
- Littleton
- Lone Tree
- Longmont
- Louisville
- Loveland
- Northglenn
- Parker
- Superior
- Thornton
- Westminster
- Windsor

Counties: Adams • Arapahoe • Boulder • Broomfield • Denver • Douglas • Jefferson • Larimer • Weld

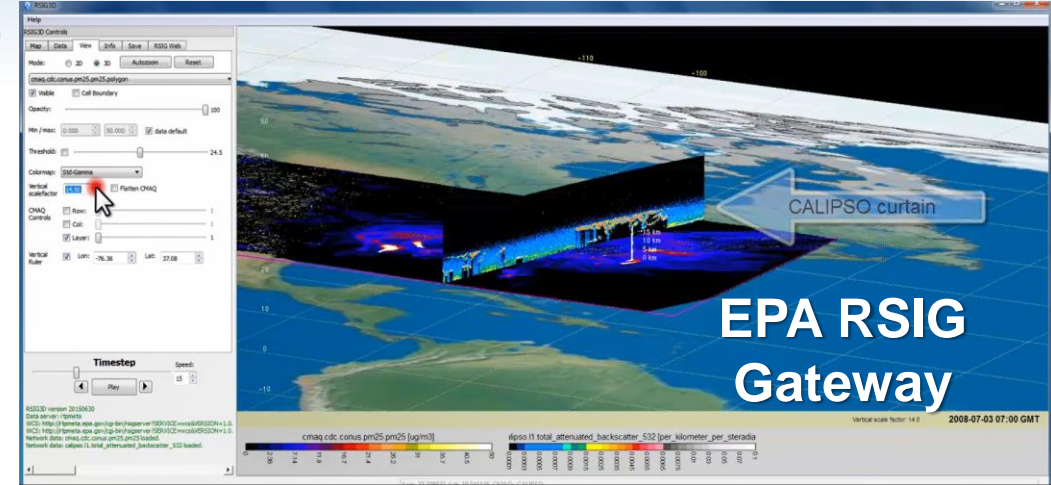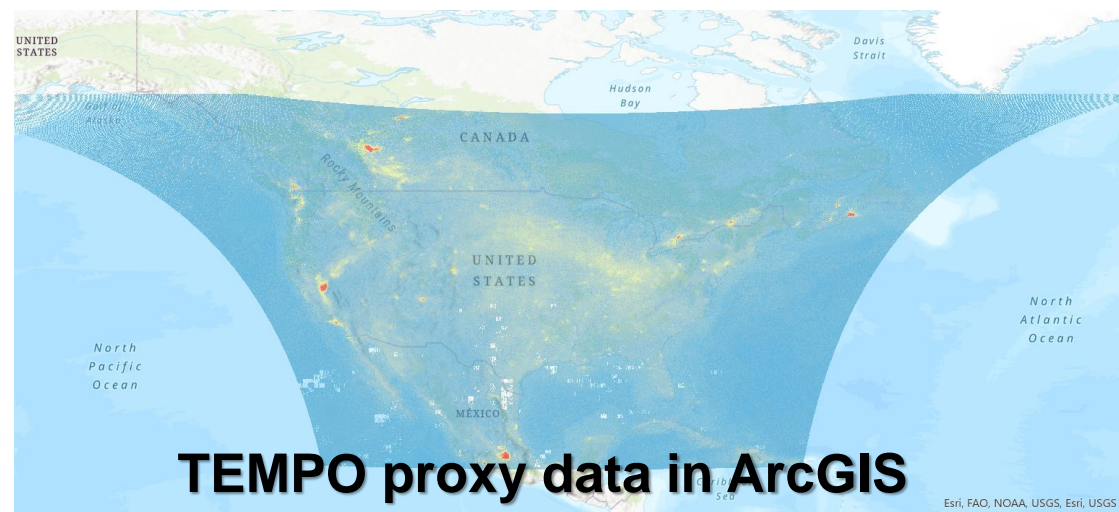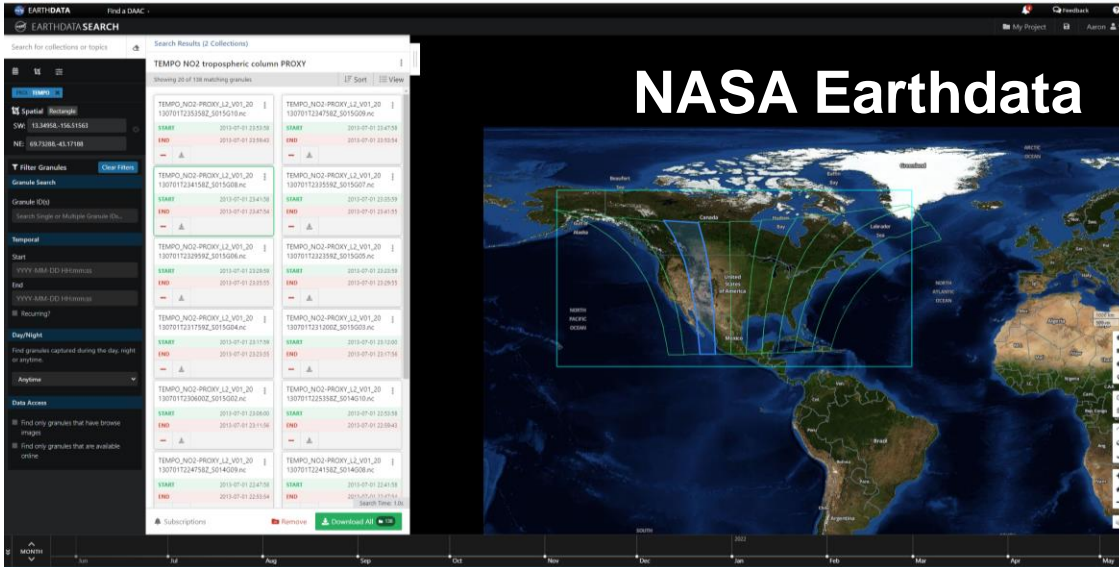Part of 2015 nonattainment area, outside 2008 nonattainment area

Green Paper here!

TEMPO EA Program – Objective #3

Align the TEMPO observing time, products, and data interfaces to user needs and applications

NASA Earthdata

EPA RSIG Gateway

Google Colab Notebook

TEMPO proxy data in ArcGIS

Publications

TEMPO Early Adopter workshop summary

https://doi.org/10.1175/BAMS-D-21-0050.1

A&WMA EM article on TEMPO!

https://online.1stflip.com/dsup/3fv8/

Joint Science Meeting for TEMPO, GeoXO ACX, & TOLNet!
May 1-5, 2023

Visualizations of GEMS NO_2, SO_2, O_3, and AOD data on NASA SPoRT Viewer

https://weather.msfc.nasa.gov/sport/viewer/

aaron.naeger@nasa.gov @NaegerAaron