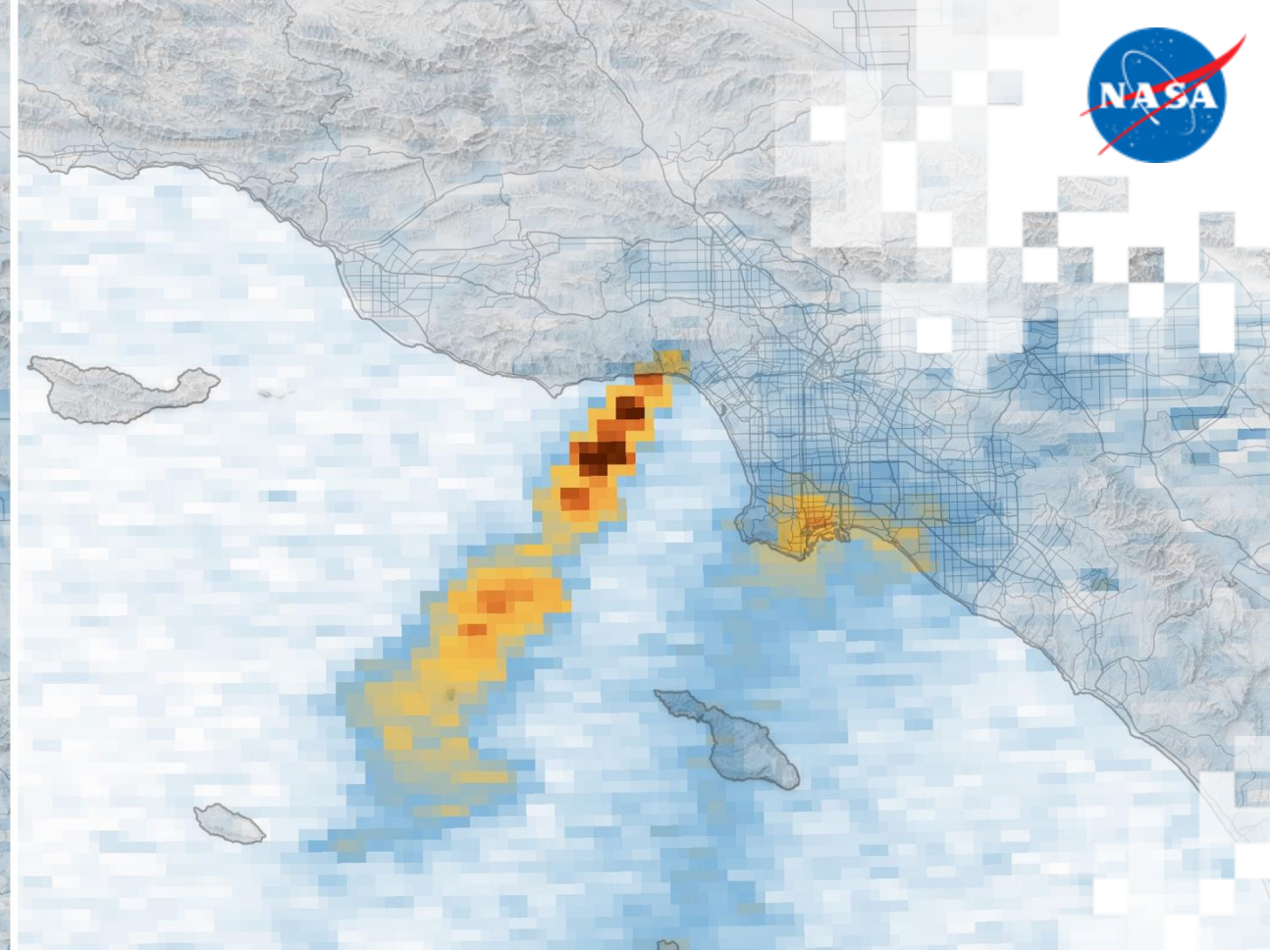
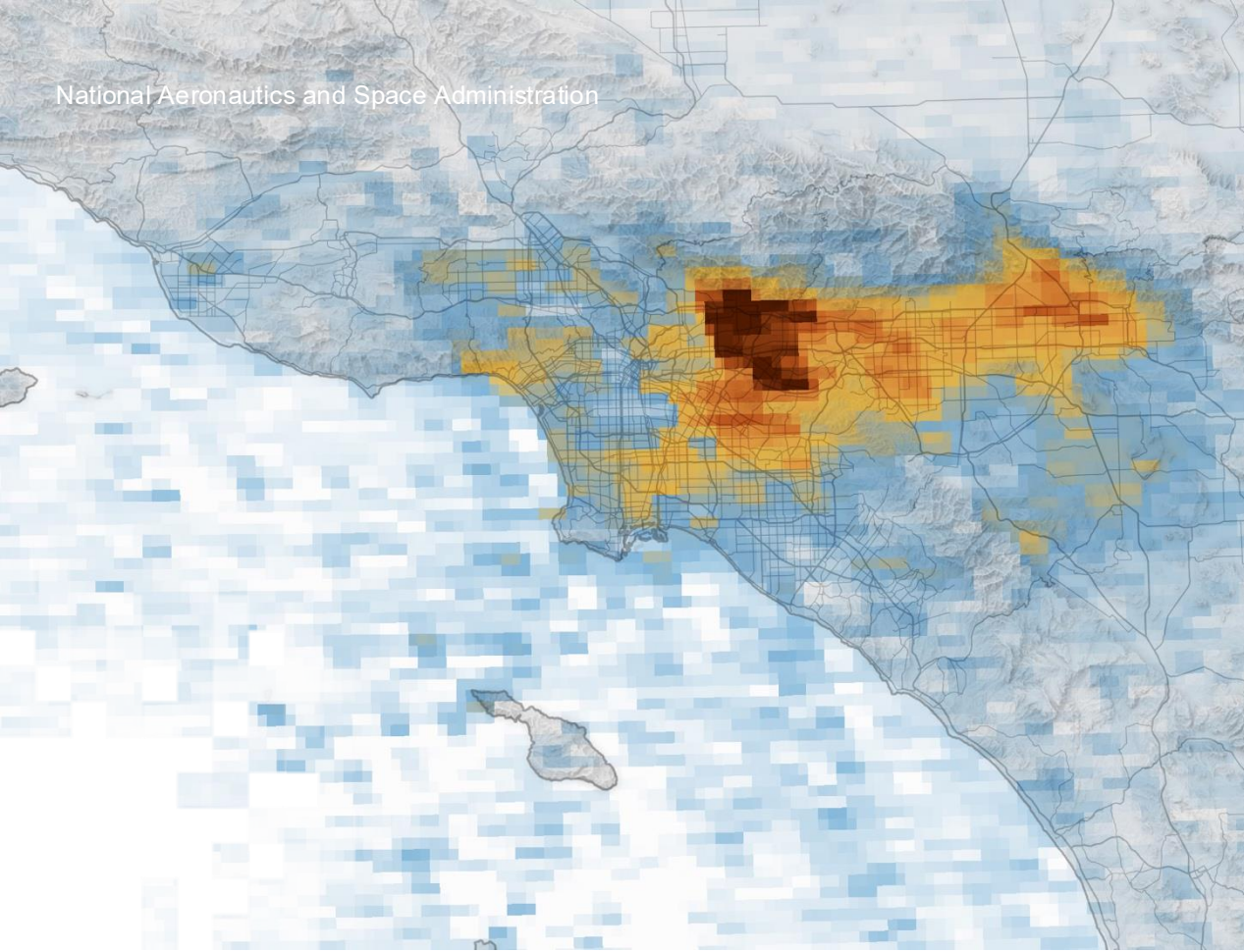


National Aeronautics and Space Administration



Introduction to Geostationary Observations for Air Quality Applications in the Western US

Day 1, Part 4: Overview of TEMPO Instrument and Its Capabilities

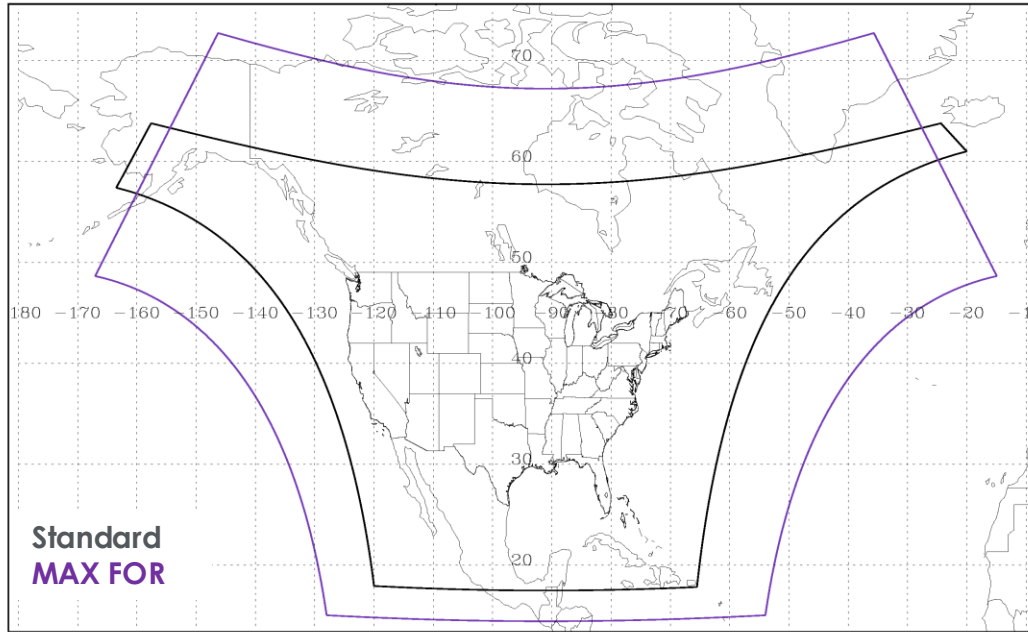
Aaron Naeger (TEMPO Applications)

August 05, 2025



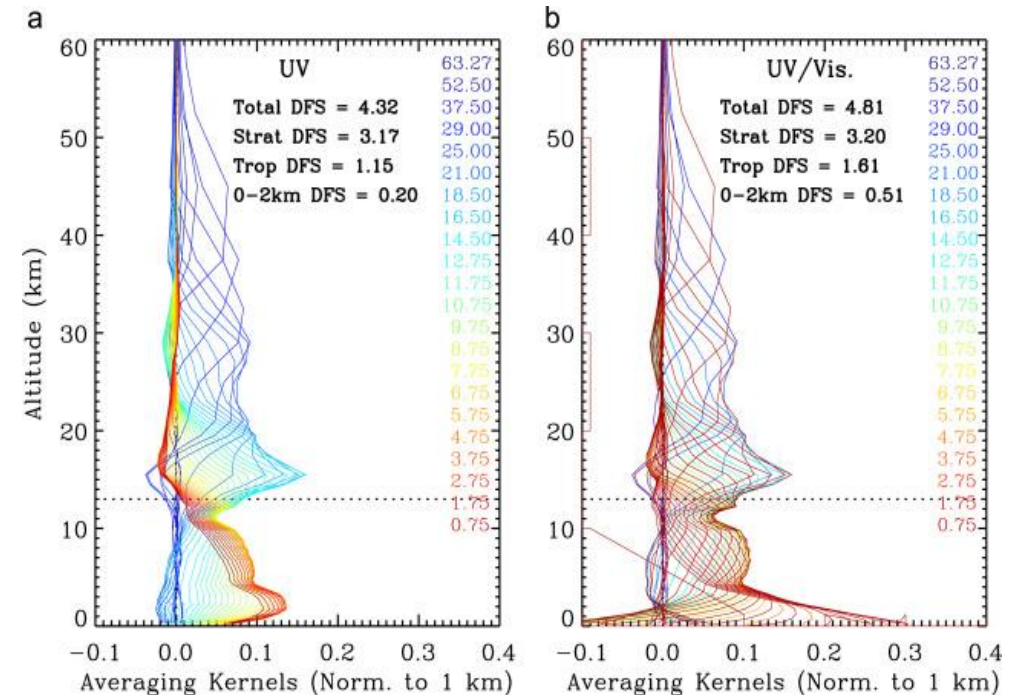
TEMPO Quick Facts

TEMPO Field of Regard Range

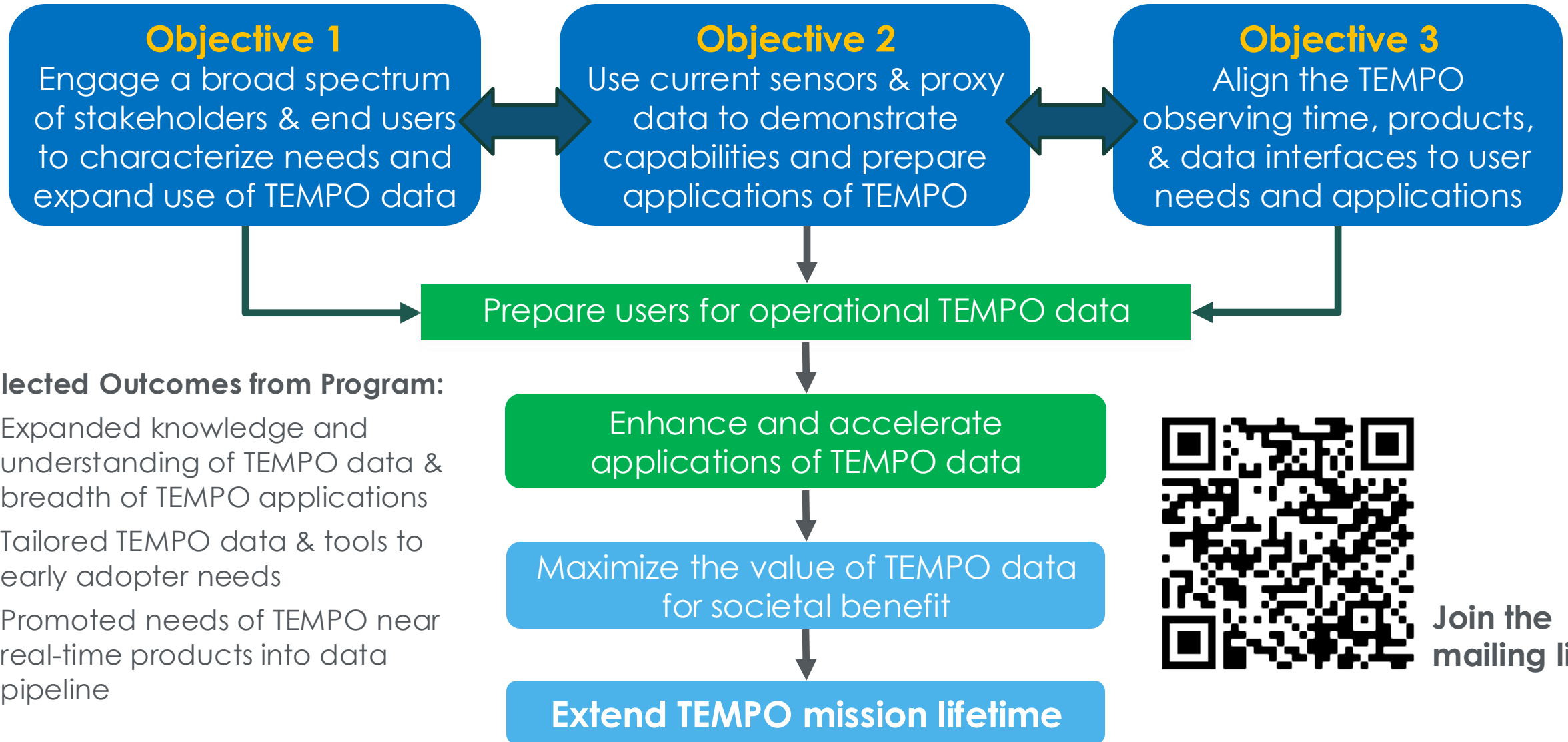


- **Launched April 7, 2023** into Geostationary Earth Orbit on SpaceX rocket to satellite host Intelsat (IS40e) @ 91°W
- **First Light** operations on **August 2, 2023**, with **nominal operations starting October 19, 2023**
- Baseline mission ended June 19, 2025
- Mission extended through September 2026

- NASA's first EVI selected in 2012 and joint project with Smithsonian Astrophysical Observatory
- UV/Visible grating spectrometer sensitive to **policy-relevant pollutants (NO_2 , SO_2 , O_3)** and aerosols
- TEMPO Field of Regard (FoR) covers greater North America, including most of Mexico, Southern and Central Canada, Puerto Rico, and Southern Alaska.



TEMPO Early Adopters to Community of Practice



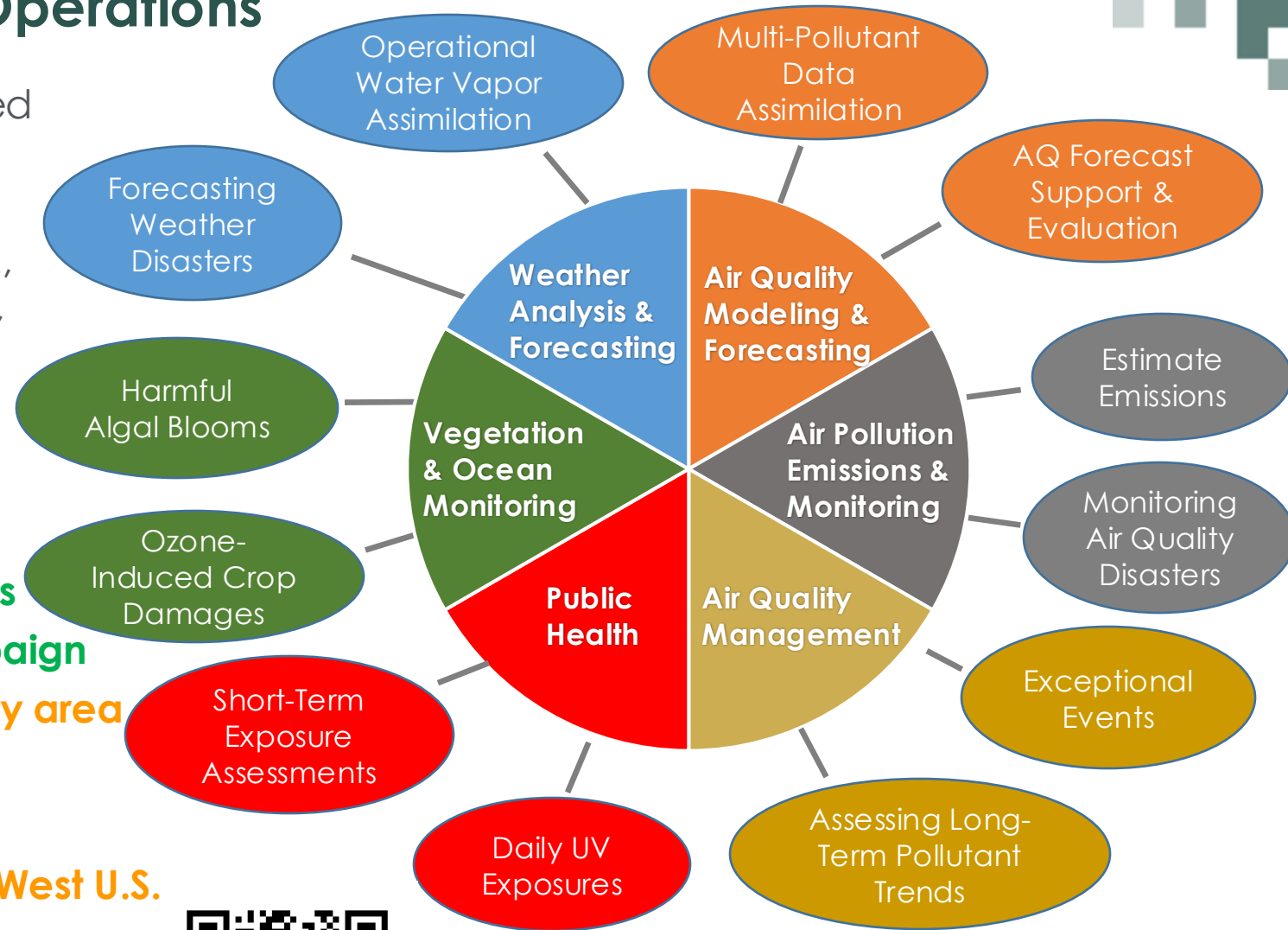
~ **680 Early Adopters (as of July 2025)** including 150+ from local, state, and regional AQ agencies



TEMPO Applications & Special Operations

- TEMPO special operations can be conducted over slice or portion of Field of Regard at higher sub-hourly frequency (e.g., 10 min)
- Focus areas include **air quality hazards** (e.g., wildfires, volcanoes), **chemistry studies** (e.g., lightning NO_x), & **field campaigns**
- Suite of special operations has been implemented since TEMPO's First Light, including operations for:
 - **2023 Coastal Texas Air Quality Observations**
 - **2025 Colorado Front Range research campaign**
 - **High resolution scanning over New York City area**
 - **Monitoring pollutants along traffic corridors**
 - **Prescribed burns in the Southeast U.S.**
 - **Assessing air quality from oil & gas wells in West U.S.**
 - **Lightning NO_x**
 - **Observing wildfires and air quality impacts**

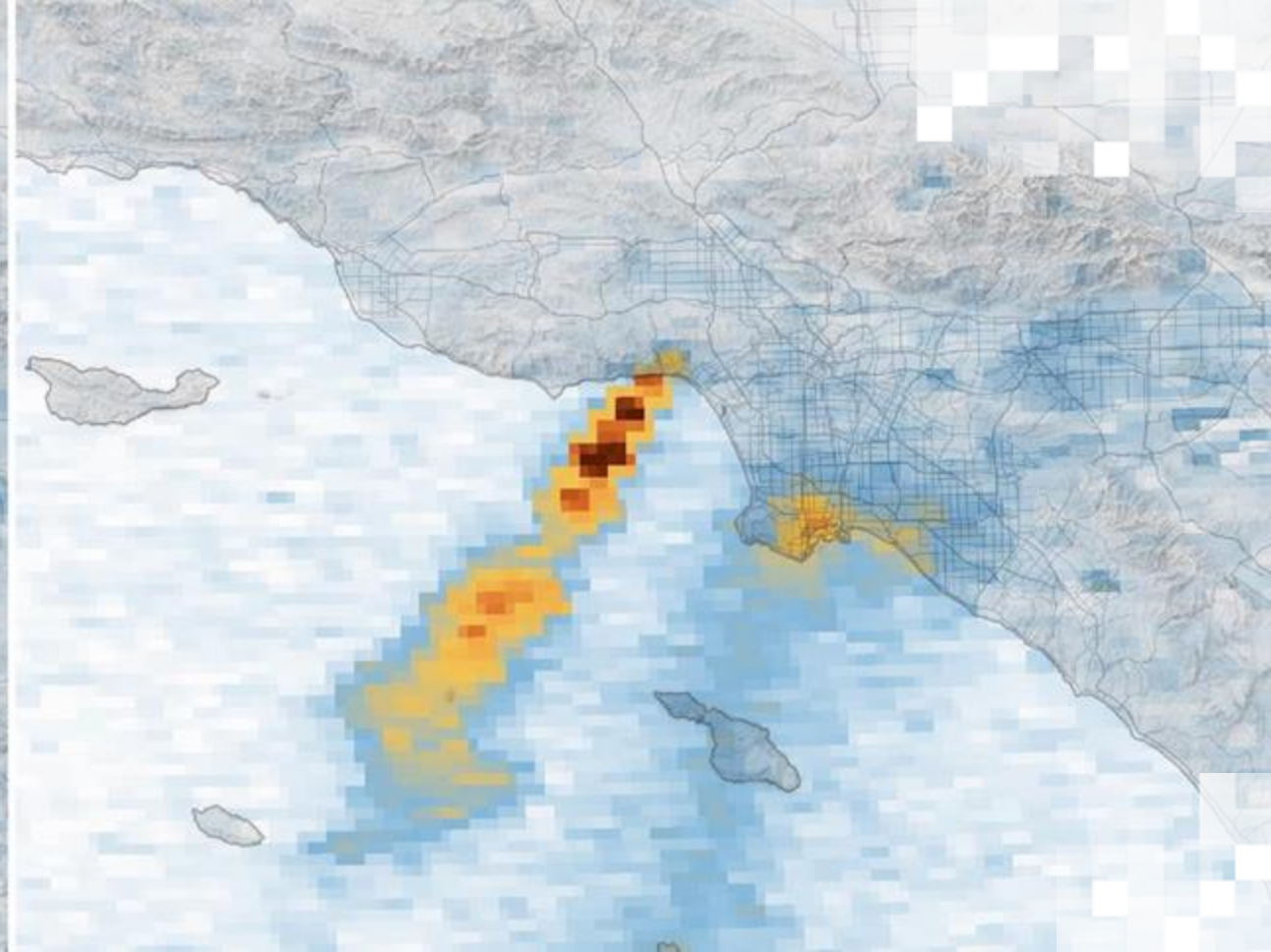
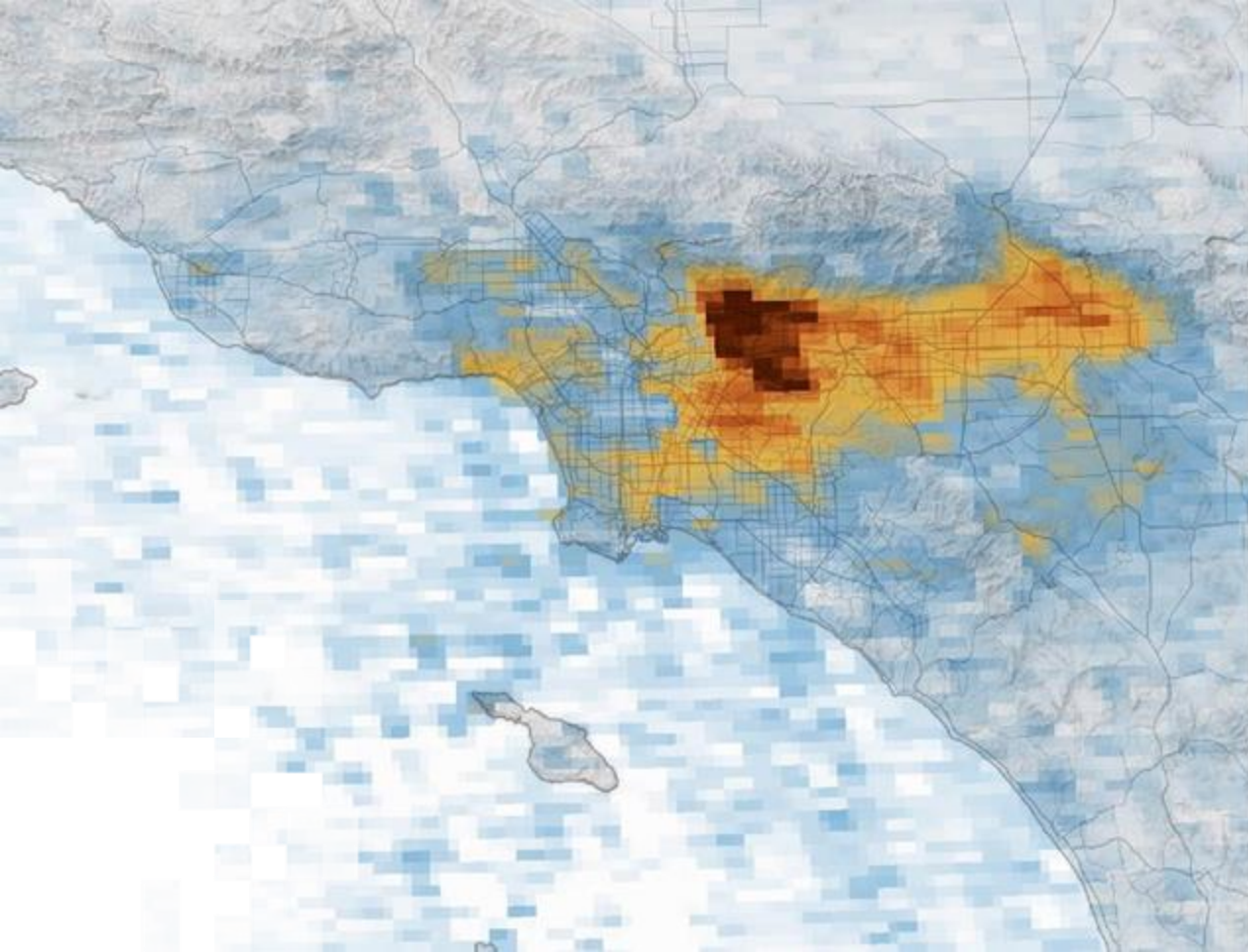
Core Applications of TEMPO



**Green
Paper!**

Early adopters provided key input on TEMPO core applications





Operations Timeline, Data Products, & Validation

Mission Phases & Operational Timeline

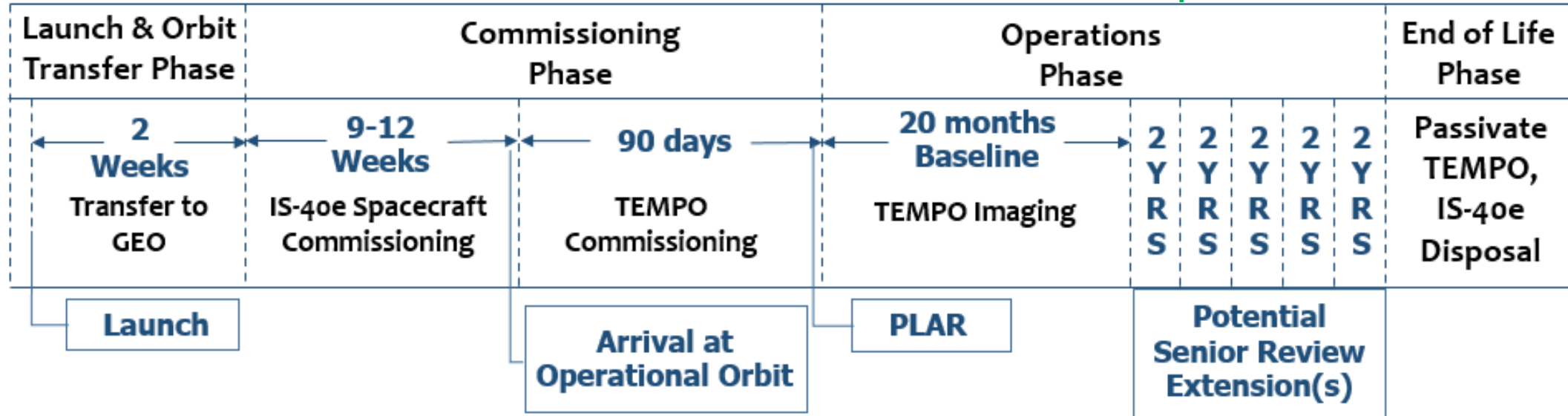
Launched
 April 7, 2023

Powered On
 June 7, 2023

Commissioning
 June 7 – Oct. 18, 2023

Baseline Mission
 Oct. 19, 2023 –
 June 19, 2025

Mission Extension
 June 20, 2025 –
 September 2026



- TEMPO was **powered on** June 7, 2023, denoting the start of the **commissioning phase** of TEMPO
- **Commissioning** lasted ~4 months with **First Light** occurring July 31 – Aug 2 with First Earth imaging on Aug 2
- Successfully passed Post Launch Acceptance Review (PLAR) in October 2023
- **Baseline mission** and **nominal operations** started October 19, 2023
- TEMPO is currently in a **mission extension phase** through September 2026
- Senior reviews and funding moving forward will determine TEMPO's lifetime; TEMPO has the potential to operate 10+ years



TEMPO's First Light on Aug 2, 2023

TEMPO performed six hourly daytime scans across the Field of Regard



TEMPO Data Products: Baseline + SNWG NRT + NOAA NRT

Level	Product	Filename	Source	Notable File Variables	Resolution ** (km ²)
L1	Radiance	RAD	Baseline + SNWG	Calibrated, geolocated radiances	2.0 x 4.75
AOD: Aerosol Optical Depth ALH: Aerosol Layer Height	L2 Cloud	CLDO4	Baseline + SNWG	Cloud fraction, Cloud pressure	2.0 x 4.75
	Ozone Total Column	O3TOT	Baseline	Total column O ₃ , UV Aerosol Index, Quality Flag	2.0 x 4.75
	Nitrogen Dioxide	NO2	Baseline + SNWG	Tropospheric VCD, Total VCD, Cloud Fraction, Main Data Quality Flag	2.0 x 4.75
	Formaldehyde	HCHO	Baseline + SNWG	Total VCD, Cloud Fraction, Main Data Quality Flag	2.0 x 4.75
	Ozone Profile	O3PROF	Baseline	O ₃ profile, Tropospheric O ₃ column, Cloud Fraction	8.0 x 4.75
	AOD & ALH	AODALH	NOAA	AOD, ALH, Data Quality Flag	2.0 x 4.75
	Aerosol Detection Product (ADP)	ADP	NOAA	Dust/Smoke Discrimination, UV Absorbing Aerosol Index	2.0 x 4.75
L3	Same as L2	Same as L2	Baseline + SNWG	Same variables as L2	** 0.02° x 0.02°
L4	Surface PM _{2.5}	PM25	NOAA	Hourly PM2.5 estimation	2 km x 2 km

****O3PROF L3 Product → 0.04 x 0.04° Resolution ***

VCD: Vertical Column Density

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



TEMPO Data Products – Versions & Release Dates

- Version 3 Level 1, 2, & 3 **baseline “provisional” products** released May 20, 2024
 - Cloud, NO₂ (nitrogen dioxide), HCHO (formaldehyde), Total Column O₃ (ozone)
 - Data latency ~ 5 - 6 hours
- Version 4 **baseline “validated” products** including O₃ profile targeted for release in early September 2025
 - Ozone profile data latency ~ 7 – 8 hours based on current ingest testing
- **SNWG near real-time (NRT)** planned for release in early September 2025
 - Cloud, NO₂, HCHO
 - Data latency ~ 2 hours

All products are free and publicly available via NASA Earthdata.

<https://search.earthdata.nasa.gov/search>

- **NOAA Aerosol Products** planned before the end of 2025
 - AOD (Aerosol Optical Depth), Aerosol Detection, PM_{2.5}
 - Data latency ~ 2 hours
 - **These data will also be made free and publicly available via NASA Earthdata.**



TEMPO Data Product Status

Version 3 “Beta” to “Provisional” Status

- TEMPO V03 (Version 3) Beta Level 1, 2, and 3 data products were upgraded to **provisional** validation status on December 9, 2024, after validation team approval. These data are now in provisional maturity, which means that product performance has been demonstrated through a large, but still (seasonally or otherwise) limited number of independent measurements. The V03 products are potentially ready for testing by operational users and may be suitable for scientific publications.

Version 3 “Provisional” to Version 4 “Validated” Status

- Products are high quality data that have been fully validated and quality checked. Validated data are deemed suitable for systematic research into long-term studies such as climate change as well as for shorter term process studies. These are publication quality data with well-defined uncertainties, but they are also subject to continuing validation, quality assurance, and further improvements in subsequent versions.



TEMPO L2+ Data Products: SNWG NRT & Enhanced

These products have no formal release date yet but are officially funded for the TEMPO mission.

Level	Product	Filename	Source	Key Product Variables	Resolution (km ²) **
L2	Glyoxal (C ₂ H ₂ O ₂)	GLYX	SNWG Enhanced	Total VCD, Cloud Fraction, Data Quality Flag	2.0 x 4.75
	Water Vapor (H ₂ O)	H2O	SNWG Enhanced		2.0 x 4.75
	Bromine (BrO)	BRO	SNWG Enhanced		2.0 x 4.75
	Sulfur Dioxide (SO ₂)	SO2	SNWG NRT	VCD (Total, Planetary Boundary Layer, & Lower/Middle/Upper Tropospheric, Lower Stratospheric)	2.0 x 4.75
	TEMPO/GOES-R Synergistic	TBD?	SNWG Enhanced	Aerosol, Fire/Hotspot, Cloud & Mask, Lightning, Snow/Ice, Precipitable Water	2.0 x 4.75
L3	Same as L2	Same as L2	SNWG	Same variables as L2	0.02° x 0.02°

VCD: Vertical Column Density

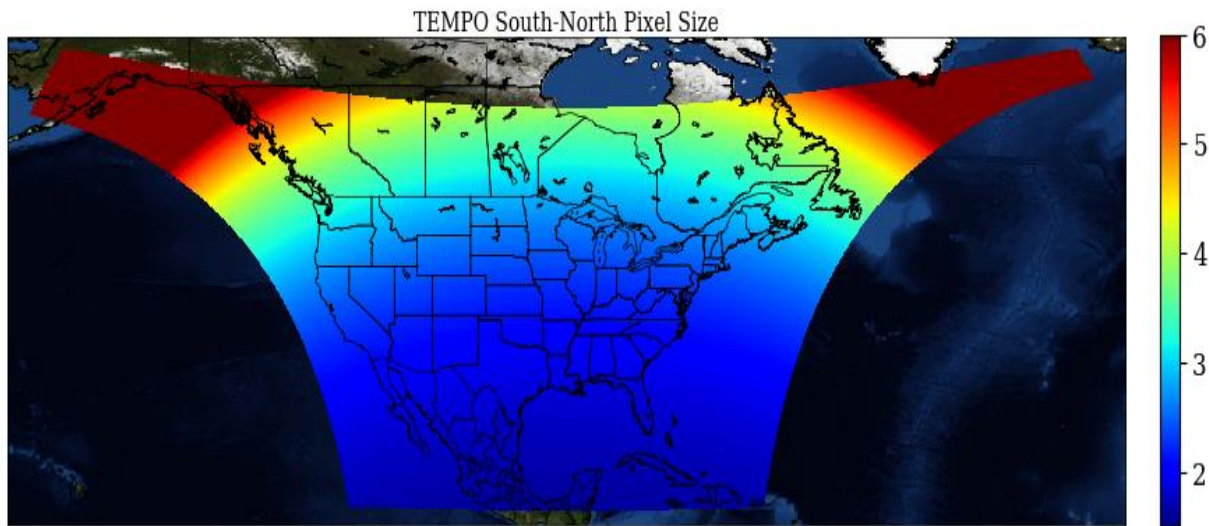
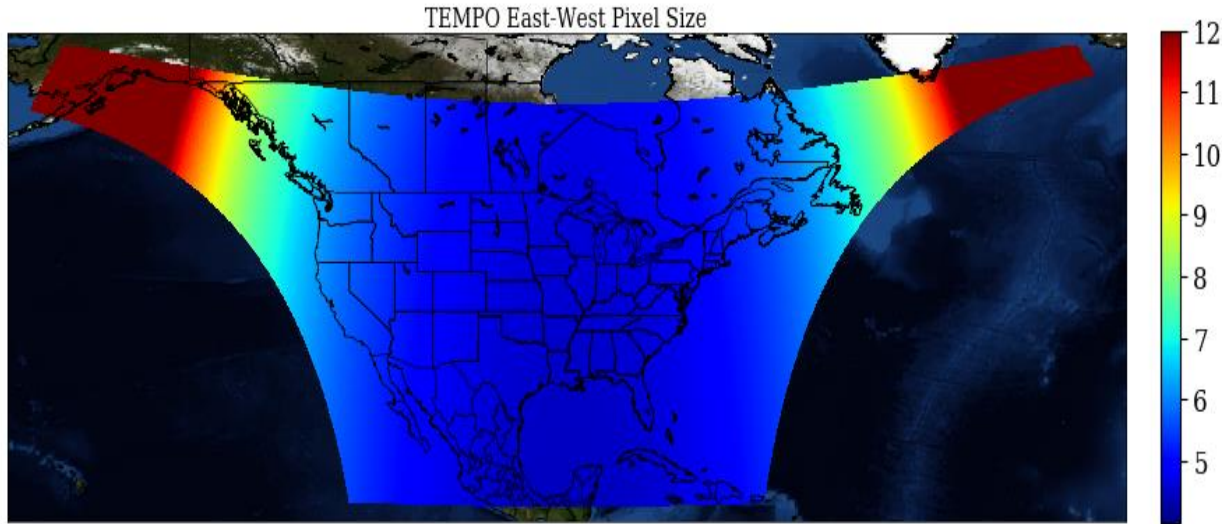
** @Center of Field of Regard 33.7°N, 91.7°W



TEMPO's Footprint Size Across the FoR

@Center of Field of Regard

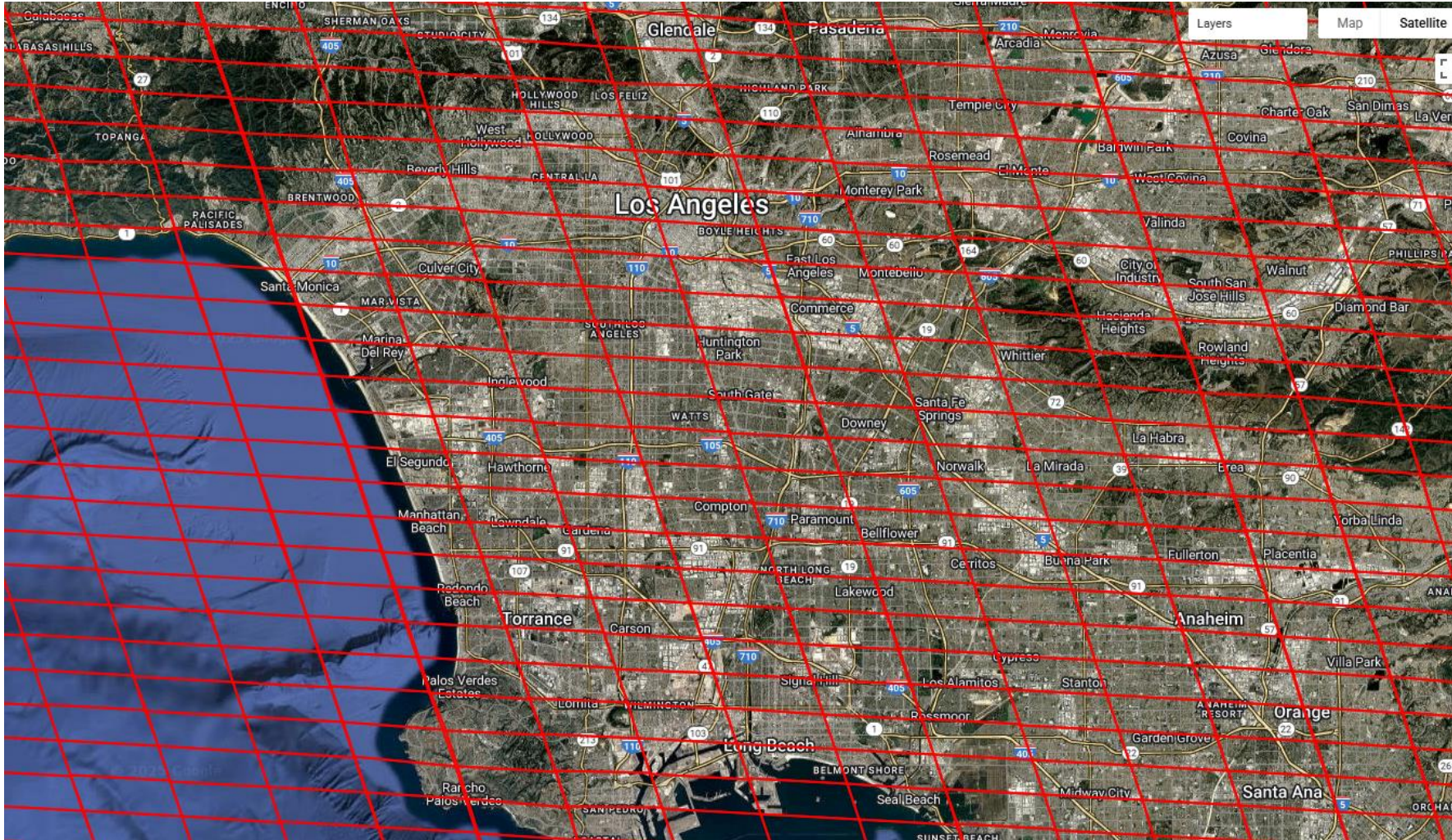
33.7°N, 91.7°W



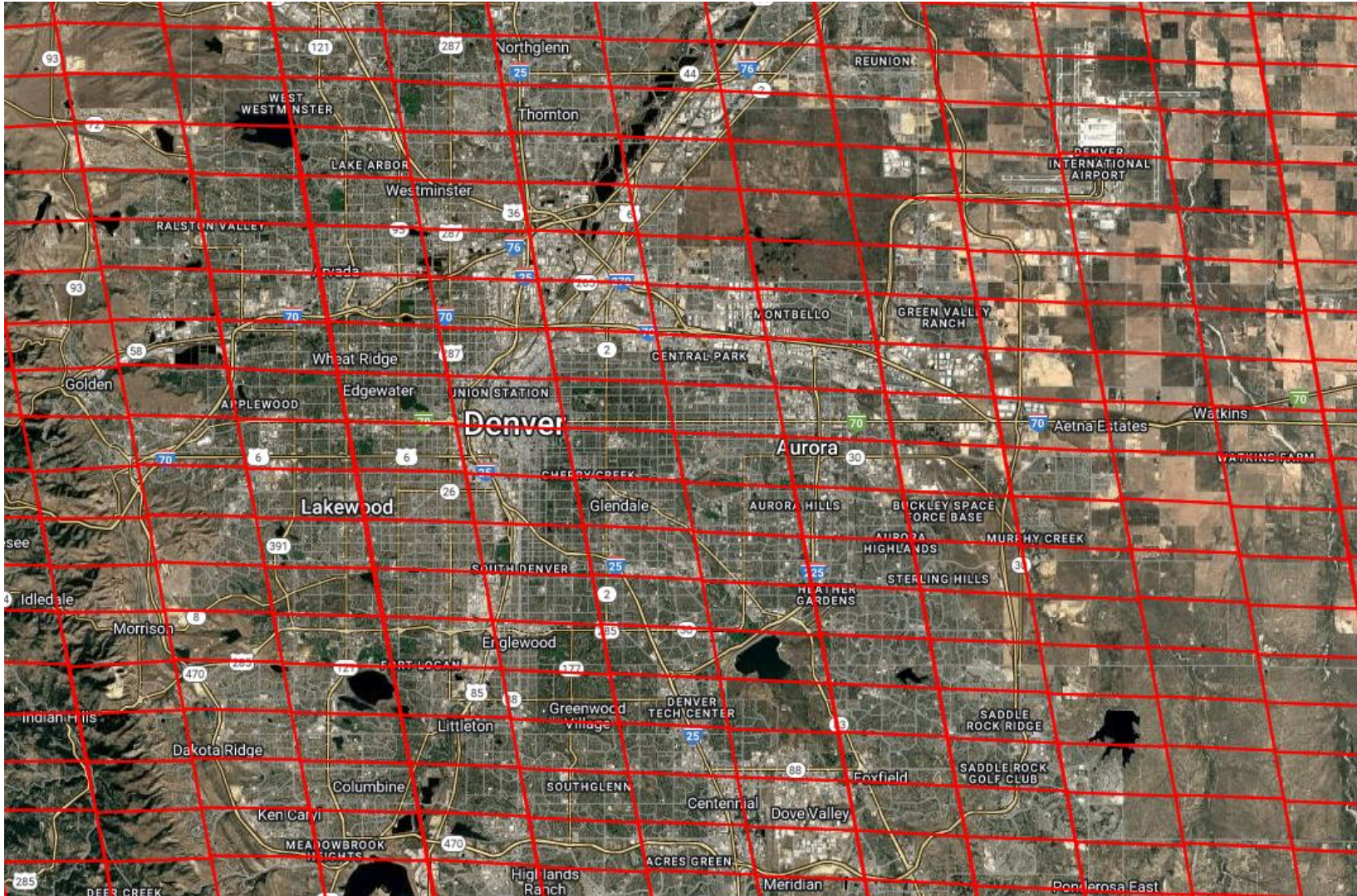
Location	N/S (km)	E/W (km)	VZA (°)
33.7°N, 91.7°W	2.0	4.8	39.1
Washington, DC	2.3	5.1	47.3
Seattle	3.3	6.5	62.5
Los Angeles	2.2	5.8	49.0
Boston	2.5	5.4	52.9
Miami	1.8	4.8	32.4
San Juan	1.7	5.4	35.8
Mexico City	1.6	4.7	24.6
Can. oil sands	4.2	5.7	67.4
Juneau	5.9	9.1	75.9



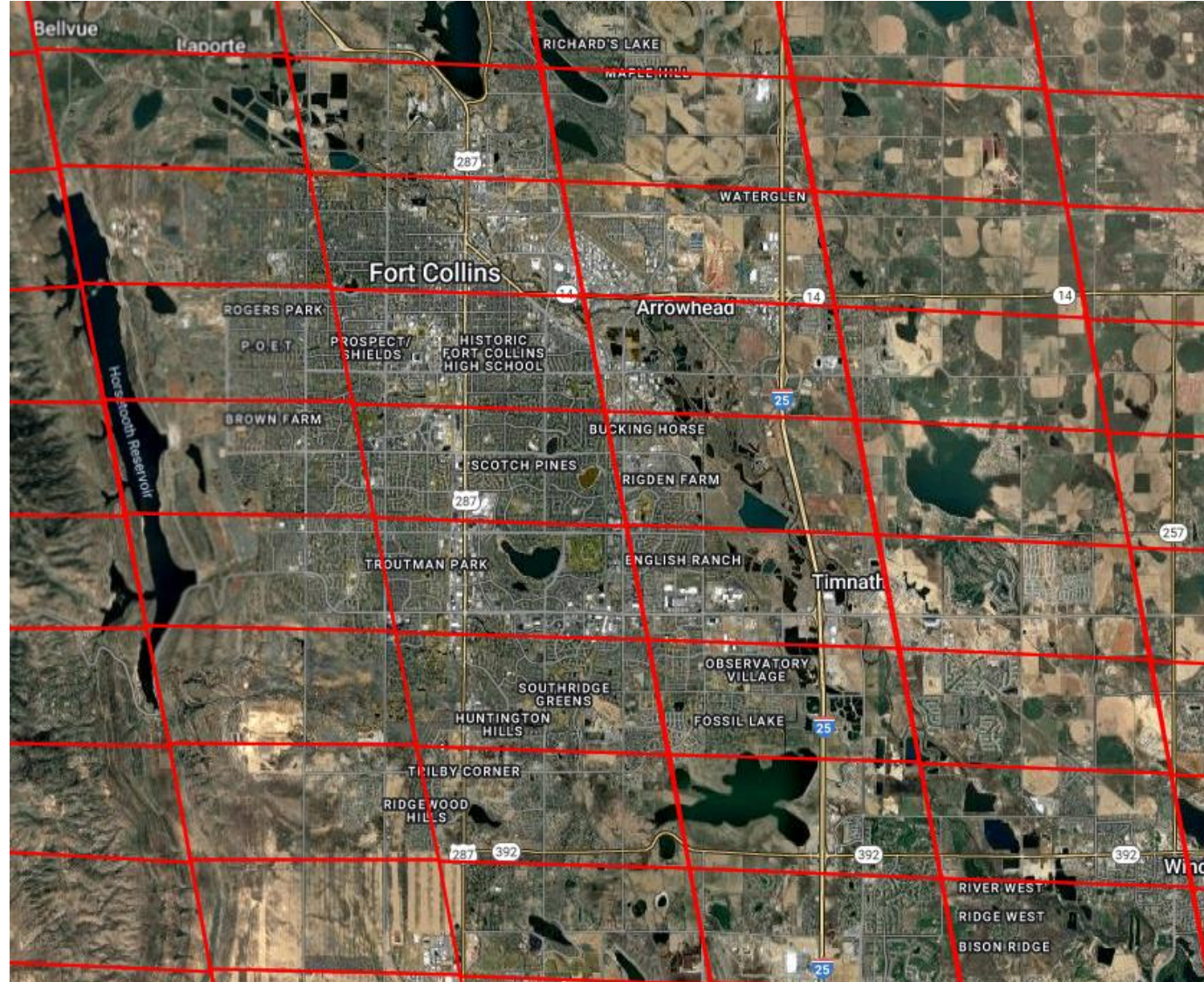
TEMPO's Footprints Across Los Angeles

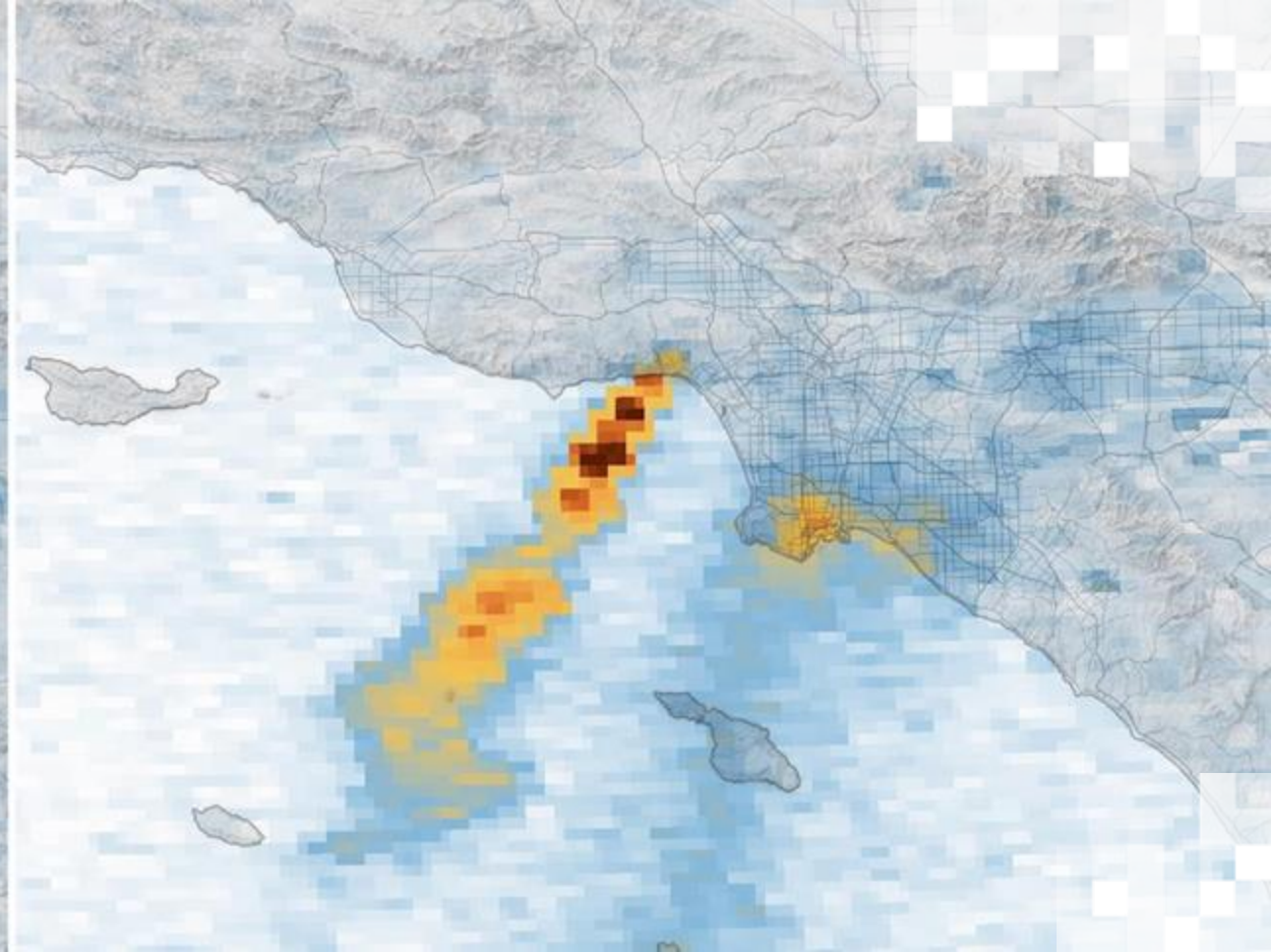
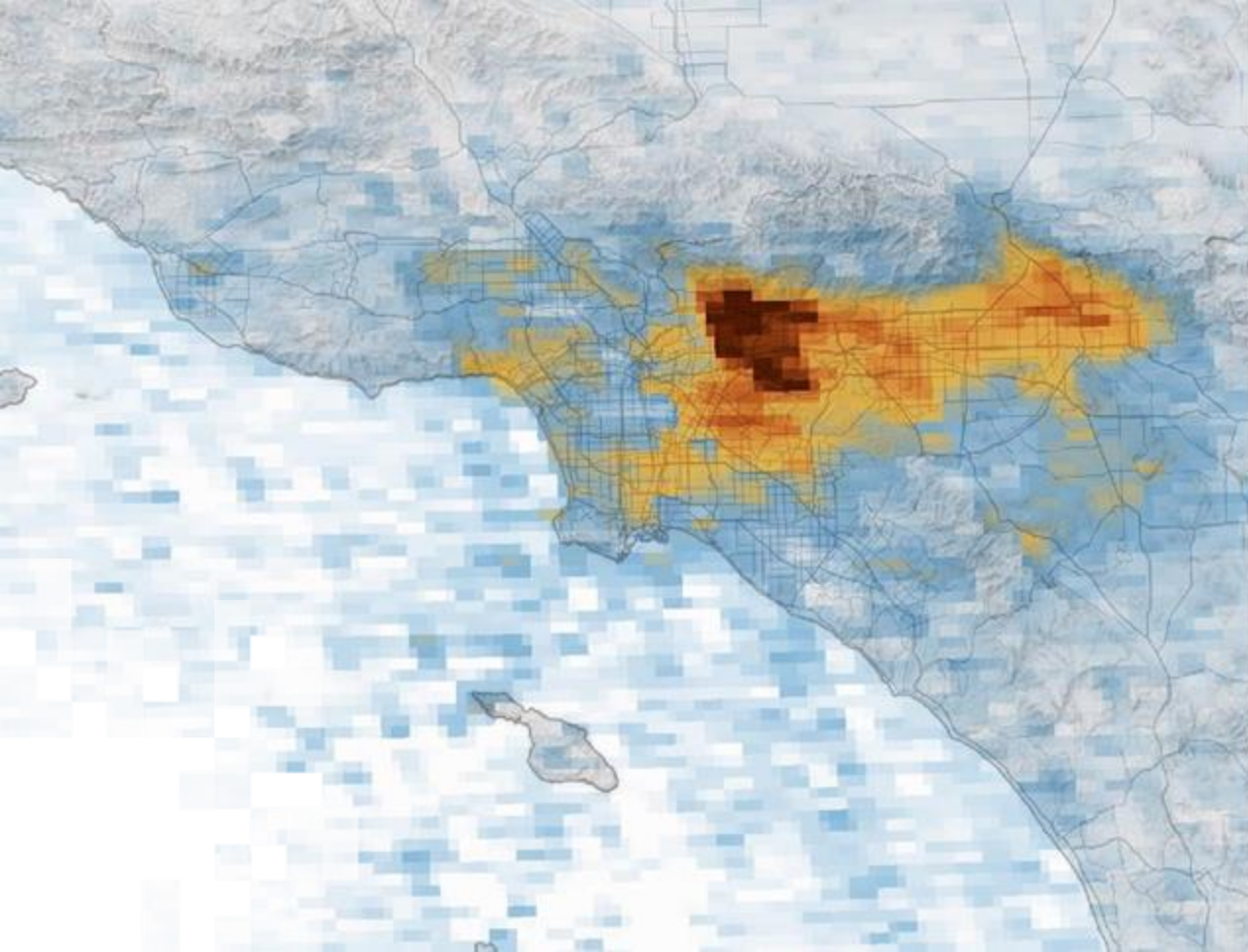


TEMPO's Footprints Across Denver



TEMPO's Footprints Across Fort Collins





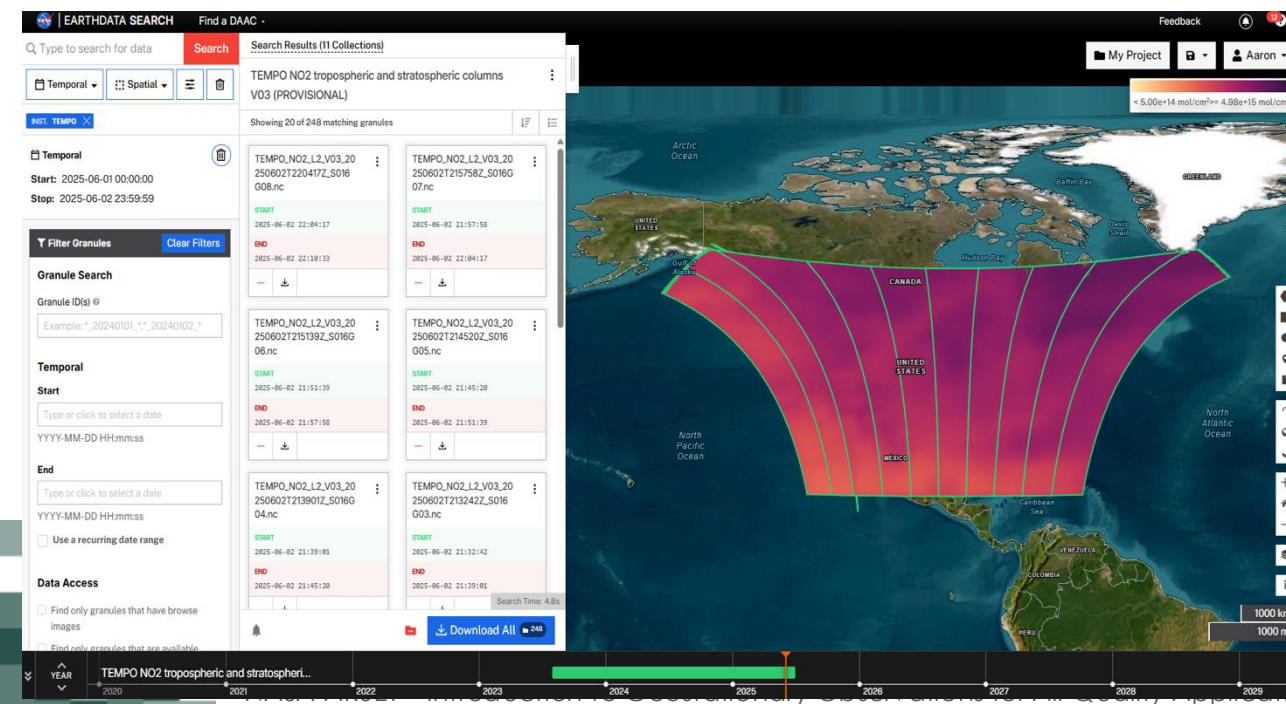
Data Access & Visualization Tools

Data Access & Visualization Tools (1)

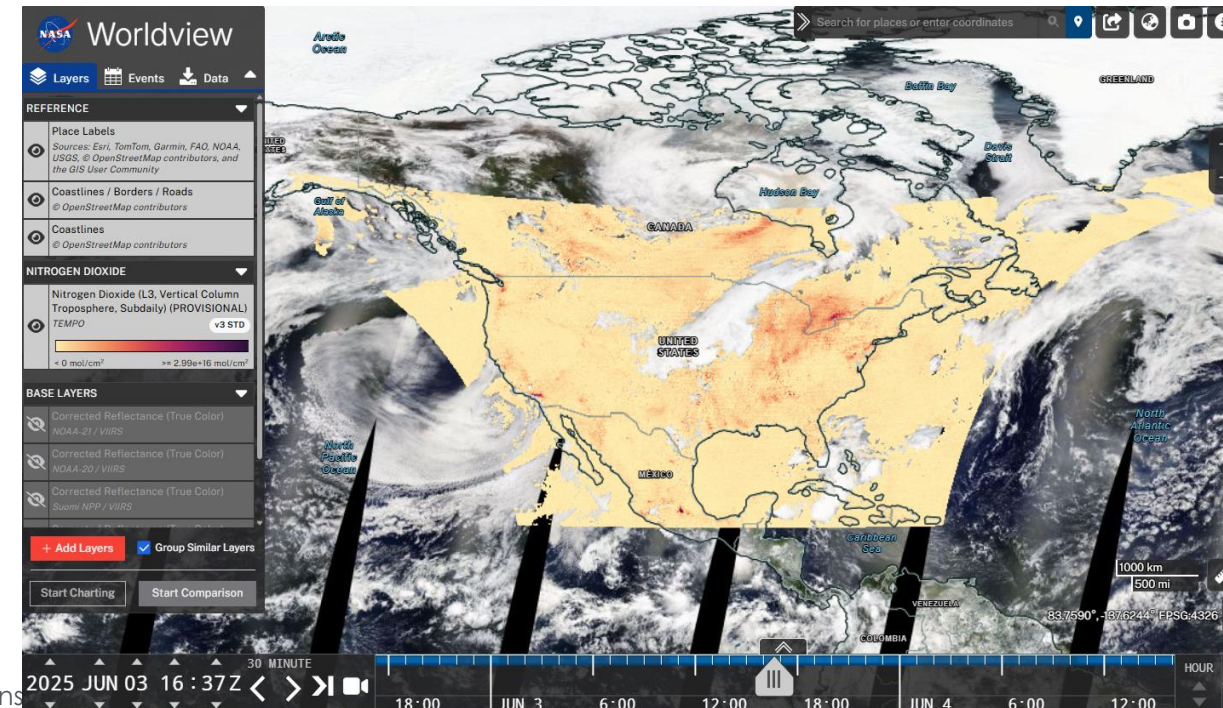
- List of data access, visualization tools, and user guides can be found at:
 - <https://asdc.larc.nasa.gov/project/TEMPO>
- NASA SPoRT Viewer provides TEMPO visualizations:
 - <https://weather.ndc.nasa.gov/sport/viewer>



Earthdata Search for Downloading TEMPO Data



Worldview for Visualizing TEMPO Data

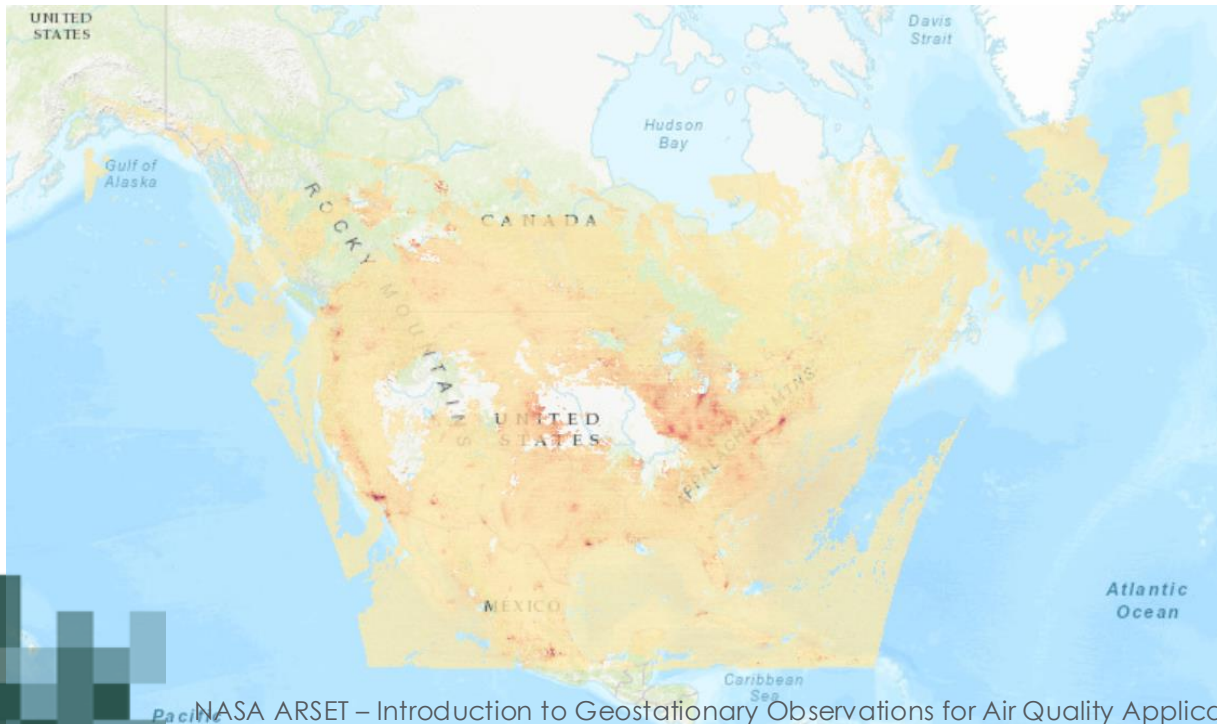


Data Access & Visualization Tools (2)

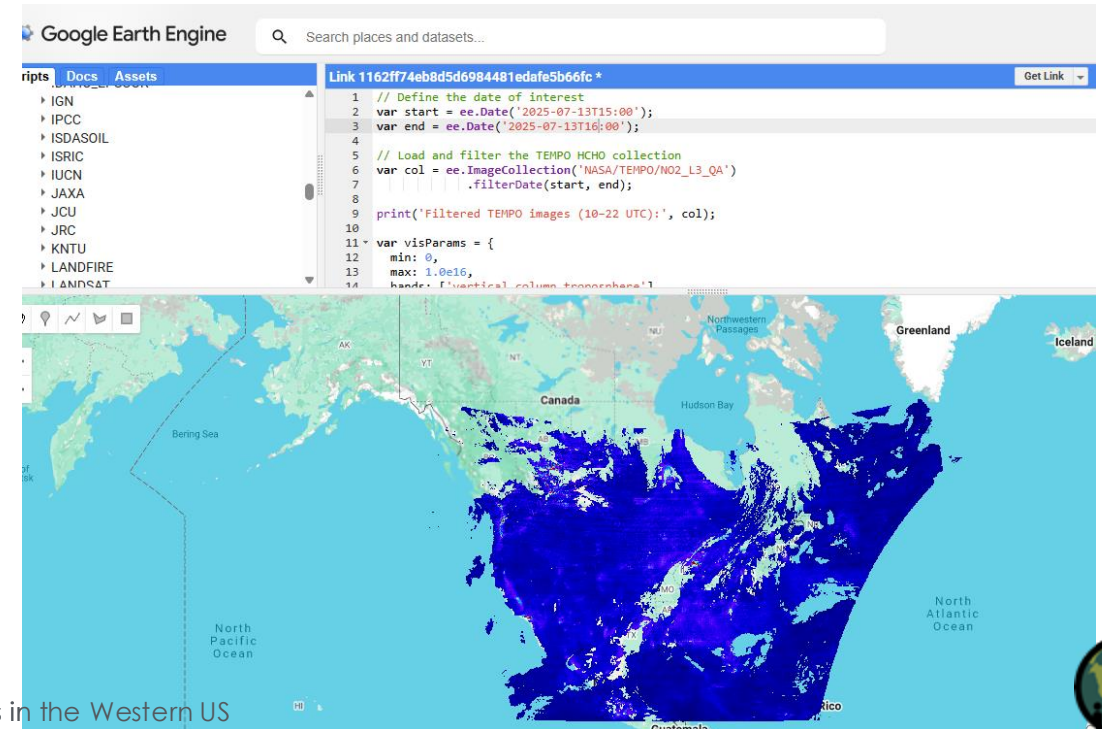
- NASA Living Atlas provides TEMPO visualizations:
 - <https://nasa.maps.arcgis.com/home/>
- Google Earth Engine provides TEMPO visualizations:
 - <https://developers.google.com/earth-engine/datasets/catalog/>

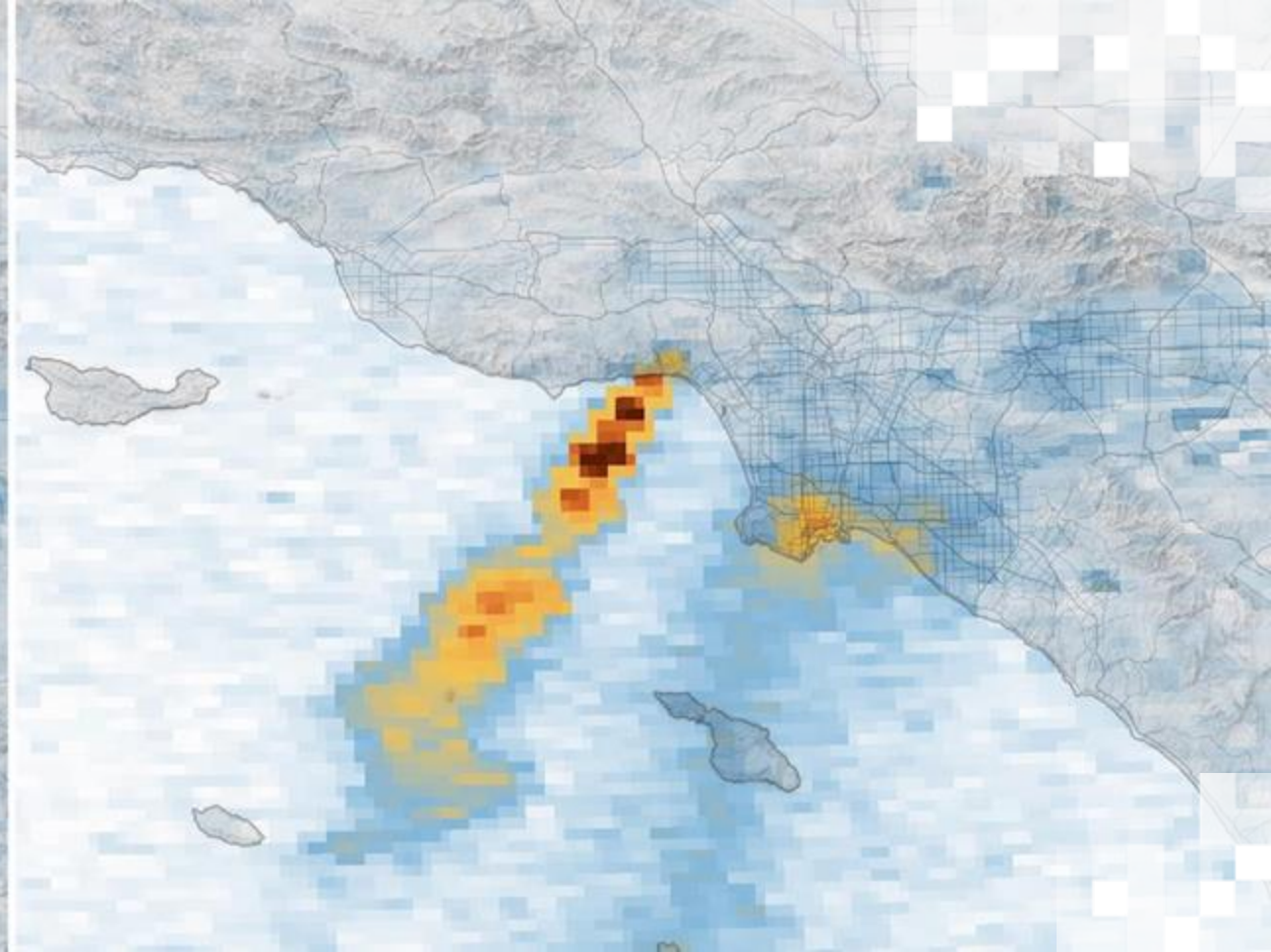
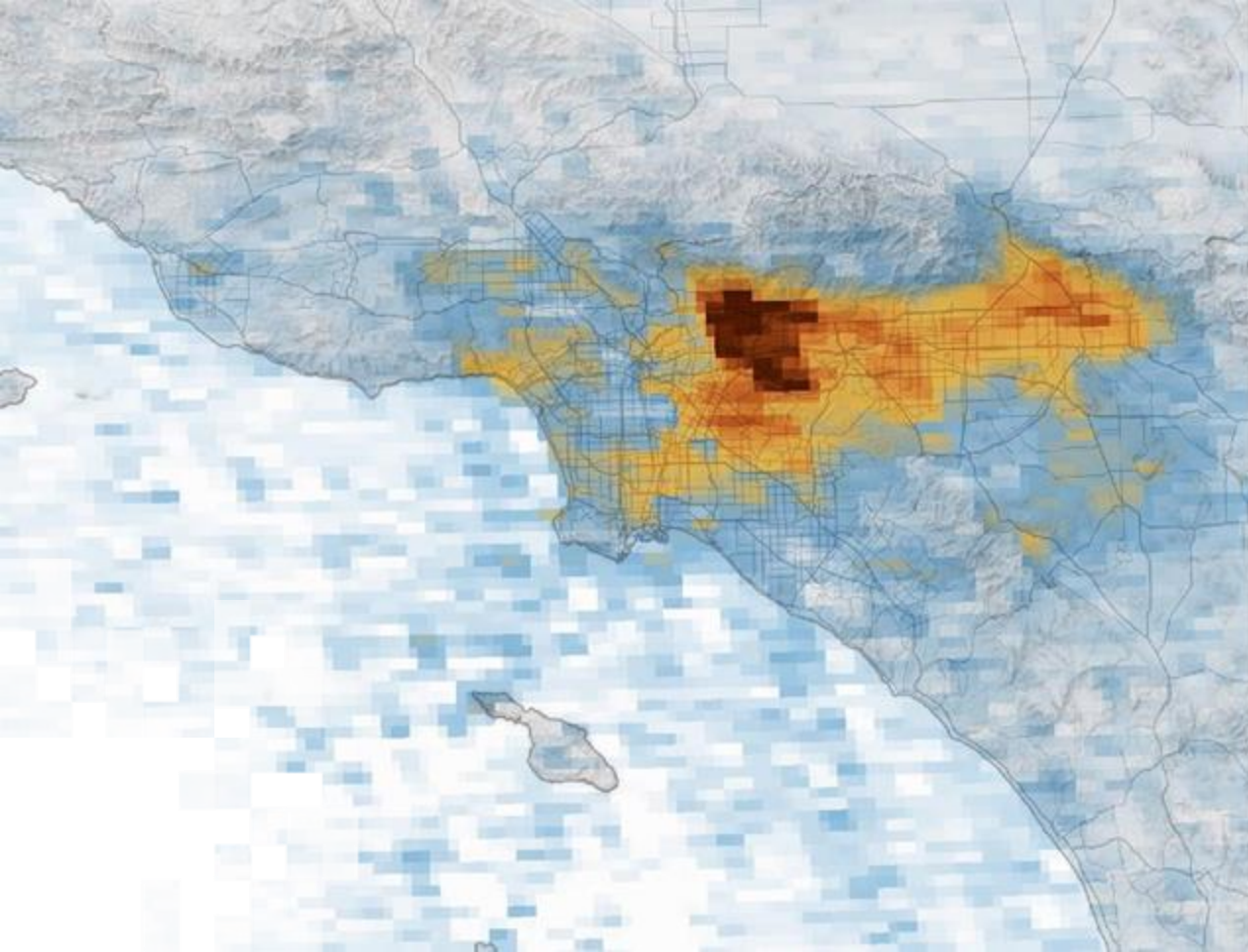


Living Atlas



Google Earth Engine

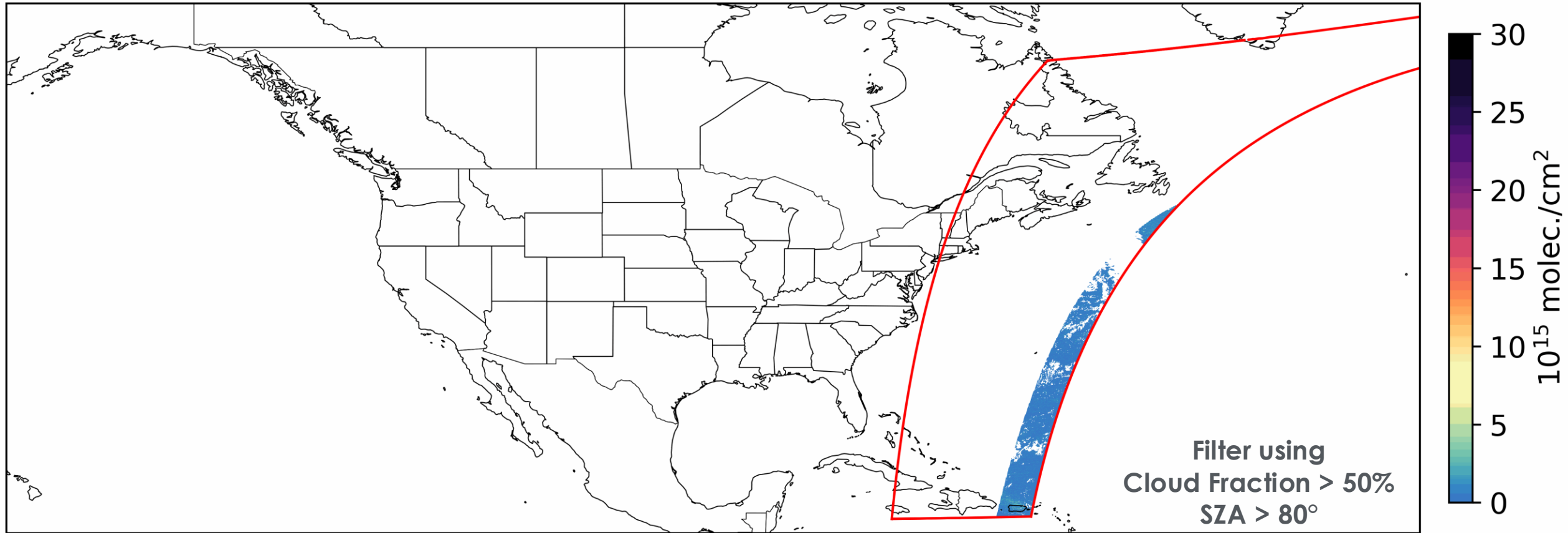




TEMPO Operational Scans & Data Files

Commissioning Phase Scans – October 8, 2023

TEMPO Tropospheric NO₂ 20231008 1116 - 1129 UTC

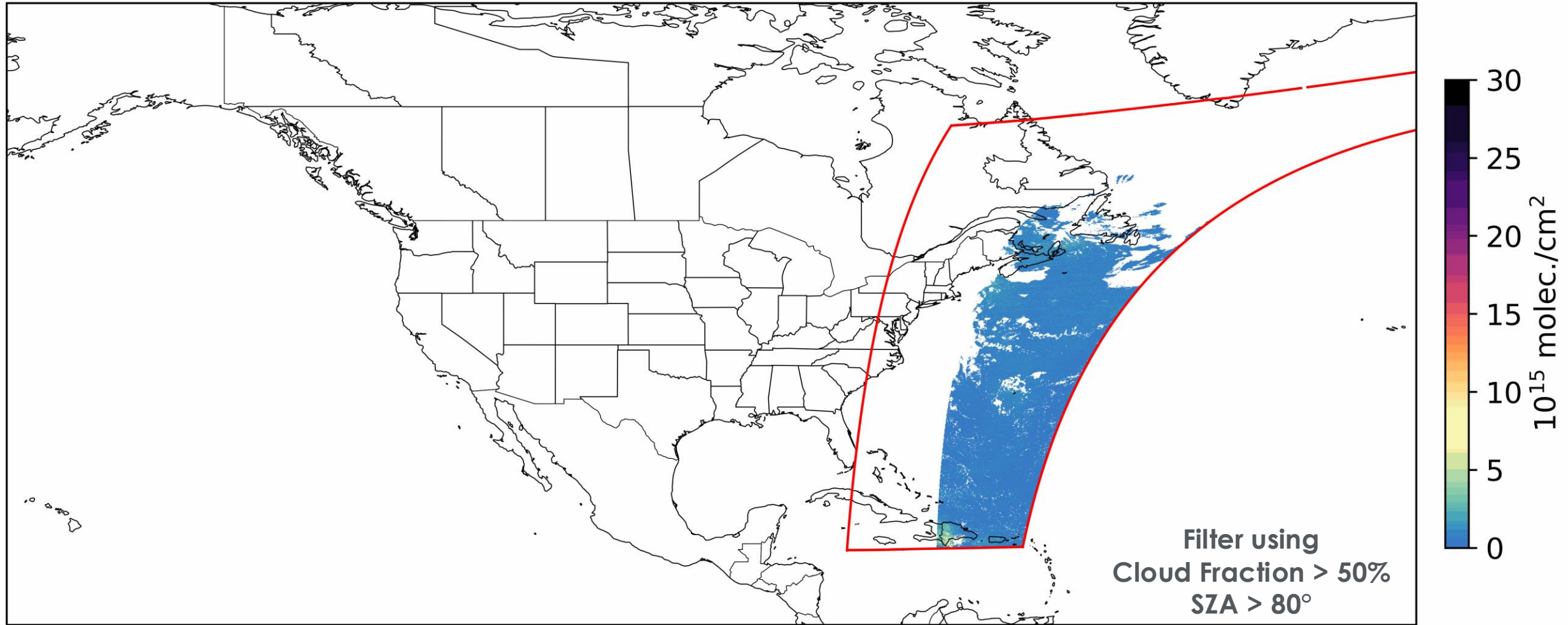


- TEMPO scan patterns during the commissioning phase were irregular with a mix of sub-hourly, hourly, and special scans including Southmost and Northmost scans to assess the maximum Field of Regard coverage.
- **The operations in this animation consisted of sub-hourly and hourly scans.**



Commissioning Phase Scans – September 18, 2023

TEMPO Tropospheric NO₂ 20230918 1122 - 1140 UTC

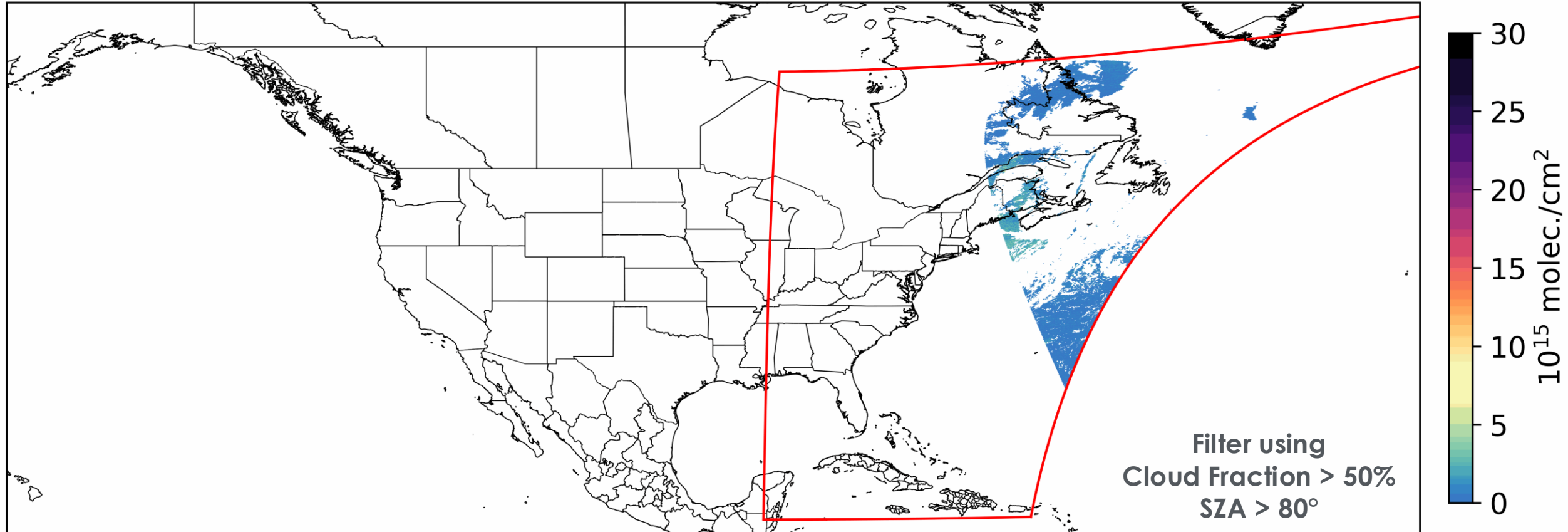


- The operations in this animation consisted of sub-hourly, hourly, Northmost, Southmost, and special scans.



Nominal Operational Scans – July 26, 2024

TEMPO Tropospheric NO₂ 20240726 1031 - 1057 UTC

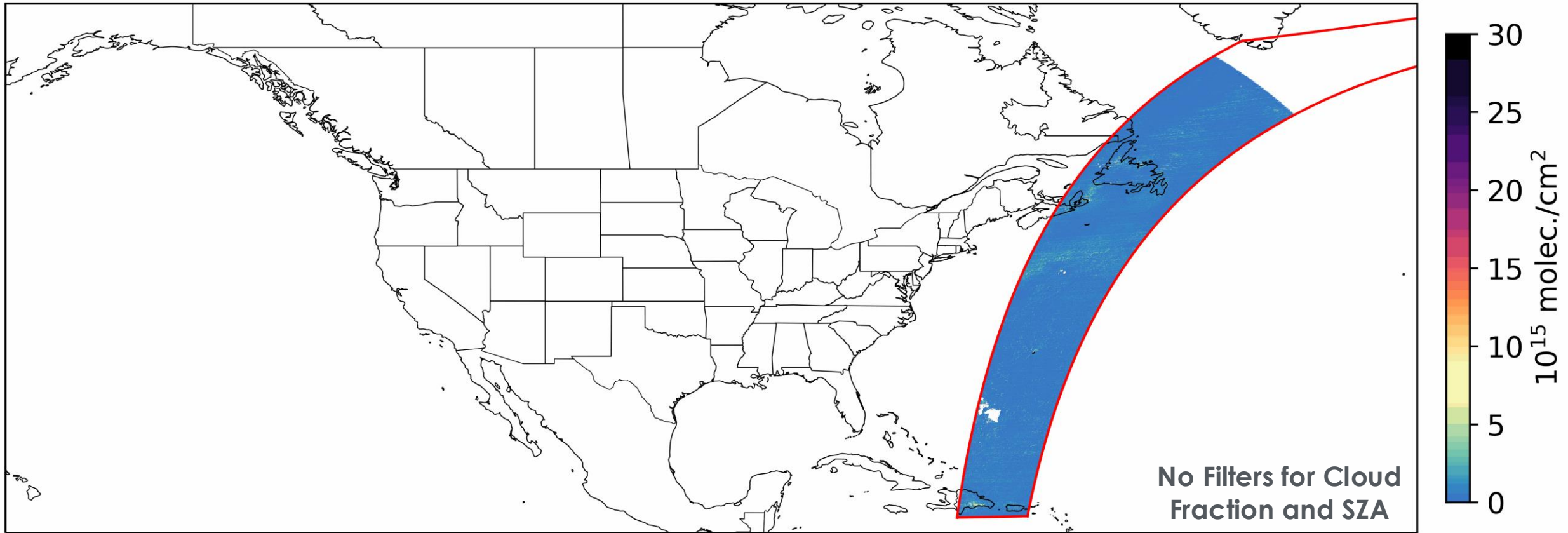


- **Nominal operations** consist of **standard (hourly) daytime scans** over full FoR (Field of Regard) and **optimized (30-40 minute) scans** over daylight portions of the FoR during the morning and afternoon.



Level 2 Granule Data Across TEMPO FoR – July 26, 2024

TEMPO Tropospheric NO₂ 20240726 1851 - 1858 UTC

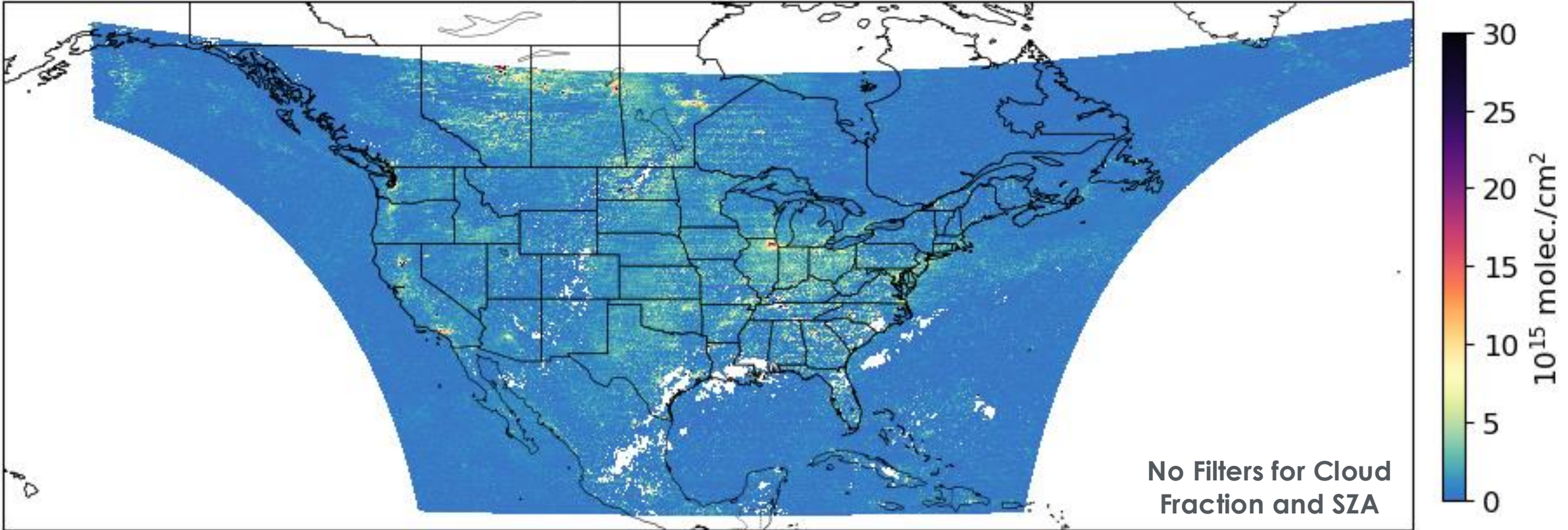


- 9 different level 2 data granules compose the full TEMPO FoR during the hourly, standard operations.
- **Note: This changed from 10 different data granules starting September 29, 2023.**



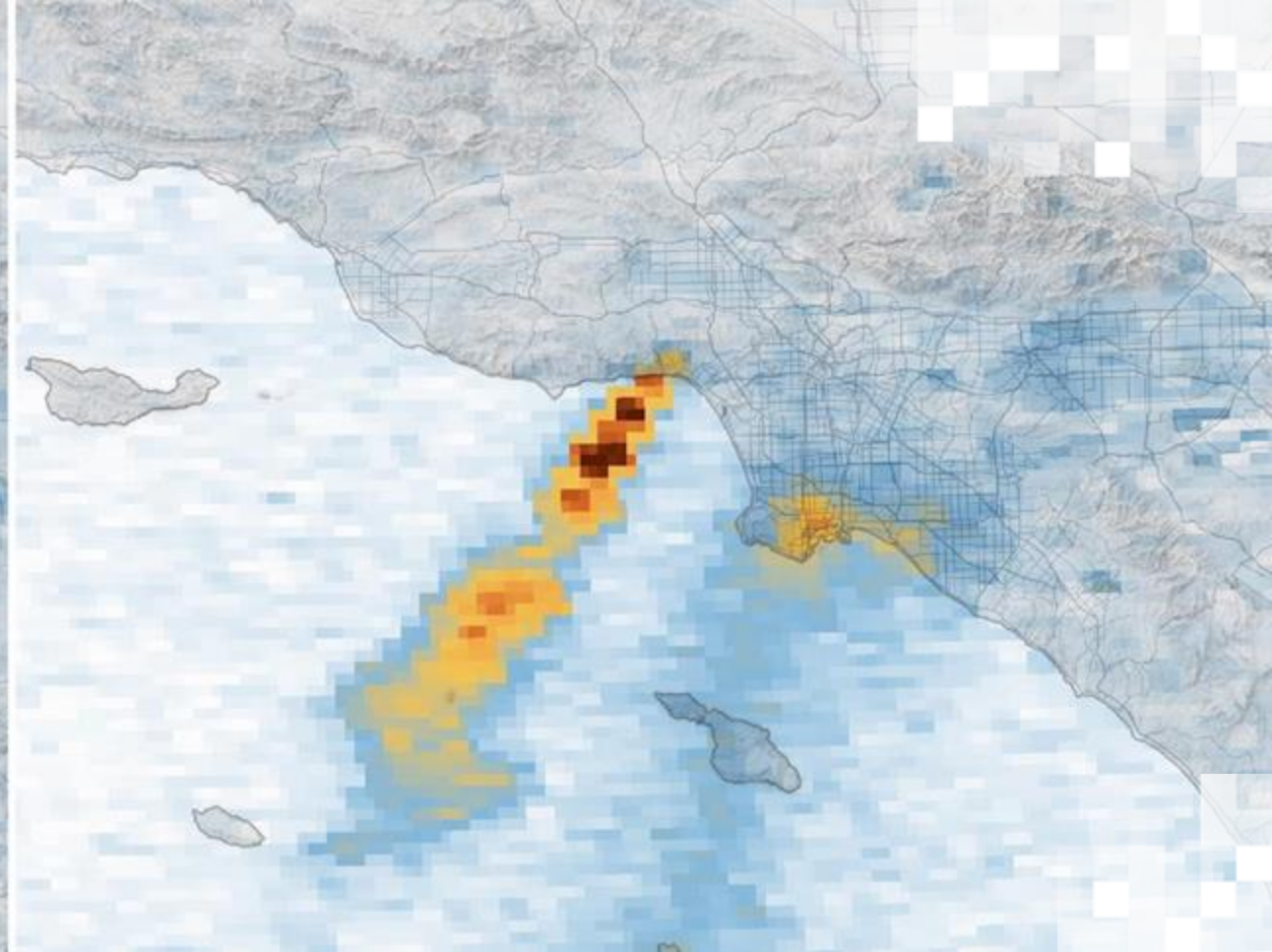
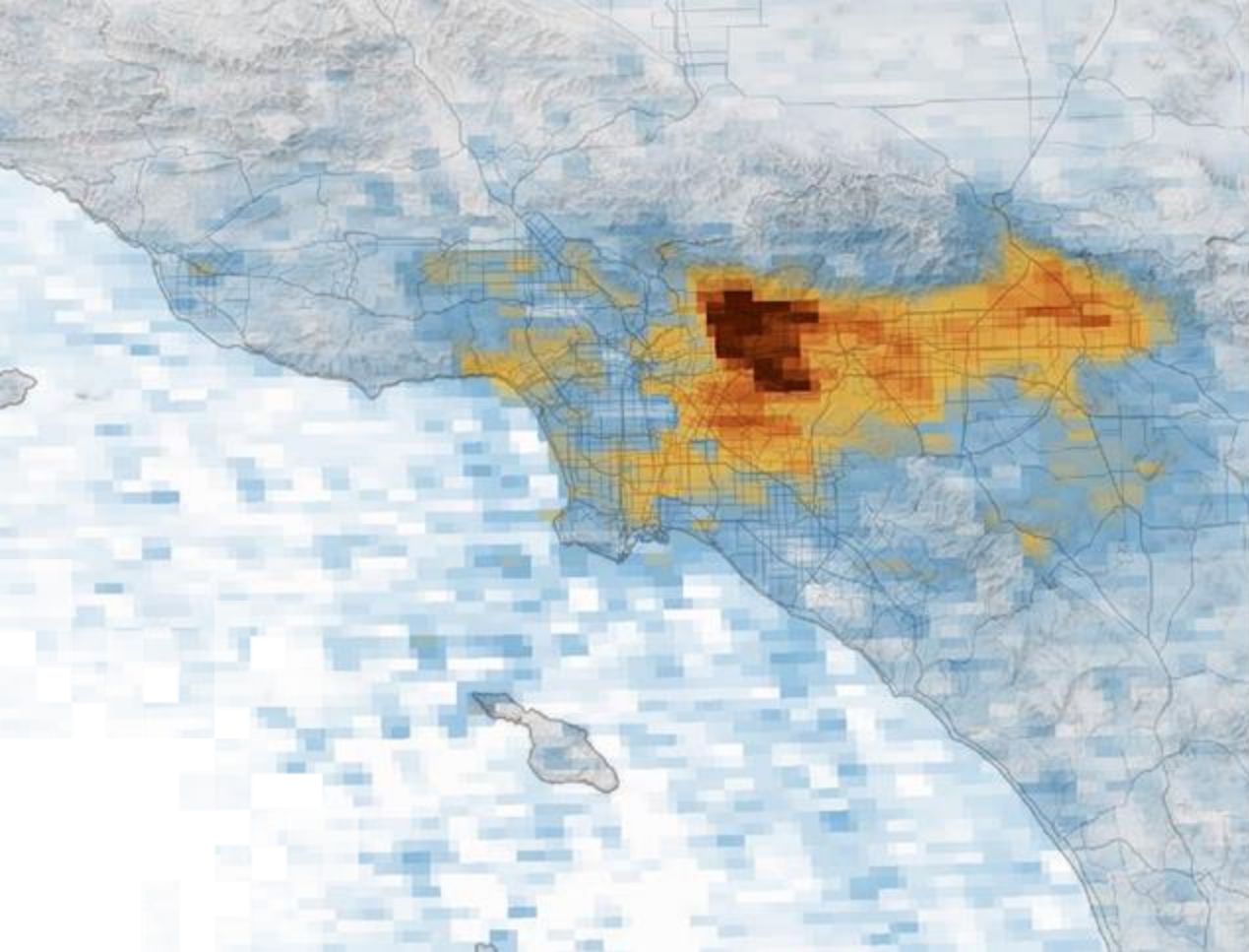
Level 3 Scan Data Across TEMPO FoR – July 26, 2024

TEMPO Tropospheric NO₂ 20240726 1851 - 1951 UTC



- Level 2 granules are regridded using an area-weighted approach onto a regular 0.02° grid across the TEMPO FoR to produce the level 3 scan files.

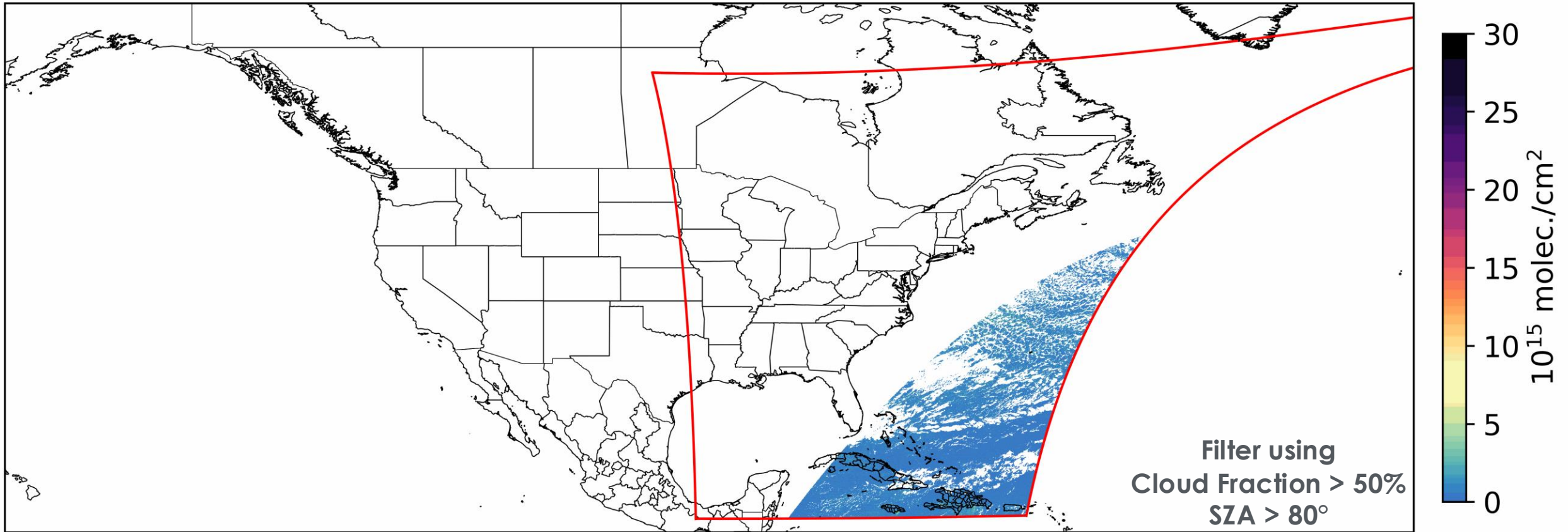




TEMPO Special Operations

Special Operation Scans – January 16, 2025

TEMPO Tropospheric NO₂ 20250116 1254 - 1327 UTC

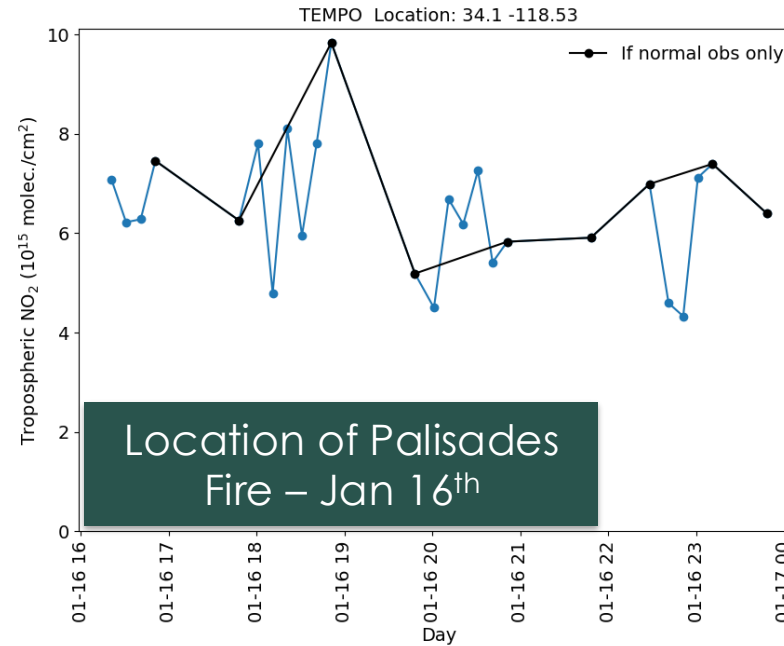
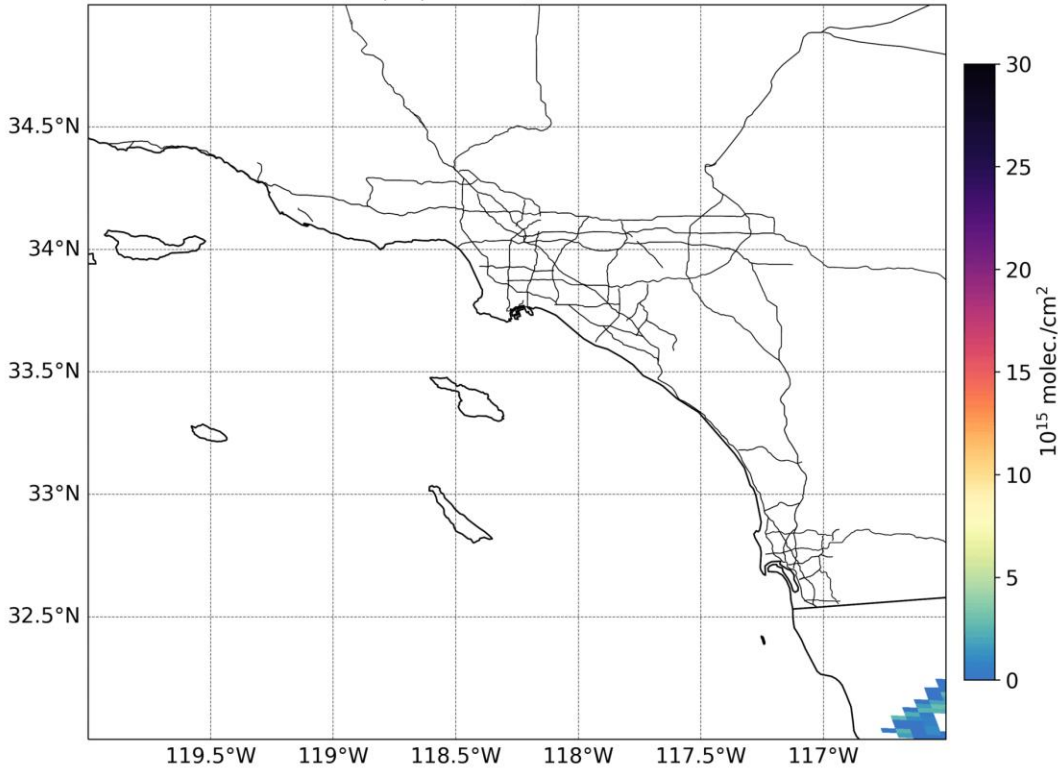


- Special operations were conducted for a 4-day period starting Jan. 16-19, 2025, which consisted of ~10-minute scans over the West Coast every other hour throughout the daytime.



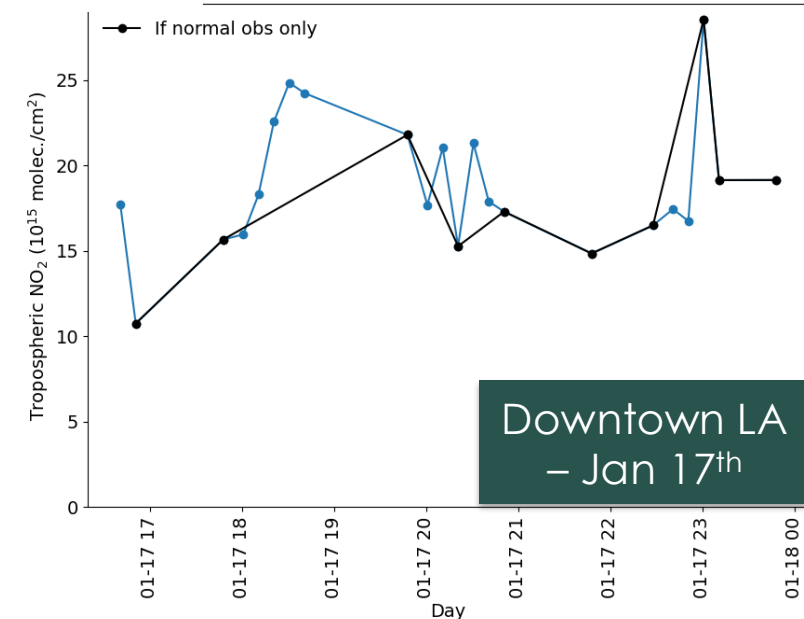
Special Operation Scans – January 16-17, 2025

TEMPO Tropospheric NO₂ 20250116 07:59 PST



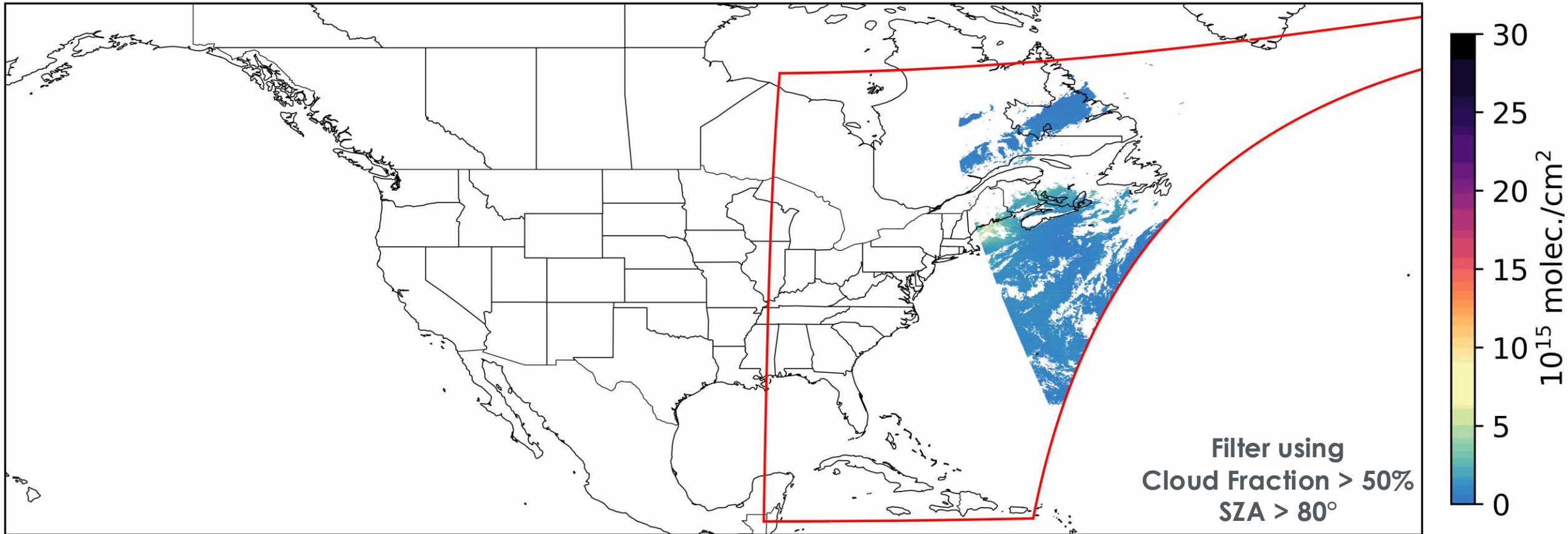
- Special scans observed variability in NO₂ columns which were not captured by standard scans
- Smoldering from the Palisades wildfire likely contributing to the NO₂ fluctuations observed by the special operations
- Special scans observed strong NO₂ variability in downtown Los Angeles the morning of Jan. 17th which was not captured by the standard scans

TEMPO Location: 34.07 -118.23



Special Operation Scans – July 25, 2025

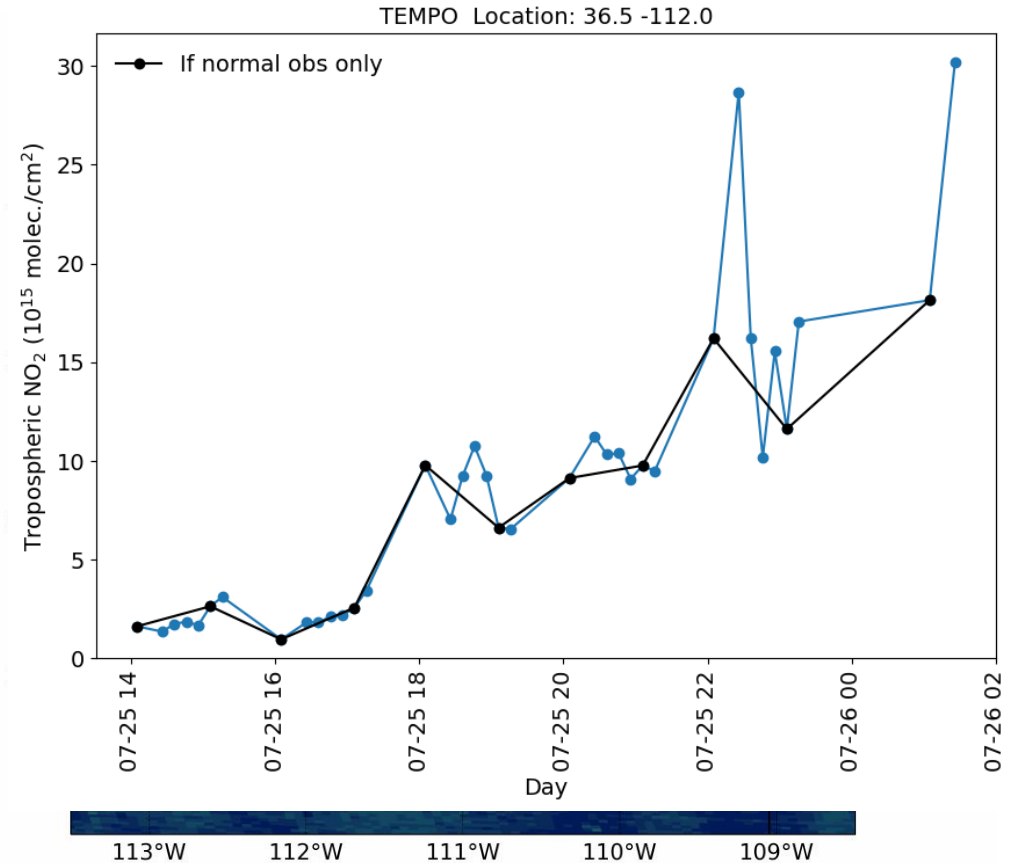
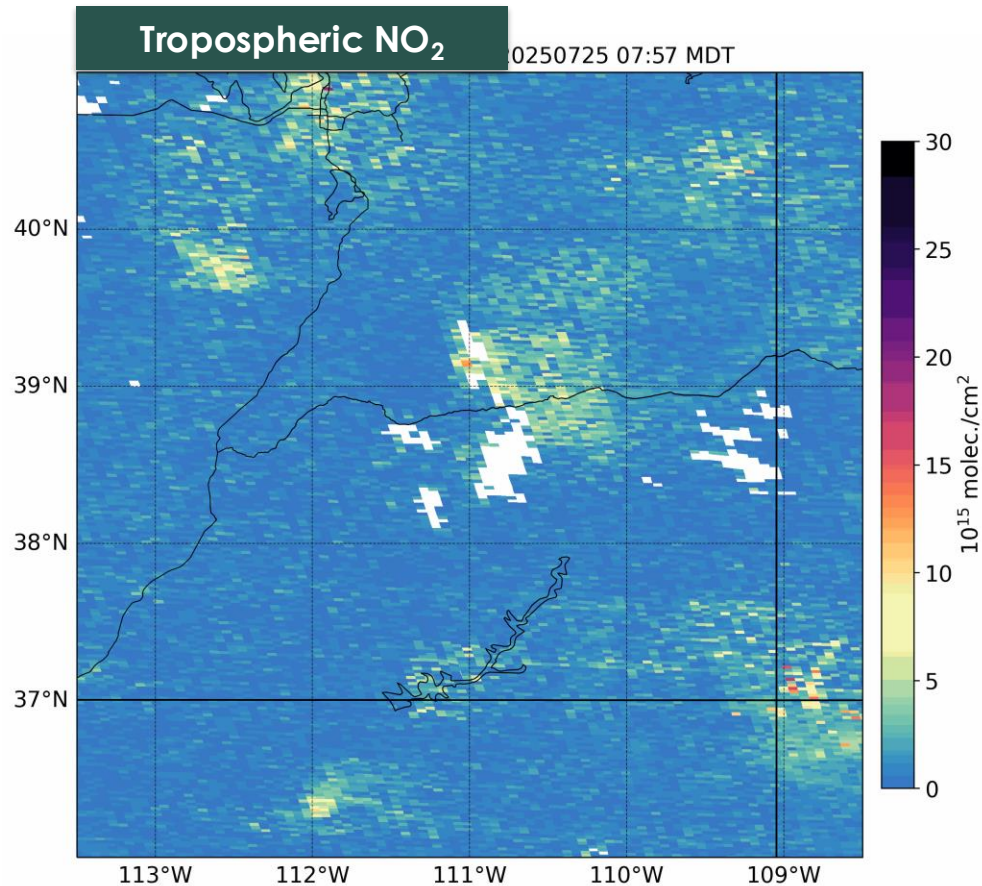
TEMPO Tropospheric NO₂ 20250725 1037 - 1103 UTC



- TEMPO performed special operation scans at 10-minute frequency over the Western U.S. every other hour during daylight.



Special Operations U.S. West Zoom – July 25, 2025

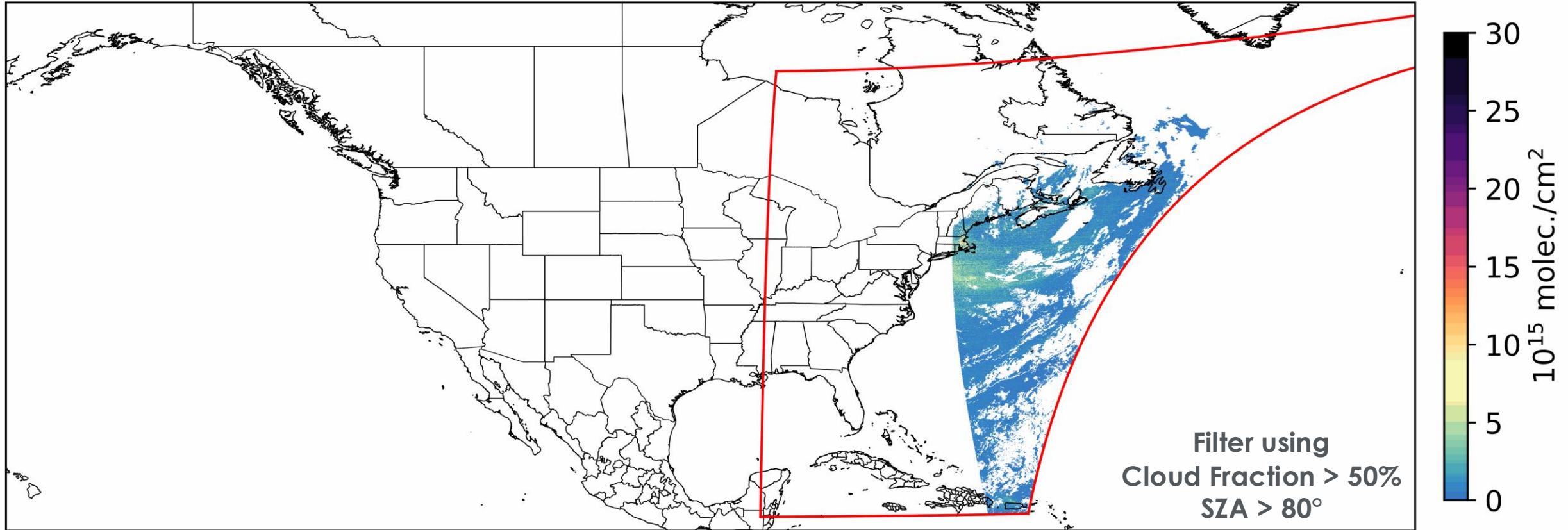


- Special operations observed highly evolving NO₂ plumes associated with wildfires.
- Total column O₃ from TEMPO observes O₃ production within the wildfire smoke plumes.
- Time series analysis of NO₂ VCDs in the vicinity of the wildfire in Grand Canyon highlights the ability of the higher frequency special operations to resolve highly evolving NO₂ plumes from wildfires.



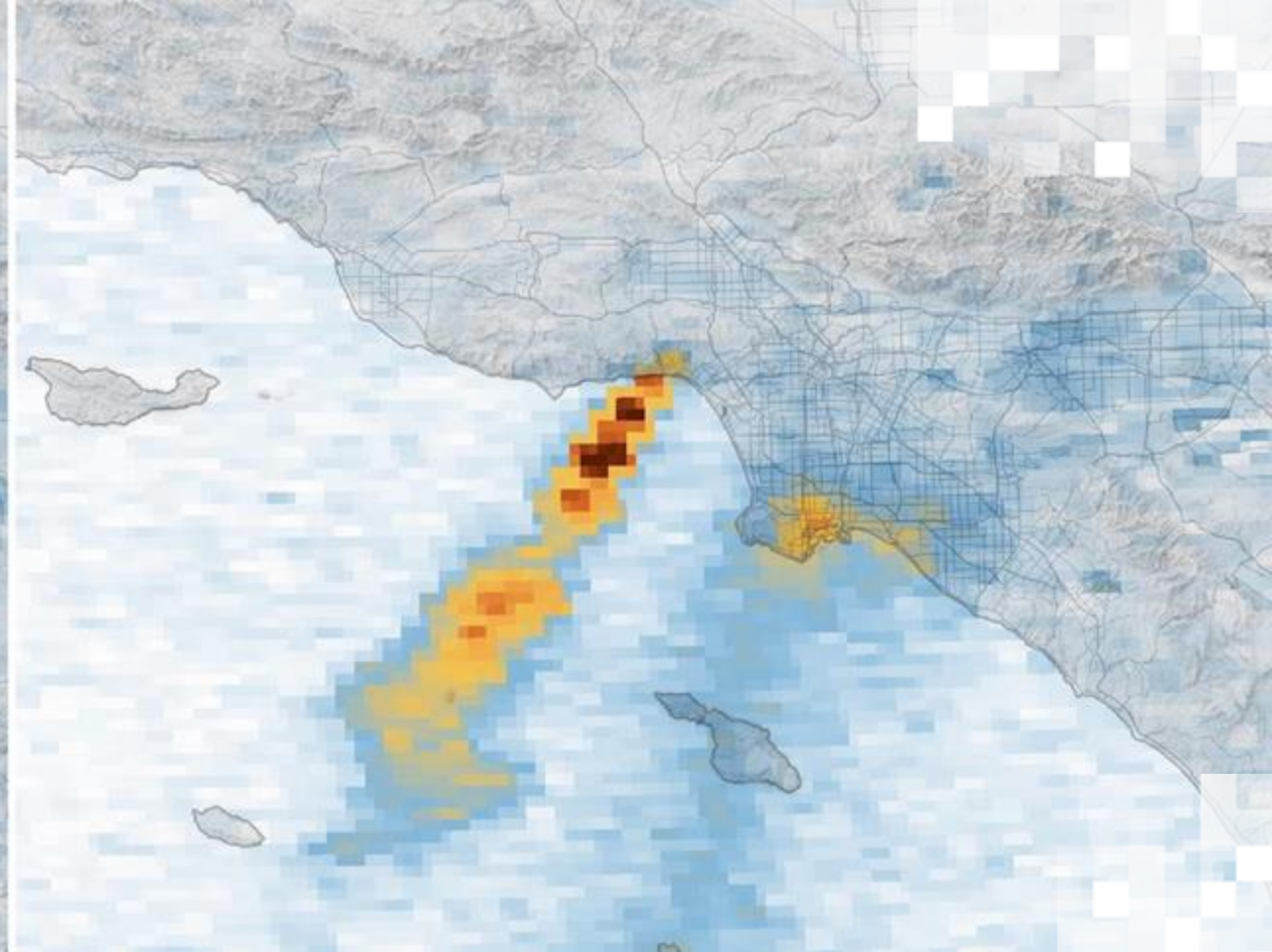
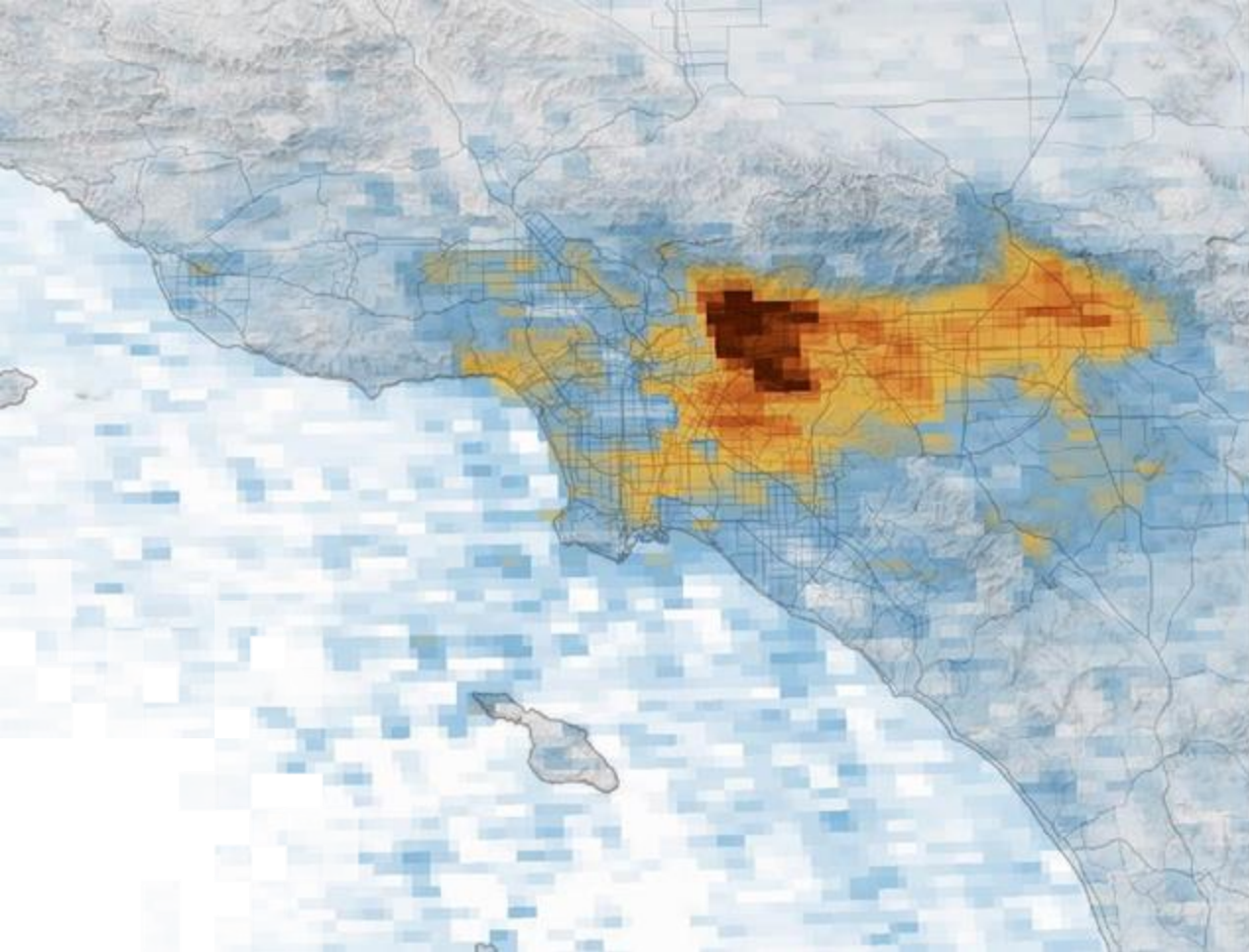
Special Operations Scans – April 17, 2025

TEMPO Tropospheric NO₂ 20250417 1108 - 1134 UTC



- TEMPO Special operations were conducted for April 17, 2025 (single day), which consisted of ~10-minute scans over the East Coast every other hour throughout the daytime.
- Special operations will lead to large gaps in coverage across other portions of the TEMPO FoR.

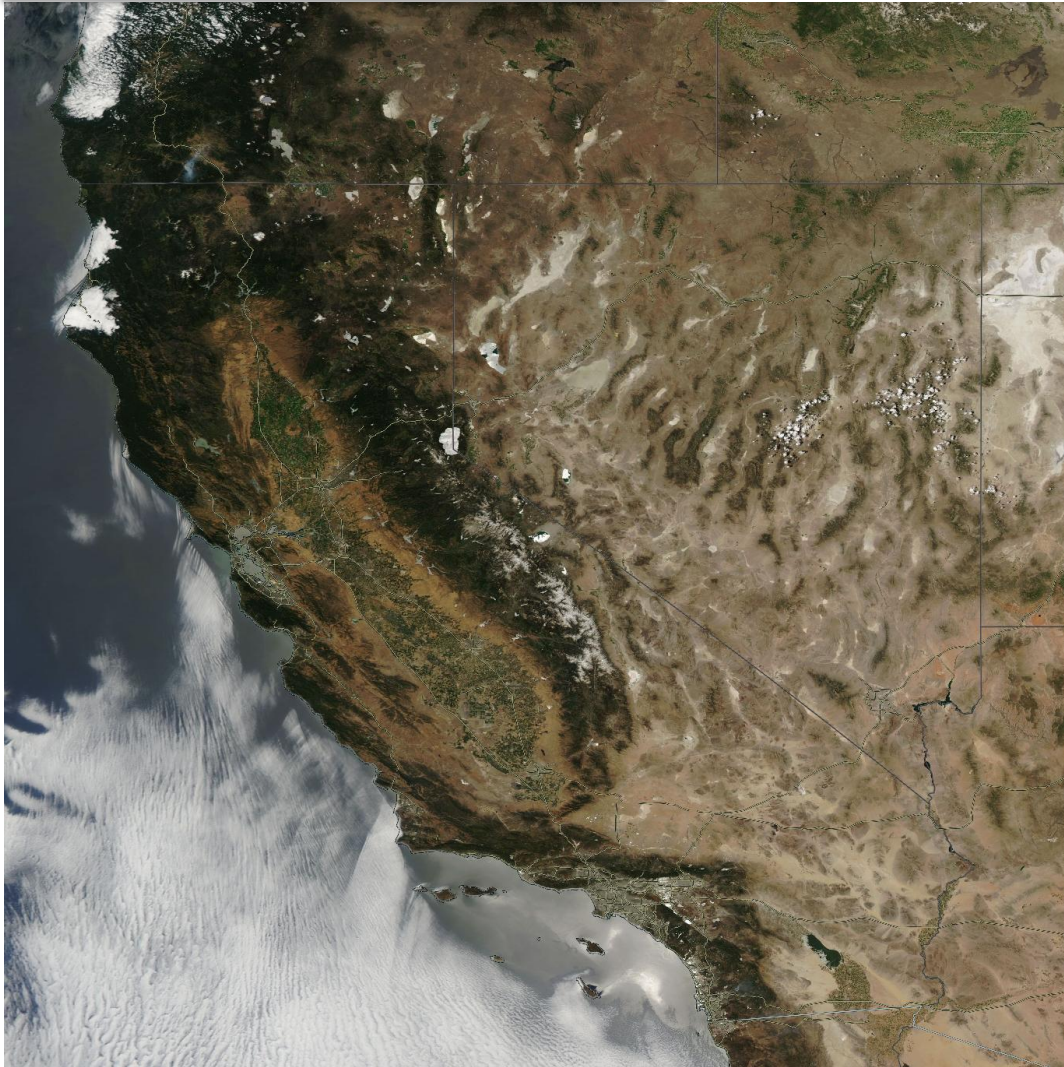




TEMPO Upcoming Data Products

Southwest U.S Zoom on June 18, 2025

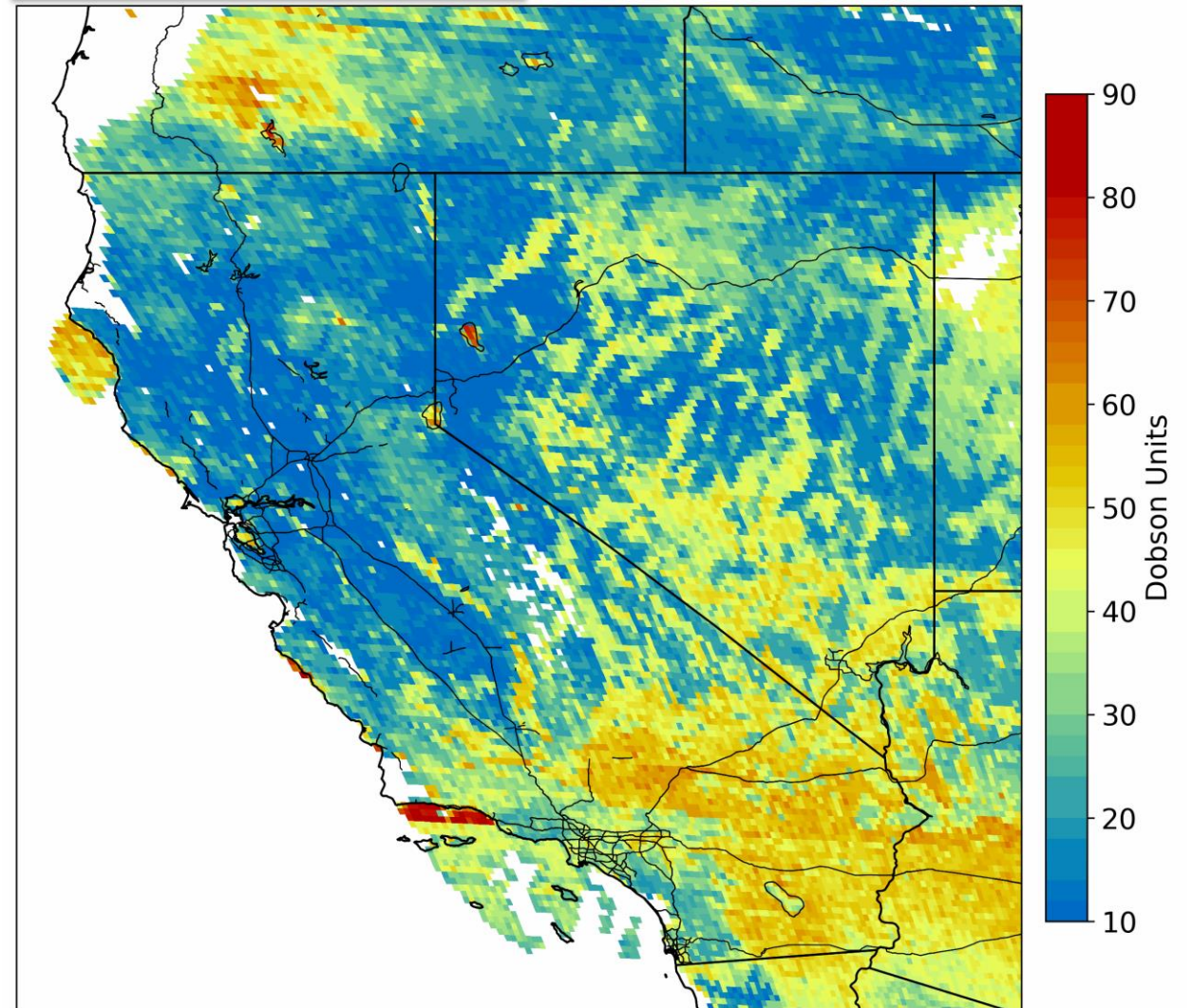
MODIS Aqua True Color ~15:00 PDT



TEMPO Filter using
Cloud Fraction > 30%
SZA > 70°

TEMPO Tropospheric O₃

20250618 07:46 PDT

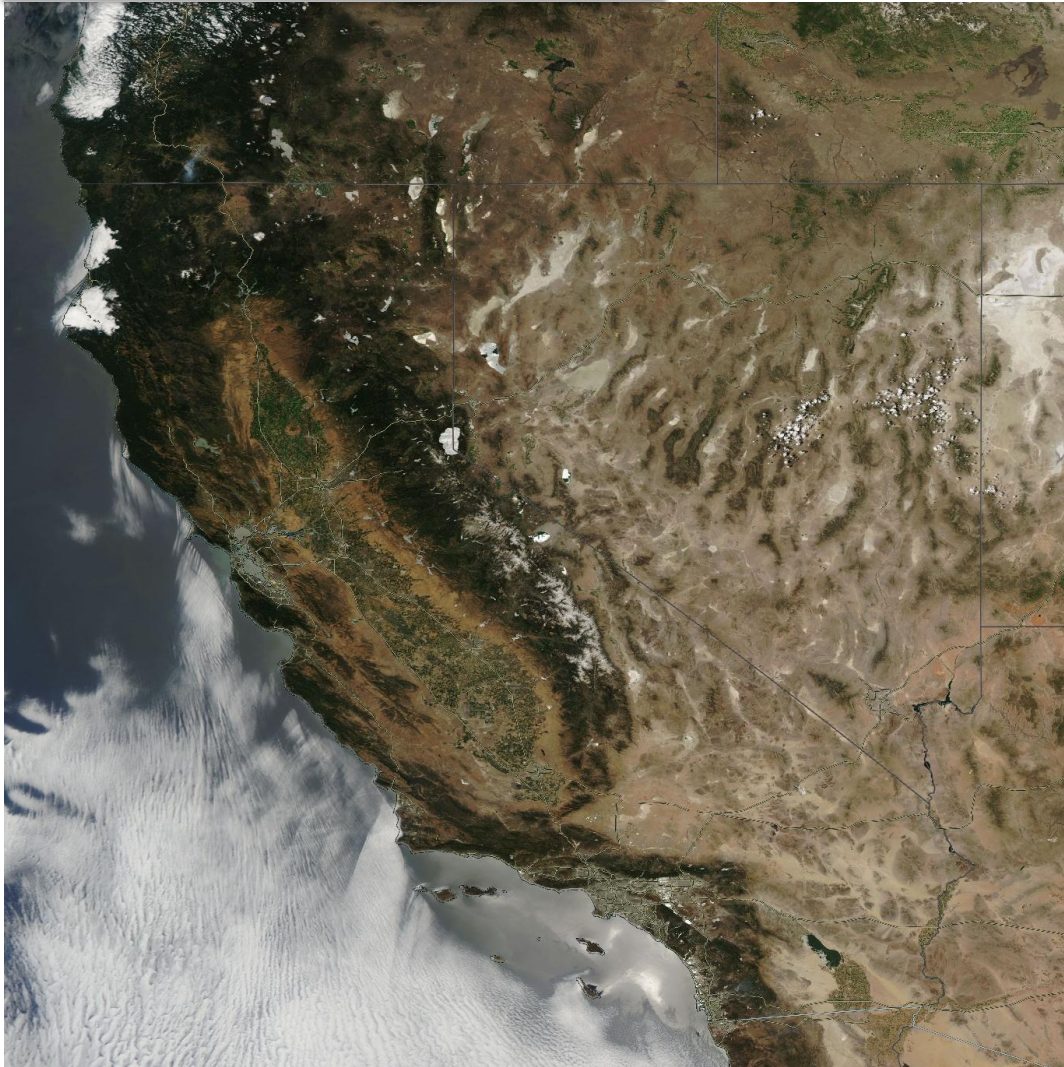


1-Day Animation of Tropospheric O₃ Columns



Southwest U.S Zoom on June 18, 2025

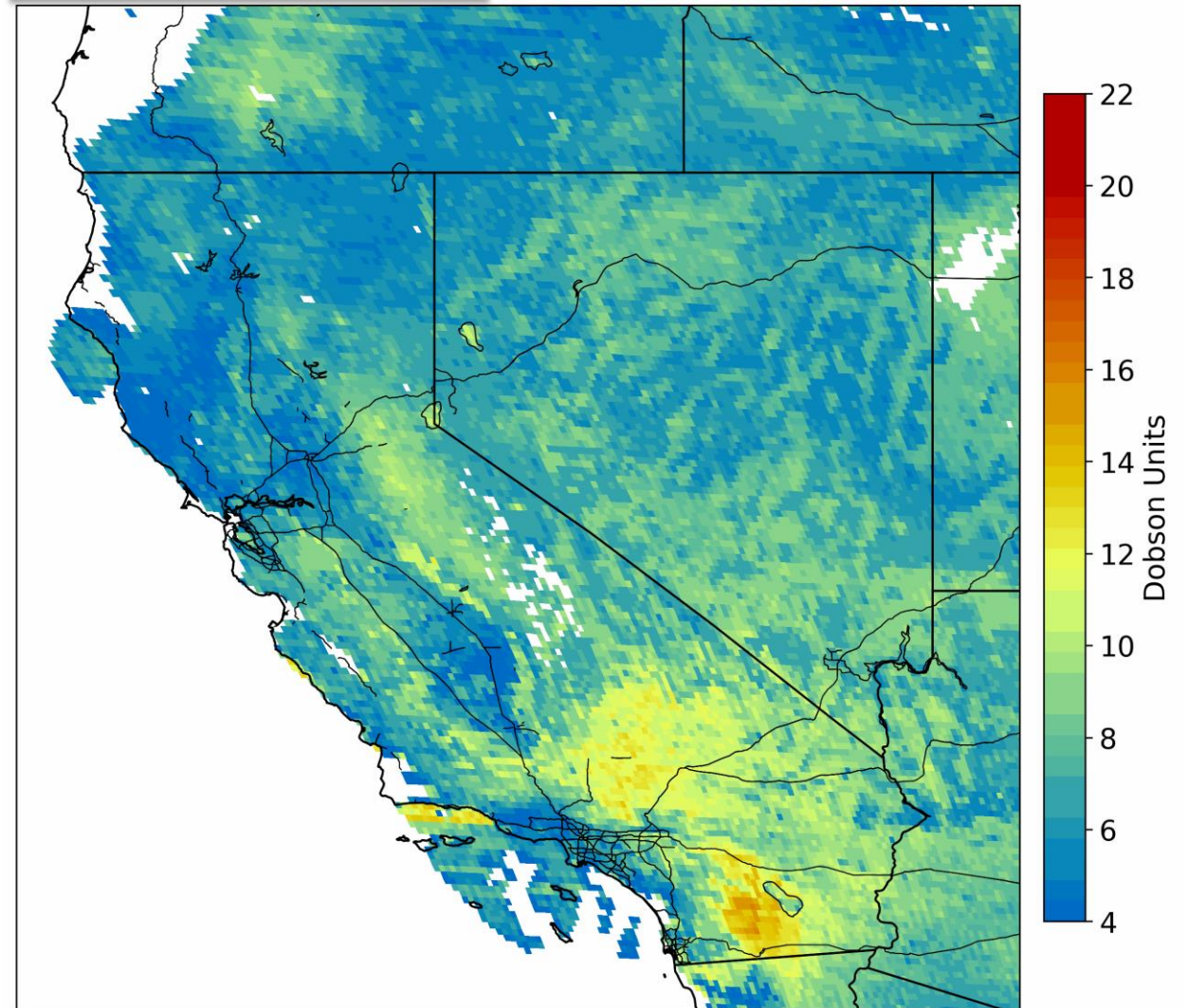
MODIS Aqua True Color ~15:00 PDT



TEMPO Filter using
Cloud Fraction > 30%
SZA > 70°

TEMPO 0-2 km O₃

20250618 07:46 PDT



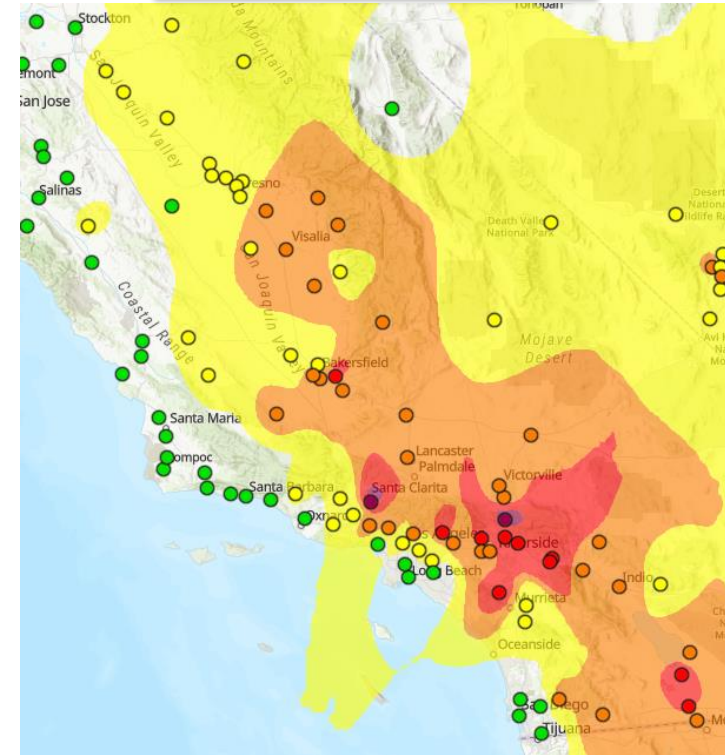
1-Day Animation of 0-2 km O₃ Columns



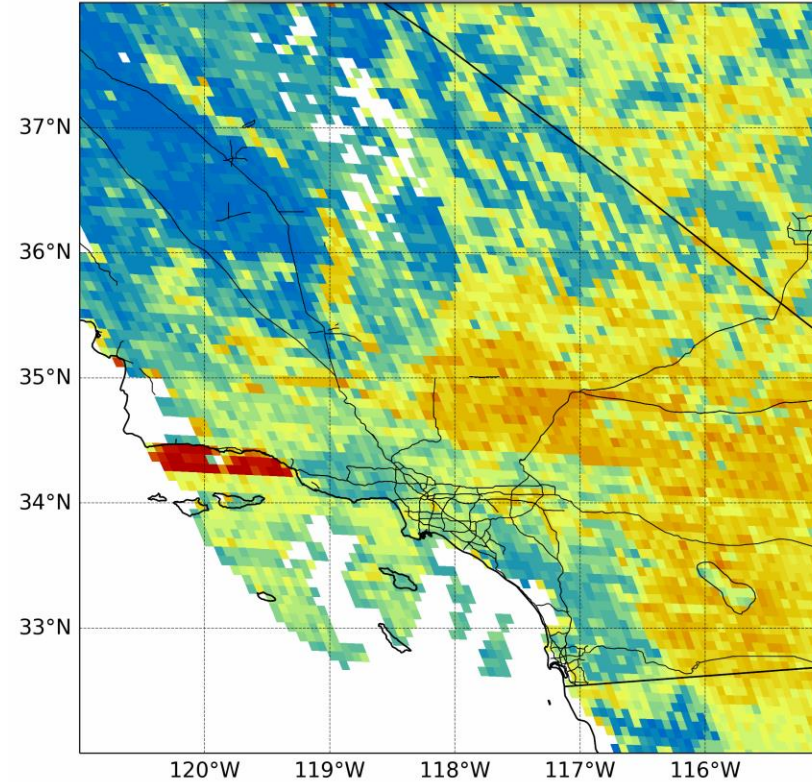
California Zoom on June 18, 2025

TEMPO Filter using
Cloud Fraction > 30%
SZA > 70°

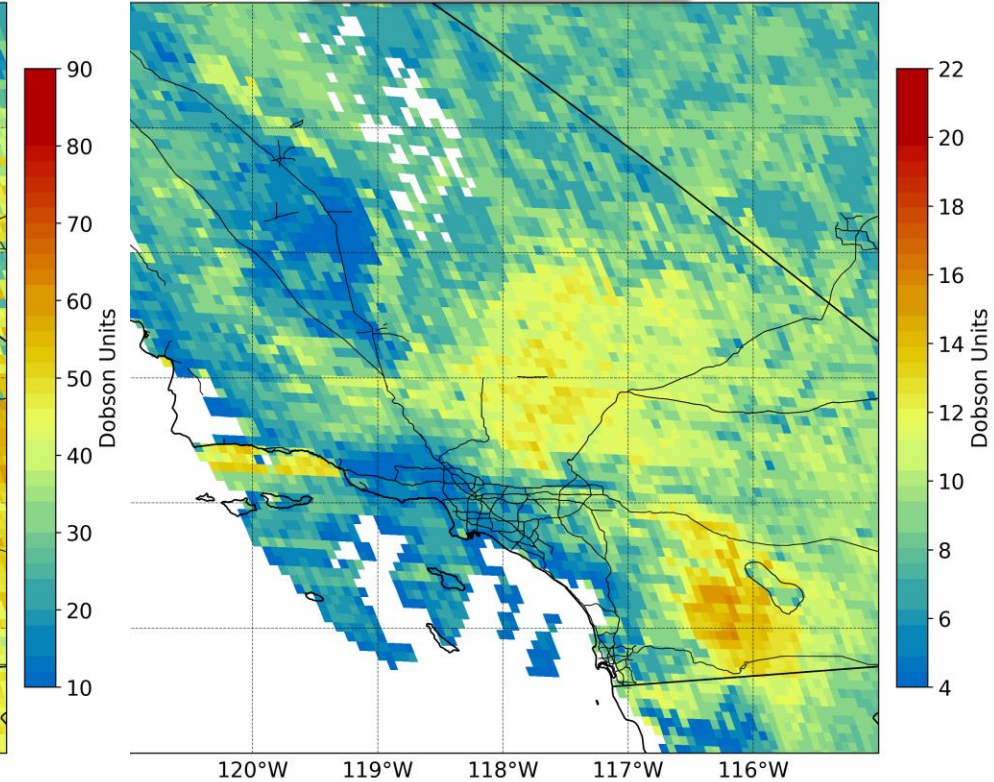
AirNow O₃ Monitors



TEMPO Tropospheric O₃ DT



TEMPO 0-2 km O₃ DT

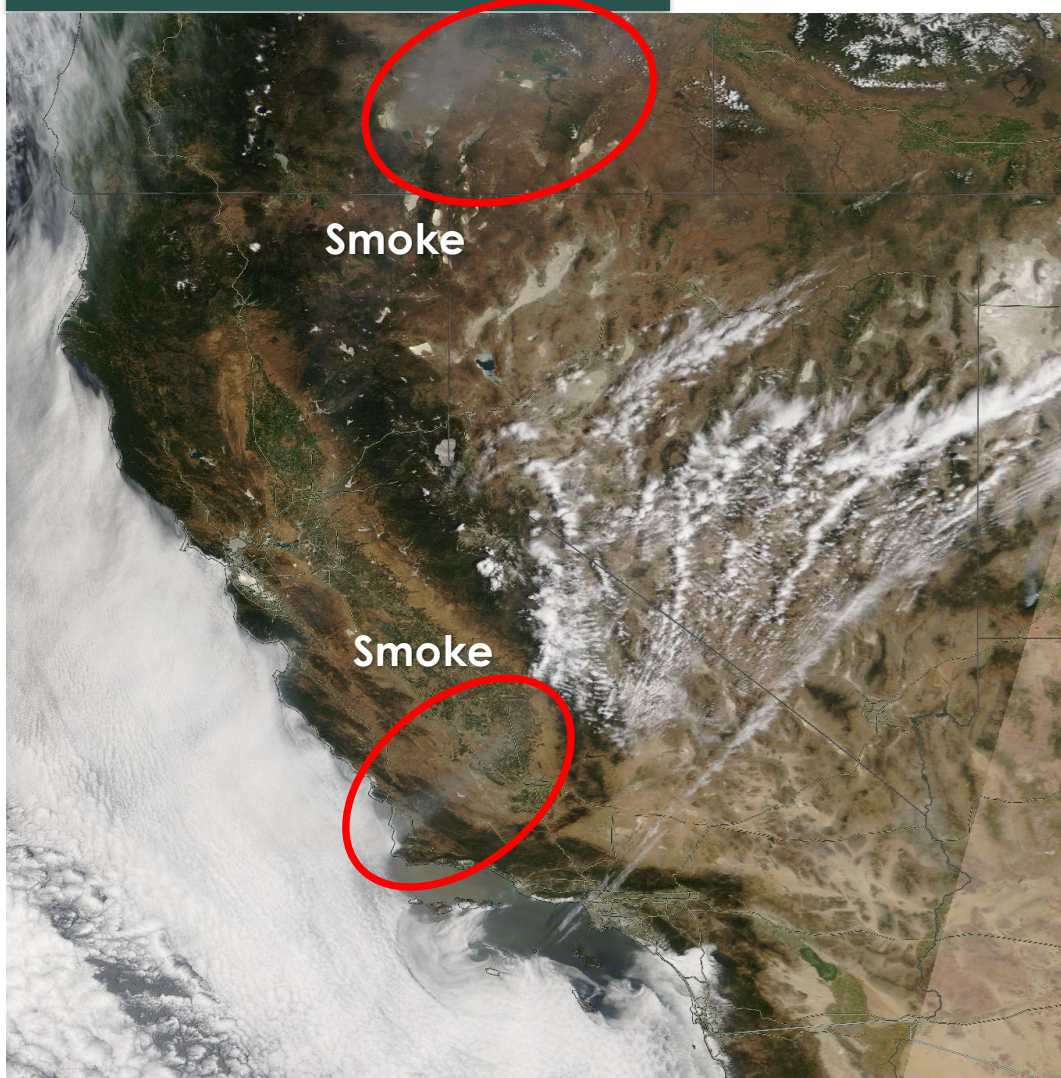


- Unhealthy to very unhealthy ozone levels measured by regulatory monitors across Southern California
- Higher amounts of TEMPO tropospheric and 0-2 km O₃ columns within the region of unhealthy ozone levels measured by regulatory monitors



Southwest U.S. Zoom on June 23, 2025

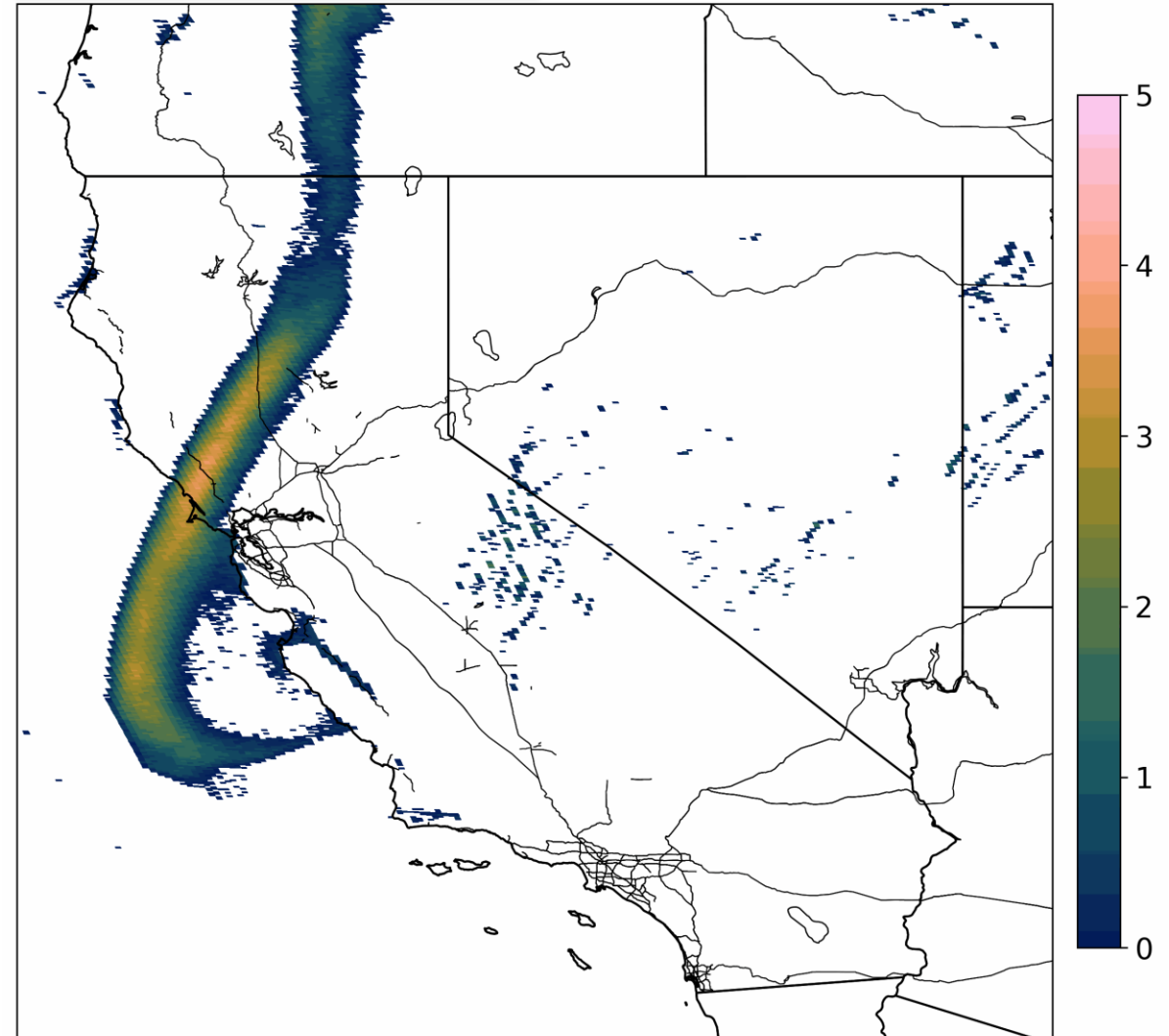
MODIS Terra True Color ~11:10 PDT



Filter using
 $\text{SZA} > 80^\circ$

TEMPO UV Aerosol Index

20250623 06:47 PDT

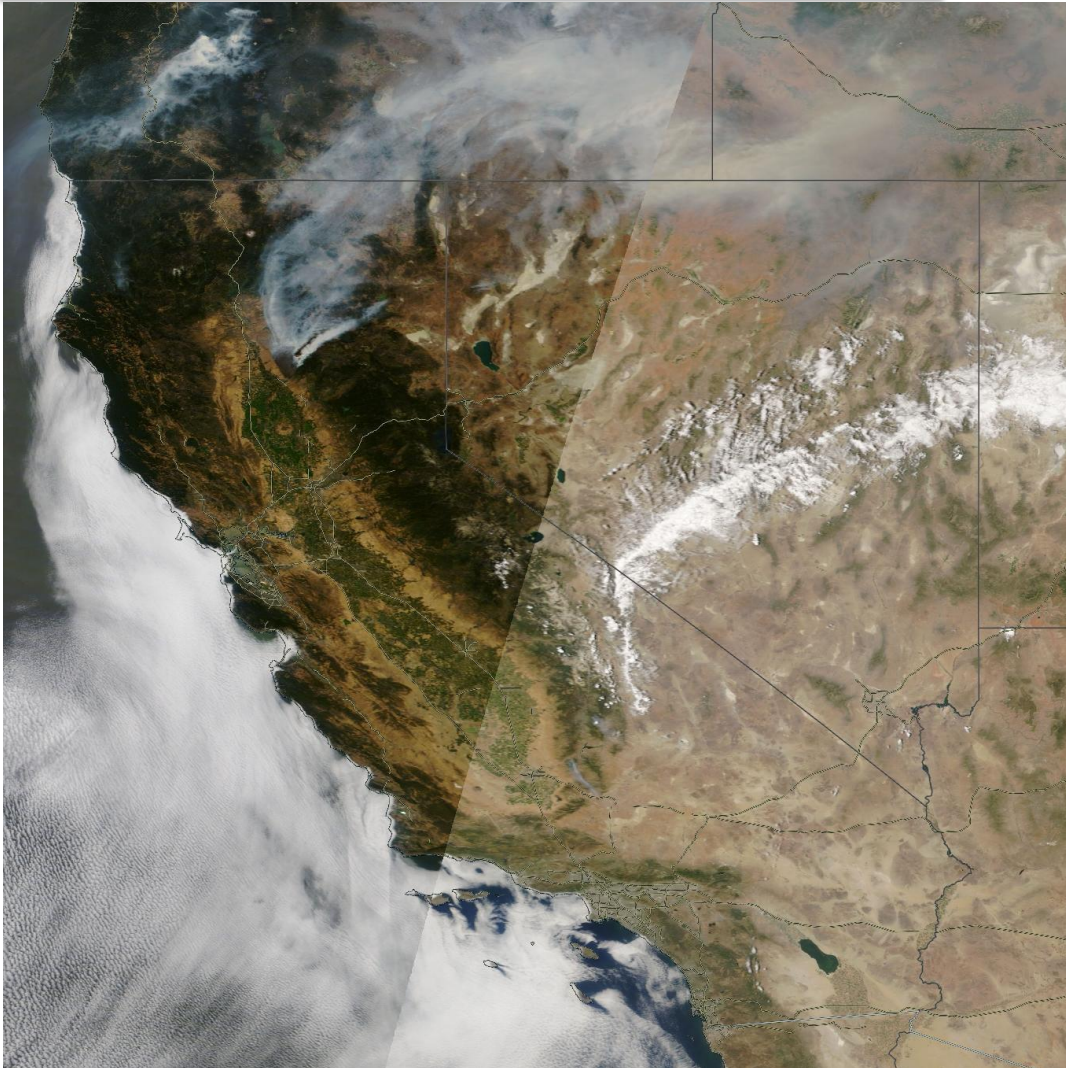


1-Day Animation of UV Aerosol Index



Southwest U.S. Zoom on July 26, 2024

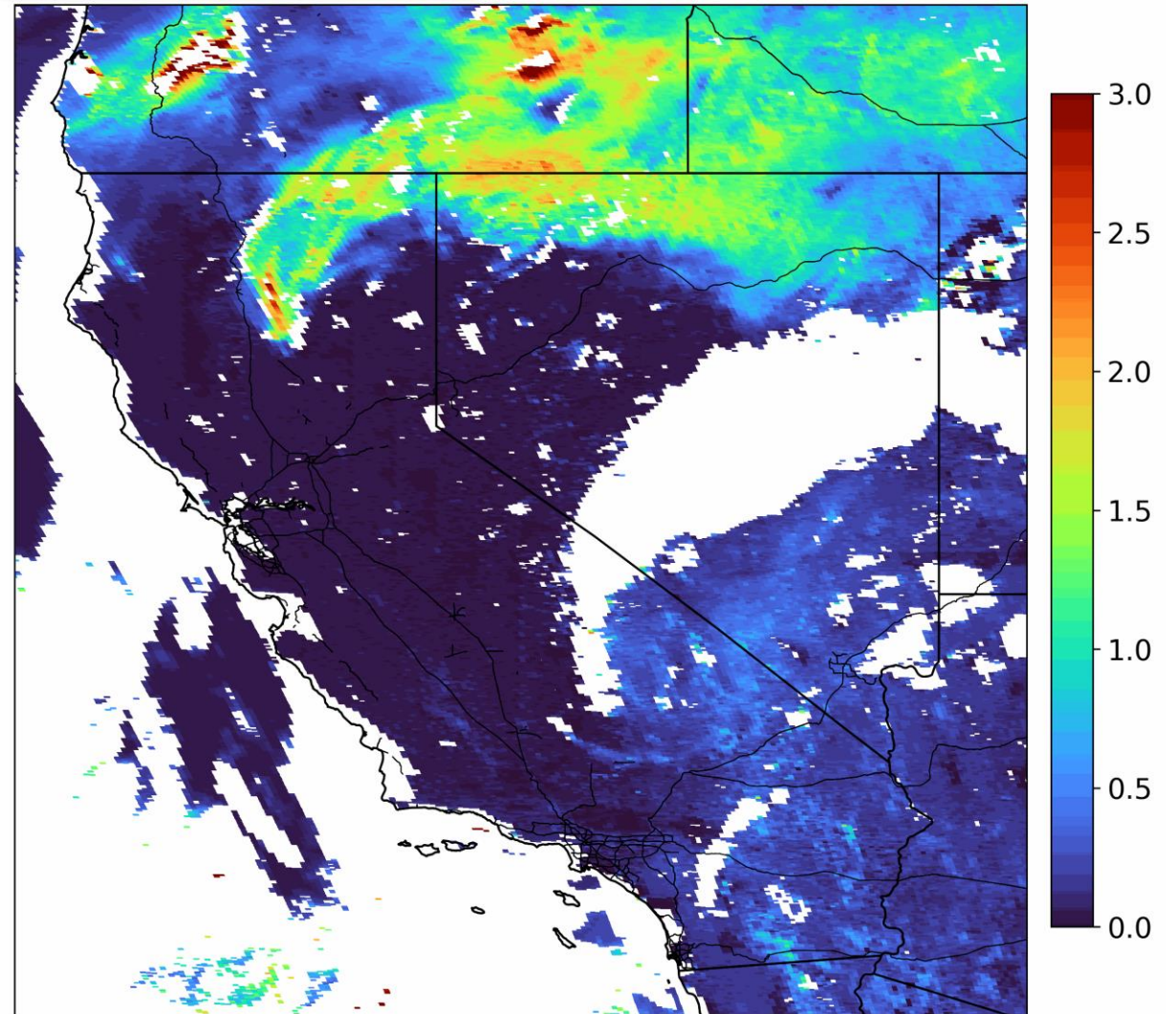
MODIS Terra True Color ~11:50 PDT (West Orbit)



AOD = Aerosol Optical Depth

TEMPO AOD @ 550 nm

20240726 07:31 PDT

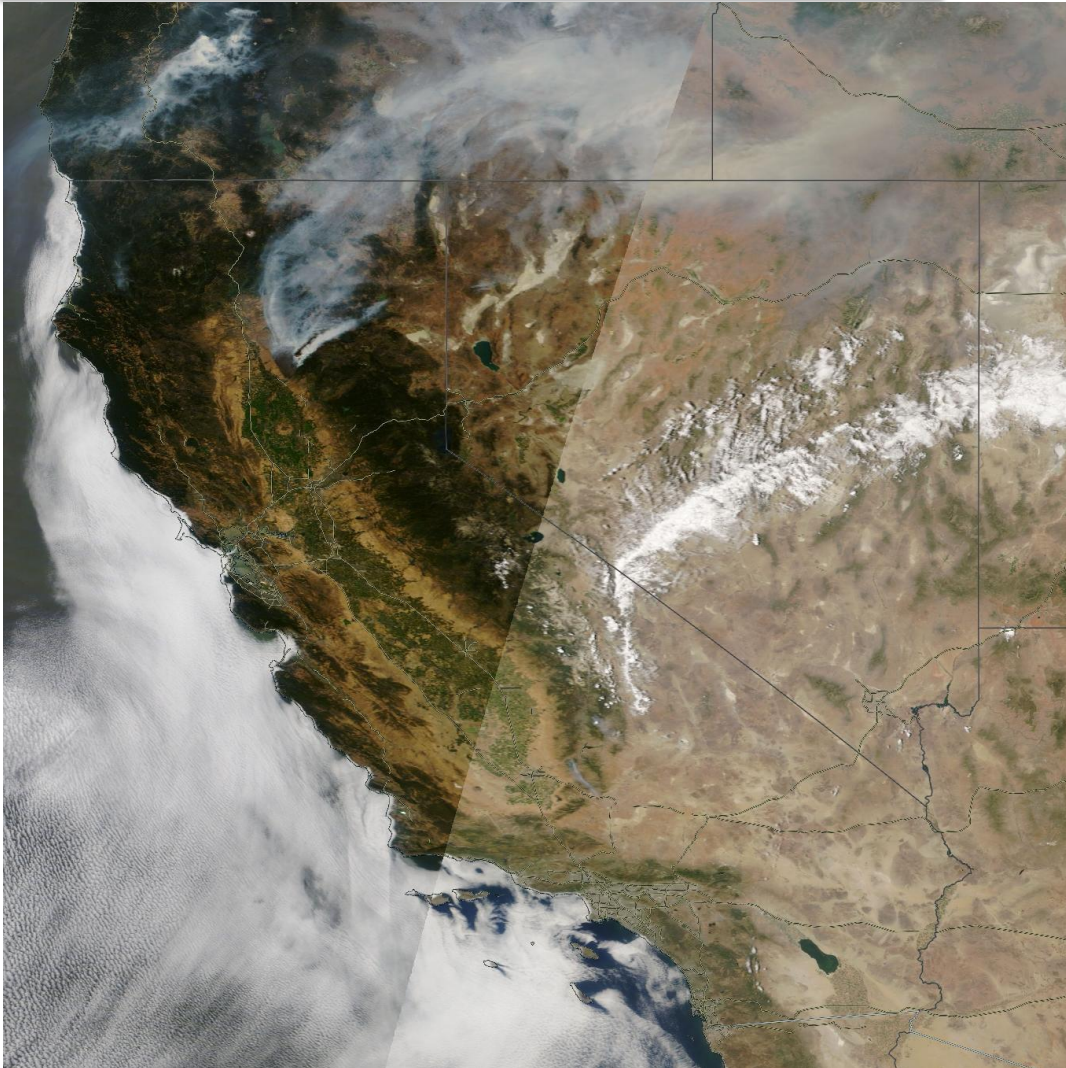


1-Day Animation of TEMPO AOD @ 550 nm



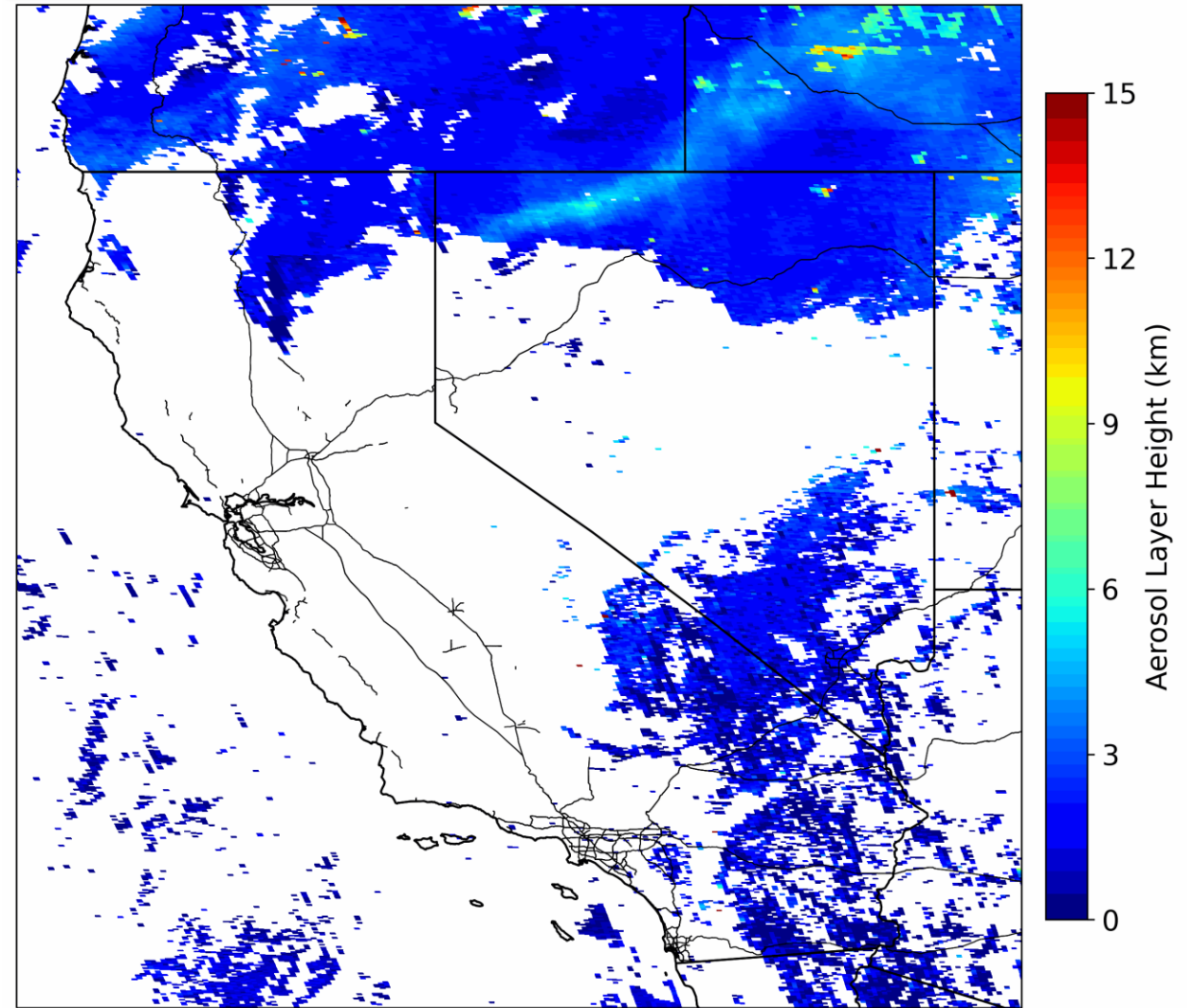
Southwest U.S. Zoom on July 26, 2024

MODIS Terra True Color ~11:50 PDT (West Orbit)



TEMPO Aerosol Layer Height

20240726 07:31 PDT

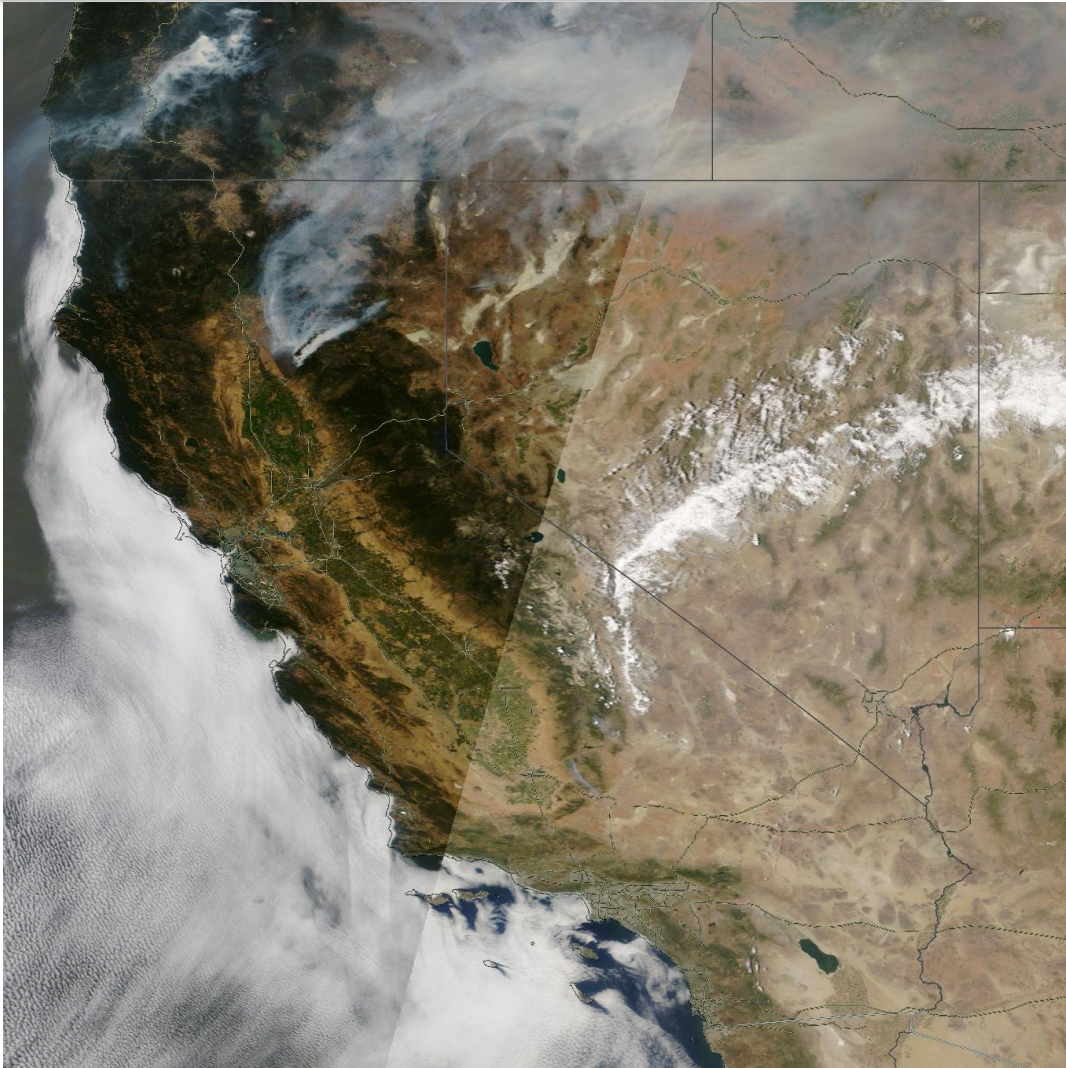


1-Day Animation of TEMPO Aerosol Layer Height



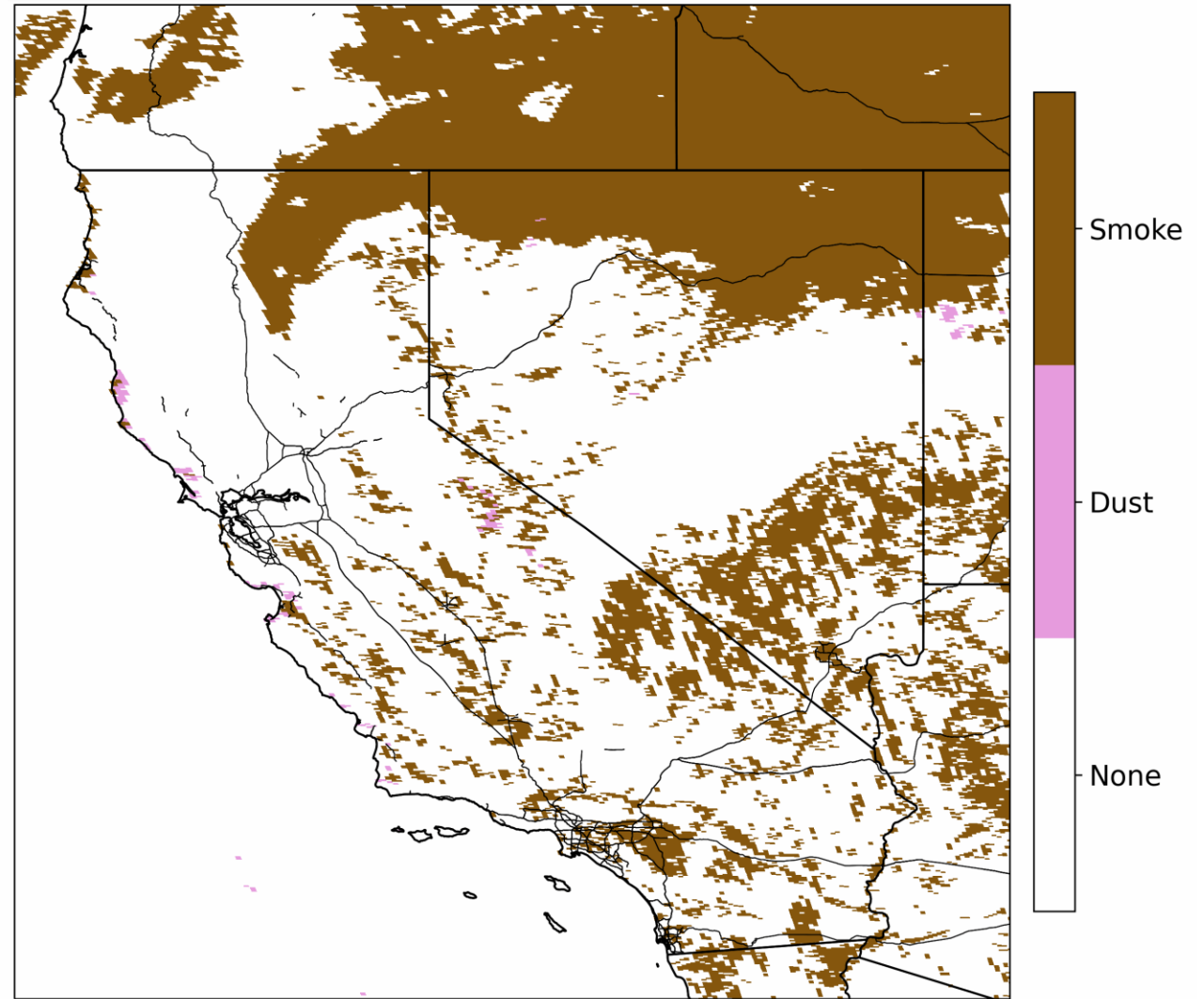
Southwest U.S. Zoom on July 26, 2024

MODIS Terra True Color ~11:50 PDT (West Orbit)



TEMPO Aerosol Detection

20240726 07:31 PDT

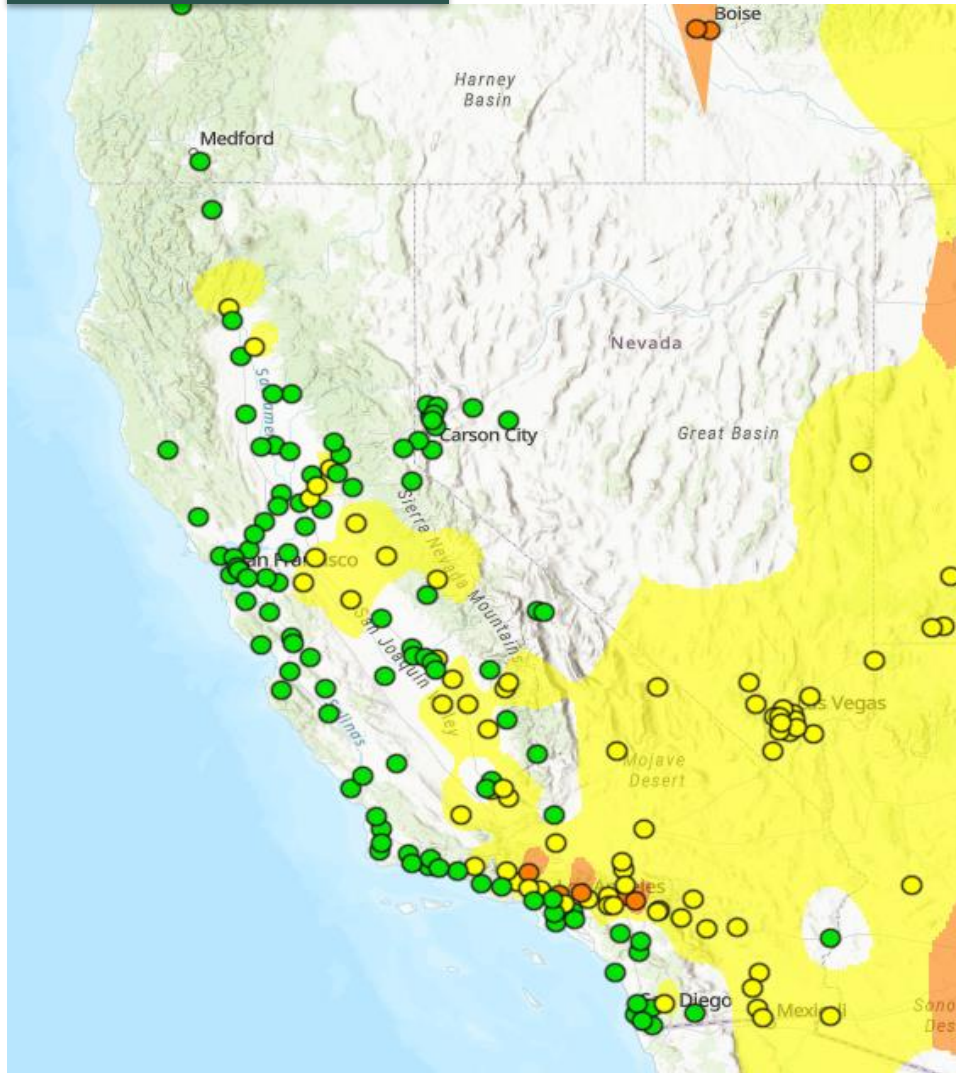


1-Day Animation of TEMPO Aerosol Detection



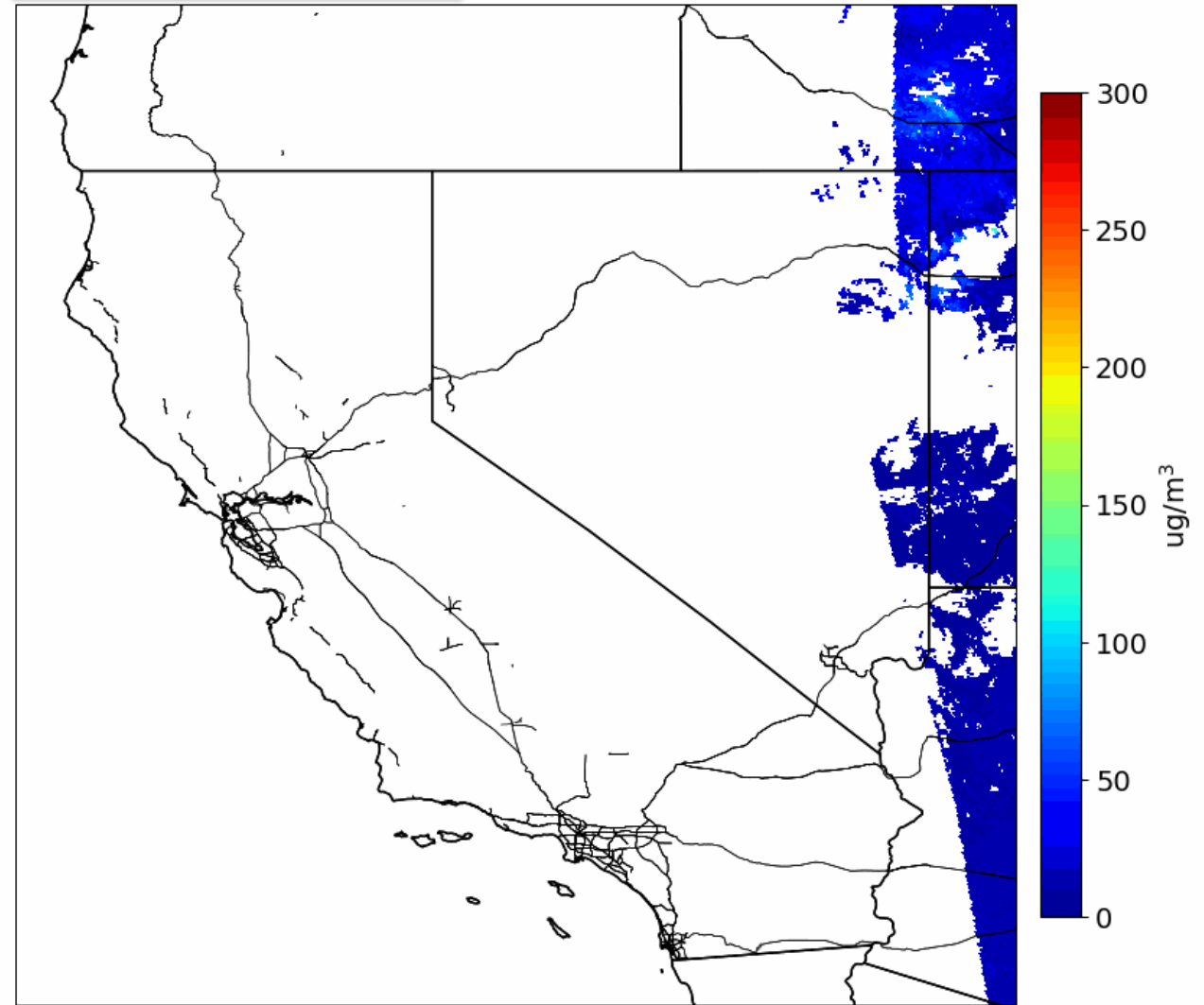
Southwest U.S. Zoom on July 26, 2024

AirNow PM2.5 monitors



TEMPO Surface PM2.5

20240726 1300 UTC



- Robust spatial and temporal coverage of TEMPO PM2.5 estimates will help monitor PM2.5 and fill the large gaps in the surface monitor coverage.



Summary of the TEMPO Mission

- TEMPO is providing a suite of trace gas and aerosol products at unprecedented spatial and temporal resolution across greater North America.
- TEMPO's "hyperspectral" capability across the ultraviolet to visible wavelength spectrum enables enhanced observations and monitoring of tropospheric O₃.
- TEMPO's hourly daylight observations allow for the monitoring of rapidly evolving pollutants from episodic events such as wildland fires.
- TEMPO can observe gaps in cloud cover, mitigate impact of clouds on monitoring air pollutants using satellite data.
- TEMPO data can support surface monitor site analysis and selection of new site locations.
- Near real-time NO₂, HCHO, and aerosol products for air quality monitoring & forecasting!
- Aerosol optical depth and aerosol layer height for aerosol plume monitoring and PM_{2.5} estimates.
- TEMPO's special observations enable frequent scans (e.g., 10 minutes) over slices of the Field of Regard for enhanced monitoring of rapidly evolving air pollutants.



Resources

- List of data access, visualization tools, and user guides can be found at:
 - <https://asdc.larc.nasa.gov/project/TEMPO>
- NASA SPoRT Viewer provides TEMPO visualizations:
 - <https://weather.ndc.nasa.gov/sport/viewer>
- Google Earth Engine provides TEMPO visualizations:
 - <https://developers.google.com/earth-engine/datasets/catalog/>
- NASA Living Atlas provides TEMPO visualizations:
 - <https://nasa.maps.arcgis.com/home/>





Thank You!

