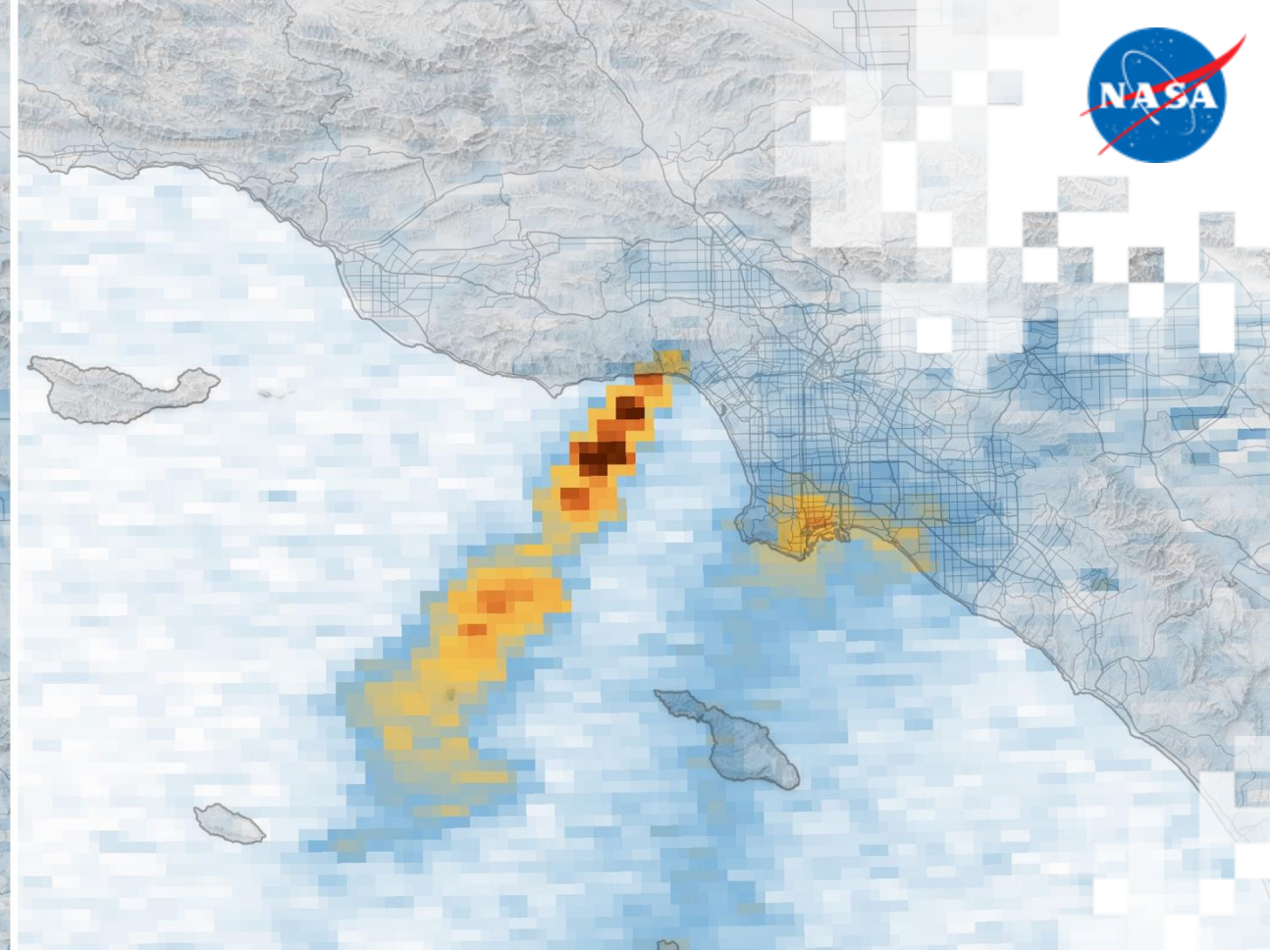
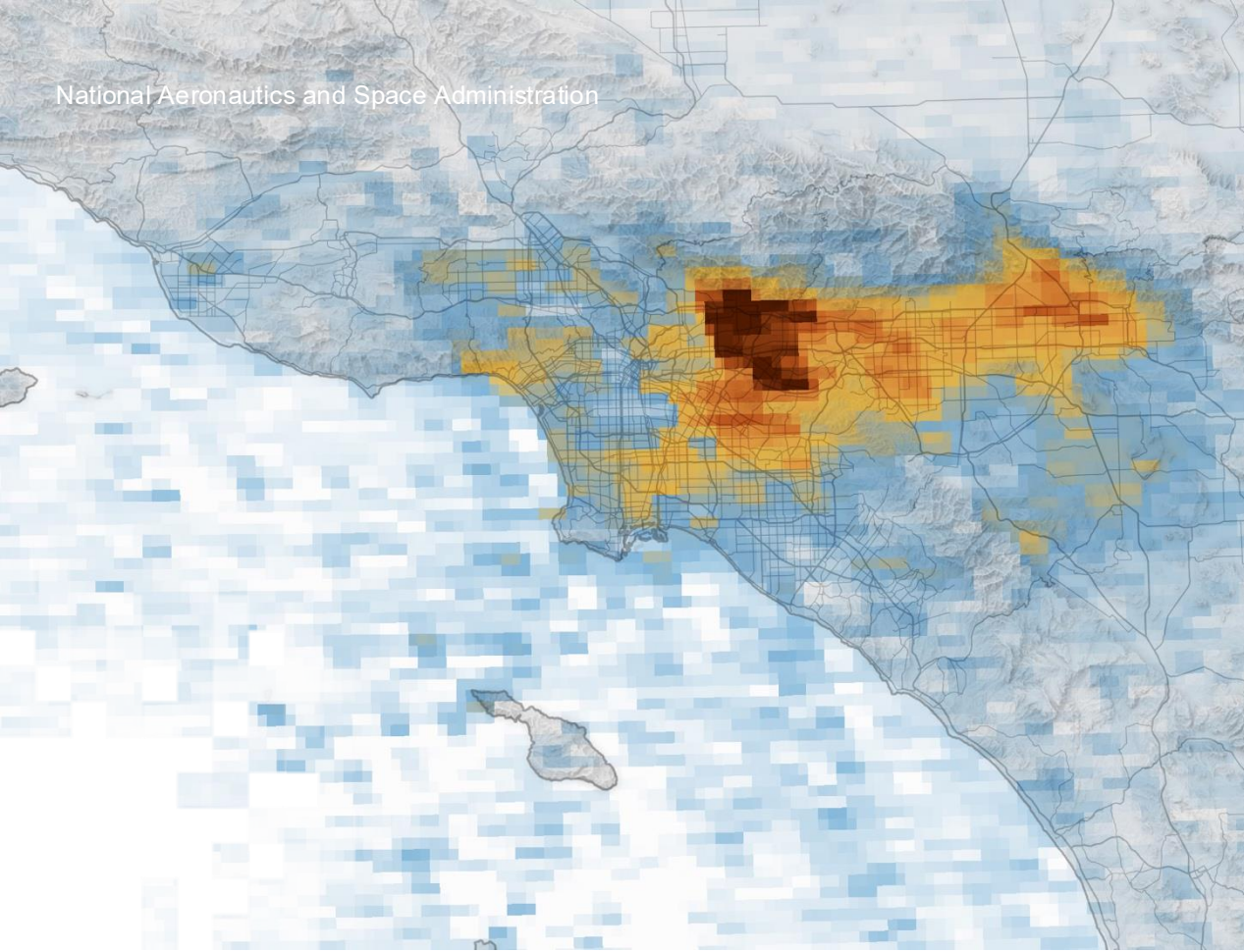


National Aeronautics and Space Administration



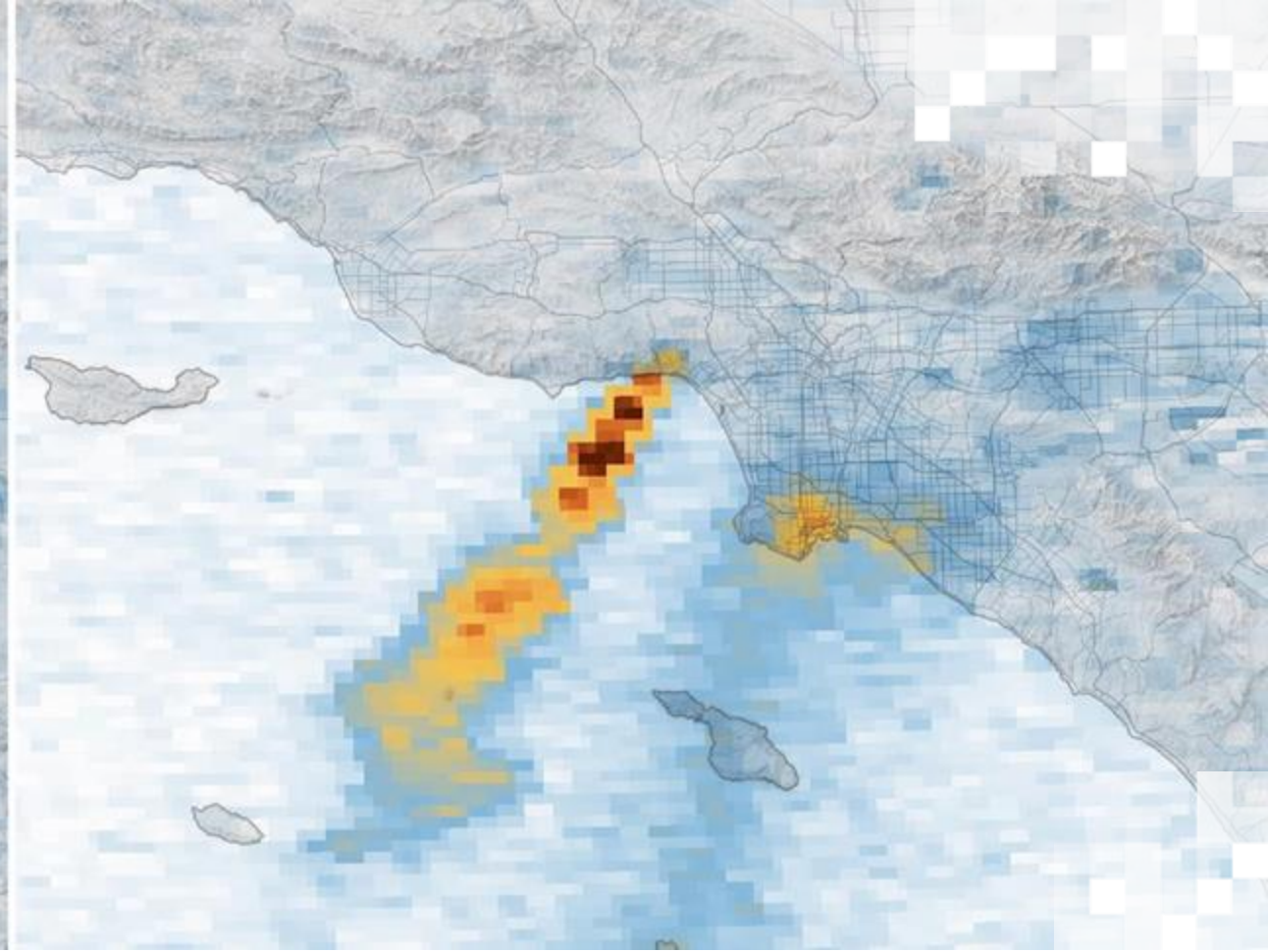
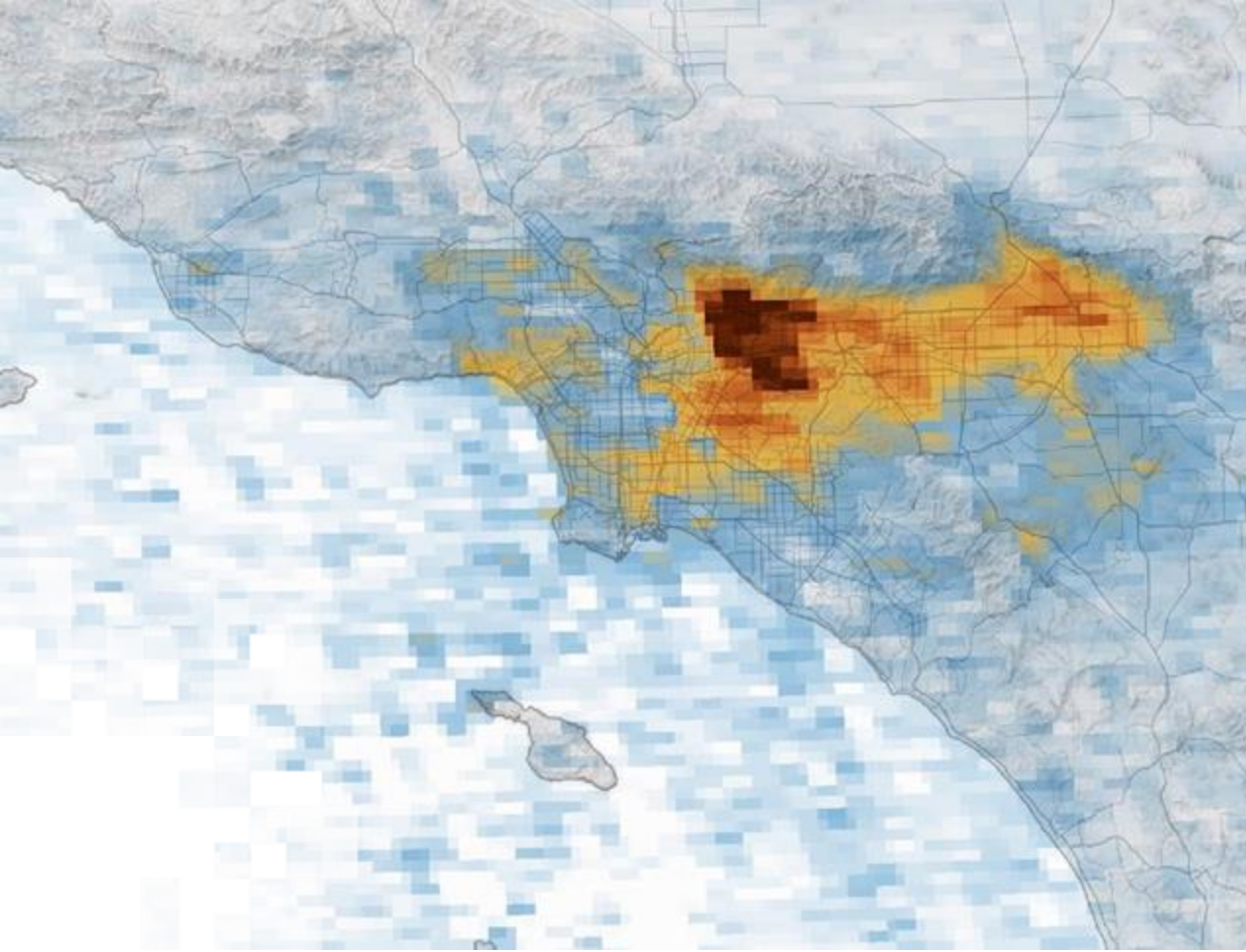
Introduction to Geostationary Observations for Air Quality Applications in the Western US

Day 1, Part 5: Analyzing Trace Gases Using TEMPO Data

Aaron Naeger (TEMPO Applications)

August 05, 2025





TEMPO Instrument & Retrieval Methods

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
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

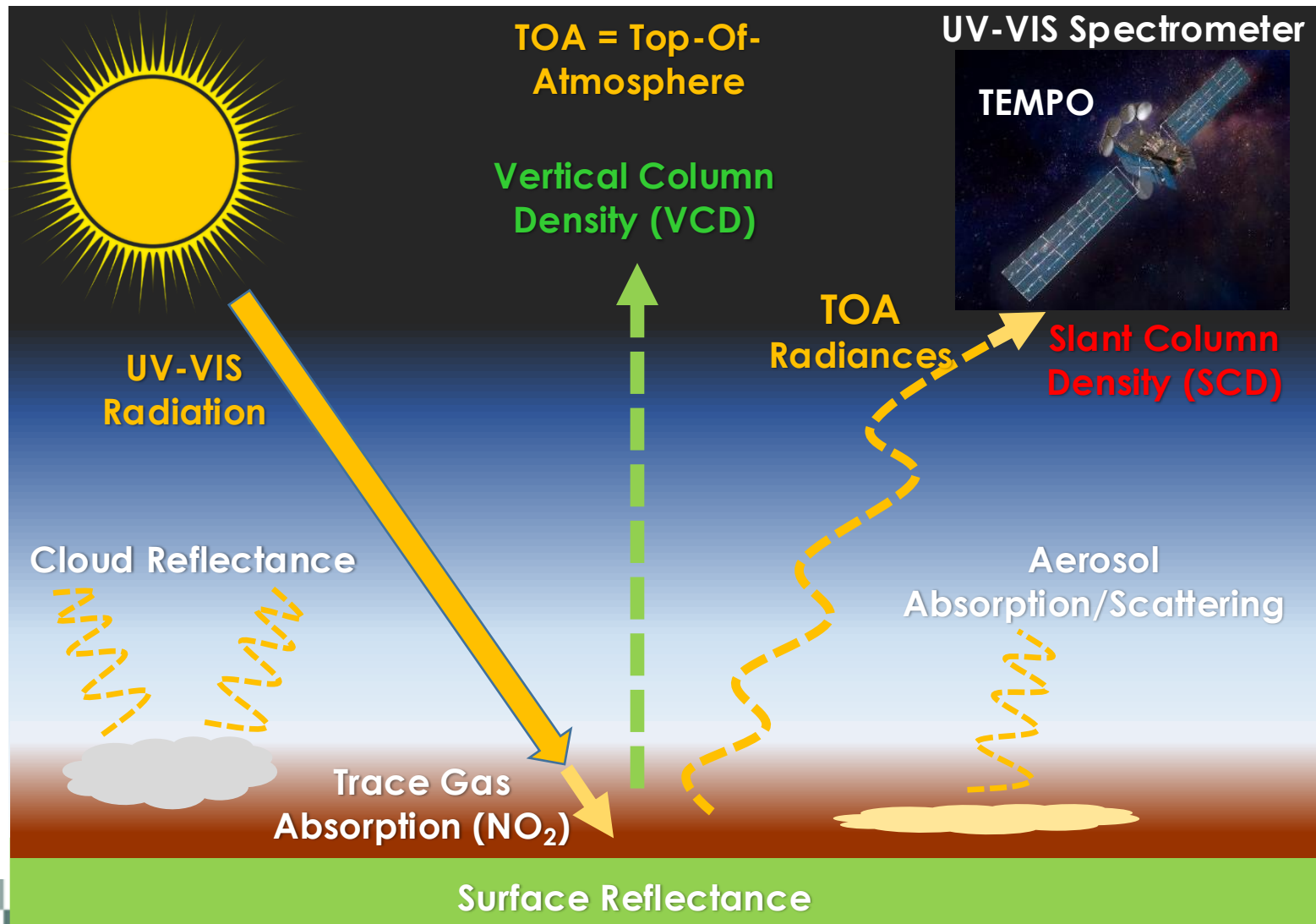
****O3PROF L3 product → 0.04 x 0.04° resolution ***

VCD: Vertical Column Density

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



How does TEMPO observe pollutants?



- TEMPO's operational trace gas retrievals are based on multi-step approach.
 - Derive **slant column densities (SCD)** via spectral fitting to measured **TOA radiances** in known trace gas absorption windows
 - Calculation of **vertical column densities (VCDs)** using **Air Mass Factors (AMF)** calculated offline with a radiative transfer model accounting for surface, atmospheric, and viewing geometry conditions

$$VCD = \frac{SCD}{AMF}$$

- **VCDs** provide information on the target trace gas within the atmospheric vertical column.

Deriving Slant to Vertical Column Data in TEMPO Retrievals

$$VCD = \frac{SCD}{AMF}$$

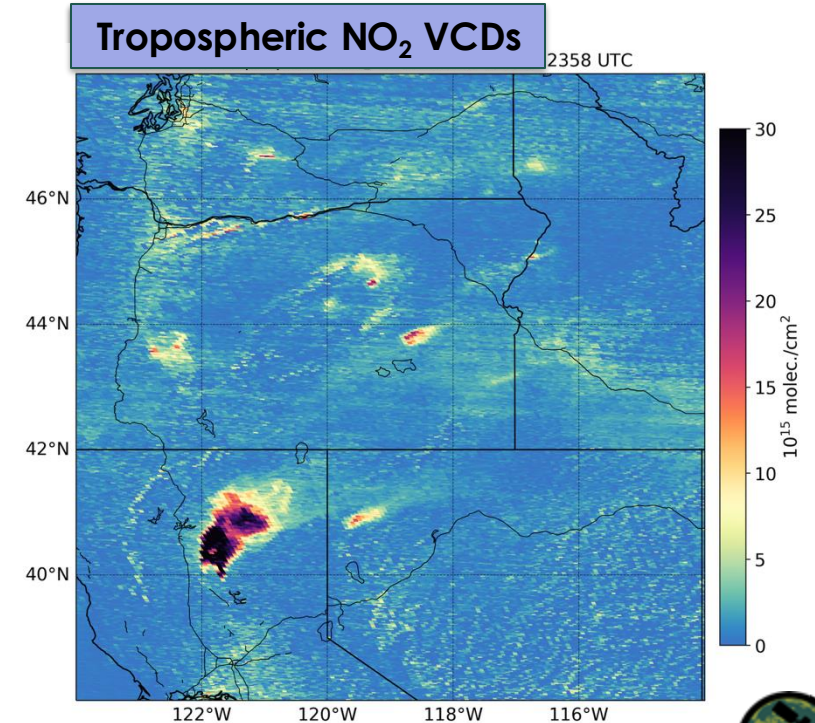
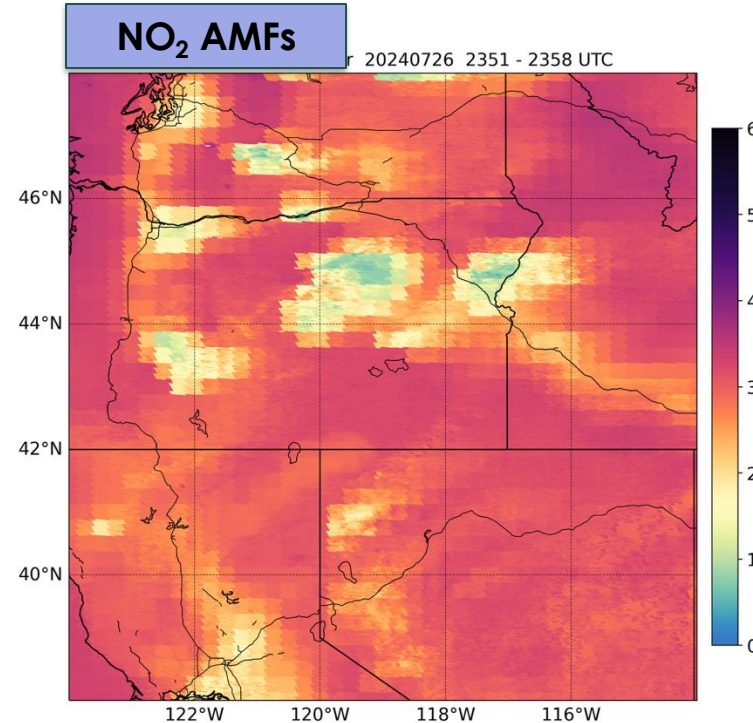
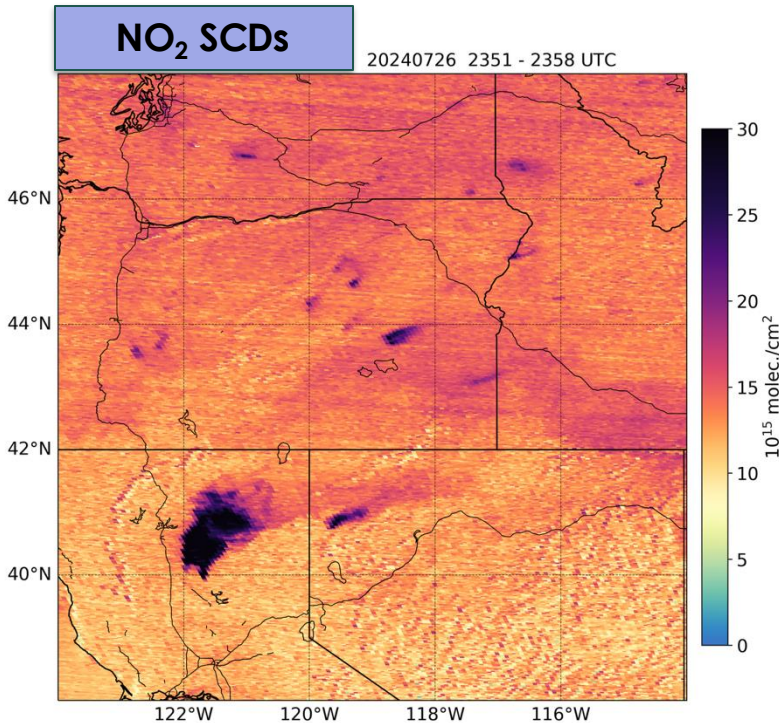
SCD – Slant Column Density

AMF – Air Mass Factor

VCD – Vertical Column Density

- TEMPO's operational trace gas retrievals employ a multi-step approach.
 - Derive **slant column densities (SCD)** via spectral fitting to measured **TOA radiances** in known trace gas absorption windows
 - Calculation of **vertical column densities (VCDs)** using **air mass factors (AMF)** calculated offline with a radiative transfer model

No Cloud Fraction Filter

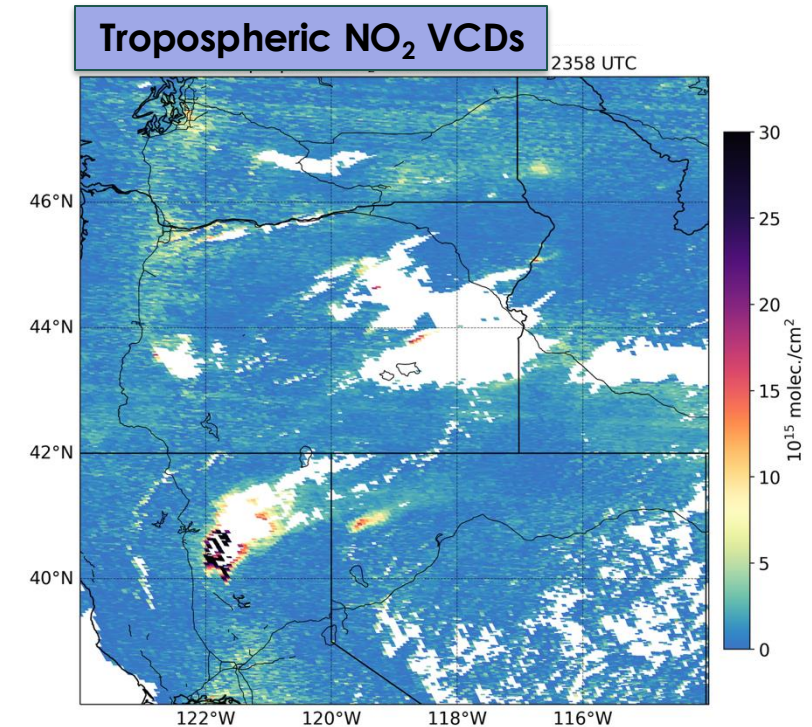
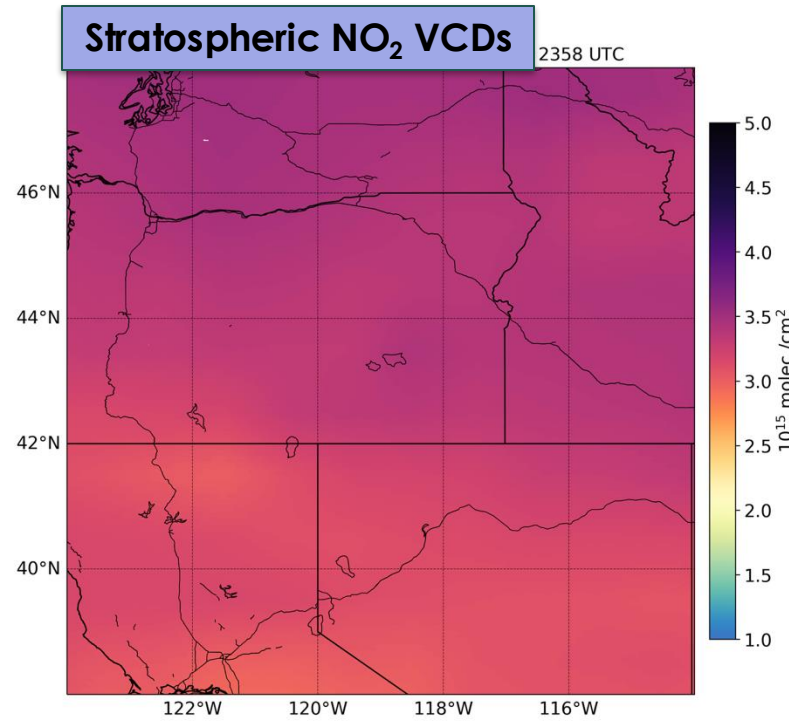
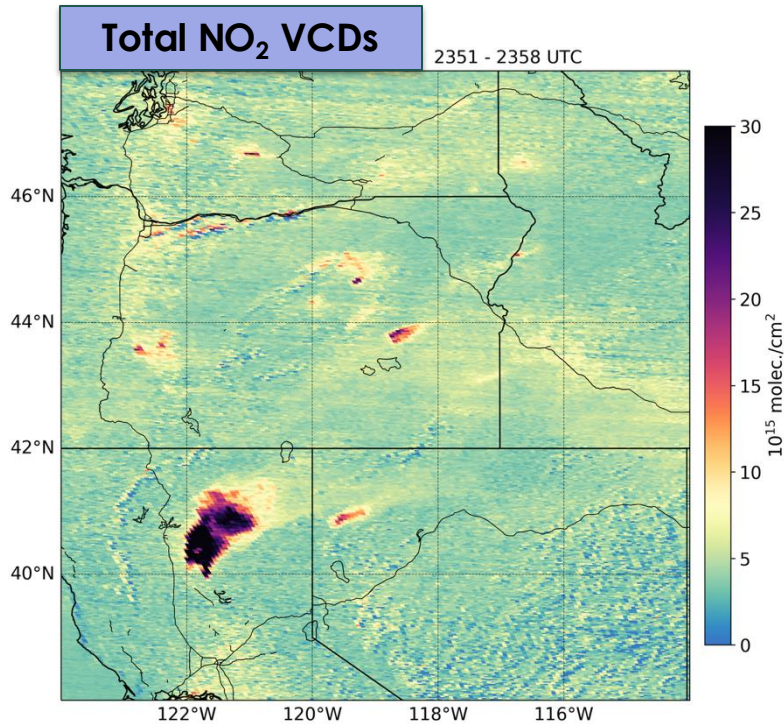


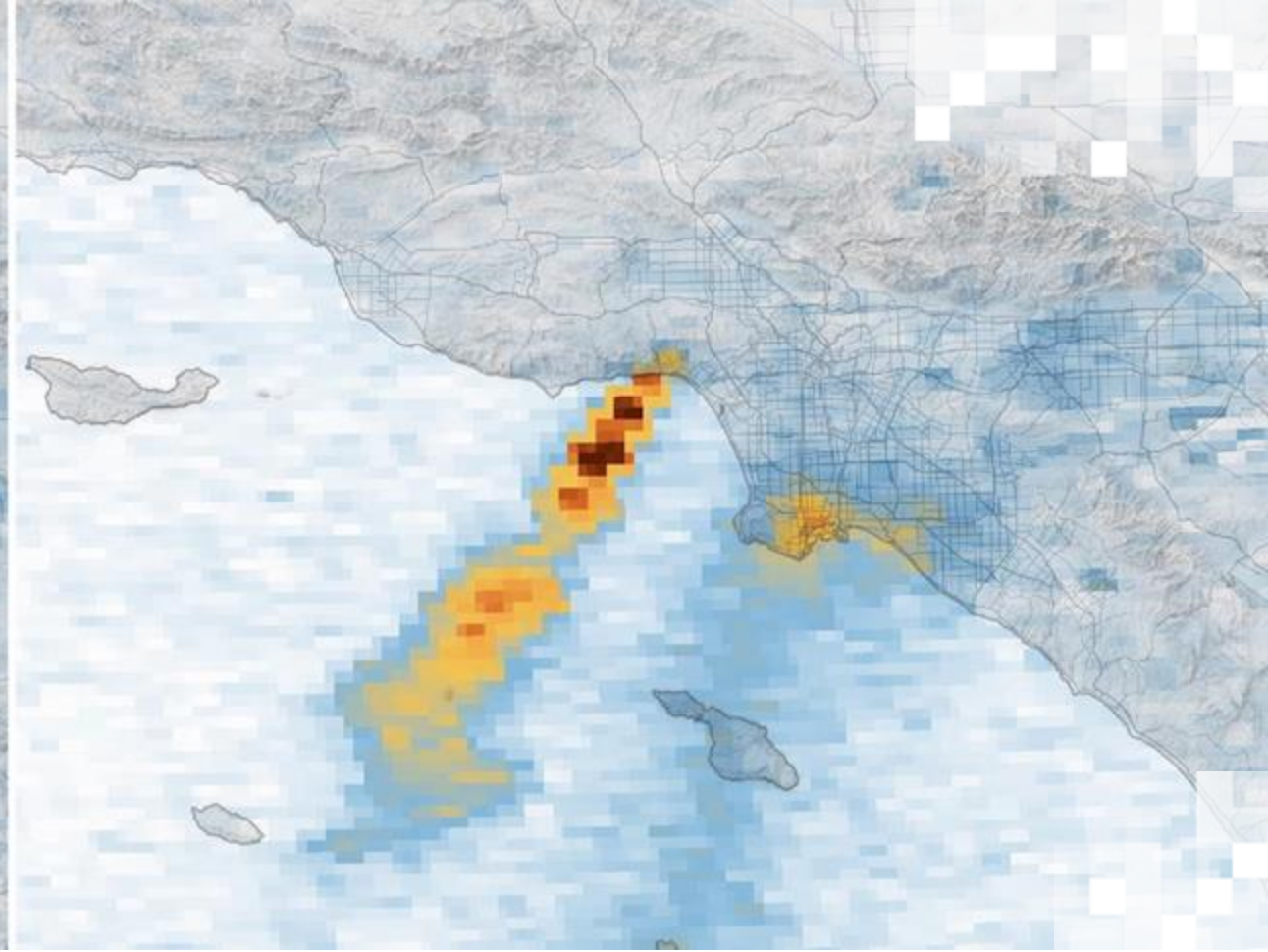
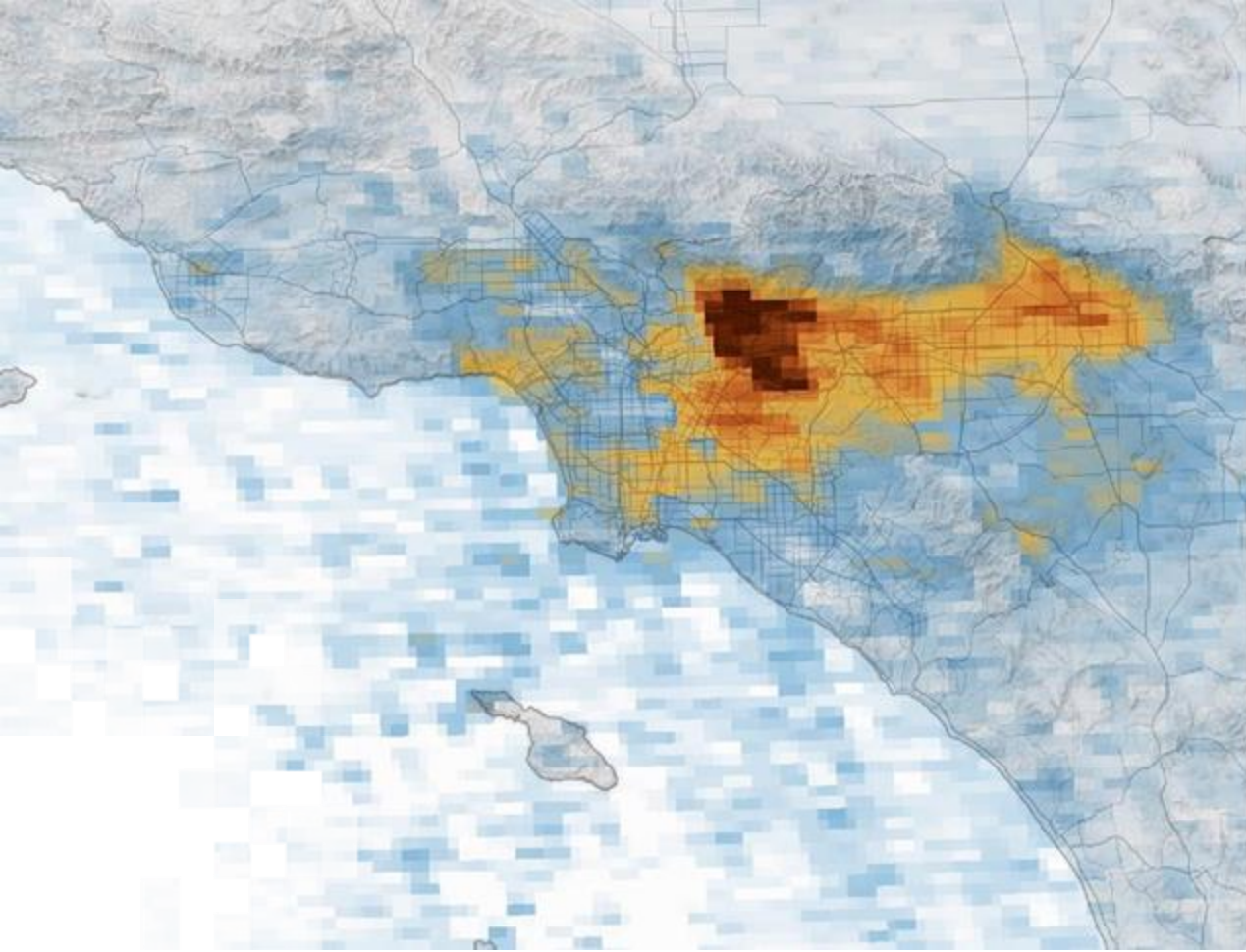
Stratosphere-Troposphere Separation in TEMPO Retrievals

- Stratosphere-troposphere separation method estimates the stratospheric NO₂ VCDs based on the SCDs, AMFs, and NO₂ columns from the GEOS-CF forecast (a priori).
- The stratospheric NO₂ VCDs are then subtracted from the total NO₂ VCDs to arrive at the tropospheric NO₂ VCDs.
- Quality assurance variables (e.g., effective cloud fraction, solar zenith angle, main data quality flags) can be used to filter lower quality (i.e., larger uncertainty) data.

No Cloud Fraction Filter

**Filter using
Cloud Fraction > 50%
SZA > 80°**





Quality Assurance & Data Filtering

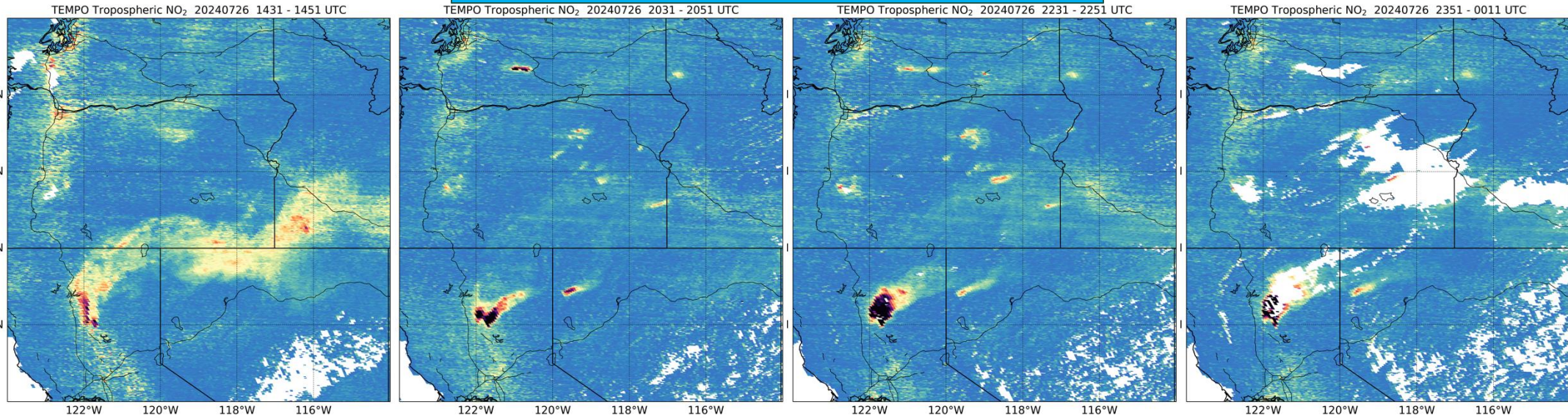
Quality Assurance Recommendations – TEMPO NO₂ & HCHO

- **Effective Cloud Fraction (eff_cloud_fraction)** variable in support_data group
 - Valid range from 0 to 1 – stricter cloud fraction threshold (e.g., `eff_cloud_fraction < 0.15`) will retain less data with less biases/uncertainties due to cloud influence
 - **Eff_cloud_fraction < 0.5 for qualitative use** – Worldview applies this threshold for TEMPO visualizations
 - **Eff_cloud_fraction < 0.2 or eff_cloud_fraction < 0.15 for quantitative use**
- **Solar Zenith Angle (solar_zenith_angle)** variable in geolocation group
 - Valid range from 0 to 90° – accuracy of NO₂ and HCHO retrievals deteriorates at large solar zenith angles > 70°
 - **solar_zenith_angle < 80° for qualitative use** – Worldview applies this threshold for TEMPO visualizations
 - **solar_zenith_angle < 70° for quantitative use**
- **Main Data Quality Flag (main_data_quality_flag)** variable in product group
 - Valid range from 0 to 2 – “0” = high-quality retrievals; “1” = suspect retrievals related to uncertainties in AMFs and large viewing geometry; “2” = outlier retrievals or no successful AMF calculation
 - **main_data_quality_flag < 2 for qualitative use** – Worldview applies this threshold for TEMPO visualizations
 - **main_data_quality_flag = 0 for quantitative use**

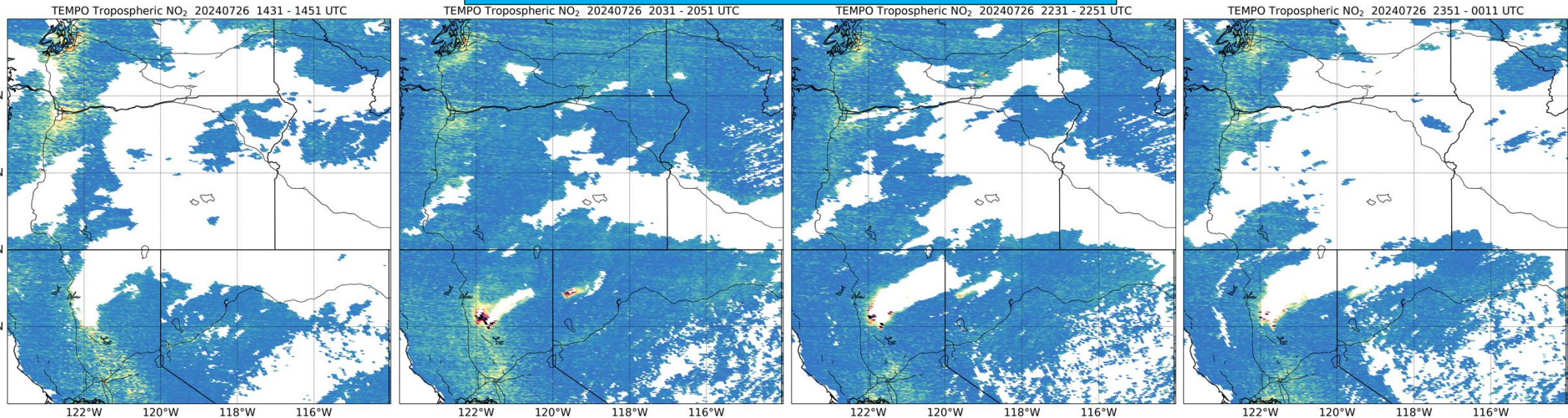


Comparing Quality Assurance Thresholds – TEMPO Tropospheric NO₂

Cloud Fraction < 50%, SZA < 80°, Flag = 0

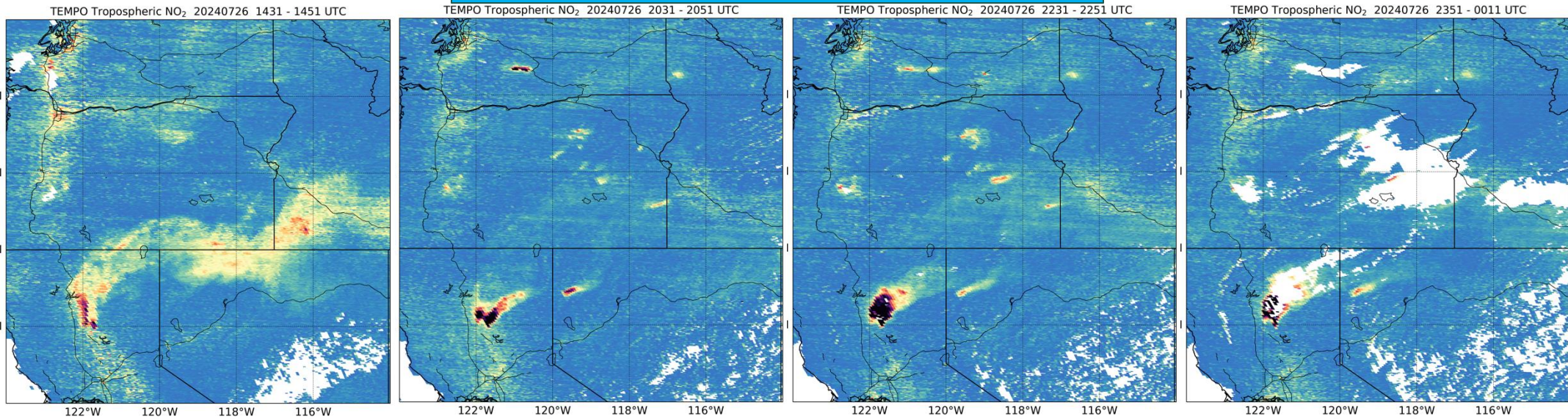


Cloud Fraction < 20%, SZA < 80°, Flag = 0

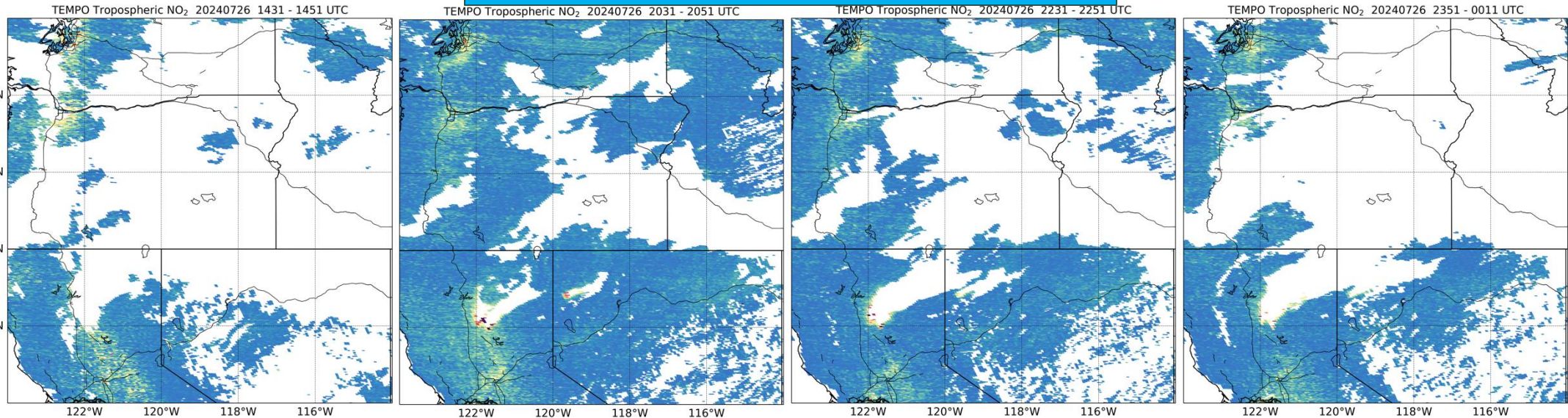


Comparing Quality Assurance Thresholds – TEMPO Tropospheric NO₂

Cloud Fraction < 50%, SZA < 80°, Flag = 0



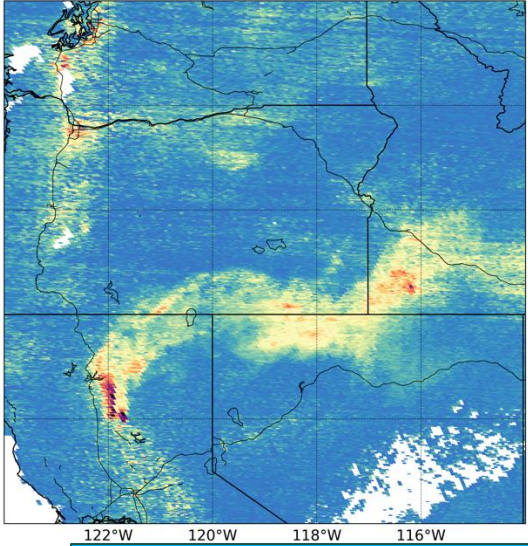
Cloud Fraction < 15%, SZA < 80°, Flag = 0



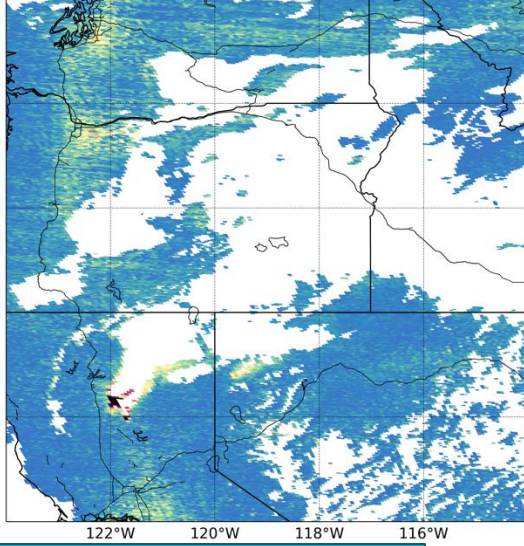
Comparing Quality Assurance Thresholds – TEMPO Tropospheric NO₂

Cloud Fraction < 50%, **SZA < 80°**, Flag = 0

TEMPO Tropospheric NO₂ 20240726 1431 - 1451 UTC

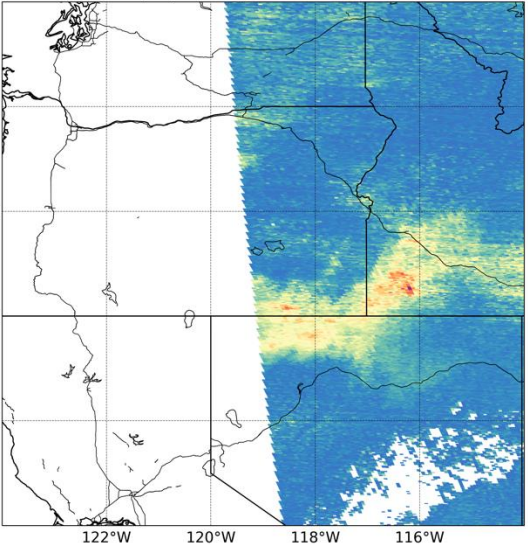


TEMPO Tropospheric NO₂ 20240727 0112 - 0131 UTC

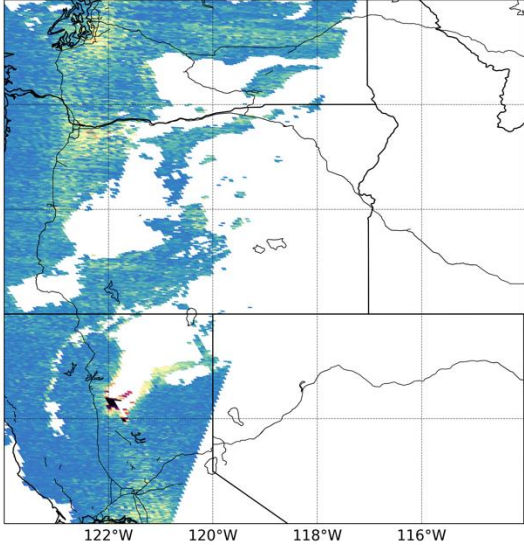


Cloud Fraction < 50%, **SZA < 70°**, Flag = 0

TEMPO Tropospheric NO₂ 20240726 1431 - 1444 UTC

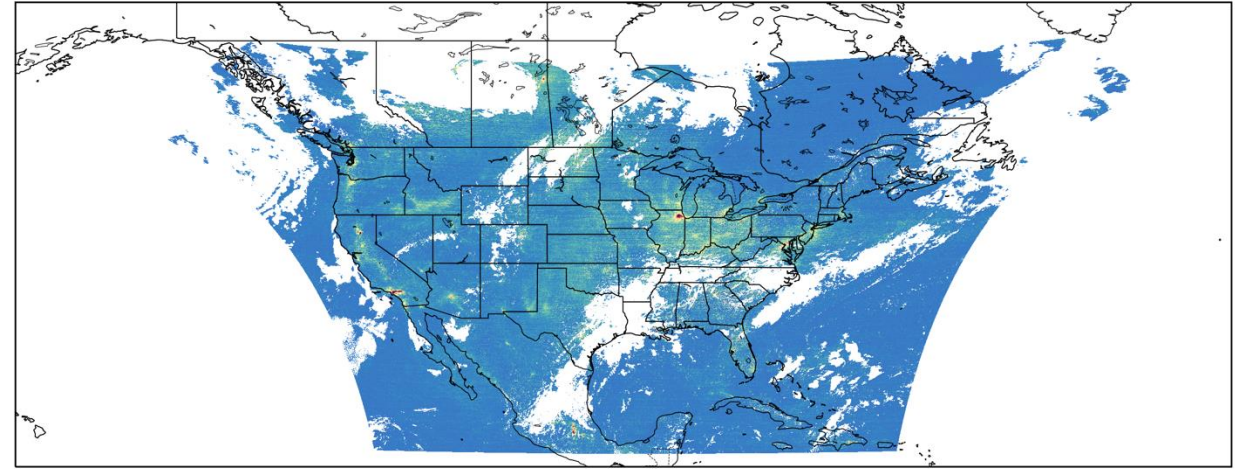


TEMPO Tropospheric NO₂ 20240727 0118 - 0131 UTC



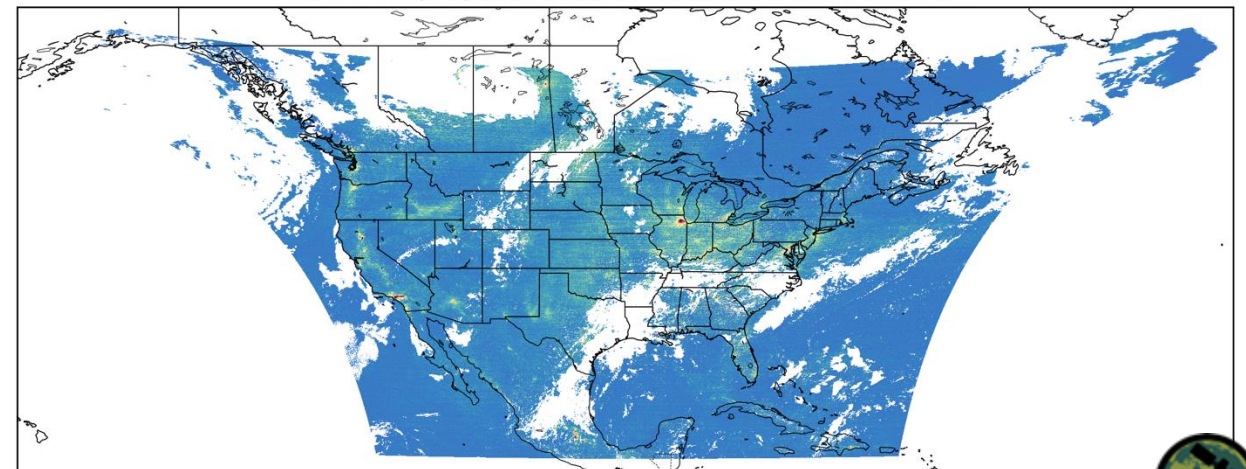
Cloud Fraction < 50%, **SZA < 80°**, **Flag = 0**

TEMPO Tropospheric NO₂ 20240726 1651 - 1751 UTC



Cloud Fraction < 50%, **SZA < 80°**, **Flag ≤ 1**

TEMPO Tropospheric NO₂ 20240726 1651 - 1751 UTC



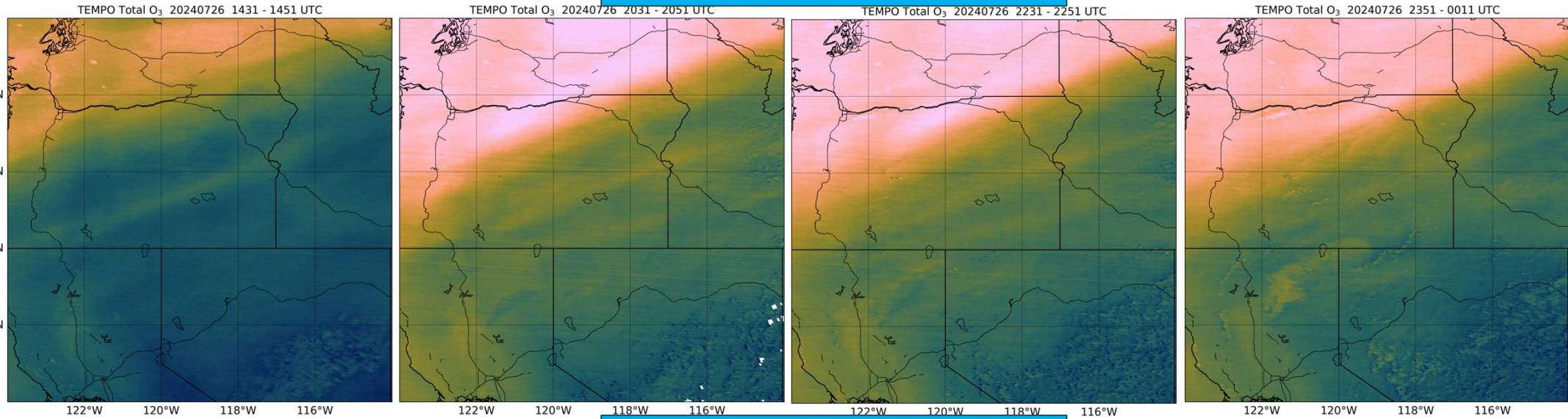
Quality Assurance Recommendations – TEMPO Total Column O₃

- **Quality Flag (quality_flag)** variable in product group
 - Valid range from 0 to 32768 – consisting of 18 different flag meanings
 - **quality_flag < 4096** for performing an analysis without considering data quality – Worldview applies this threshold along with solar zenith angle < 80°
 - **quality_flag = 0 (good sample) OR quality_flag = 5 (SO₂ present) OR quality_flag = 8 (row anomaly errors) OR quality_flag = 13** for performing an analysis with a lot of data including less accurate data
 - **quality_flag = 0 (good sample)** for retaining the highest quality data
- **Solar Zenith Angle (solar_zenith_angle)** variable in geolocation group
 - Valid range from 0 to 90° - quality of total column O₃ data degrades at large solar zenith angles
 - Filtering via **quality_flag** variable will disregard solar zenith angles > 84°
 - Users must apply solar zenith angle threshold for filtering data associated with lower solar zenith angles
 - Worldview visualizations apply solar zenith angle < 80° threshold

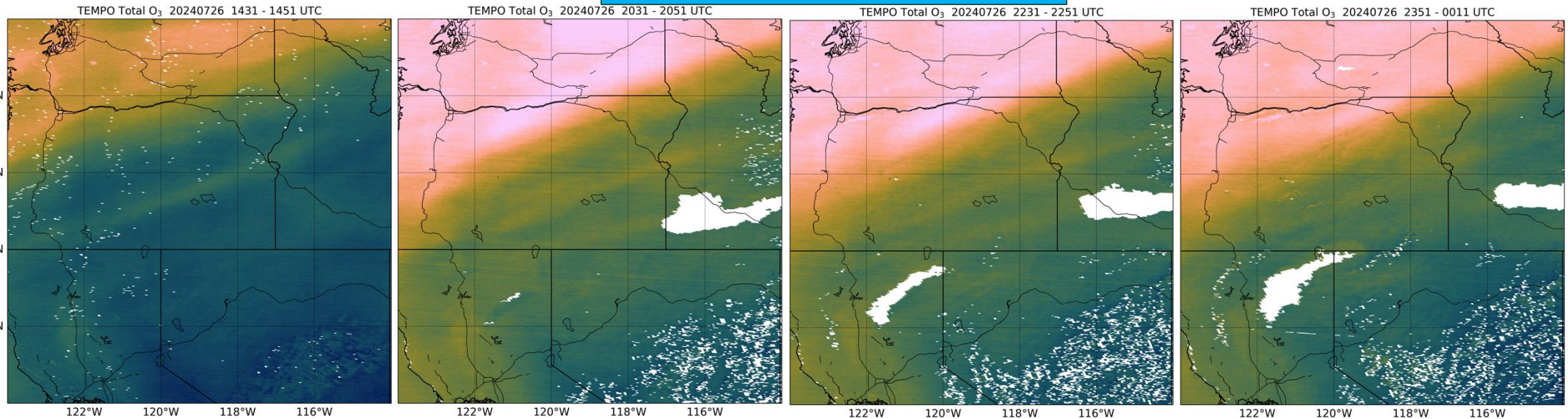


Comparing Quality Assurance Thresholds – TEMPO Total Column O₃

Quality Flag < 4096

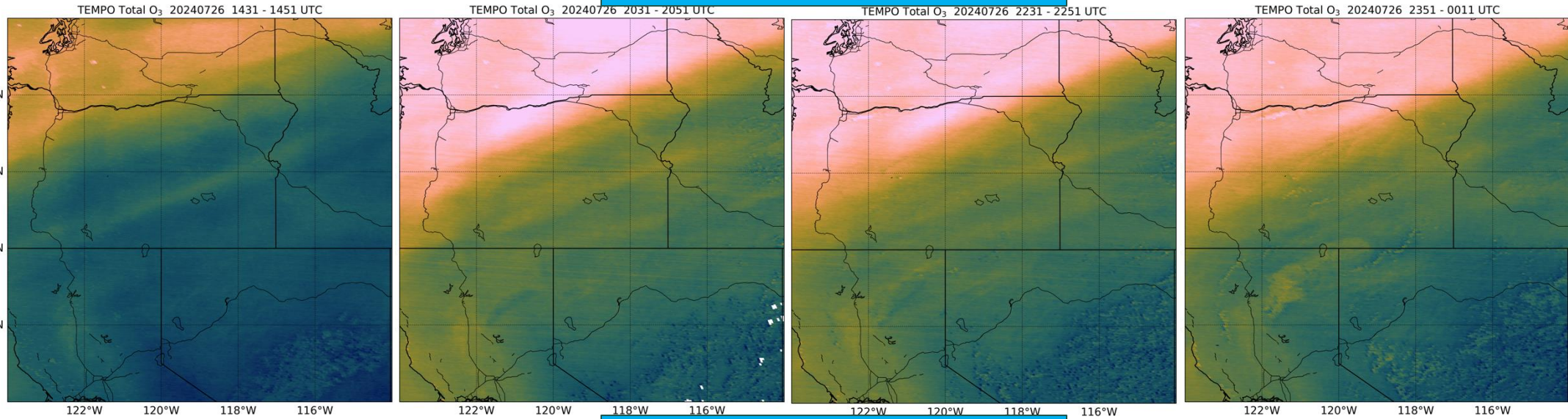


Quality Flag = 0, 5, 8, 13

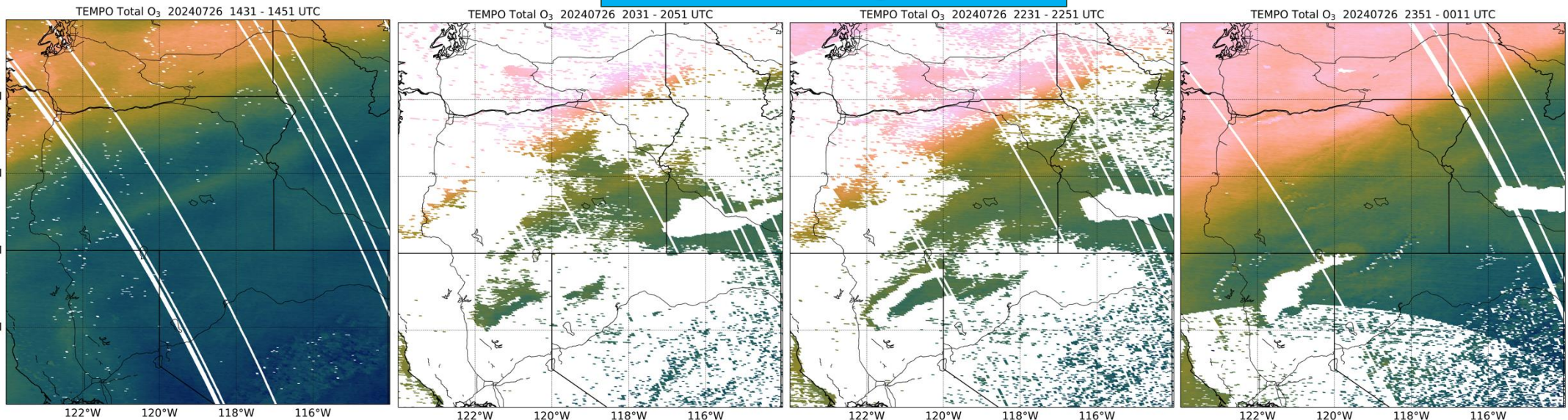


Comparing Quality Assurance Thresholds – TEMPO Total Column O₃

Quality Flag < 4096

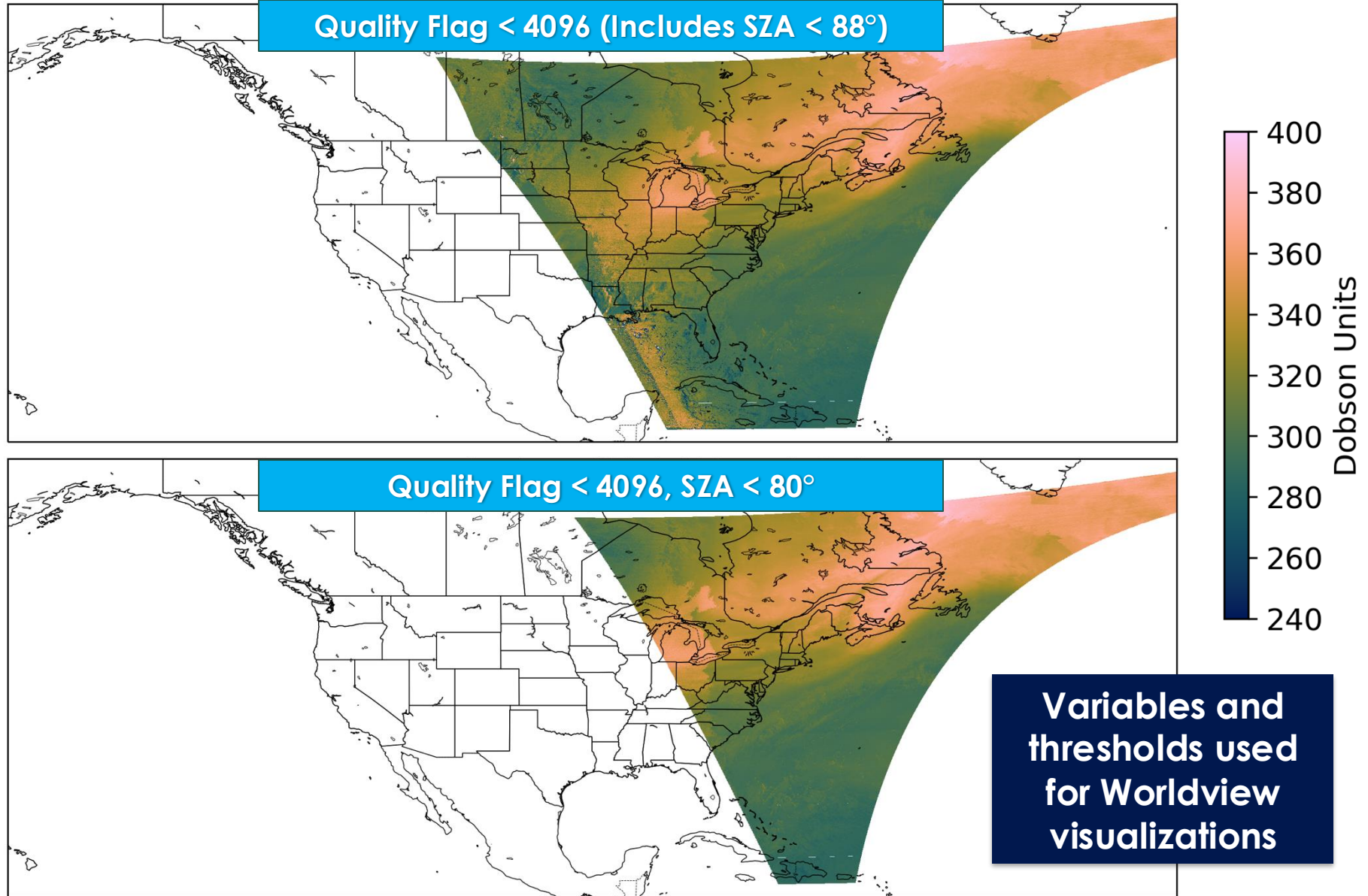


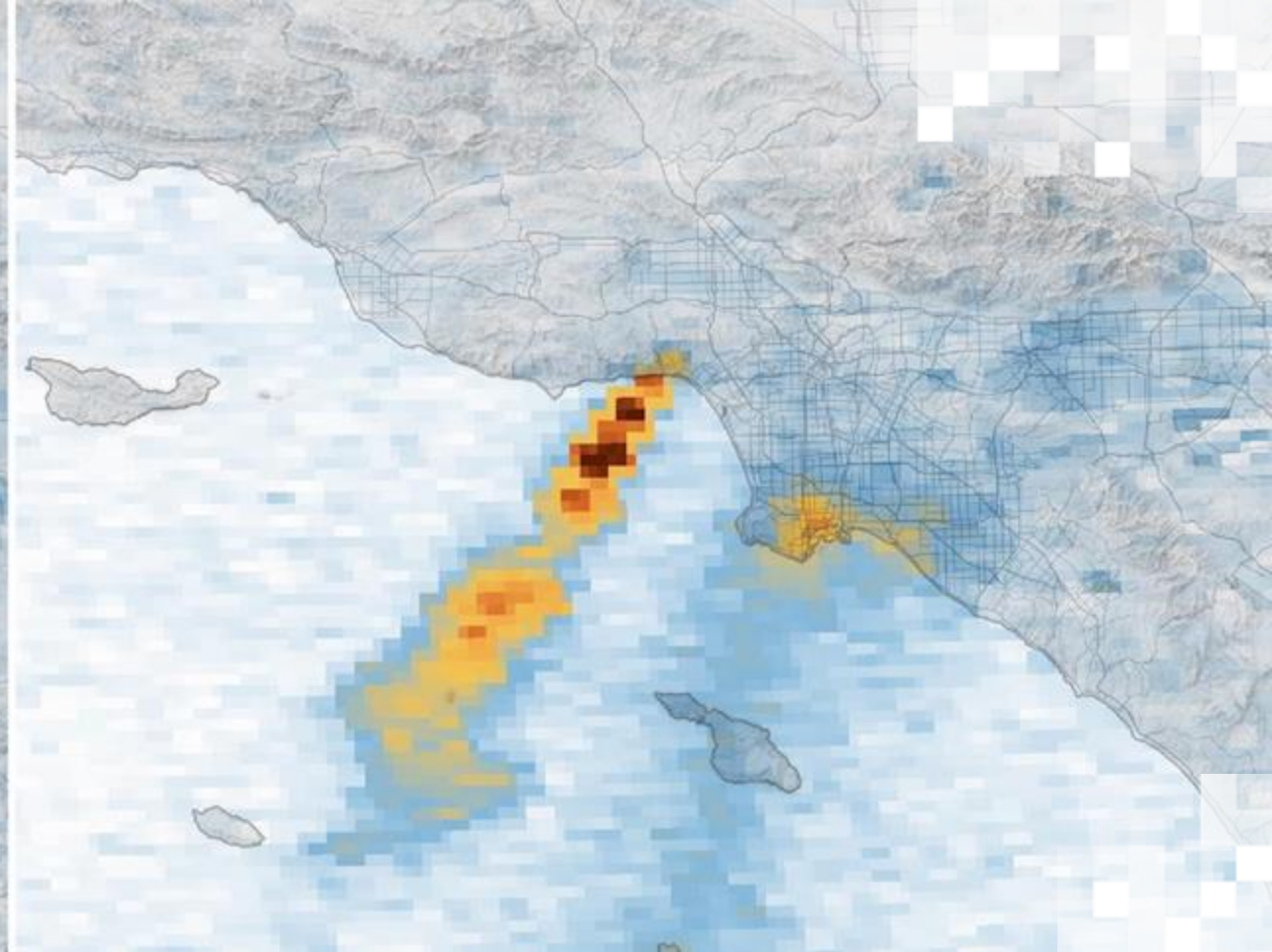
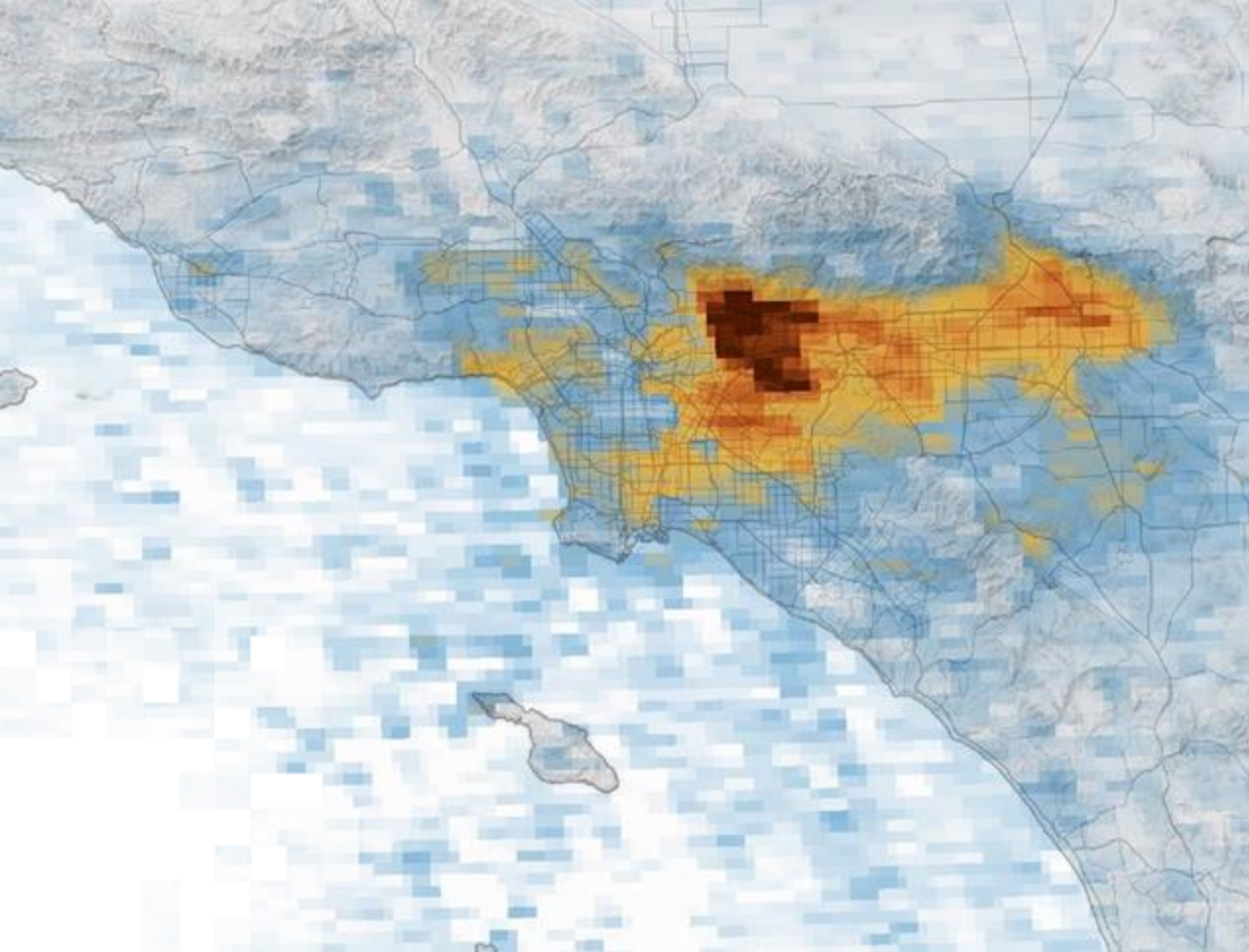
Quality Flag != 0



Comparing Quality Assurance Thresholds – TEMPO Total Column O₃

TEMPO Total O₃ 20240726 1111 - 1151 UTC





TEMPO Level 2 Trace Gas Examples

Southwest Zoom NO₂ - June 18, 2025

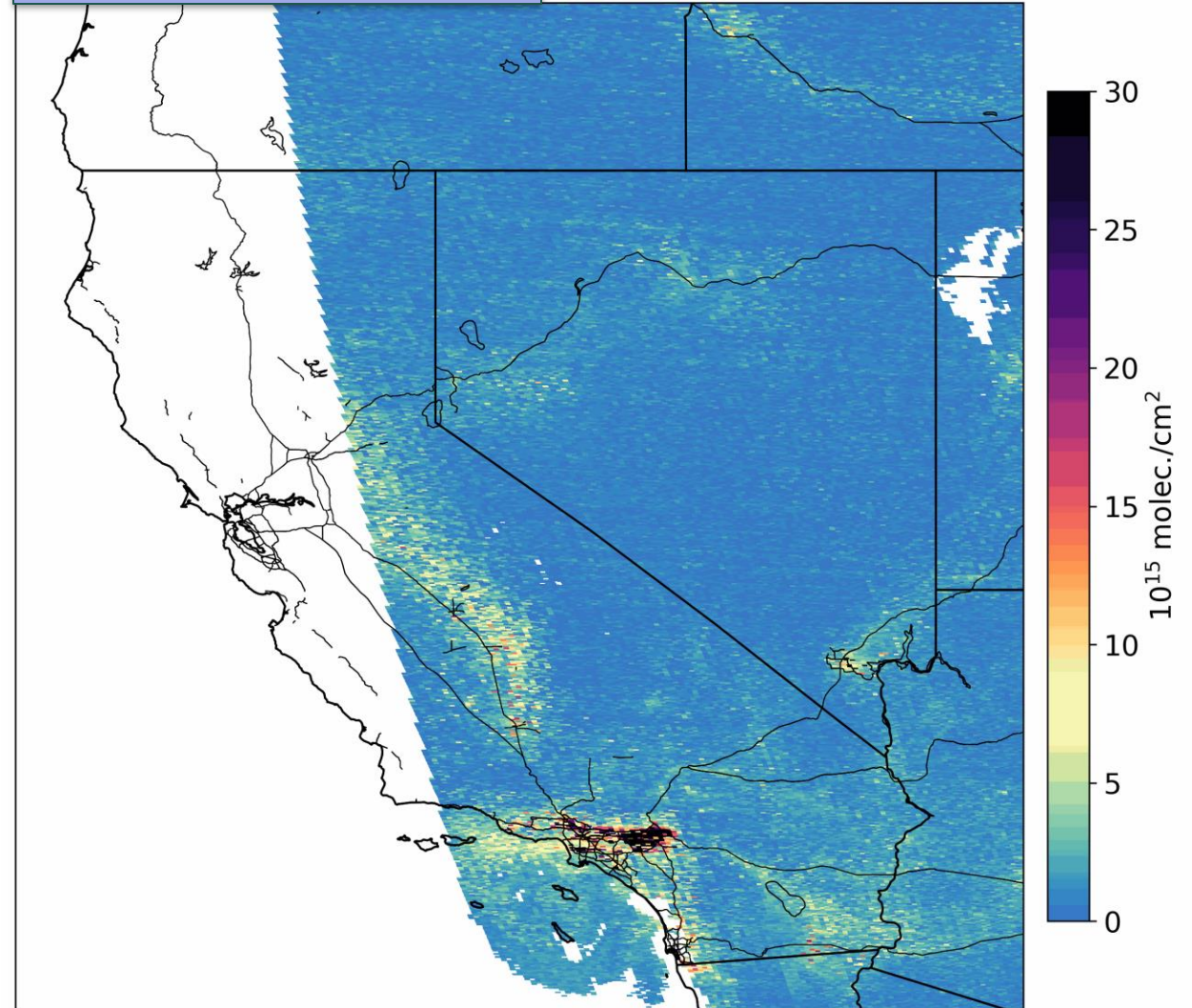
MODIS Aqua True Color ~15:00 PDT



Filter using
Cloud Fraction > 50%
SZA > 80°

TEMPO Tropospheric NO₂

20250618 06:46 PDT

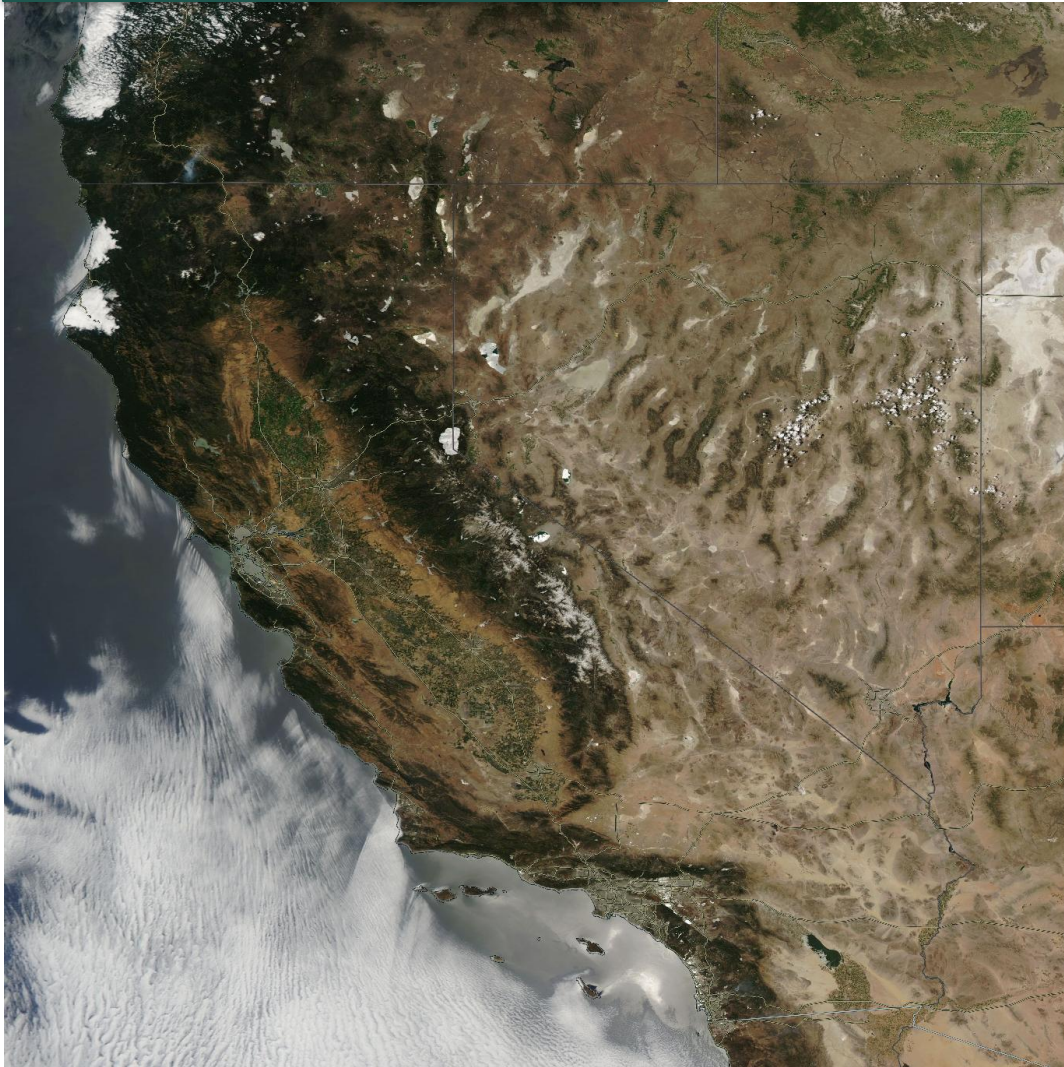


1-Day Animation of Tropospheric NO₂ VCDs from TEMPO



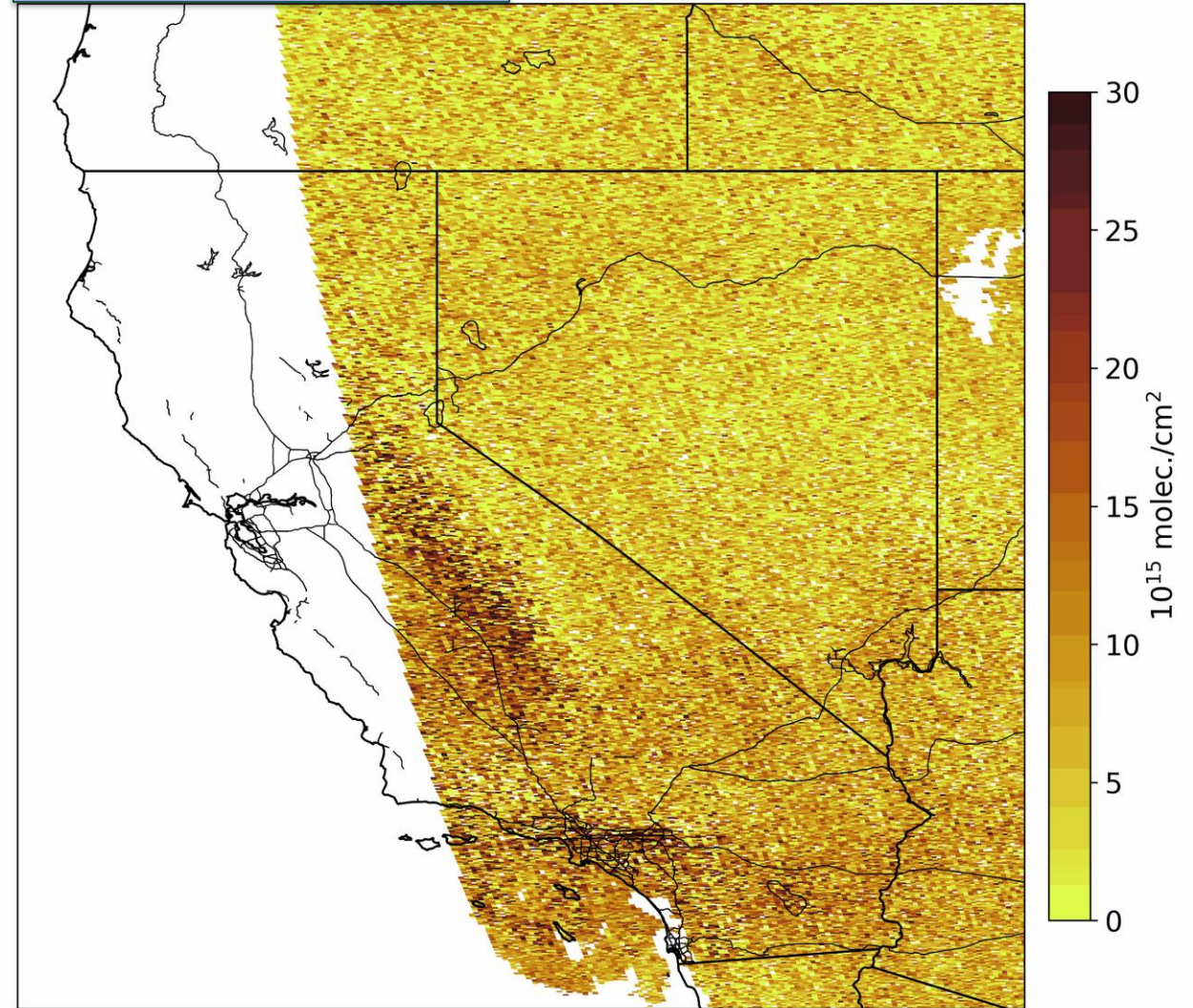
Southwest Zoom HCHO - June 18, 2025

MODIS Aqua True Color ~15:00 PDT



Filter using
Cloud Fraction > 50%
SZA > 80°

TEMPO Total Column HCHO 20250618 06:46 PDT

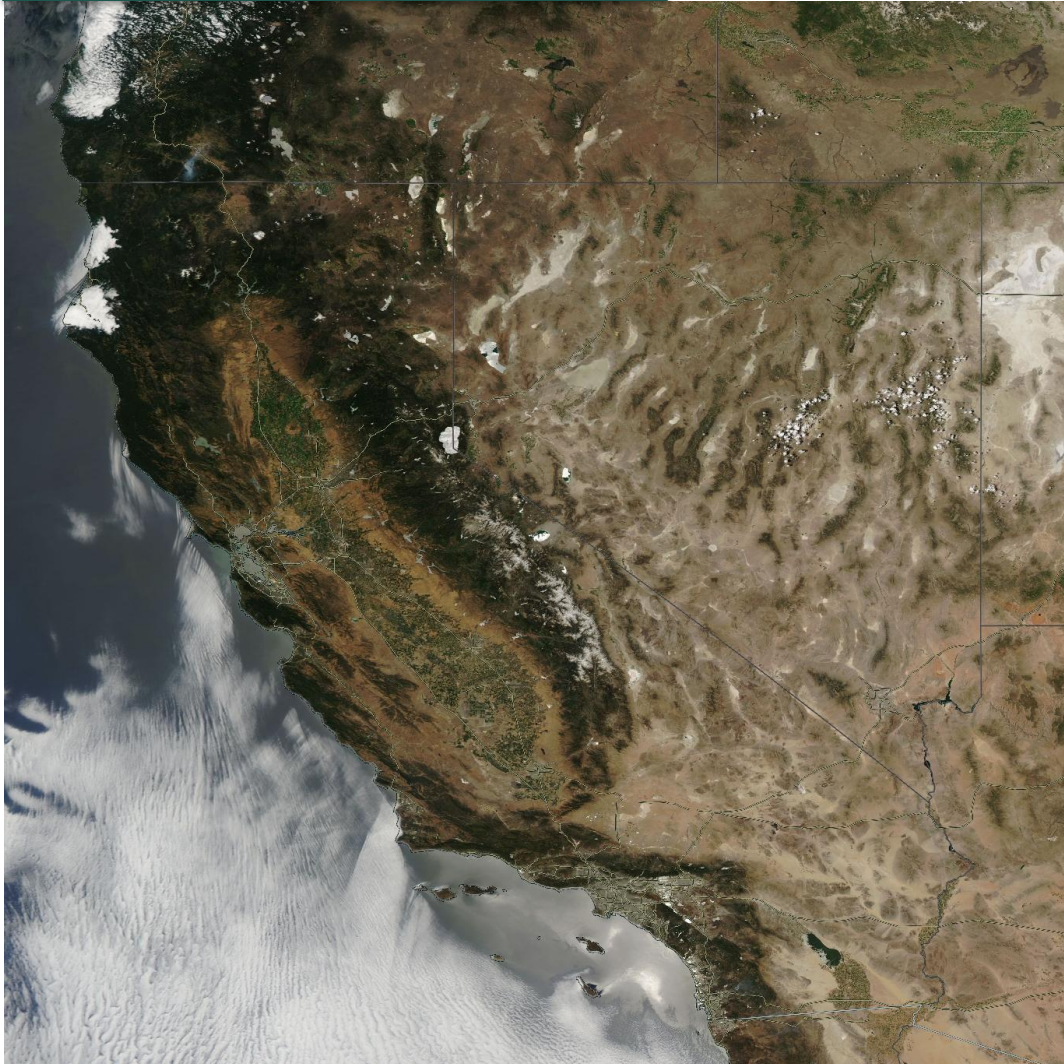


1-Day Animation of Total HCHO VCDs from TEMPO



Southwest Zoom O₃ - June 18, 2025

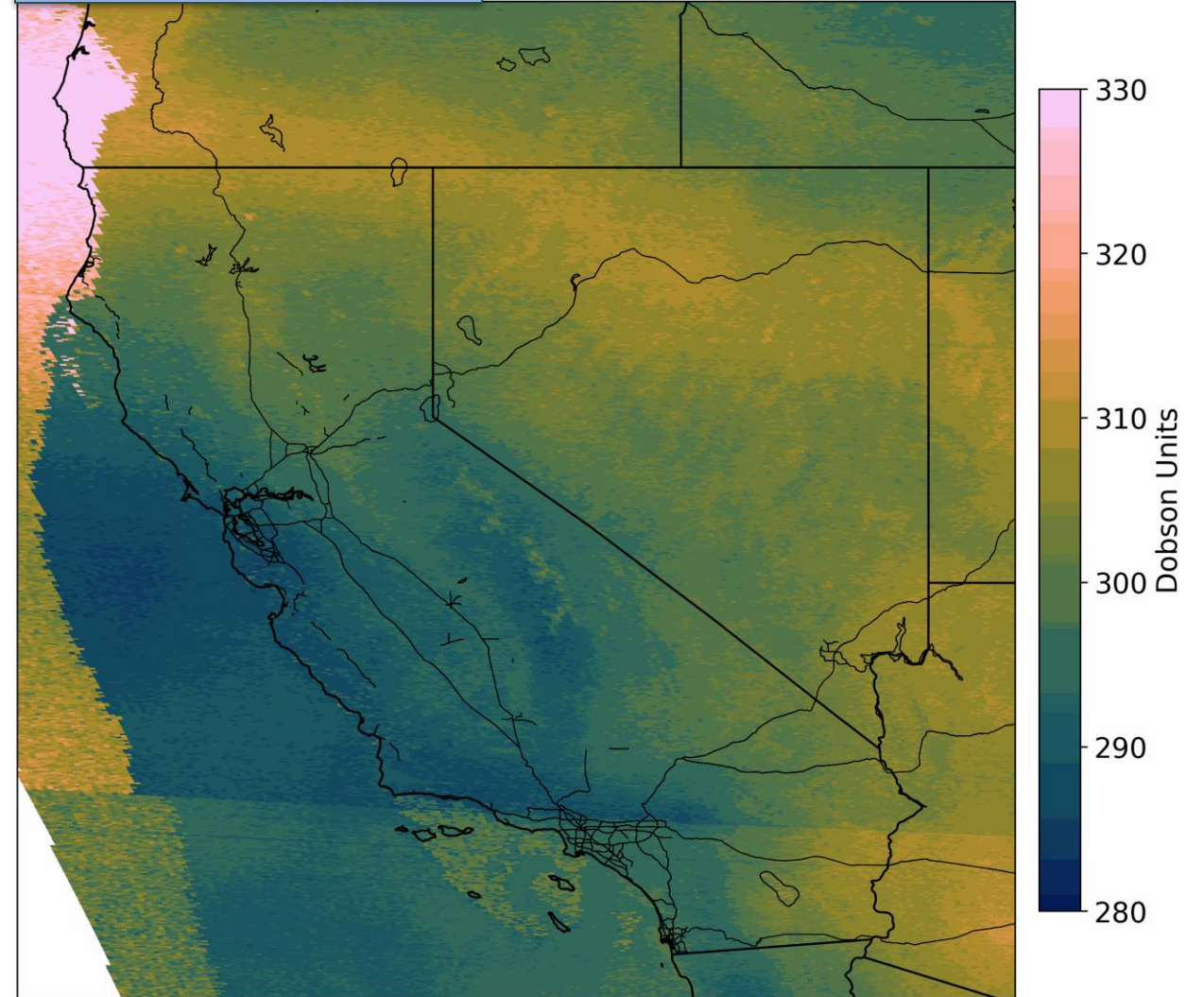
MODIS Aqua True Color ~15:00 PDT



Filter using
SZA > 80°

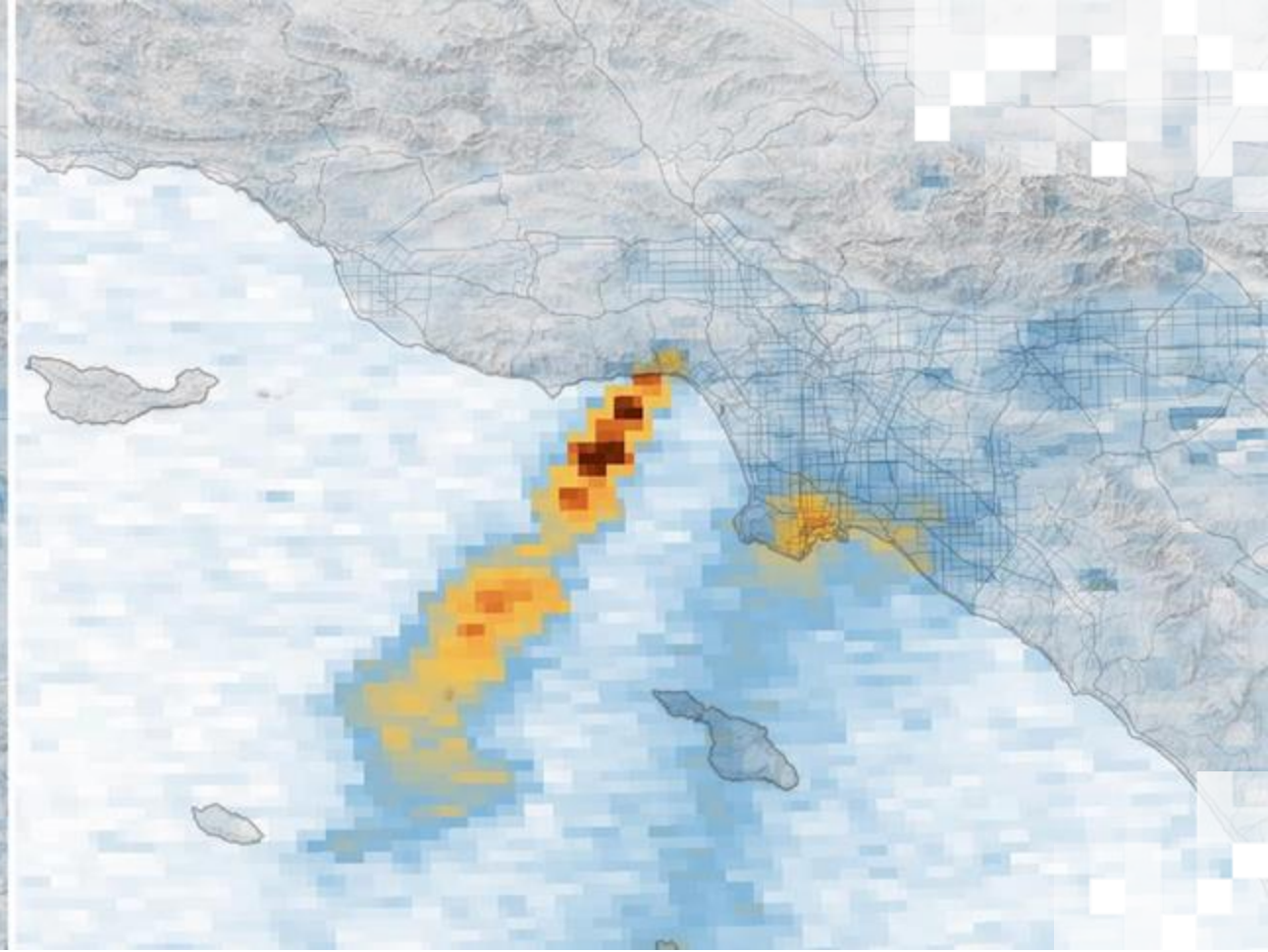
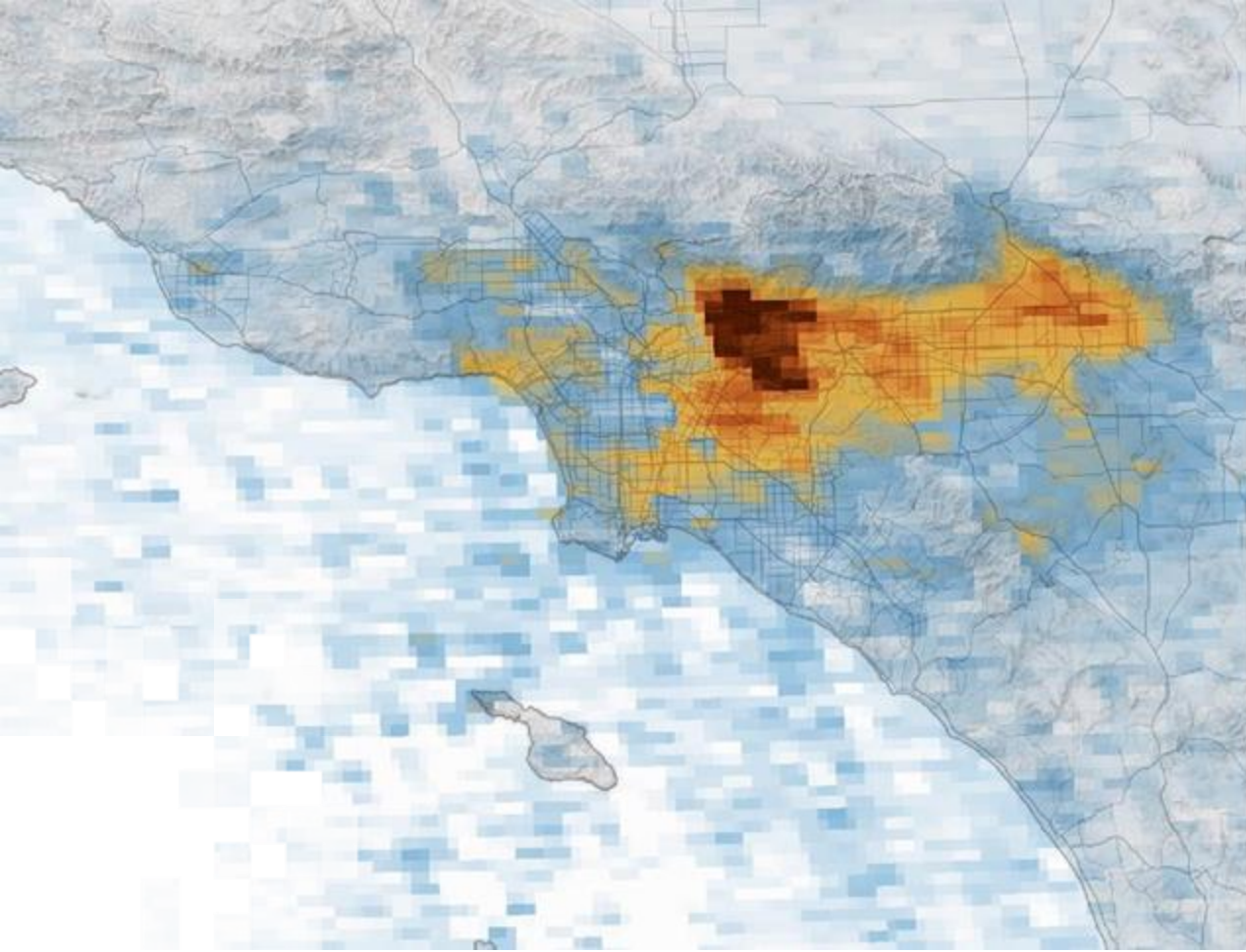
TEMPO Total Column O₃

20250618 06:46 PDT



1-Day Animation of Total Column O₃ from TEMPO





Validation of TEMPO Products

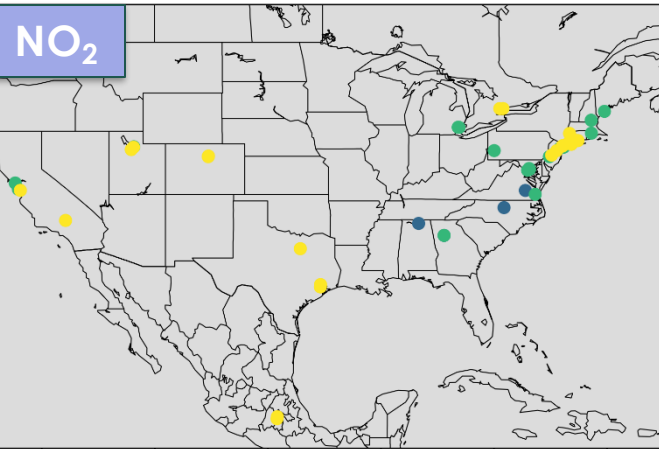
TEMPO Validation at Pandora Network Sites

Filter using
Cloud fraction > 15%
SZA > 70°

Correlation

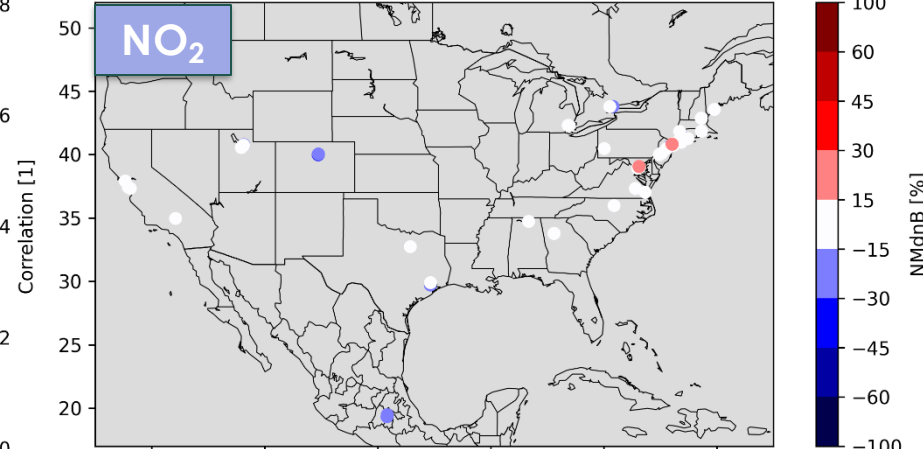
Mean Biases

totNO₂ [# / cm³] Correlation(TEMPO, Pandora)



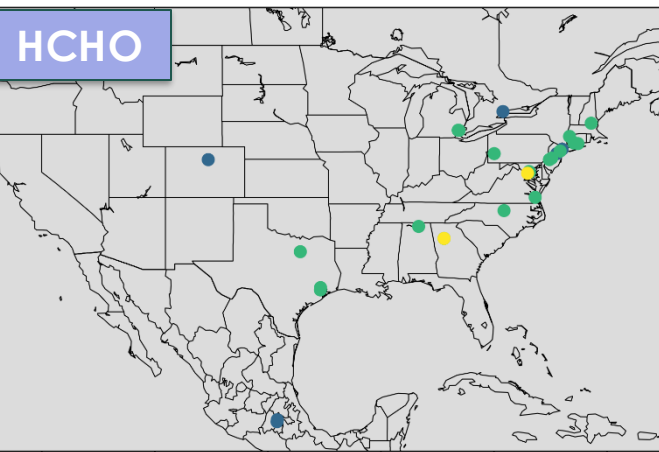
2023-08-02 to 2025-05-18

(TEMPO - Pandora)_(50%) / Pandora_(50%)



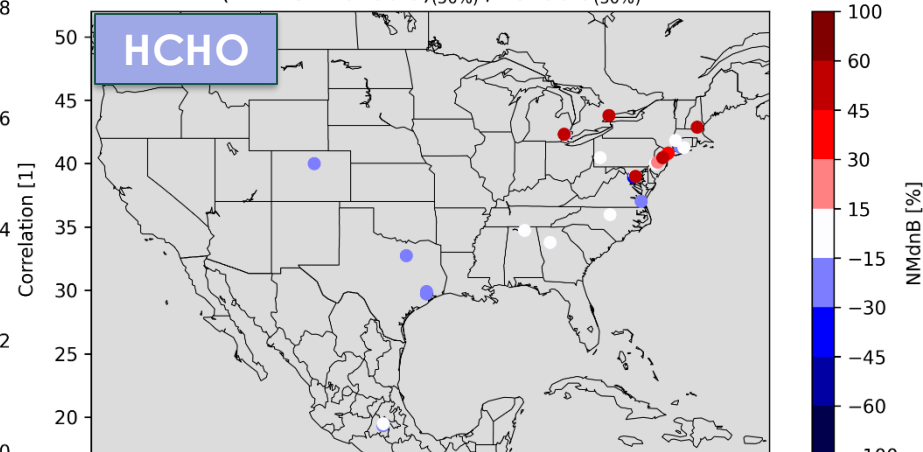
2023-08-02 to 2025-05-18

totHCHO [# / cm³] Correlation(TEMPO, Pandora)



2023-08-02 to 2025-05-18

(TEMPO - Pandora)_(50%) / Pandora_(50%)



2023-08-02 to 2025-05-18

TEMPO NO₂ –

1. Reproduces spatial variability
2. Low fractional biases by locations
3. Correlates well at most sites
4. Even reproduces relatively small intra-regional urban/rural gradients quite well

TEMPO HCHO –

1. Correlates at the site-level
2. Has reasonable bias with some individual sites needing investigation
3. Site-specific time correlation
4. Intra-regional site-level gradients are challenging, perhaps due to pixel averaging

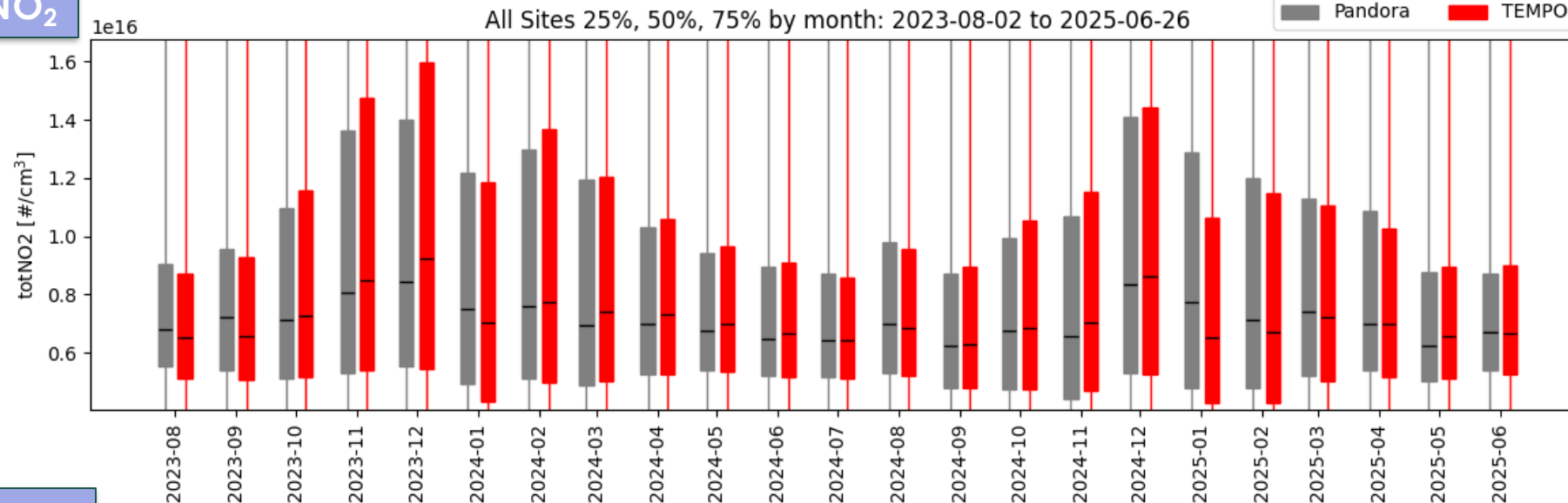


TEMPO vs. Pandora Across All Sites Per Month

Filter using
Cloud Fraction > 15%
SZA > 70°

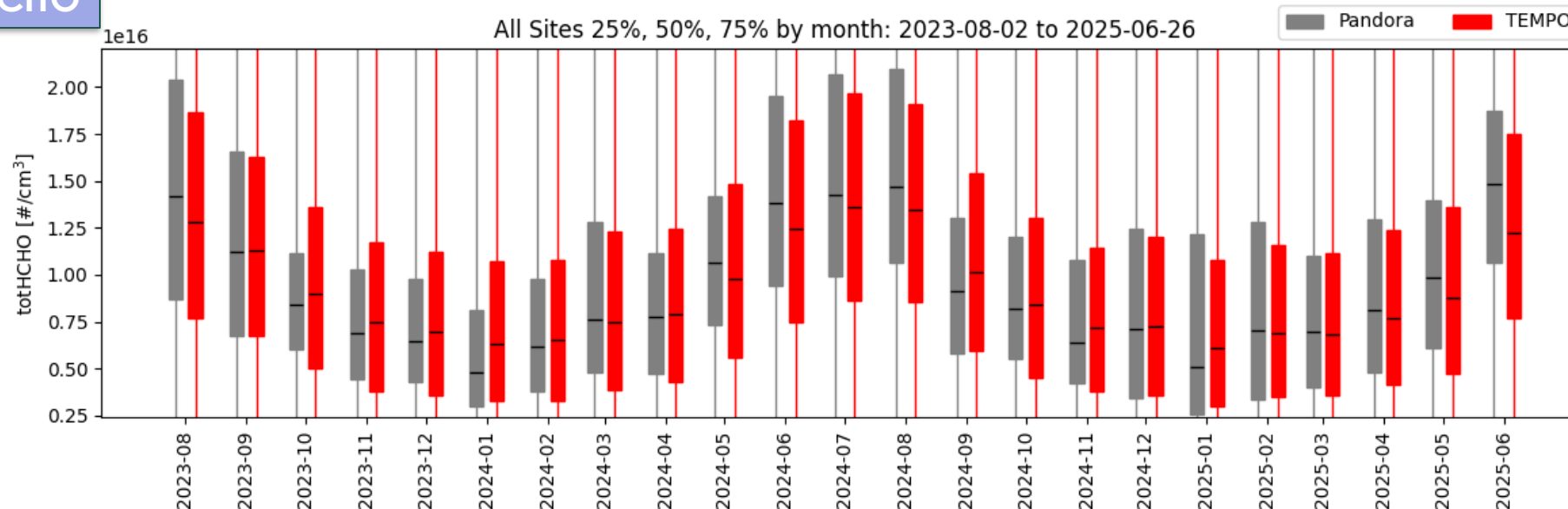


NO₂



TEMPO **NO₂** captures Pandora seasonal pattern ($r=0.82$) with good bias (NMB=3%)

HCHO



TEMPO **HCHO** captures seasonal pattern ($r=0.98$) with good bias (NMB=-3%)

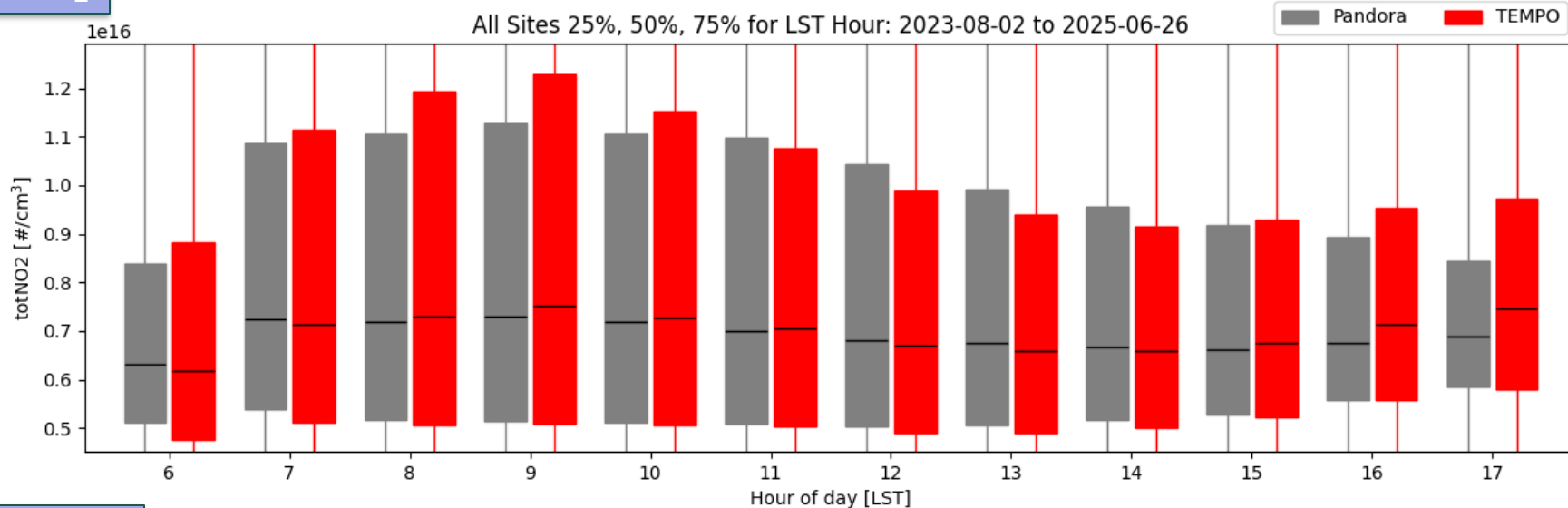


TEMPO vs. Pandora Across All Sites Per Hour of Day

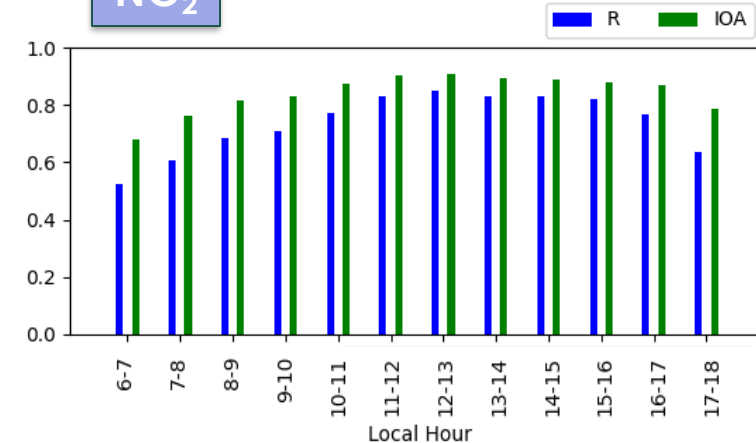
Filter using
Cloud fraction > 15%
SZA > 70°



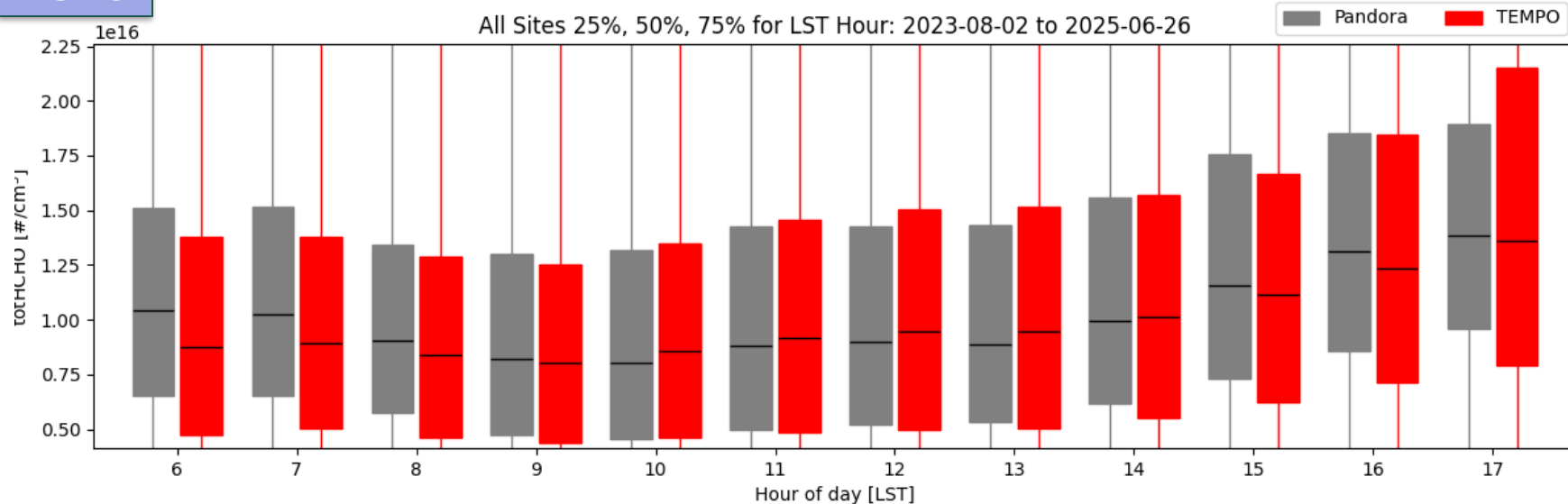
NO₂



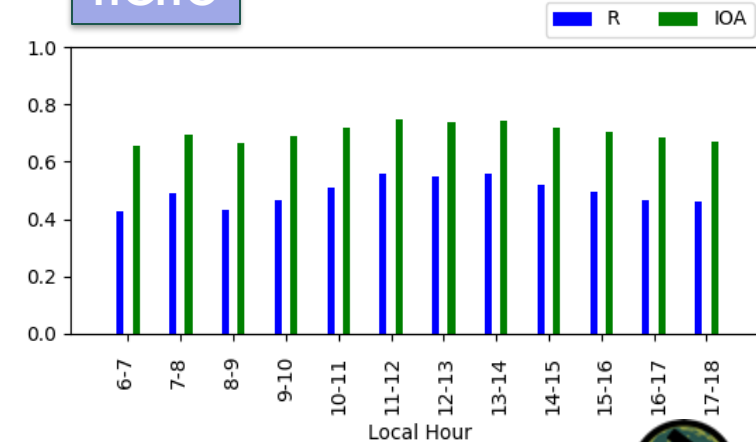
NO₂

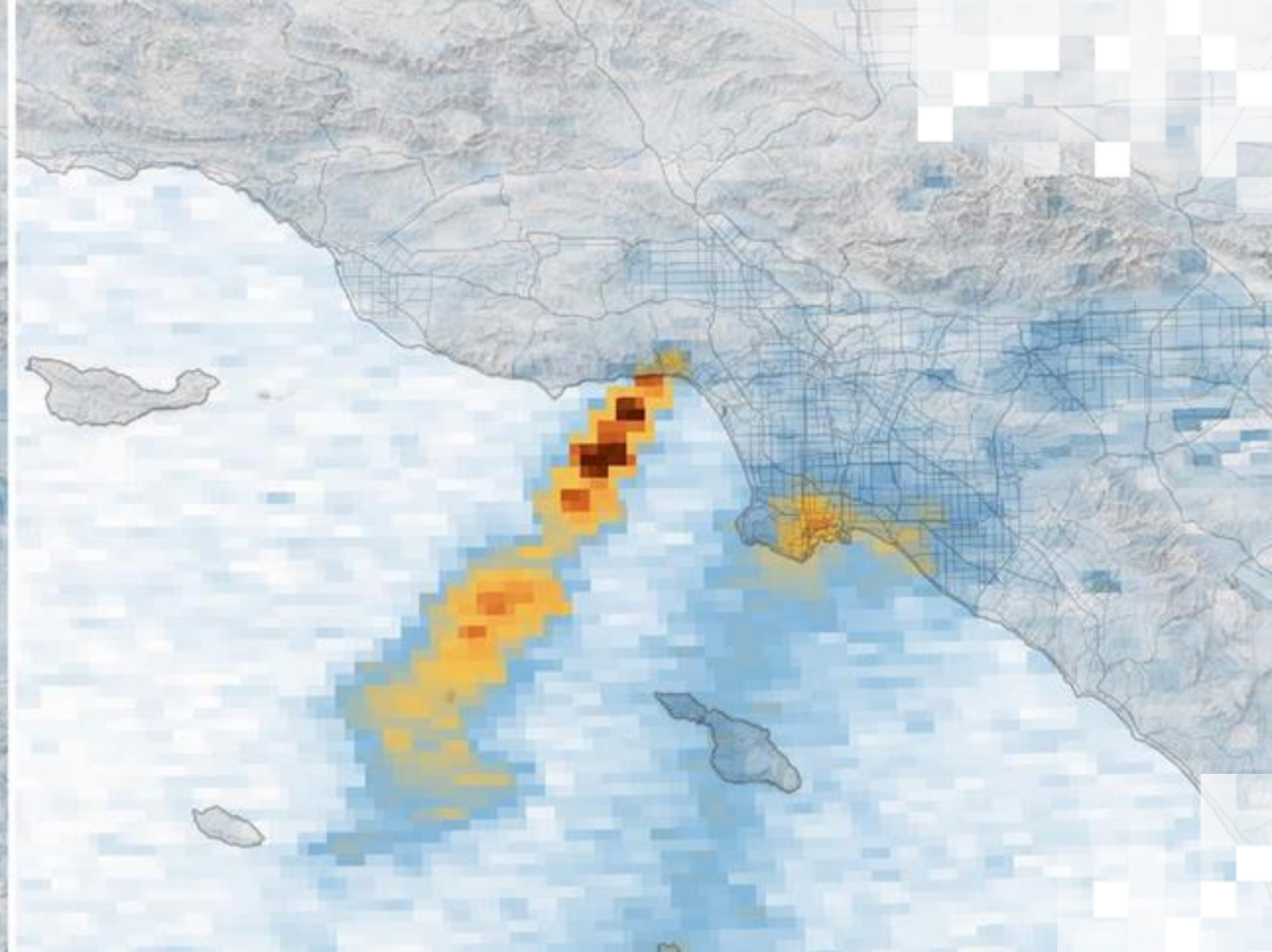
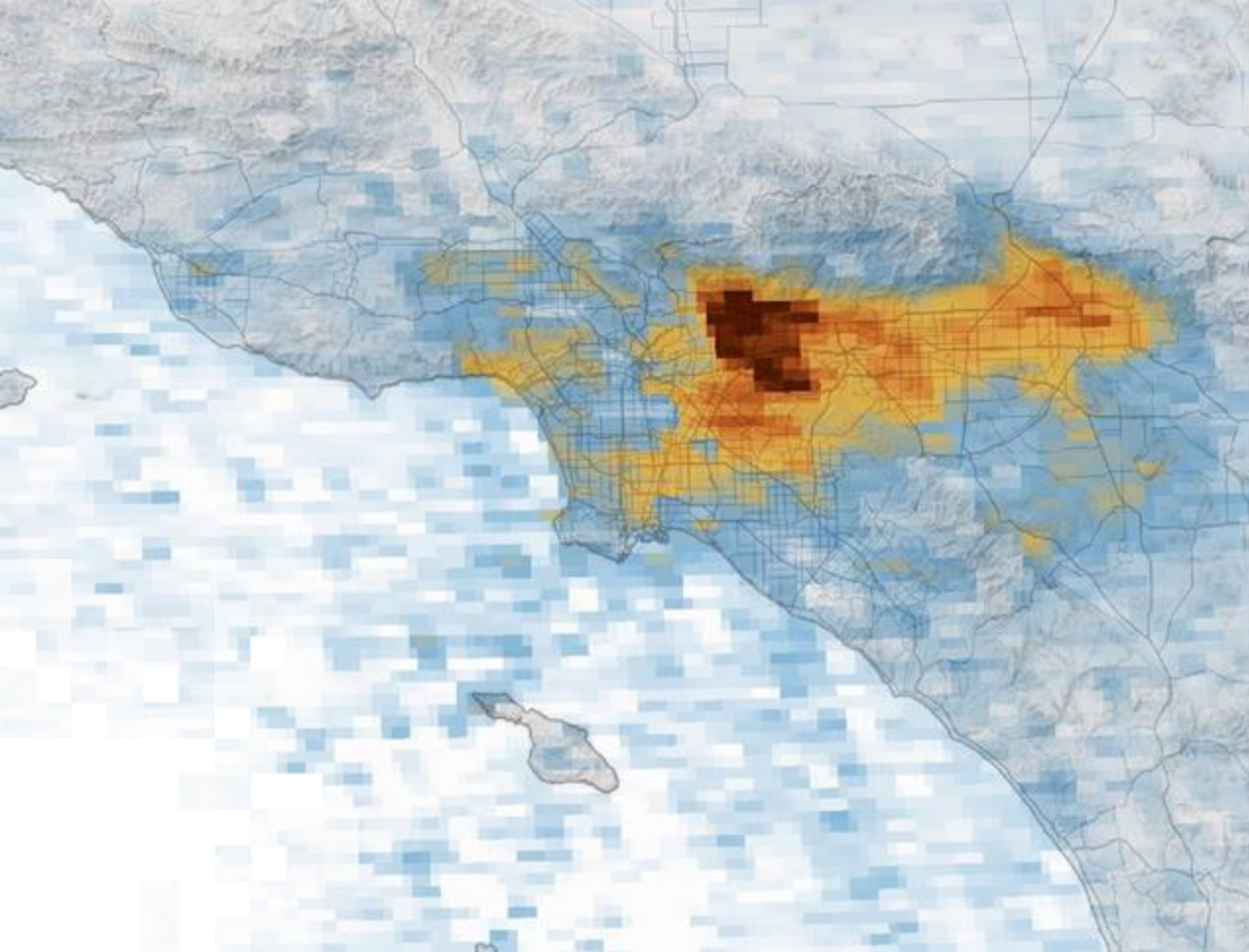


HCHO



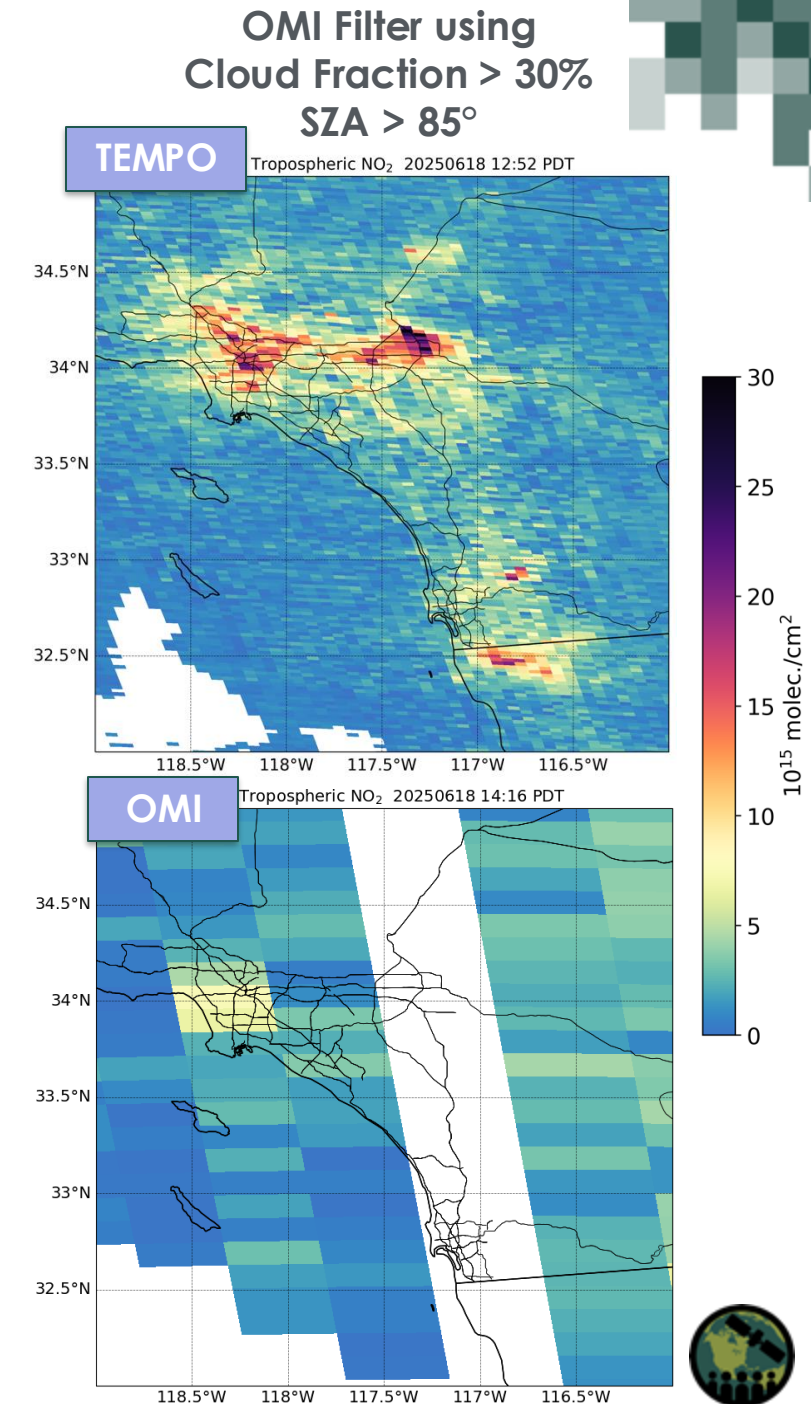
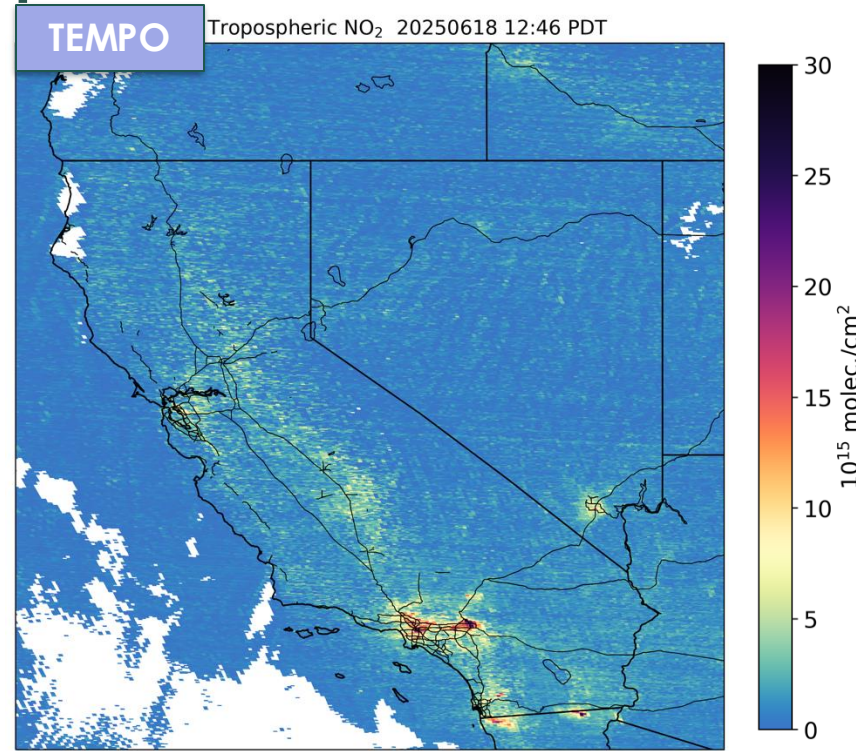
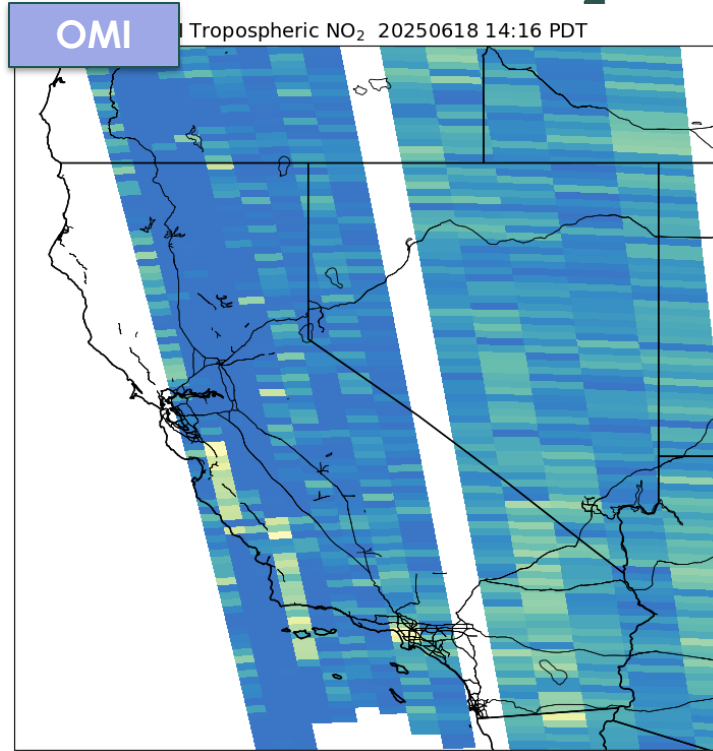
HCHO





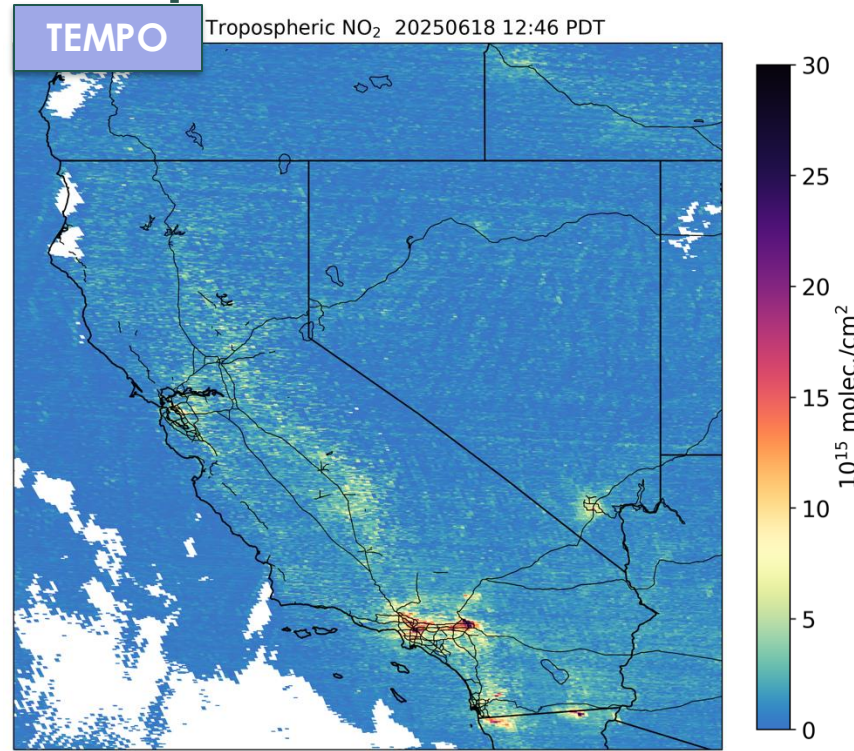
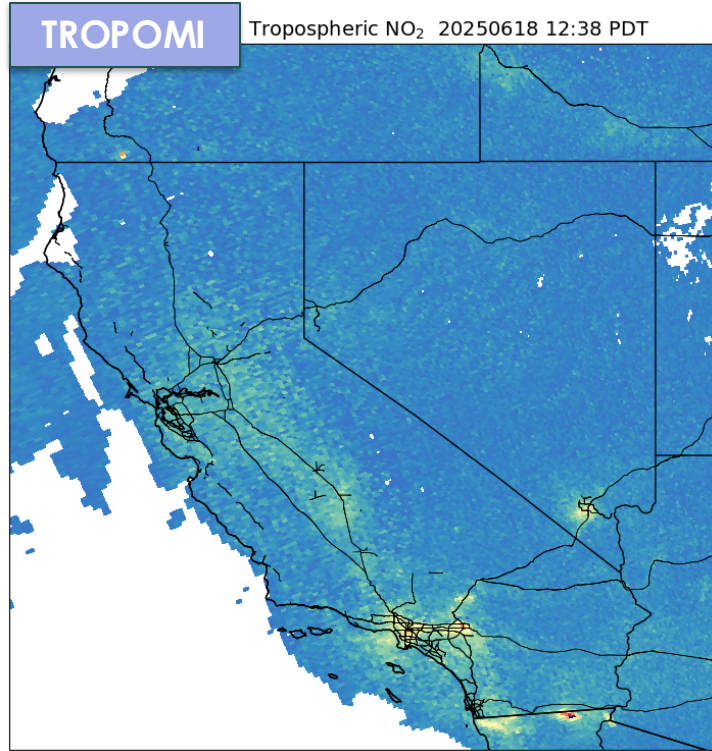
TEMPO vs. OMI and TROPOMI

TEMPO vs. OMI NO₂ Comparison



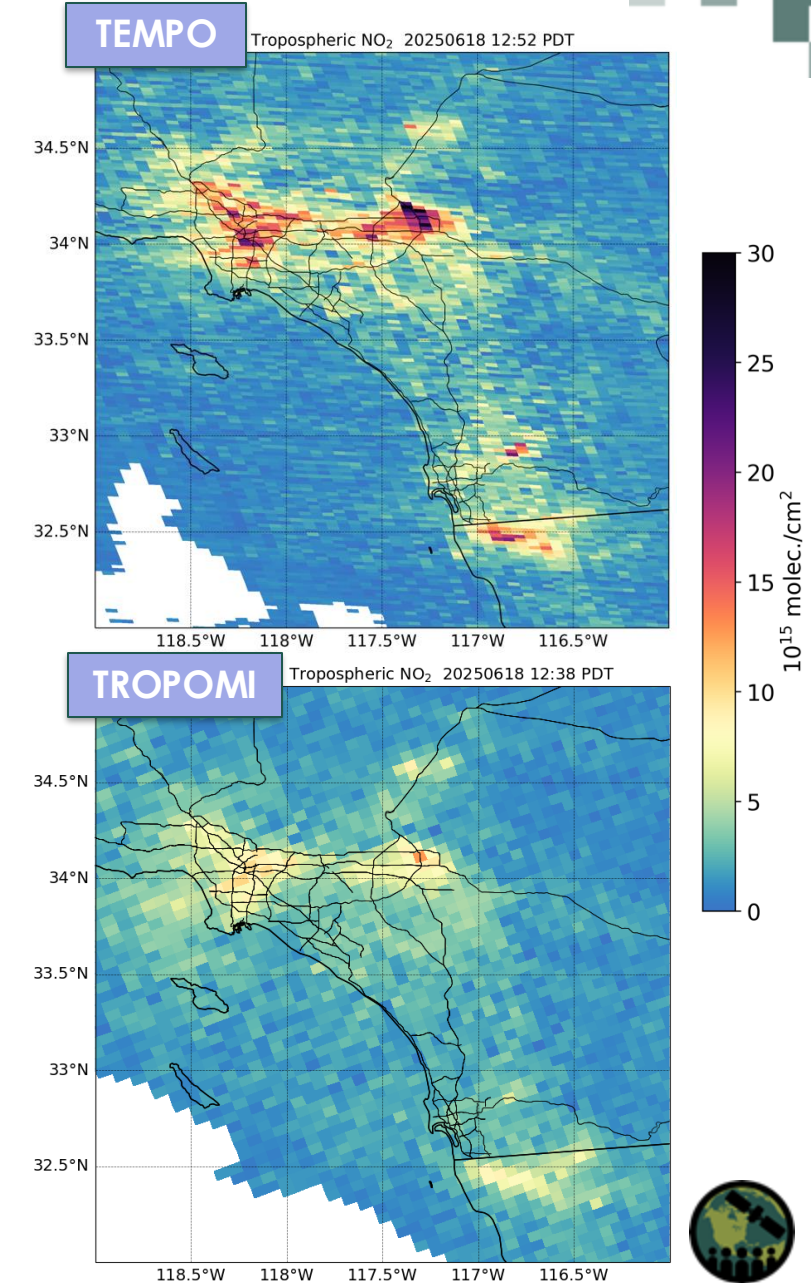
- NASA's Low-Earth orbiting OMI (Ozone Monitoring Instrument), launched in 2004, provides midday observations of air pollutants across the globe at a spatial resolution of 13 km x 24 km (at nadir).
- TEMPO NO₂ tropospheric VCDs are larger than TROPOMI in urban areas including Los Angeles, Las Vegas, and Mexicali.
- TEMPO's much higher resolution of ~ 2.1 km x 5.6 km compared to OMI's is contributing to the NO₂ differences between the two sensors.

TEMPO vs. TROPOMI NO₂ Comparison



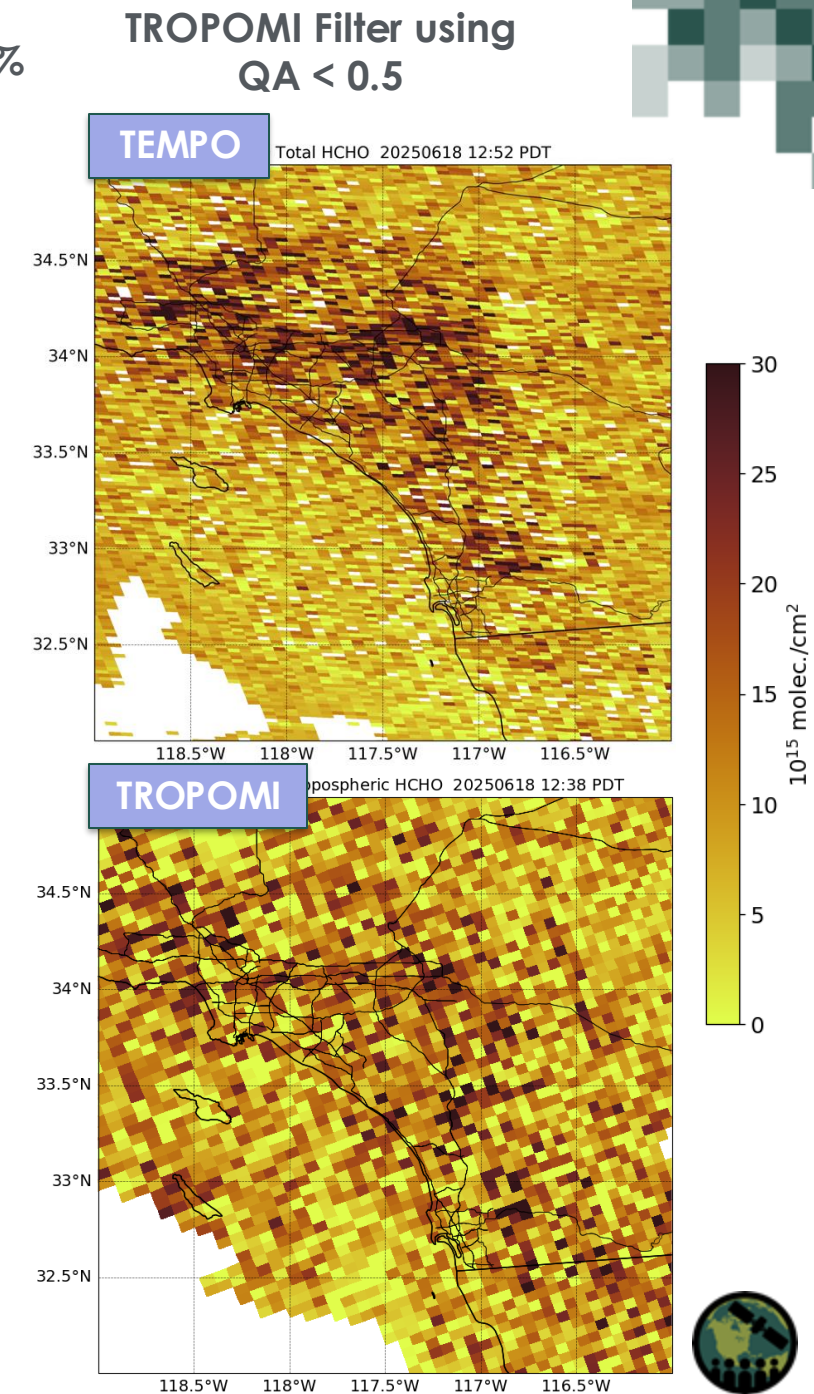
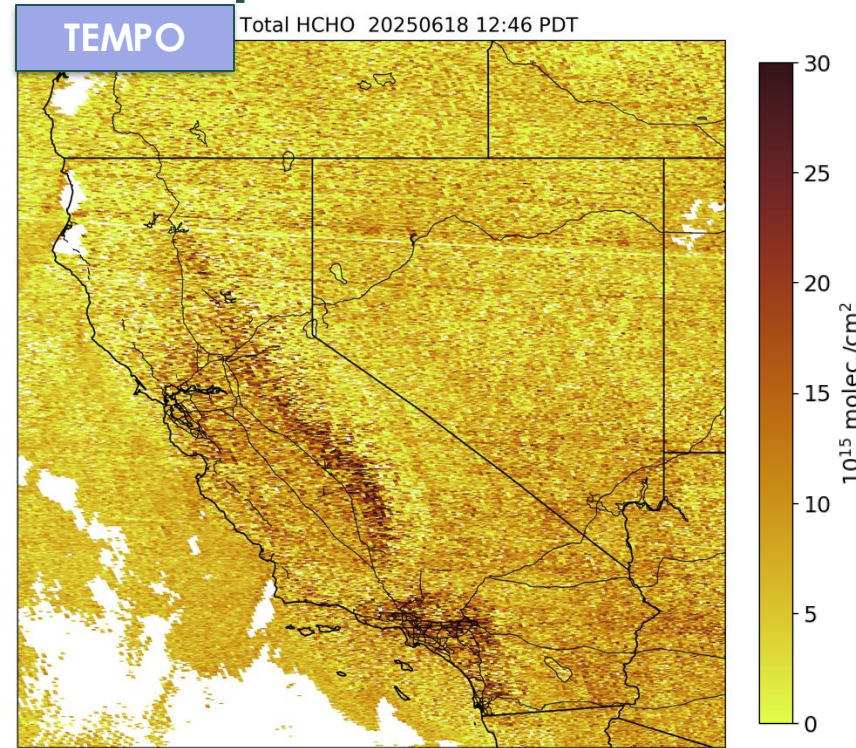
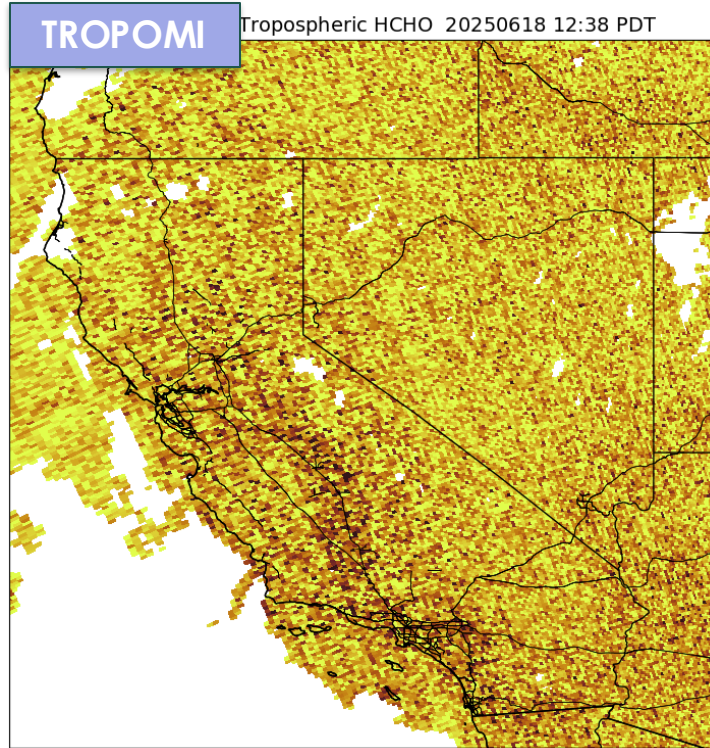
TEMPO Filter using
Cloud Fraction > 50%
SZA > 80°

TROPOMI Filter using
QA < 0.75



- Low-Earth orbiting TROPOMI (Tropospheric Monitoring Instrument), launched in 2017 by the European Space Agency, provides midday observations of air pollutants across the globe at a spatial resolution of 5.5 km x 3.5 km (at nadir).
- TEMPO NO₂ tropospheric VCDs are larger than TROPOMI in urban areas including Los Angeles, San Diego, and Tijuana.
- TEMPO's higher resolution is likely contributing to slight NO₂ differences.

TEMPO vs. TROPOMI HCHO Comparison

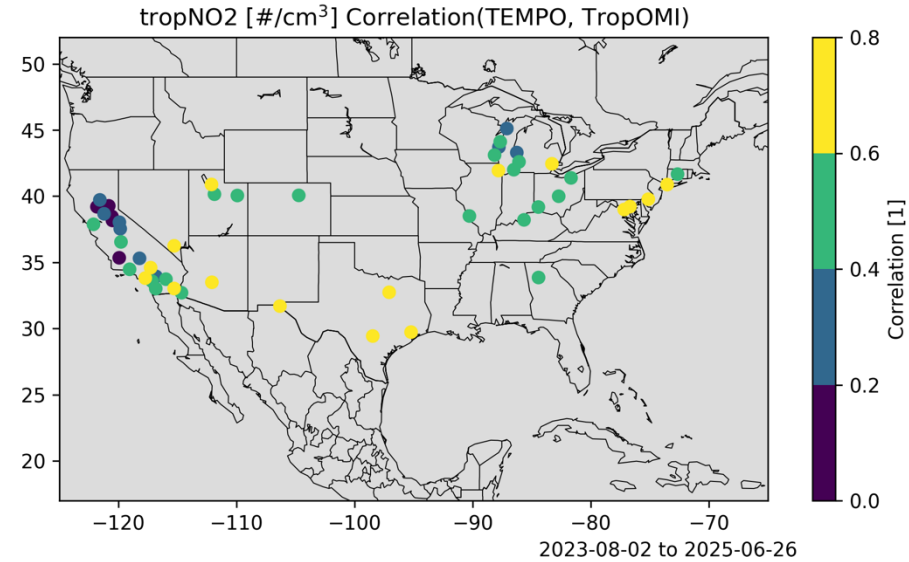
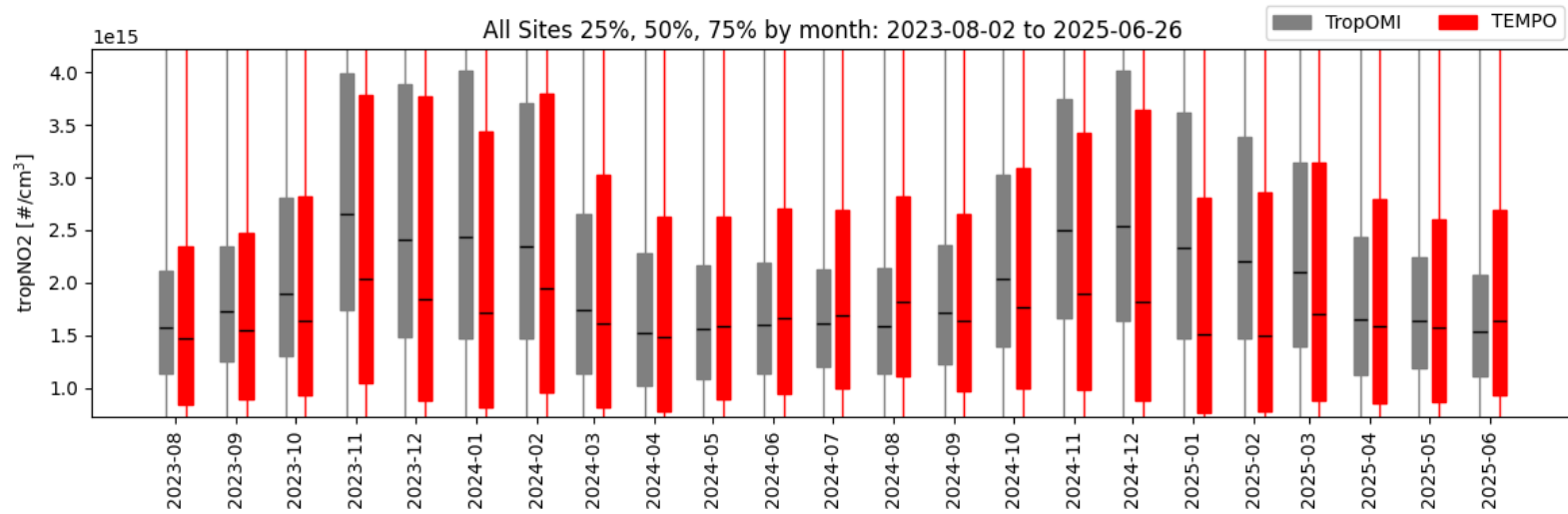


- TEMPO and TROPOMI HCHO VCDs show an overall good comparison.
- On average, TROPOMI HCHO VCDs are larger than TEMPO.
- During the summer, TEMPO has shown to observe larger VCDs at higher ranges, likely explaining the larger VCDs across the Los Angeles basin for this summer case.

TEMPO vs. TROPOMI NO₂ Comparison

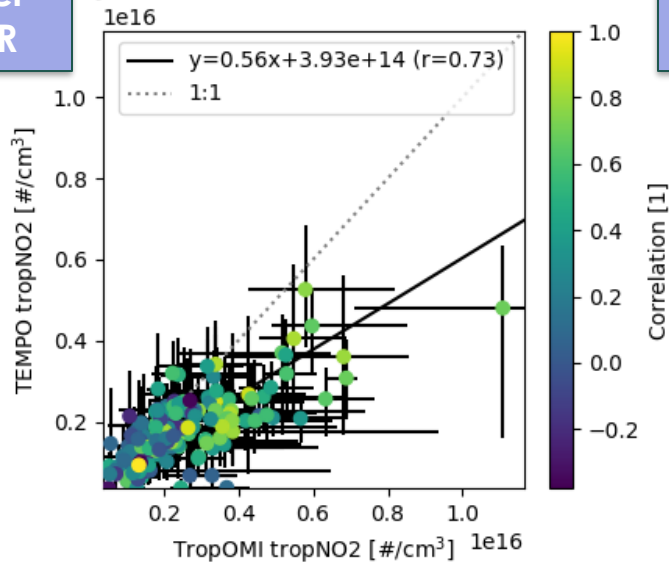
TEMPO Filter using
Cloud Fraction > 15%
SZA > 70°

TROPOMI Filter using
QA < 0.75



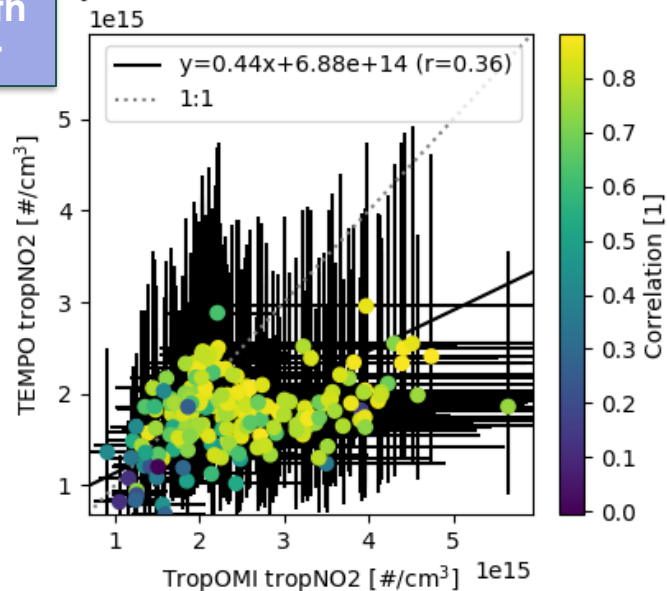
Boulder-
NCAR

By Week: 2023-08-02 to 2025-06-26

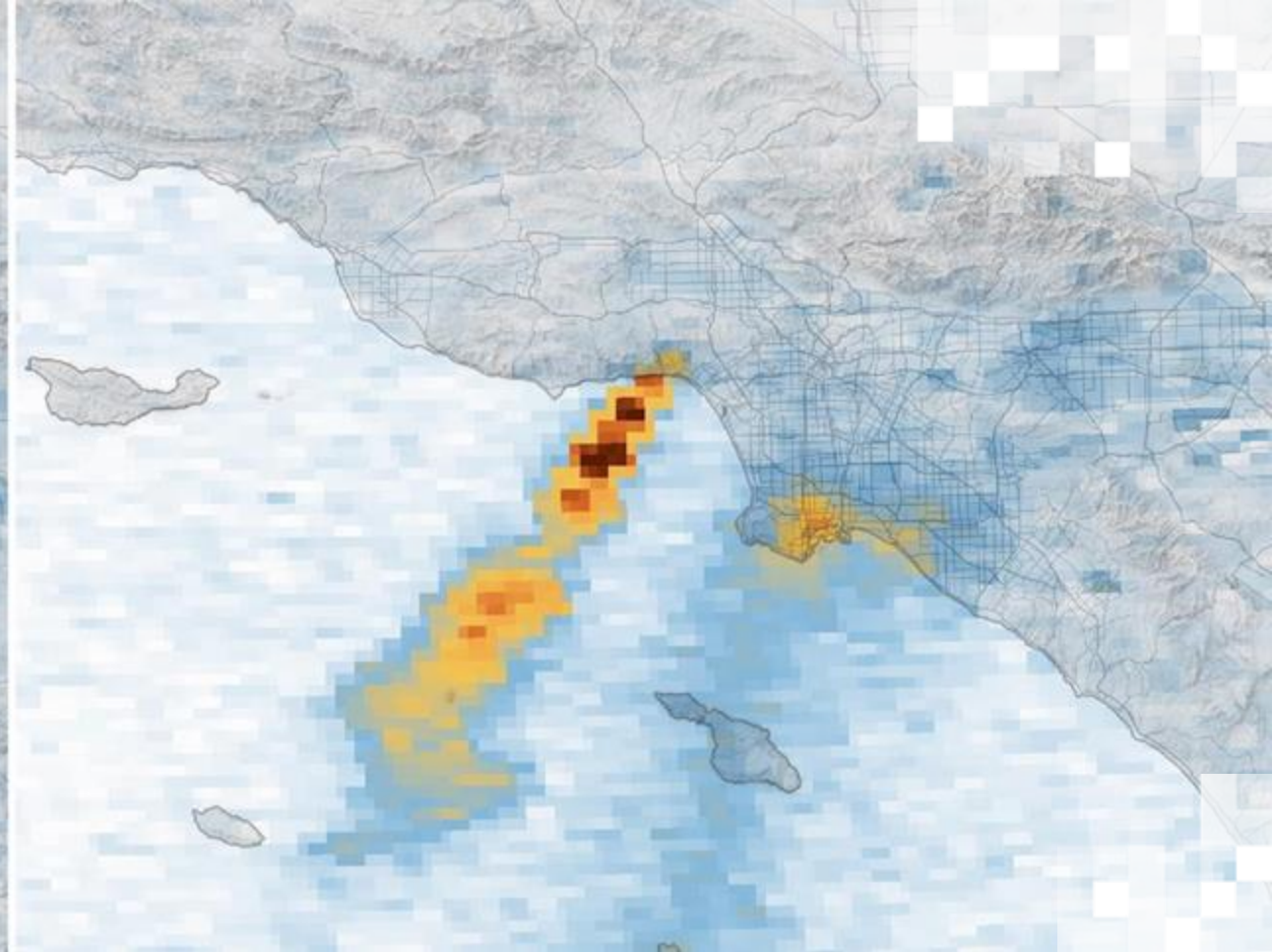
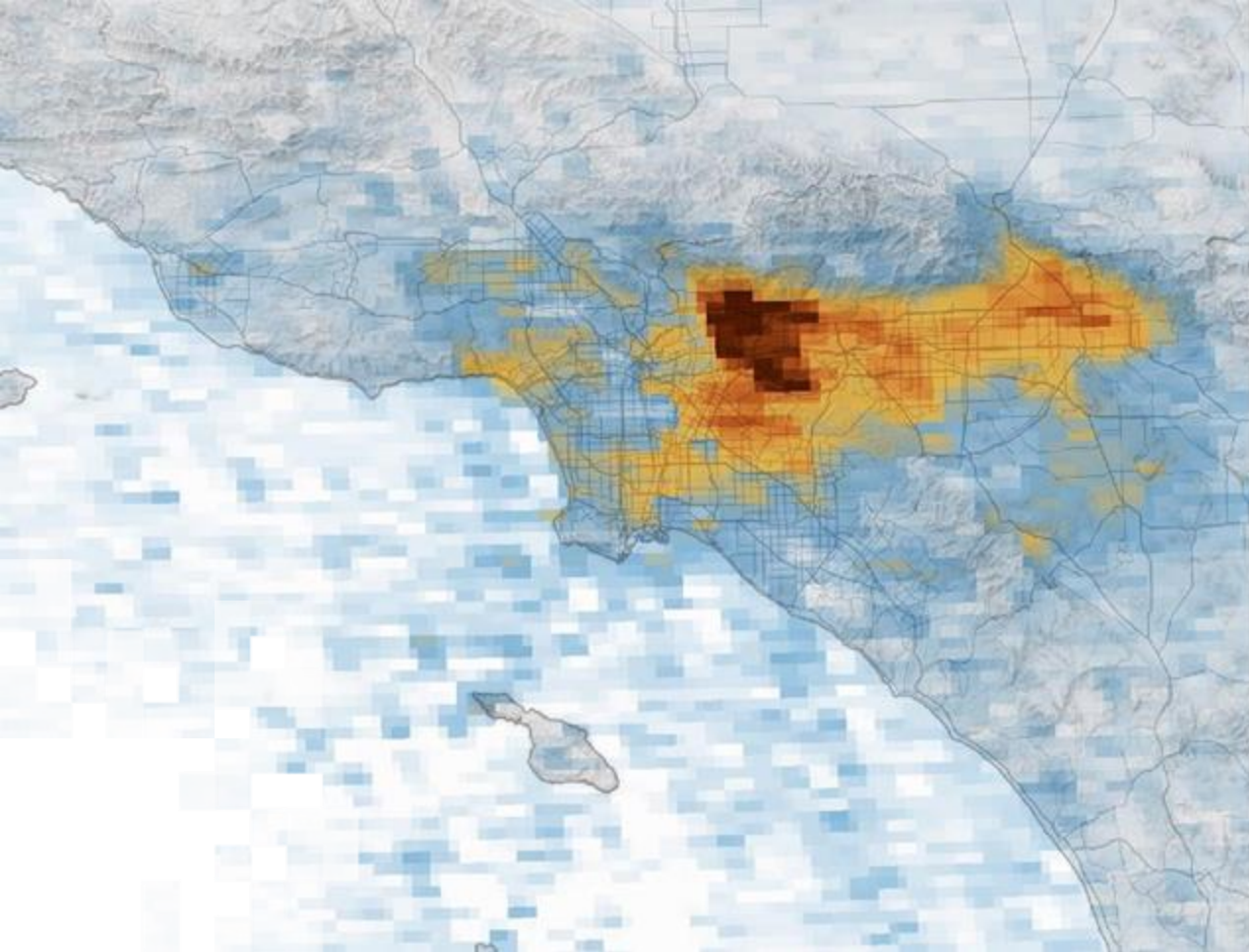


LA South
Coast

By Week: 2023-08-02 to 2025-06-26



- TEMPO is higher than TROPOMI at Pandora sites with NMB (normalized mean bias) of 19%.
- However, TEMPO is lower than TROPOMI in Nonattainment Areas (NAA) with NMB of -11%.
- TROPOMI may have high bias in low NO₂ conditions.
- Better correlations between TEMPO and TROPOMI in Boulder compared to Los Angeles.



TEMPO Data File Structure

Level 3 Data Files

Number of TEMPO scans (e.g., ScanID) throughout the daylight hours varies depending on time of year, with ~16 total scans during June and ~13 total scans during December.

The number of TEMPO scans will be higher on days when TEMPO special operations occur.

- 30 total scans on June 19, 2025, when special operations targeted at lightning NO_x were implemented.

TEMPO Level 2 NO₂ Files

- Level 2 files contain metadata along with 4 different groups with unique variables.
- Groups Include:
 - geolocation
 - product
 - qa_statistics
 - support_data
- A couple data variables are not contained within the groups:
 - mirror_step, xtrack
- File Sizes: ~100 MB

Name	Long Name	Type
TEMPO_NO2_L2_V03_20240726T181807Z_S010G05.nc	TEMPO Level 2 nitrogen dioxide product	Local File
geolocation	geolocation	—
latitude	pixel center latitude	Geo2D
latitude_bounds	pixel corner latitude	Geo2D
longitude	pixel center longitude	Geo2D
longitude_bounds	pixel corner longitude	Geo2D
relative_azimuth_angle	relative azimuth angle at pixel center	Geo2D
solar_azimuth_angle	solar azimuth angle at pixel center	Geo2D
solar_zenith_angle	solar zenith angle at pixel center	Geo2D
time	radiance exposure start time	1D
viewing_azimuth_angle	viewing azimuth angle at pixel center	Geo2D
viewing_zenith_angle	viewing zenith angle at pixel center	Geo2D
mirror_step	scan mirror position index	1D
product	product	—
main_data_quality_flag	main data quality flag	Geo2D
vertical_column_stratosphere	stratosphere nitrogen dioxide vertical column	Geo2D
vertical_column_troposphere	troposphere nitrogen dioxide vertical column	Geo2D
vertical_column_troposphere_uncertainty	troposphere nitrogen dioxide vertical column uncertainty	Geo2D
qa_statistics	qa_statistics	—
fit_convergence_flag	radiance fit convergence flag	Geo2D
fit_rms_residual	radiance fit RMS residual	Geo2D
support_data	support_data	—
albedo	surface albedo	Geo2D
amf_cloud_fraction	cloud fraction	Geo2D
amf_cloud_pressure	cloud pressure	Geo2D
amf_diagnostic_flag	nitrogen dioxide air mass factor diagnostic flag	Geo2D
amf_stratosphere	nitrogen dioxide stratospheric air mass factor	Geo2D
amf_total	nitrogen dioxide air mass factor	Geo2D
amf_troposphere	nitrogen dioxide tropospheric air mass factor	Geo2D
eff_cloud_fraction	effective cloud fraction	Geo2D
fitted_slant_column	nitrogen dioxide fitted slant column	Geo2D
fitted_slant_column_uncertainty	nitrogen dioxide fitted slant column uncertainty	Geo2D
gas_profile	vertical profile of nitrogen dioxide partial column	Geo2D
ground_pixel_quality_flag	ground pixel quality flag	Geo2D
scattering_weights	scattering weights	Geo2D
snow_ice_fraction	fraction of pixel area covered by snow and/or ice	Geo2D
surface_pressure	surface pressure	Geo2D
temperature_profile	air temperature	Geo2D
terrain_height	terrain height	Geo2D
tropopause_pressure	tropopause pressure	Geo2D
vertical_column_total	nitrogen dioxide vertical column	Geo2D
vertical_column_total_uncertainty	nitrogen dioxide vertical column uncertainty	Geo2D
xtrack	pixel index along slit	1D

TEMPO Level 2 HCHO Files

- Level 2 files contain metadata along with 4 different groups with unique variables.
- Groups Include:
 - geolocation
 - product
 - qa_statistics
 - support_data
- A couple data variables are not contained within the groups:
 - mirror_step, xtrack
- File Sizes: ~100 MB

Name	Long Name	Type
▼ TEMPO_HCHO_L2_V03_20240726T181807Z_S010G05.nc	TEMPO Level 2 formaldehyde product	Local File
▼ geolocation	geolocation	—
latitude	pixel center latitude	Geo2D
latitude_bounds	pixel corner latitude	Geo2D
longitude	pixel center longitude	Geo2D
longitude_bounds	pixel corner longitude	Geo2D
relative_azimuth_angle	relative azimuth angle at pixel center	Geo2D
solar_azimuth_angle	solar azimuth angle at pixel center	Geo2D
solar_zenith_angle	solar zenith angle at pixel center	Geo2D
time	radiance exposure start time	1D
viewing_azimuth_angle	viewing azimuth angle at pixel center	Geo2D
viewing_zenith_angle	viewing zenith angle at pixel center	Geo2D
mirror_step	scan mirror position index	1D
▼ product	product	—
main_data_quality_flag	main data quality flag	Geo2D
vertical_column	formaldehyde vertical column	Geo2D
vertical_column_uncertainty	formaldehyde vertical column uncertainty	Geo2D
▼ qa_statistics	qa_statistics	—
fit_convergence_flag	radiance fit convergence flag	Geo2D
fit_rms_residual	radiance fit RMS residual	Geo2D
▼ support_data	support_data	—
albedo	surface albedo	Geo2D
amf	formaldehyde air mass factor	Geo2D
amf_cloud_fraction	cloud fraction	Geo2D
amf_cloud_pressure	cloud pressure	Geo2D
amf_diagnostic_flag	formaldehyde air mass factor diagnostic flag	Geo2D
background_correction	background correction	Geo2D
eff_cloud_fraction	effective cloud fraction	Geo2D
fitted_slant_column	formaldehyde fitted slant column	Geo2D
fitted_slant_column_uncertainty	formaldehyde fitted slant column uncertainty	Geo2D
gas_profile	vertical profile of formaldehyde partial column	Geo2D
ground_pixel_quality_flag	ground pixel quality flag	Geo2D
scattering_weights	scattering weights	Geo2D
snow_ice_fraction	fraction of pixel area covered by snow and/or ice	Geo2D
surface_pressure	surface pressure	Geo2D
temperature_profile	air temperature	Geo2D
terrain_height	terrain height	Geo2D
xtrack	pixel index along slit	1D



TEMPO Level 2 O₃ Files

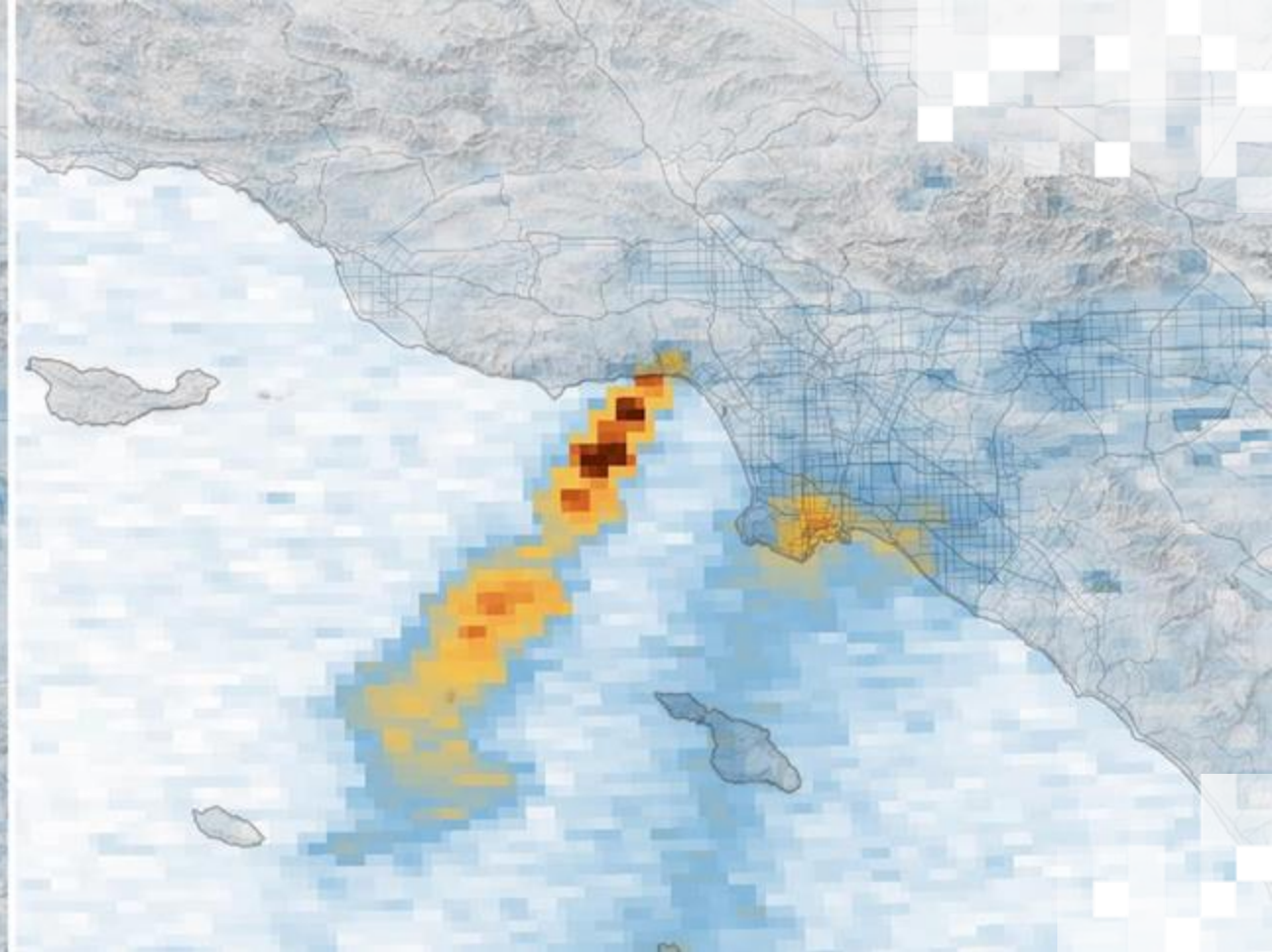
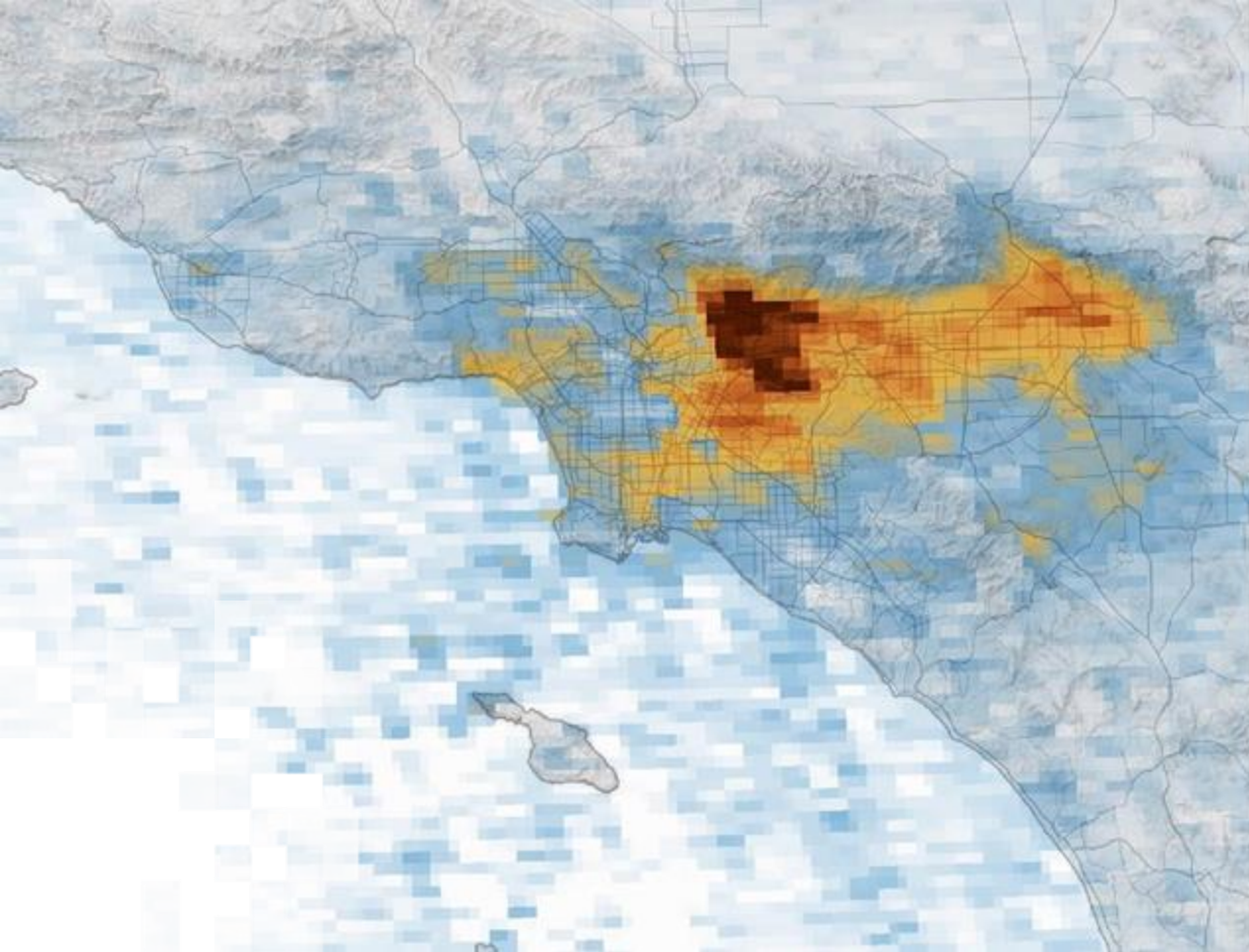
- Level 2 files contain metadata along with 4 different groups with unique variables.
- Groups Include:
 - geolocation
 - product
 - qa_statistics (**no variables for O₃ files**)
 - support_data
- A couple data variables are not contained within the groups:
 - mirror_step, xtrack
- File Sizes: ~100 MB

Name	Long Name	Type
TEMPO_03TOT_L2_V03_20240726T181807Z_S010G05.nc	TEMPO Level 2 total ozone product	Local File
geolocation	geolocation	—
latitude	latitude	Geo2D
latitude_bounds	latitude bounds	Geo2D
longitude	longitude	Geo2D
longitude_bounds	longitude bounds	Geo2D
relative_azimuth_angle	relative azimuth angle	Geo2D
solar_azimuth_angle	solar azimuth angle	Geo2D
solar_zenith_angle	solar zenith angle	Geo2D
time	time	1D
viewing_azimuth_angle	viewing azimuth angle	Geo2D
viewing_zenith_angle	viewing zenith angle	Geo2D
mirror_step	scan mirror position index	1D
product	product	—
column_amount_o3	column amount o3	Geo2D
fc	fc	Geo2D
o3_below_cloud	o3 below cloud	Geo2D
quality_flag	quality flag	Geo2D
radiative_cloud_frac	radiative cloud frac	Geo2D
so2_index	so2 index	Geo2D
uv_aerosol_index	uv aerosol index	Geo2D
qa_statistics	qa_statistics	—
support_data	support_data	—
a_priori_layer_o3	a priori layer o3	Geo2D
algorithm_flags	algorithm flags	Geo2D
cal_adjustment	cal adjustment	2D
cloud_pressure	cloud pressure	Geo2D
dNdR	dNdR	Geo2D
ground_pixel_quality_flag	ground pixel quality flag	Geo2D
layer_efficiency	layer efficiency	Geo2D
lut_wavelength	lut wavelength	1D
N_value	N value	Geo2D
N_value_residual	N value residual	Geo2D
ozone_sensitivity_ratio	ozone sensitivity ratio	Geo2D
radiance_bpix_flag_accepted	radiance bpix flag accepted	Geo2D
step1_o3	step1 o3	Geo2D
step2_o3	step2 o3	Geo2D
step1_N_value_residual	step 1 N value residual	Geo2D
step2_N_value_residual	step 2 N value residual	Geo2D
surface_reflectivity_at_331nm	surface reflectivity at 331nm	Geo2D
surface_reflectivity_at_360nm	surface reflectivity at 360nm	Geo2D
temp_sensitivity_ratio	temp sensitivity ratio	Geo2D
terrain_height	terrain height	Geo2D
terrain_pressure	terrain pressure	Geo2D
xtrack	pixel index along slit	1D

TEMPO Level 3 NO₂ Files

- Level 3 files contain metadata along with 4 different groups with unique variables.
- Groups Include:
 - geolocation
 - product
 - qa_statistics
 - support_data
- Several data variables are not contained within the groups:
 - latitude, longitude, time, weight
- File Sizes: ~800 MB

Name	Long Name	Type
▼ TEMPO_NO2_L3_V03_20240726T175132Z_S010.nc	TEMPO Level 3 nitrogen dioxide product	Local File
▼ geolocation	geolocation	—
relative_azimuth_angle	relative azimuth angle at pixel center	Geo2D
solar_zenith_angle	solar zenith angle at pixel center	Geo2D
viewing_zenith_angle	viewing zenith angle at pixel center	Geo2D
latitude	latitude	1D
longitude	longitude	1D
▼ product	product	—
main_data_quality_flag	main data quality flag	Geo2D
vertical_column_stratosphere	stratosphere nitrogen dioxide vertical column	Geo2D
vertical_column_troposphere	troposphere nitrogen dioxide vertical column	Geo2D
vertical_column_troposphere_uncertainty	troposphere nitrogen dioxide vertical column uncertainty	Geo2D
▼ qa_statistics	qa_statistics	—
max_vertical_column_stratosphere_sample	stratosphere nitrogen dioxide vertical column	Geo2D
max_vertical_column_total_sample	nitrogen dioxide vertical column	Geo2D
max_vertical_column_troposphere_sample	troposphere nitrogen dioxide vertical column	Geo2D
max_vertical_column_troposphere_uncertainty_sample	troposphere nitrogen dioxide vertical column uncertainty	Geo2D
min_vertical_column_stratosphere_sample	stratosphere nitrogen dioxide vertical column	Geo2D
min_vertical_column_total_sample	nitrogen dioxide vertical column	Geo2D
min_vertical_column_troposphere_sample	troposphere nitrogen dioxide vertical column	Geo2D
min_vertical_column_troposphere_uncertainty_sample	troposphere nitrogen dioxide vertical column uncertainty	Geo2D
num_vertical_column_stratosphere_samples	num vertical column stratosphere samples	Geo2D
num_vertical_column_total_samples	num vertical column total samples	Geo2D
num_vertical_column_troposphere_samples	num vertical column troposphere samples	Geo2D
num_vertical_column_troposphere_uncertainty_samples	num vertical column troposphere uncertainty samples	Geo2D
▼ support_data	support_data	—
albedo	surface albedo	Geo2D
amf_cloud_fraction	cloud fraction	Geo2D
amf_cloud_pressure	cloud pressure	Geo2D
amf_stratosphere	nitrogen dioxide stratospheric air mass factor	Geo2D
amf_total	nitrogen dioxide air mass factor	Geo2D
amf_troposphere	nitrogen dioxide tropospheric air mass factor	Geo2D
eff_cloud_fraction	effective cloud fraction	Geo2D
fitted_slant_column	nitrogen dioxide fitted slant column	Geo2D
fitted_slant_column_uncertainty	nitrogen dioxide fitted slant column uncertainty	Geo2D
snow_ice_fraction	fraction of pixel area covered by snow and/or ice	Geo2D
surface_pressure	surface pressure	Geo2D
terrain_height	terrain height	Geo2D
tropopause_pressure	tropopause pressure	Geo2D
vertical_column_total	nitrogen dioxide vertical column	Geo2D
vertical_column_total_uncertainty	nitrogen dioxide vertical column uncertainty	Geo2D
time	scan start time	—
weight	sum of area weights	Geo2D



TEMPO Level 2 vs. Level 3 Data

TEMPO Level 3 Product Methodology

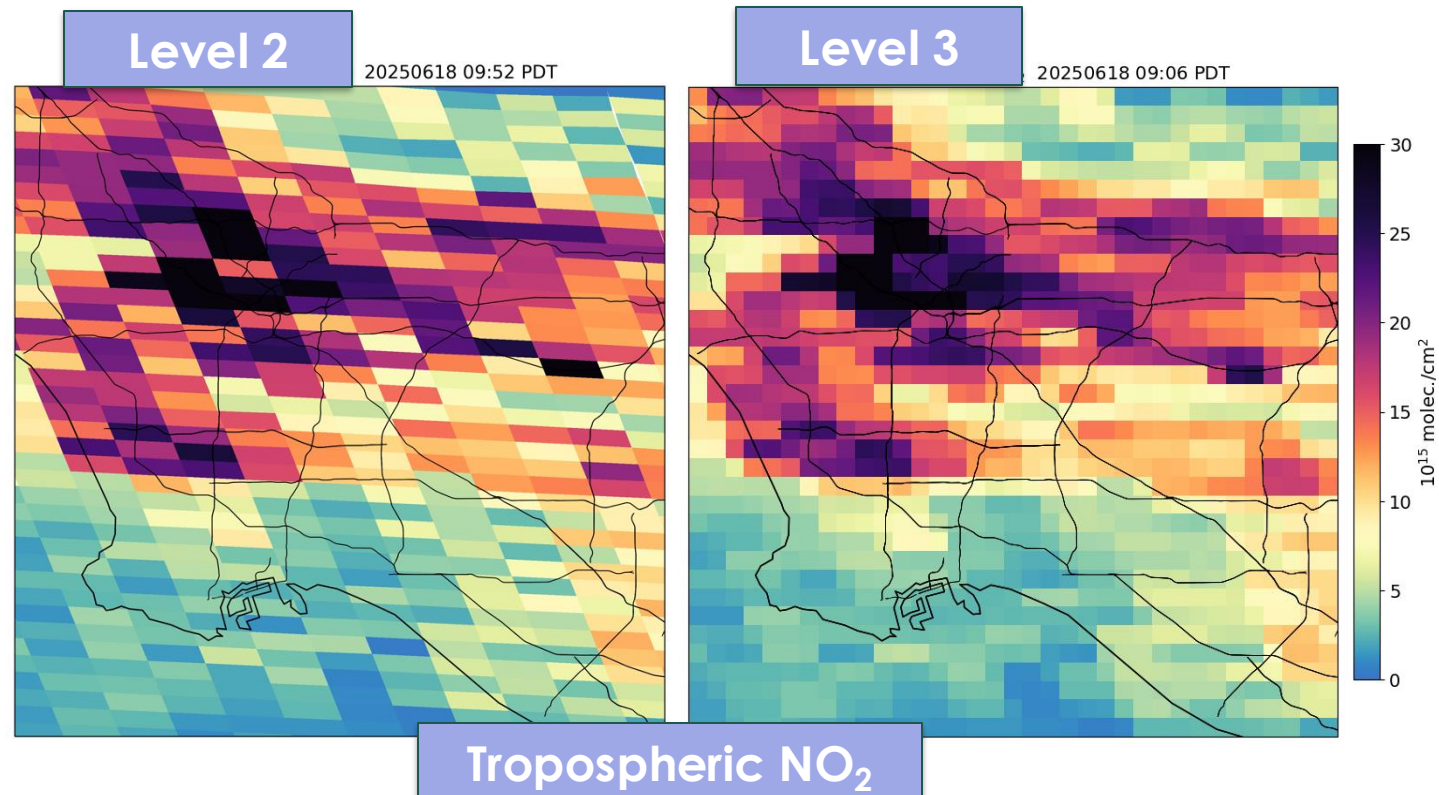
- Level 2 data are regridded using an area-weighted approach onto a regular 0.02° grid across the TEMPO FoR to produce the level 3 data product.
- The soon-to-be-released O₃ profile product employs the same method except the level 2 data are regridded onto a regular 0.04° grid.
- The method is purely geometric regridding where the contributions to a grid point are weighted by the geometric area of overlap of each level 2 pixel (footprint).

$$V(j) = \frac{\sum(a(j,i) * v(i))}{\sum a(j,i)}$$

a(j,i) = Polygonal area where Level 2 pixel, i, overlaps Level 3 grid point, j.

v(i) = Value of Level 2 pixel, i.

V(j) = Computed area-weighted mean value for Level 3 grid point, j.

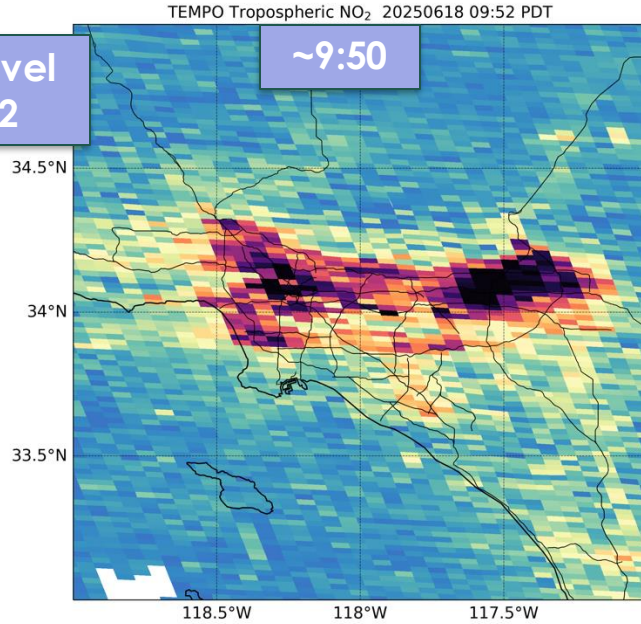


TEMPO Level 2 vs. Level 3 NO₂ Comparison

Filter using
Cloud Fraction > 50%
SZA > 80°

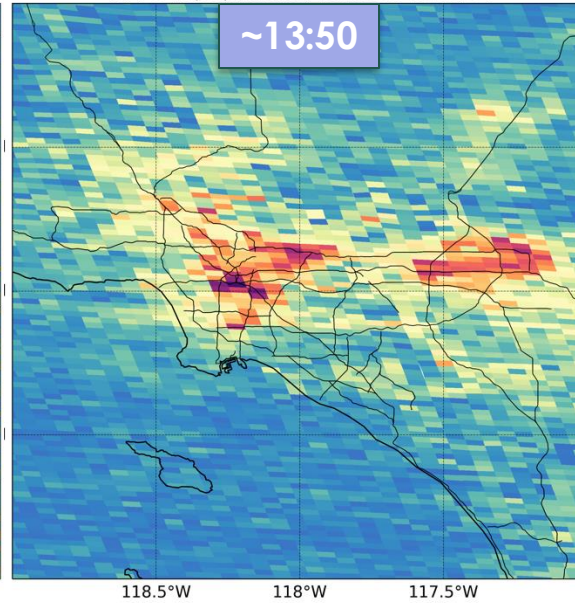


Level
2



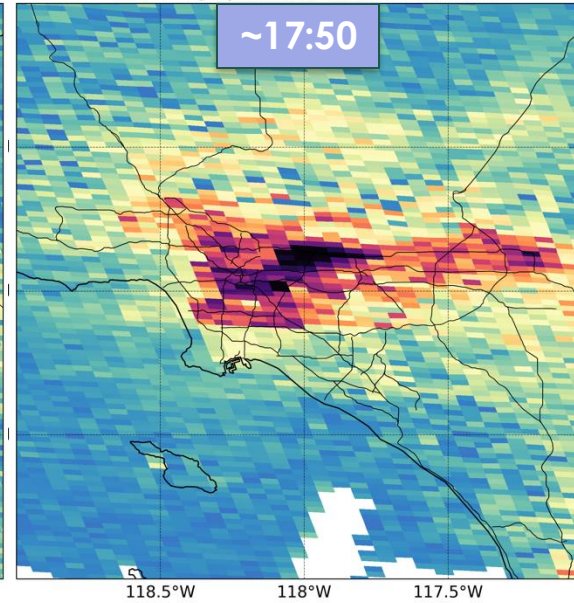
TEMPO Tropospheric NO₂ 20250618 13:52 PDT

~13:50

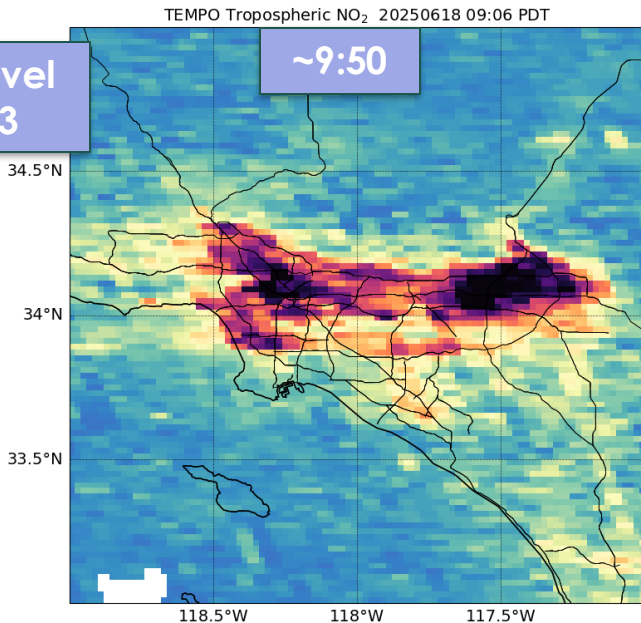


TEMPO Tropospheric NO₂ 20250619 17:53 PDT

~17:50

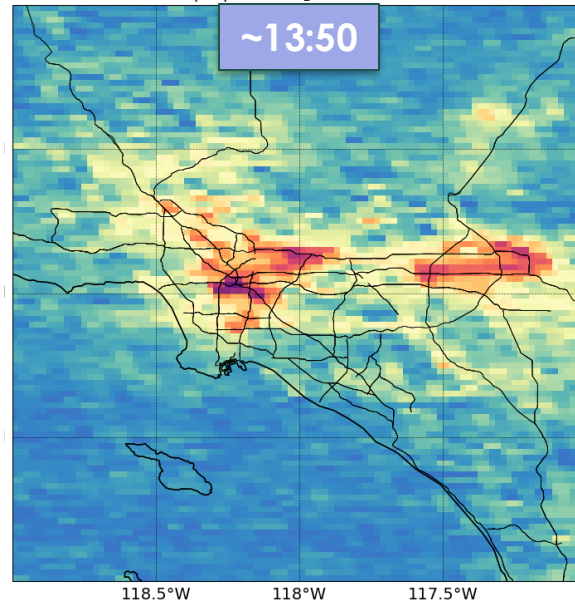


Level
3



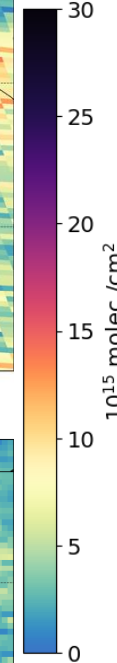
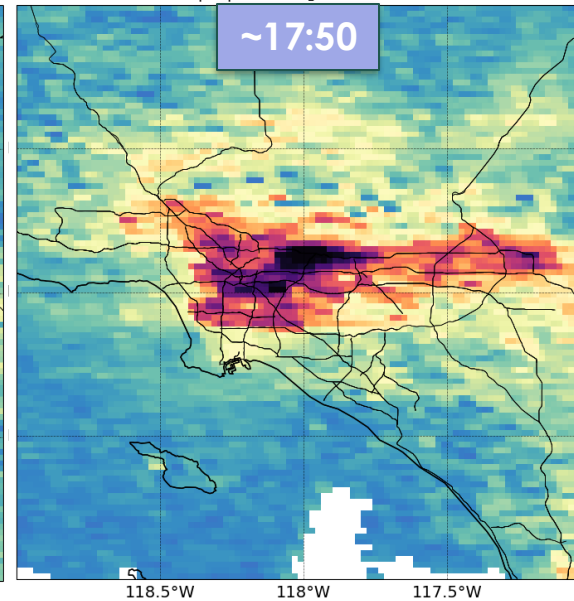
TEMPO Tropospheric NO₂ 20250618 13:06 PDT

~13:50



TEMPO Tropospheric NO₂ 20250619 17:26 PDT

~17:50

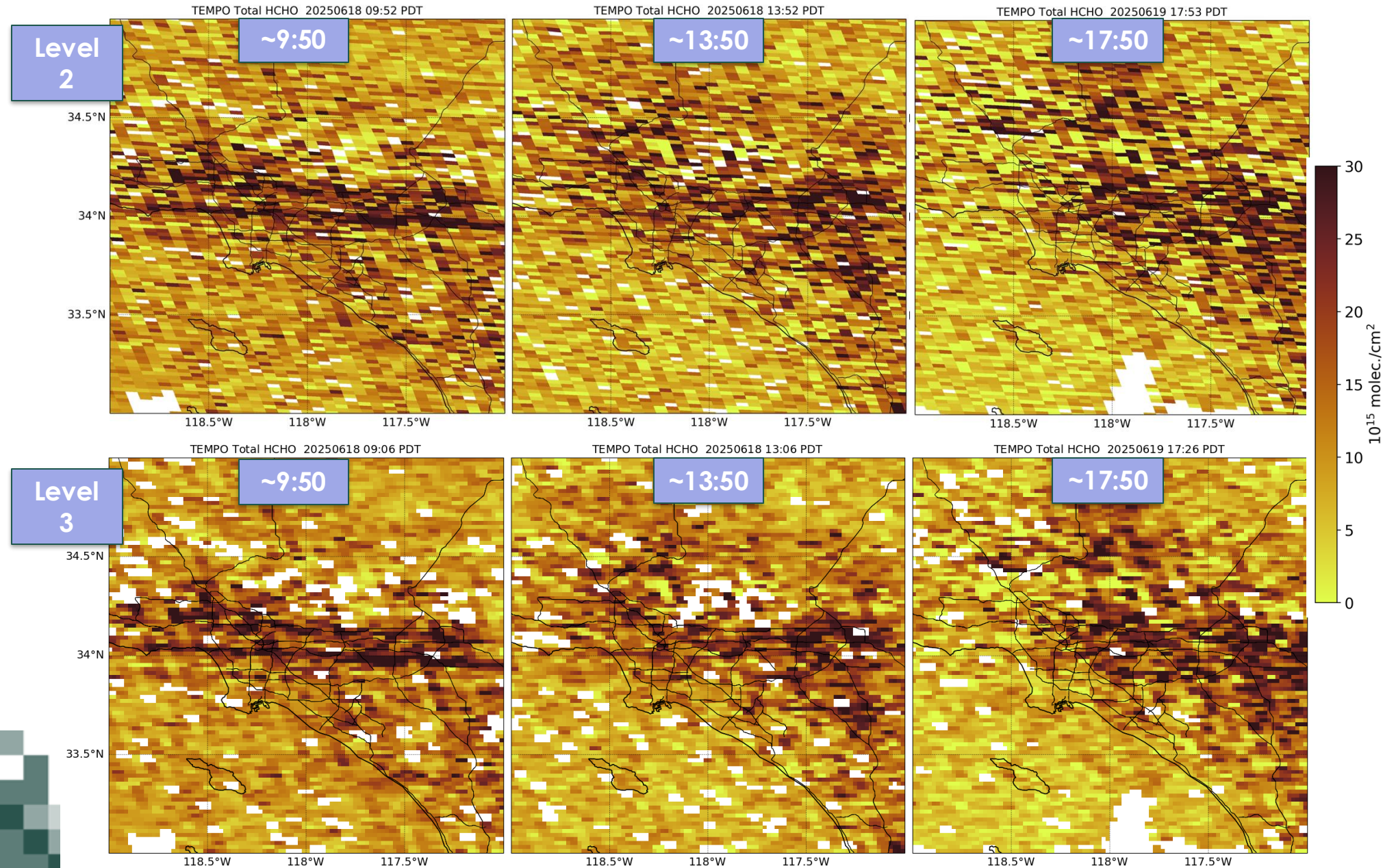


- Level 3 NO₂ maps have a smoother appearance compared to the level 2 NO₂ maps.
- Areas of large NO₂ gradients and fine-scale hot spots can appear noticeably different between the level 2 and level 3 maps.



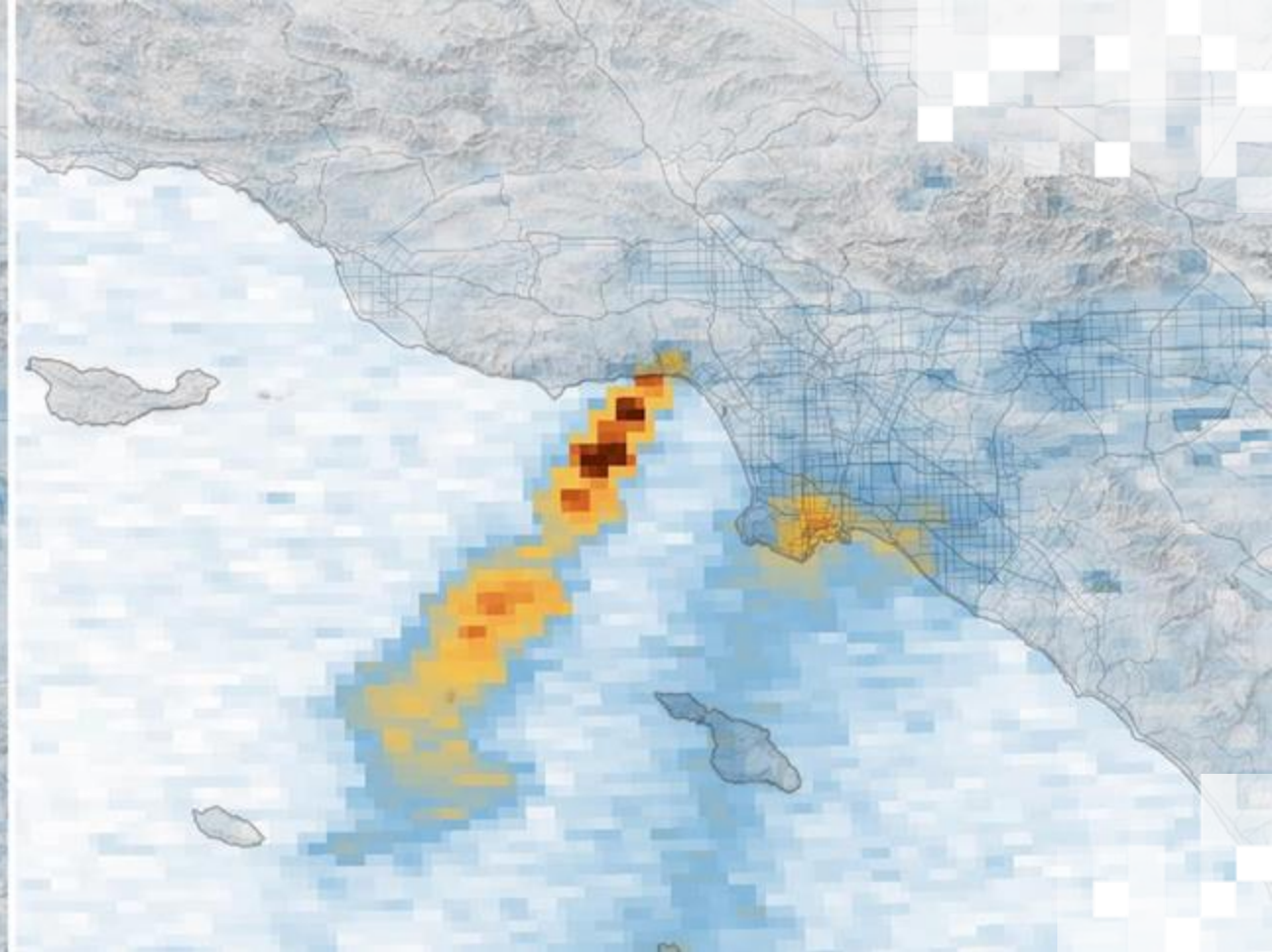
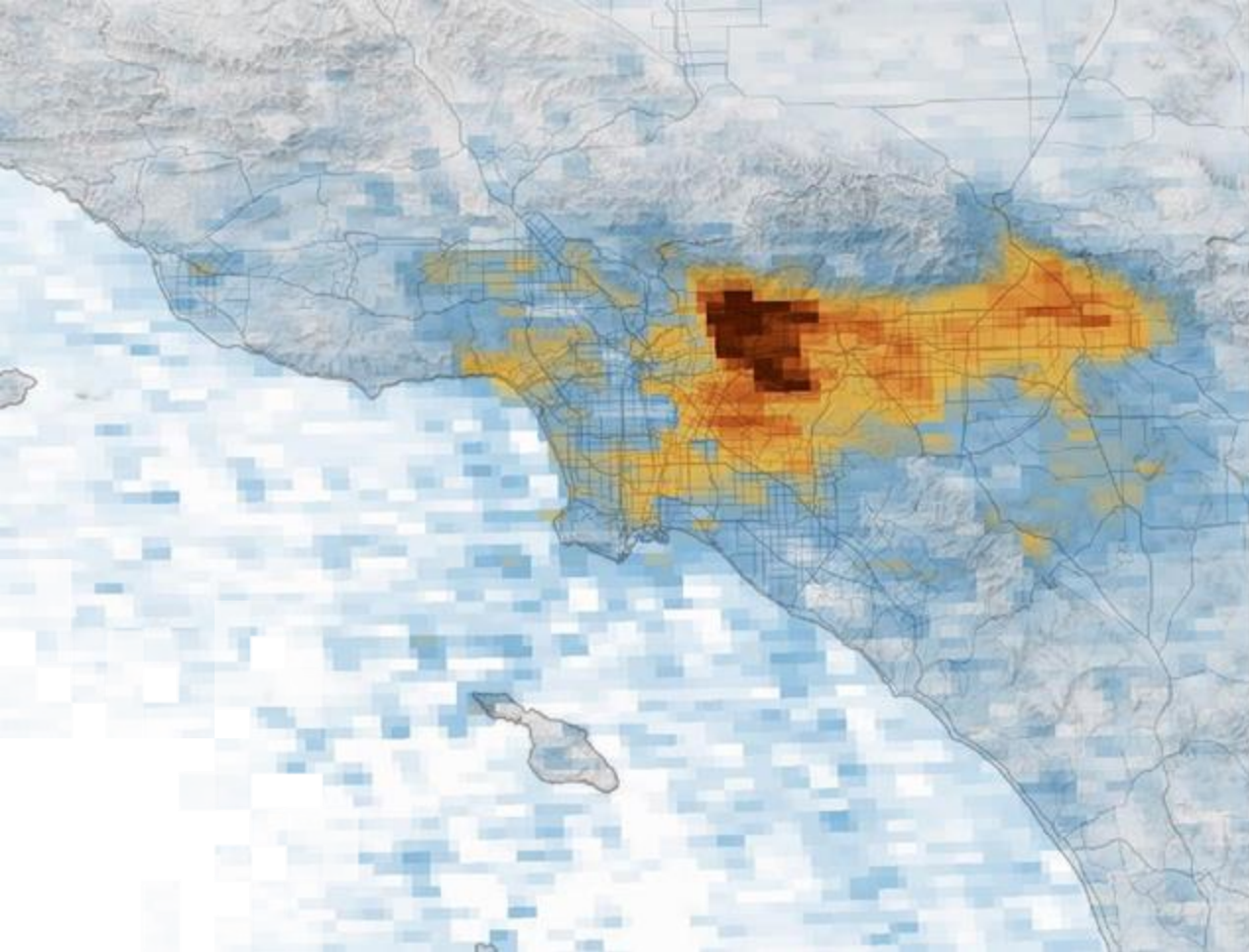
TEMPO Level 2 vs. Level 3 HCHO Comparison

Filter using
Cloud Fraction > 50%
SZA > 80°



- The level 3 HCHO maps are smoother, similar to the NO₂ comparison.
- HCHO retrieval is noisier than NO₂, leading to larger HCHO gradients and differences between the level 2 and level 3 data.





Upcoming TEMPO Trace Gas Products

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

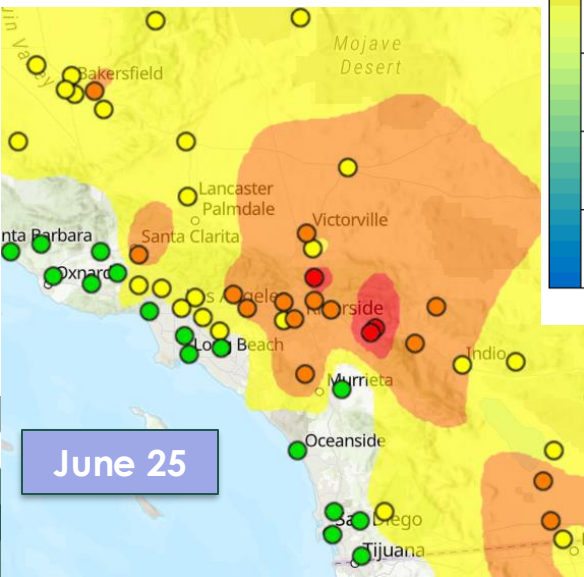
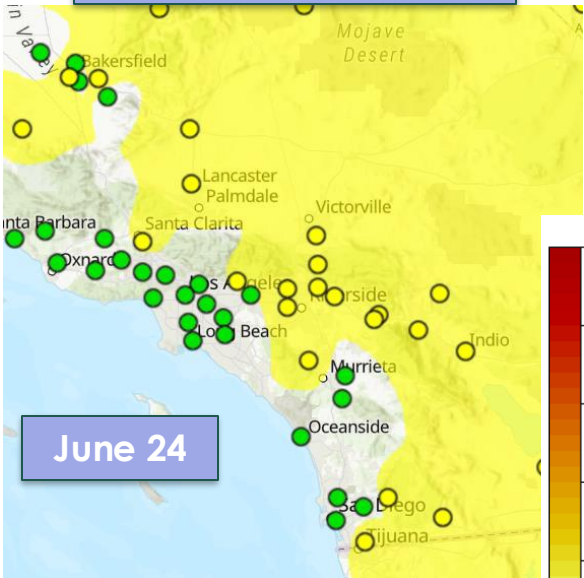


Southern California Zoom on June 24-25, 2025 – O₃ Profile

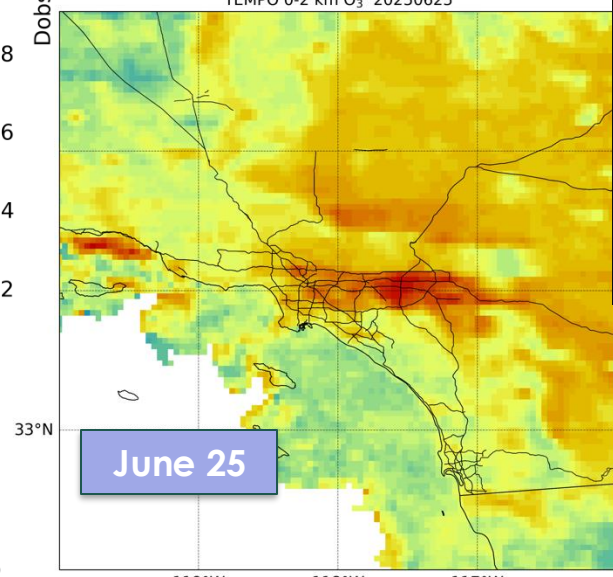
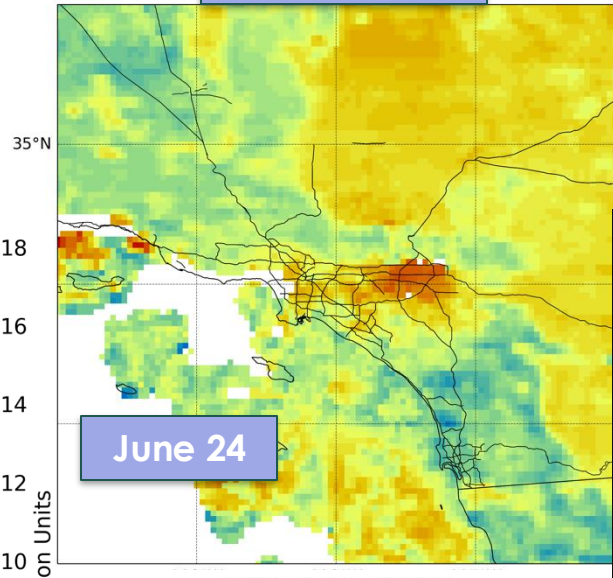
TEMPO Filter using
Cloud Fraction > 30%
SZA > 70°



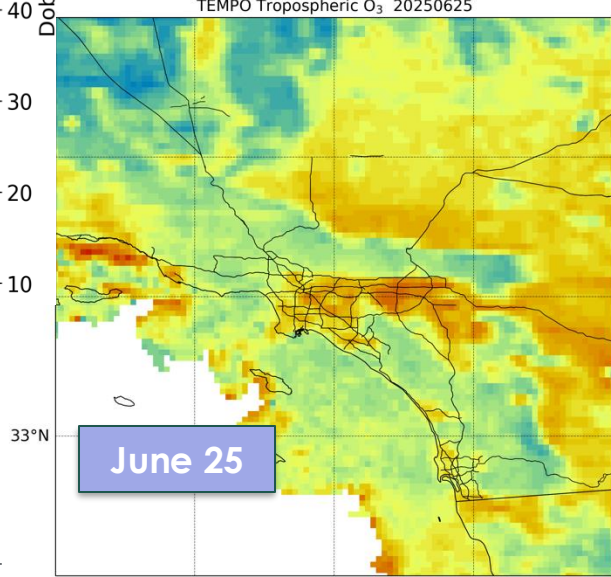
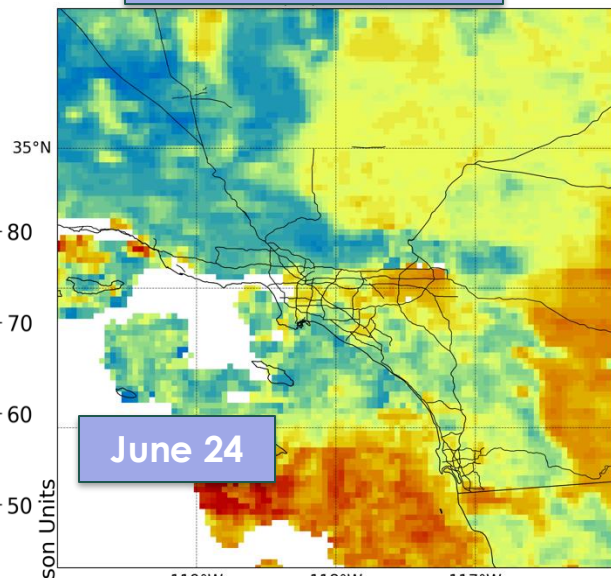
AirNow O₃ Monitors



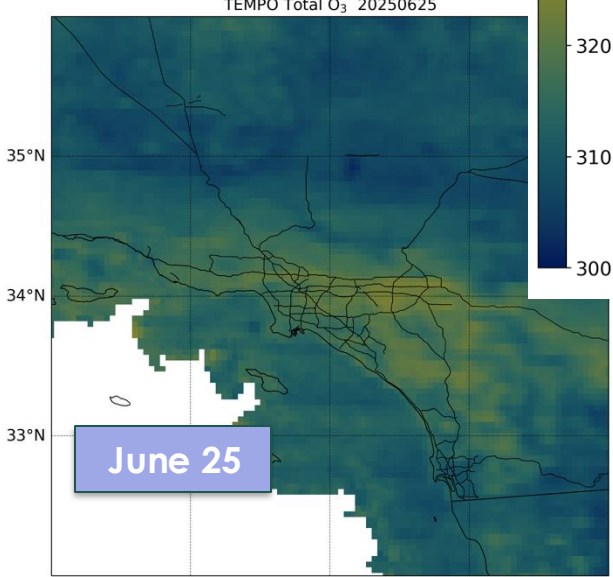
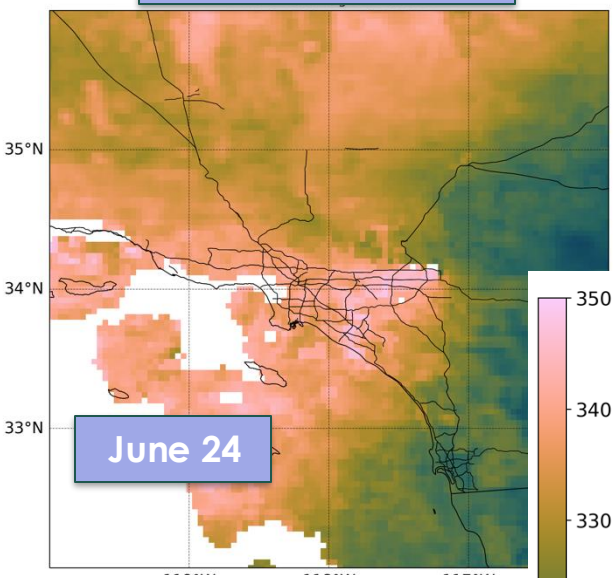
0-2 km O₃



Tropospheric O₃



Total Column O₃



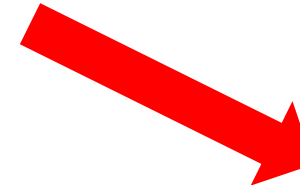
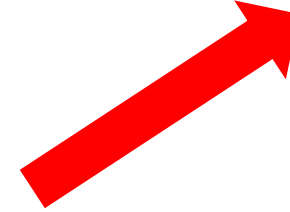
Summary of TEMPO Mission Capabilities & Strengths

- The TEMPO mission uses complex retrieval algorithms to provide data products for monitoring criteria air pollutants (NO_2 , O_3) in the tropospheric column.
- Users need to apply quality assurance variables for removing TEMPO data associated with larger errors or uncertainties from their analysis.
 - Quality assurance must be applied to both the level 2 and 3 products.
 - Using strict quality assurance tends to remove large NO_2 columns from wildland fire smoke.
- TEMPO's version 3 provisional NO_2 and HCHO products show overall good agreement to the Pandora validation network and TROPOMI data.
- The regridding method for TEMPO's level 3 products leads to a slightly smoother spatial appearance of the data compared to the level 2 products.
- TEMPO observes small-scale emission sources and fine-scale pollutant gradients that have not been adequately resolved by current satellite missions.
- Upcoming O_3 profile product offers enhanced capabilities to monitor and characterize ozone concentrations in the tropospheric layer.



Resources

- NASA Worldview for Visualizations of TEMPO and OMI
 - <https://worldview.earthdata.nasa.gov/>
- Google Earth Engine for Visualizations of TEMPO and TROPOMI
 - <https://developers.google.com/earth-engine/datasets/catalog/>
- Copernicus Data Space Ecosystem for Visualizations of TROPOMI
 - <https://dataspace.copernicus.eu/explore-data/data-collections/sentinel-data/sentinel-5p>
- TEMPO Validation Results
 - <https://gaftp.epa.gov/Air/aqmg/bhenders/share/TEMPO/>





Thank You!

