

weather.msfc.nasa.gov/tempo/



Tropospheric Emissions:
Monitoring of Pollution
Hourly Measurement of Pollution



Smithsonian Astrophysical
Observatory



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



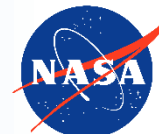
Characterizing Ozone Production Regimes with TEMPO Data

Aaron Naeger
& **TEMPO Team**

NASA Marshall Space Flight Center, Huntsville, AL



U.S. Government sponsorship acknowledged.



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UAH
THE UNIVERSITY OF
ALABAMA IN HUNTSVILLE



TEMPO Data Product Updates



TEMPO Products: SAO Baseline + SNWG NRT + NOAA Aerosol



Level	Product	Filename	Developer	Notable File Variables	Validation Status	Resolution (km ²) *
L1	Radiance	RAD	SAO + SNWG	Radiances	Provisional	2.0 x 4.75
	Radiance (twilight)	RADT	SAO	Radiances	Provisional	2.0 x 4.75
L2	Cloud	CLDO4	SAO/GSFC + SNWG	Cloud Fraction, Cloud Pressure	Provisional	2.0 x 4.75
	Ozone Total Column	O3TOT	SAO/GSFC	Total Column O ₃ , UV Aerosol Index	Provisional	2.0 x 4.75
	Nitrogen Dioxide	NO ₂	SAO + SNWG	Tropospheric VCD, Total VCD	Provisional	2.0 x 4.75
	Formaldehyde	HCHO	SAO + SNWG	Total VCD, Cloud Fraction	Provisional	2.0 x 4.75
	Ozone Profile	O3PROF	SAO	O ₃ Profile, Tropospheric O ₃ column	Beta	8.0 x 4.75
	AOD & ALH	AODALH	NOAA	AOD, ALH	N/A	2.0 x 4.75
	Aerosol Detection Product (ADP)	ADP	NOAA	Dust/Smoke Discrimination, UV Aerosol Index	N/A	2.0 x 4.75
L3	Same as L2	Same as L2	SAO/GSFC + SNWG	Same Variables as L2	Same as above	0.02°x 0.02° *
L4	Surface PM _{2.5}	PM25	NOAA	Hourly PM _{2.5} Estimation	N/A	2 km x 2 km

Latest product versions: Version 4 (standard) & Version 2 (NRT)

SNWG: Satellite Needs Working Group - near real-time products (~2-3 hours) – public release Sept. 17, 2025

NOAA: National Oceanic and Atmospheric Administration

SAO: Smithsonian Astrophysical Observatory

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

* O3PROF L3 Product → 0.04 x 0.04° Resolution



TEMPO Product Release & Tools



Public Release	Date	Details
V01	2/5/2024	Limited 3 weeks released
V02	2/26/2024	Level 1 (spectra) released
V03	5/20/2024	L1, L2/3 cloud, NO ₂ , H ₂ CO, total O ₃ (provisional) V3 O ₃ profile (ASDC 6/9/2025, not for the public)
V04	9/17/2025	Ozone Profile (beta), L1 + other L2/L3 (provisional) Reprocessing starting this week
NRT V02	9/17/2025	L1, L2/3 cloud, NO ₂ , H ₂ CO (funded by SNWG)

- TEMPO data publicly available at NASA's ASDC (~6 hours latency, NRT with 2-3 hours latency).



TEMPO website for data access, visualization tools, and user guides links



NASA SPoRT Viewer for O₃ Profile imagery

- Wealth of tools:
 - Earthdata Search
 - NASA Worldview
 - NASA ArcGIS services
 - RSIG (EPA)
 - TEMPO-Lite (SAO)
 - NASA SPoRT Viewer
 - Google Earth Engine



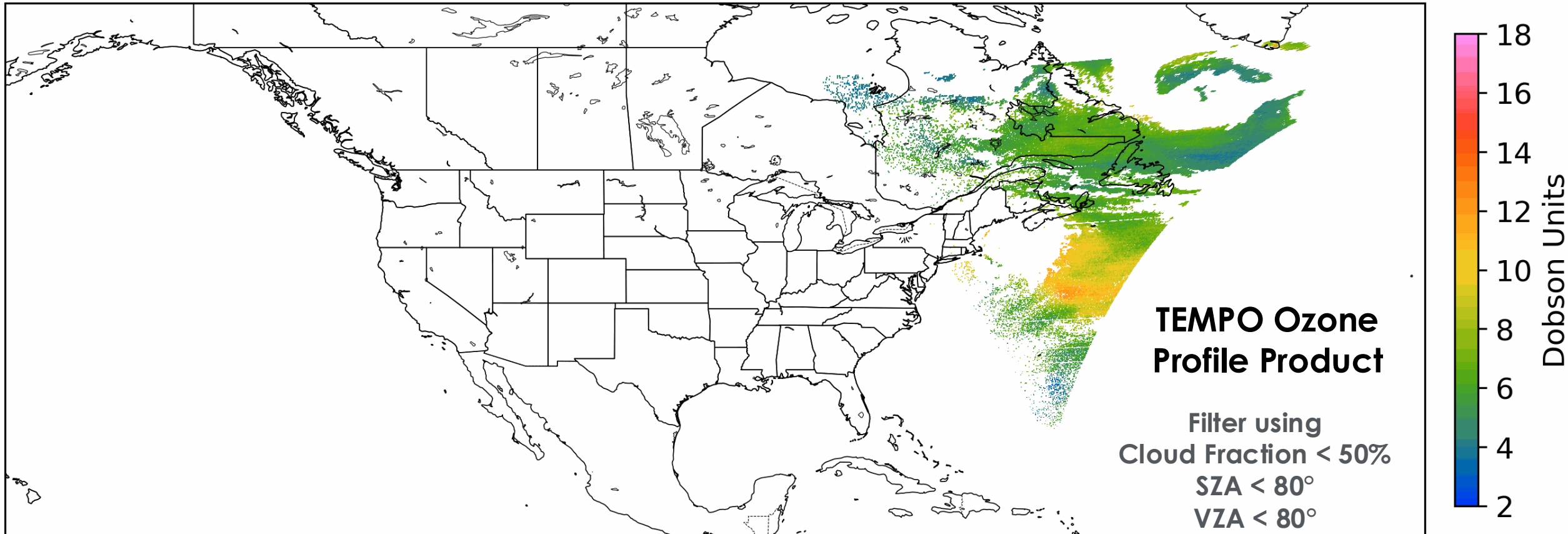
Worldview for visualizing TEMPO



July 2024 Ozone Exceedance

Nominal Operation Scans – July 23, 2024

TEMPO 0-2 km O₃ 20240723 1030 - 1057 UTC



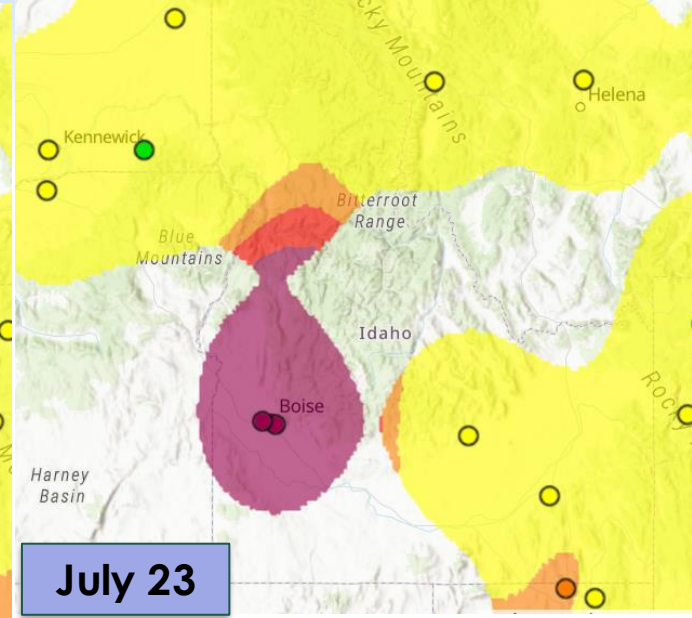
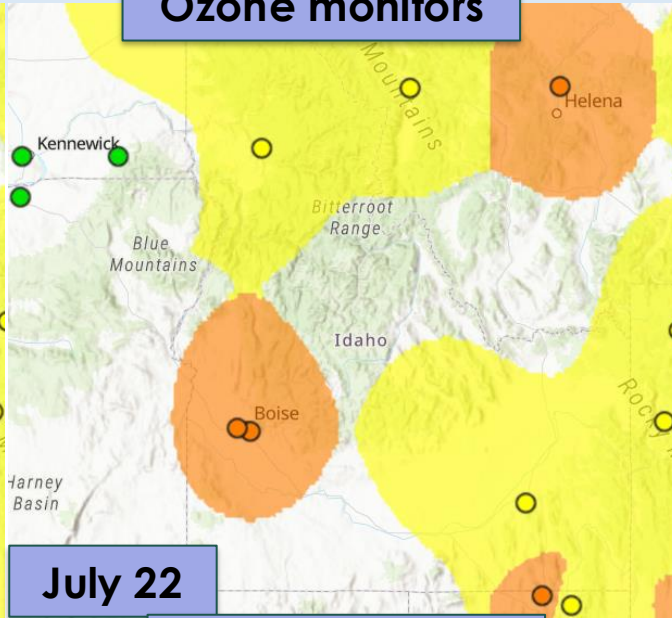
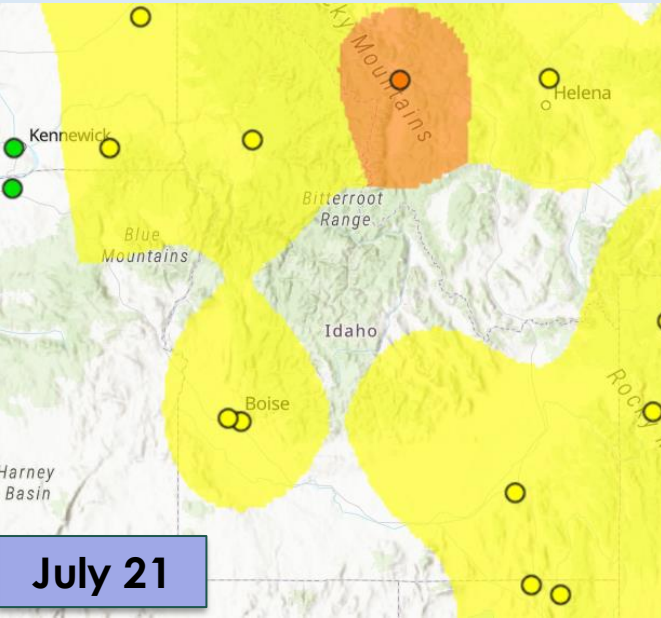
- **Nominal operations** consist of **standard (hourly) daytime scans** over full FoR and **optimized (~30-40 minute) scans** over daylight portions of the FoR during the morning and afternoon



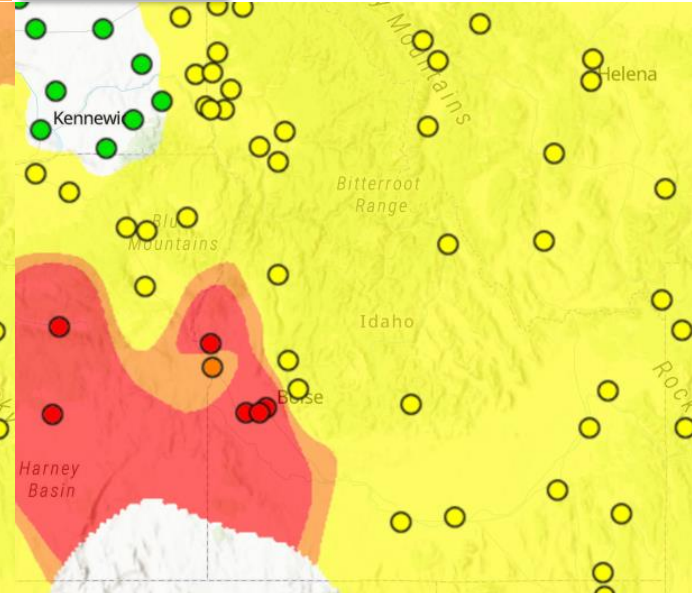
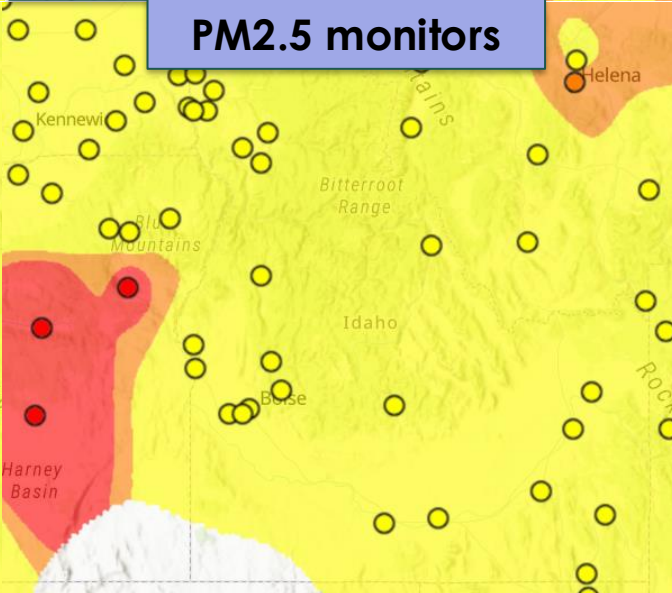
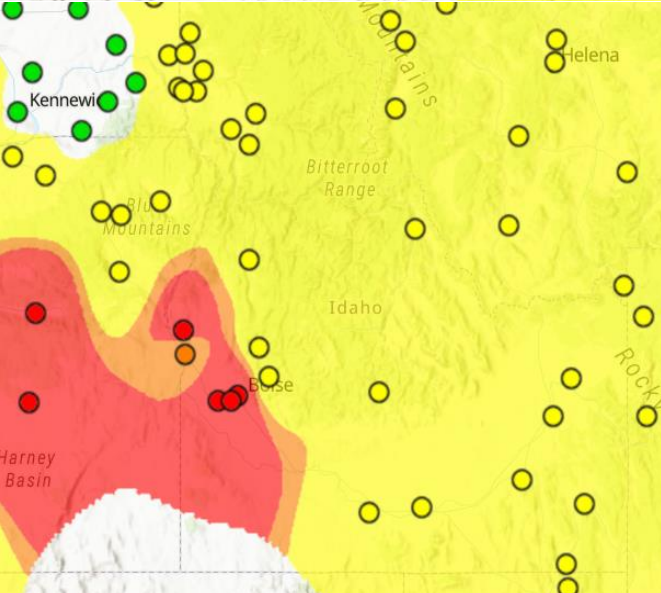
AirNow O₃ & PM_{2.5} monitors



Ozone monitors



PM_{2.5} monitors



- Surface monitors measured unhealthy O₃ and PM_{2.5} levels across Idaho and Oregon from July 21-23
- O₃ levels reached very unhealthy with daily O₃ concentrations near 120 ppb in Boise



MODIS True Color Imagery



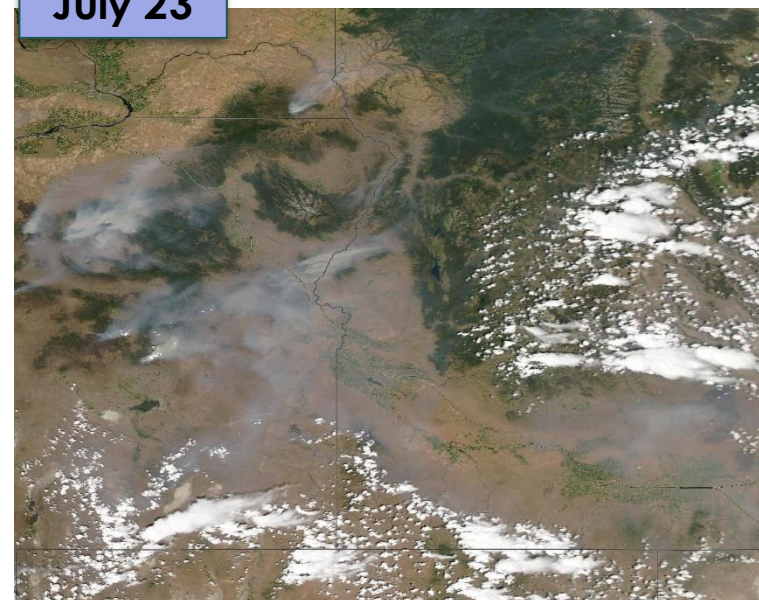
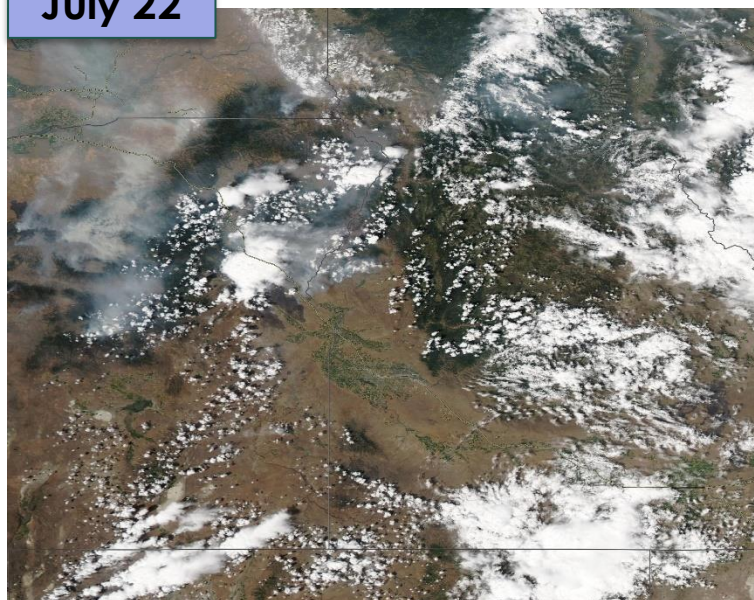
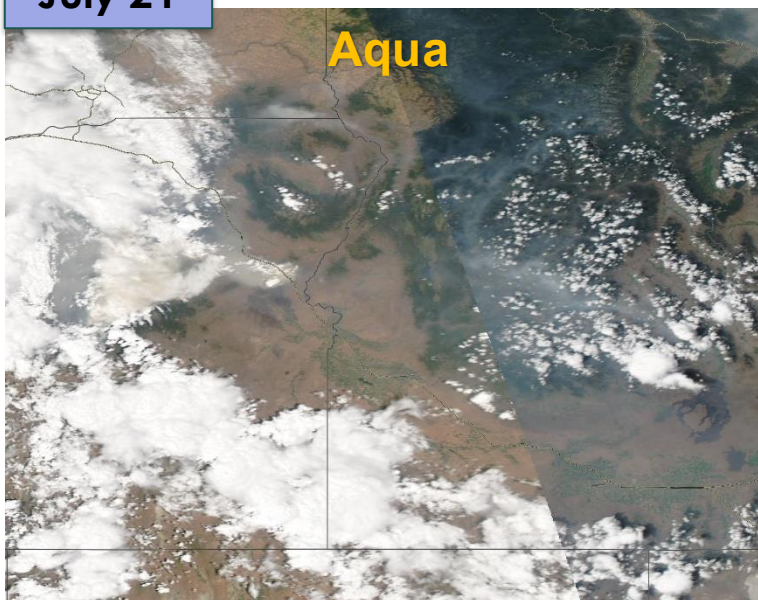
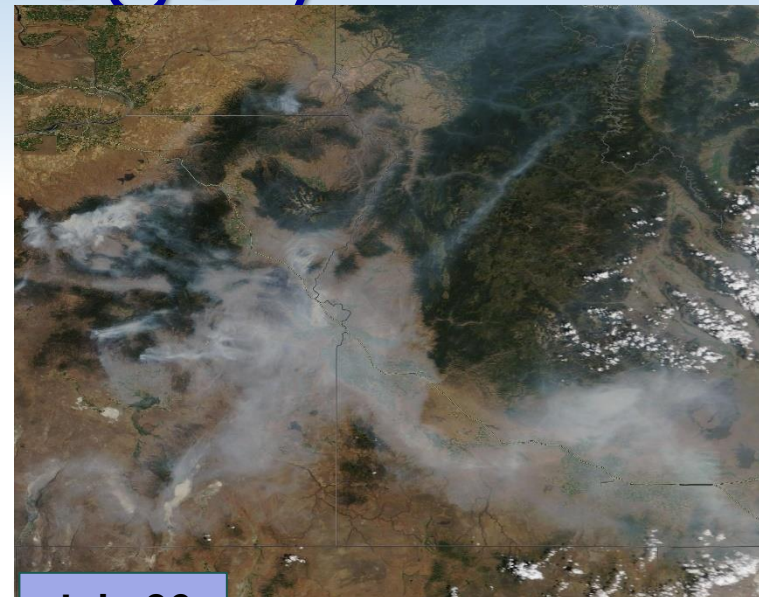
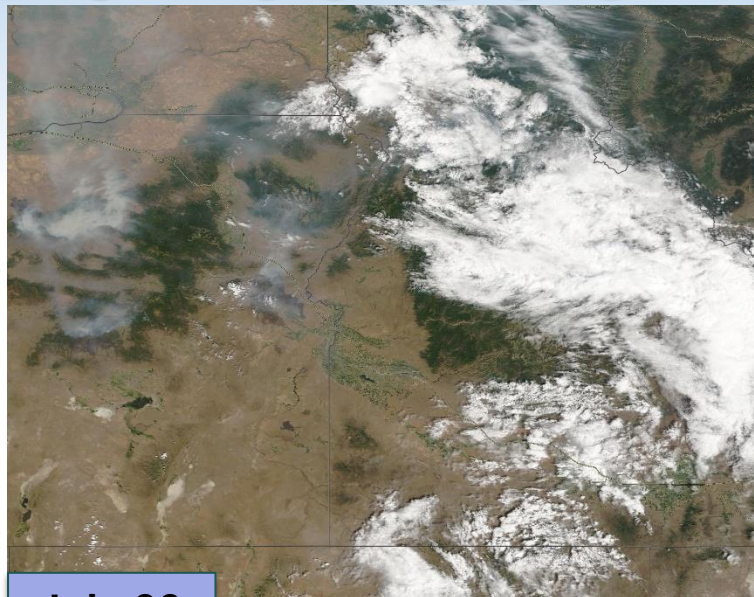
Terra

July 21

Aqua

July 22

July 23



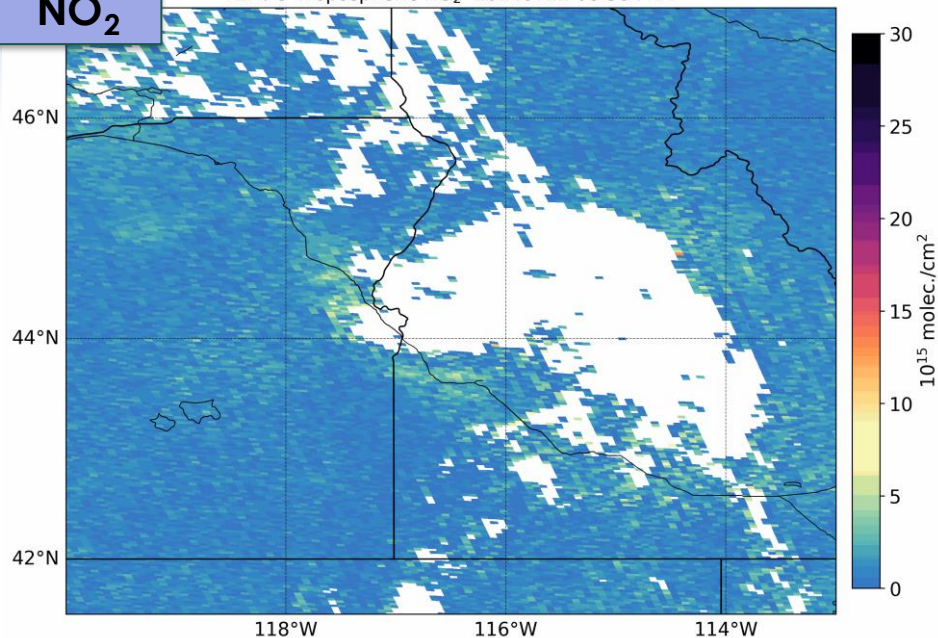


TEMPO NO₂, HCHO, & UVAI – July 22



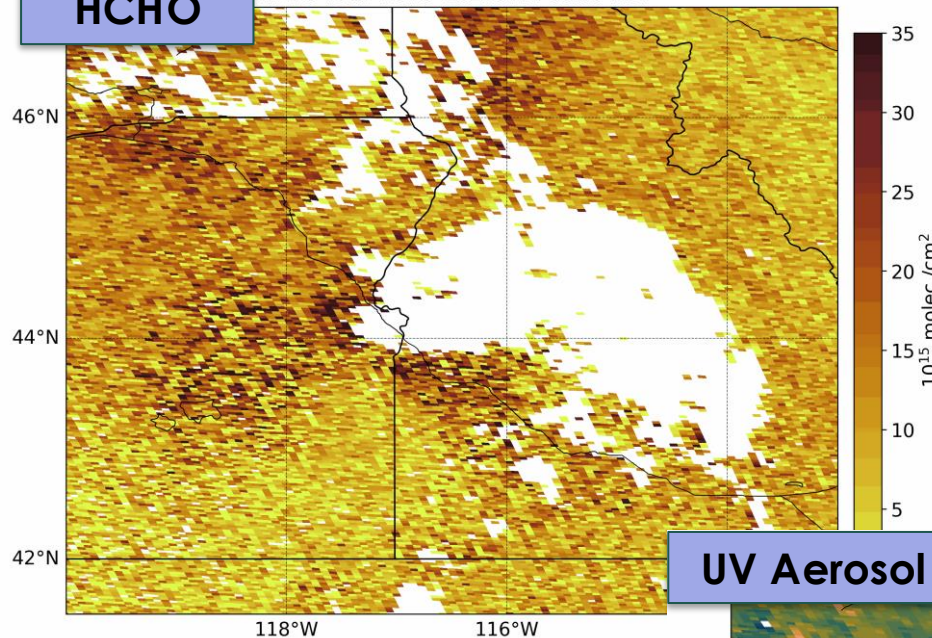
NO₂

TEMPO Tropospheric NO₂ 20240722 08:36 MDT



HCHO

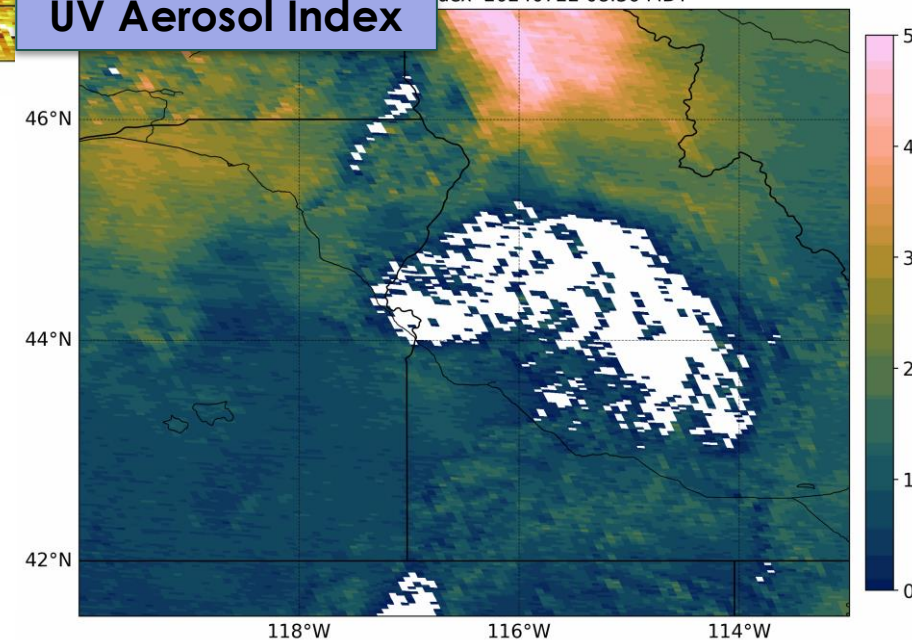
TEMPO Total HCHO 20240722 08:36 MDT



Filter using
Cloud Fraction < 50%
SZA < 80°

UV Aerosol Index

20240722 08:36 MDT



- TEMPO observed large NO₂ and HCHO plumes associated with the wildfire smoke plumes
- Elevated HCHO columns within the smoke plumes were transported further downwind
- The absorbing smoke aerosols lead to the strongly positive UV Aerosol Index values

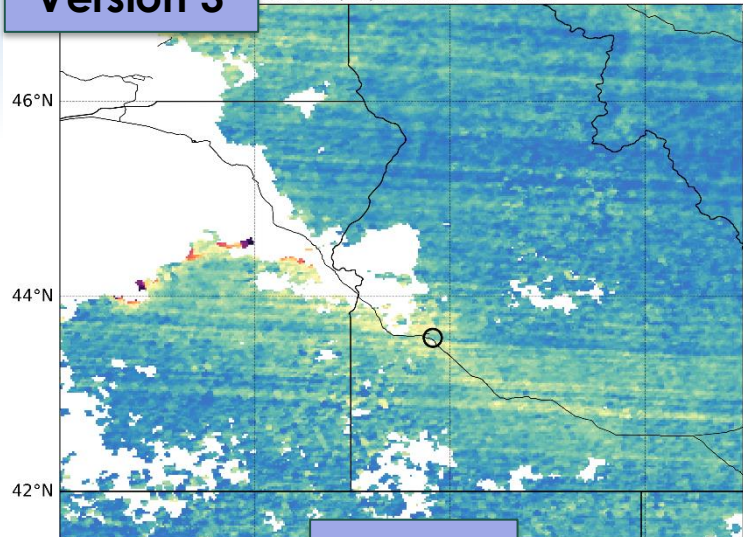


TEMPO V3 vs V4 NO₂ – Daily Average

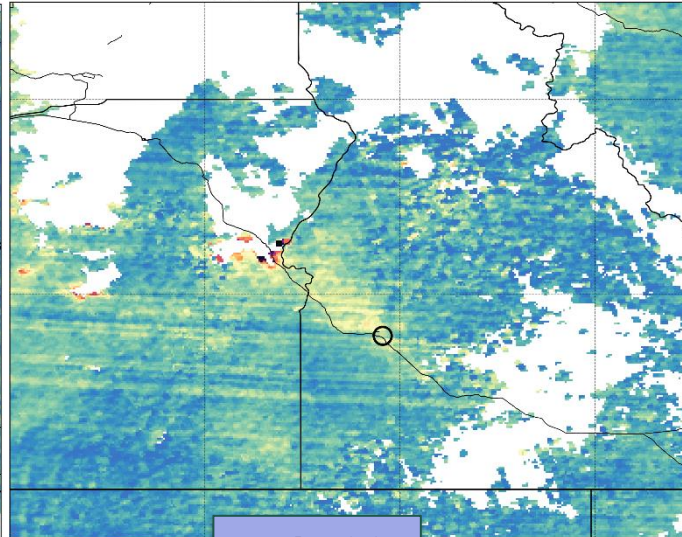


Version 3

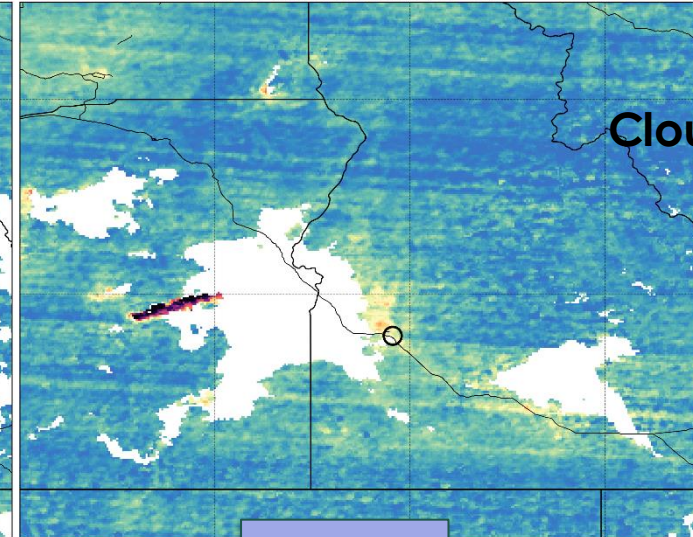
TEMPO Tropospheric NO₂ 20240721



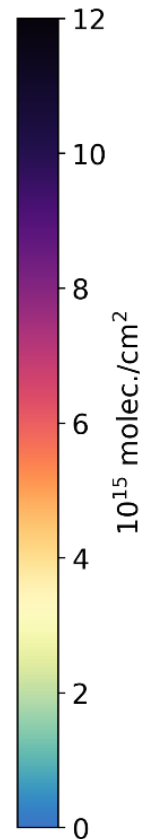
TEMPO Tropospheric NO₂ 20240722



TEMPO Tropospheric NO₂ 20240723

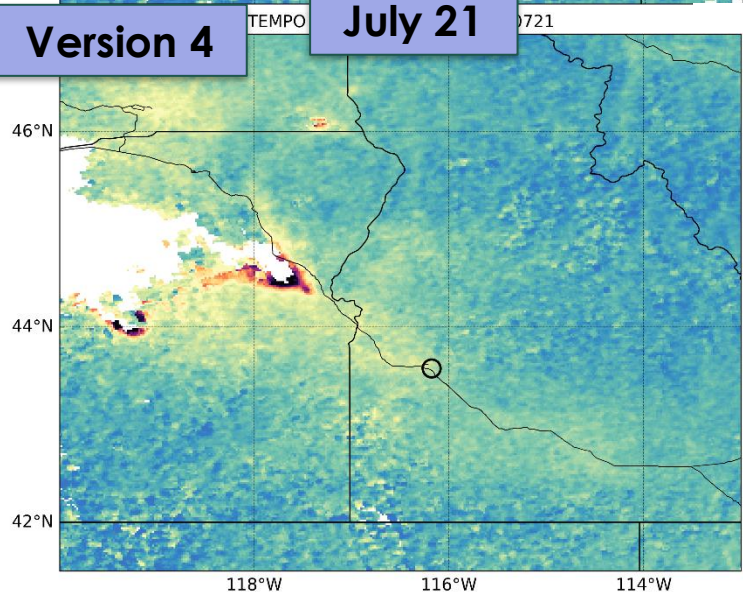


Filter using
Cloud Fraction < 20%
SZA < 80°

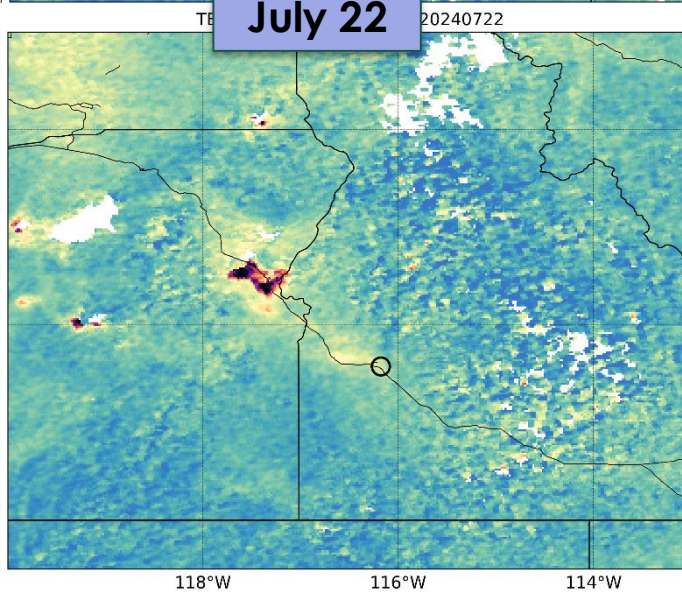


Version 4

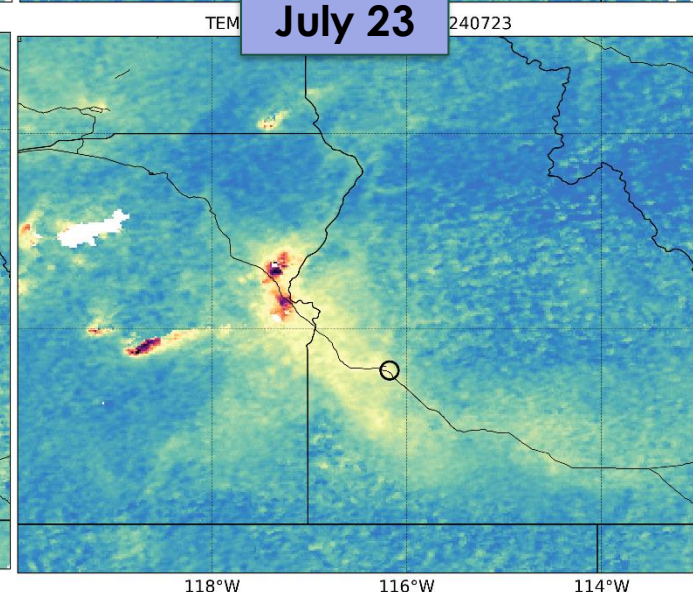
July 21



July 22



July 23



- Destriping and more accurate cloud retrieval contributed to improved V4 NO₂ results



TEMPO HCHO & NO₂ – Daily Average



HCHO

TEMPO Total HCHO 20240721

TEMPO Total HCHO 20240722

TEMPO Total HCHO 20240723

18
16
14
12
10
8
6
4
2
0
10¹⁵ molec./cm²

Filter using
Cloud Fraction < 20%
SZA < 80°

July 21

July 22

July 23

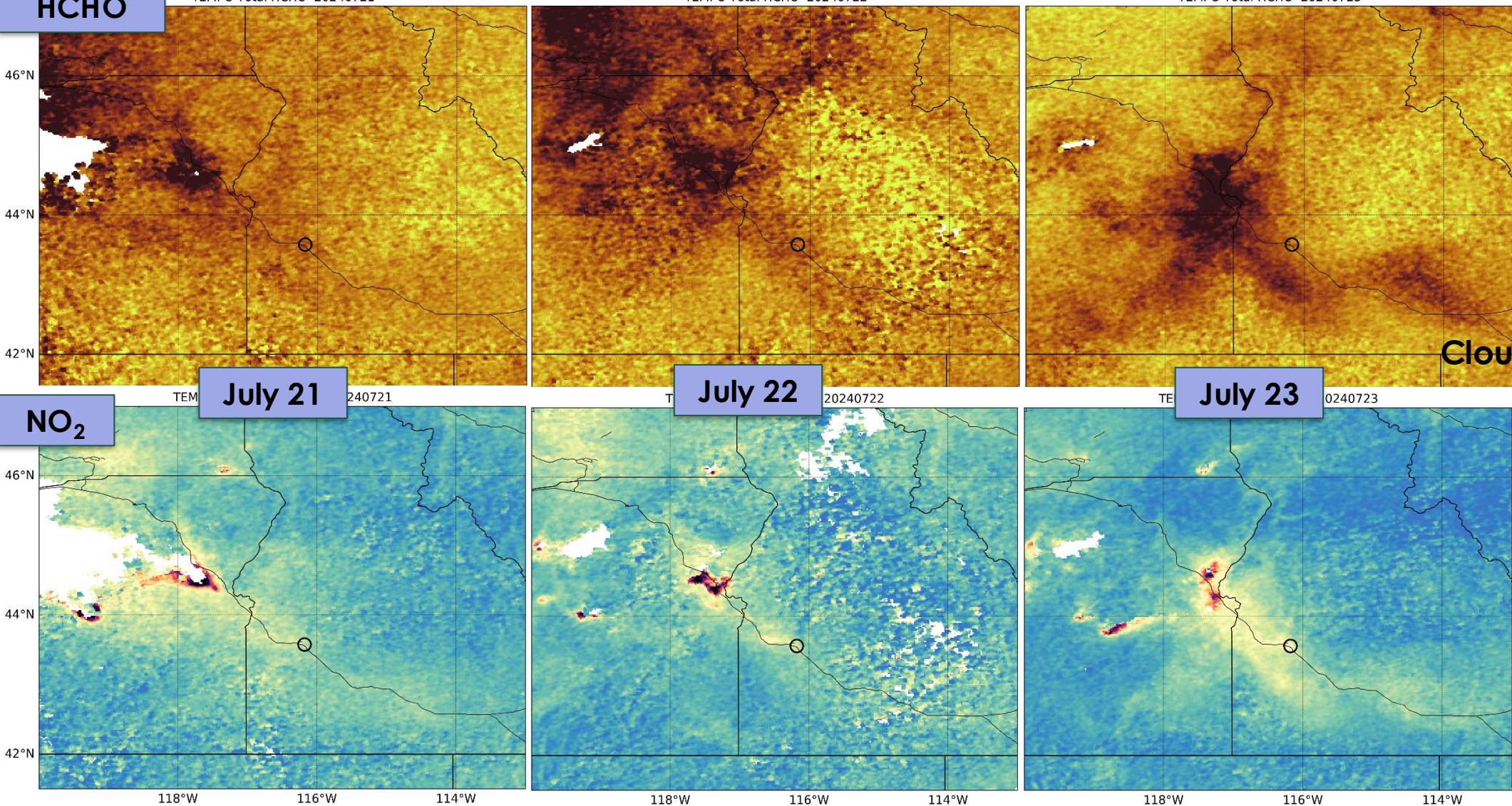
NO₂

TEMPO Total NO₂ 20240721

TEMPO Total NO₂ 20240722

TEMPO Total NO₂ 20240723

12
10
8
6
4
2
0
10¹⁵ molec./cm²



- Surface monitors measured unhealthy O₃ and PM_{2.5} levels across Idaho and Oregon from July 21-23



TEMPO O₃ Total - Daily Average

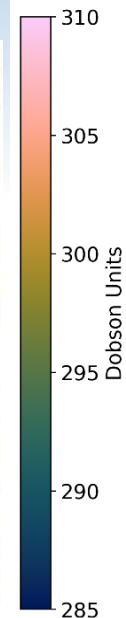
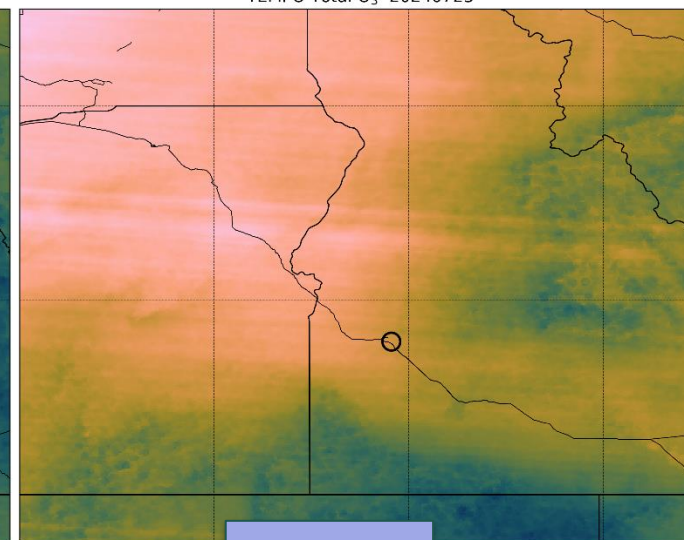
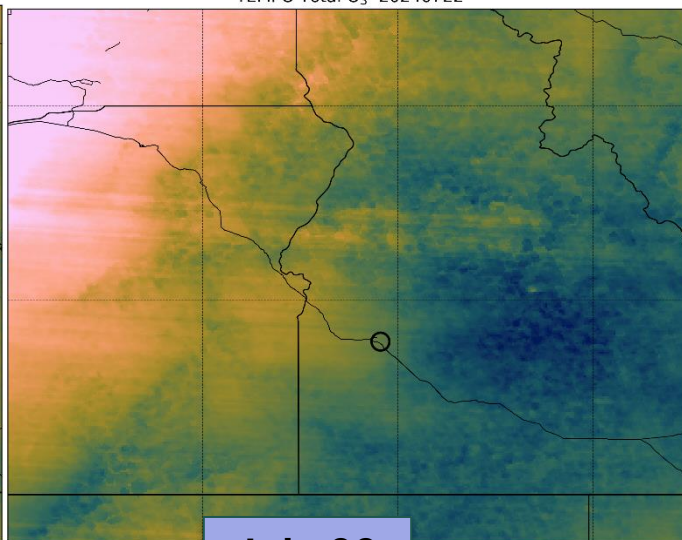
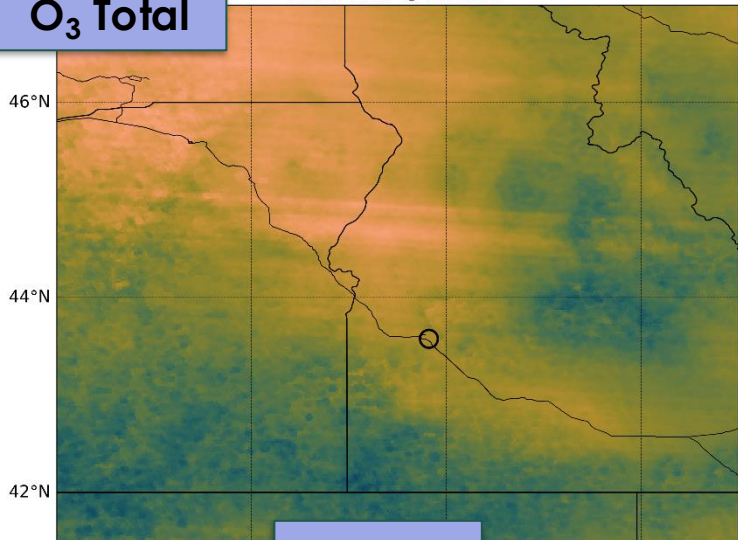


O₃ Total

TEMPO Total O₃ 20240721

TEMPO Total O₃ 20240722

TEMPO Total O₃ 20240723

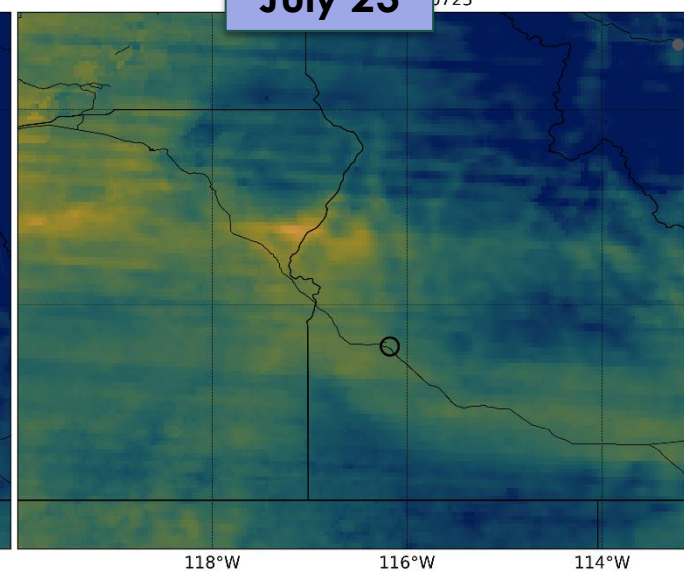
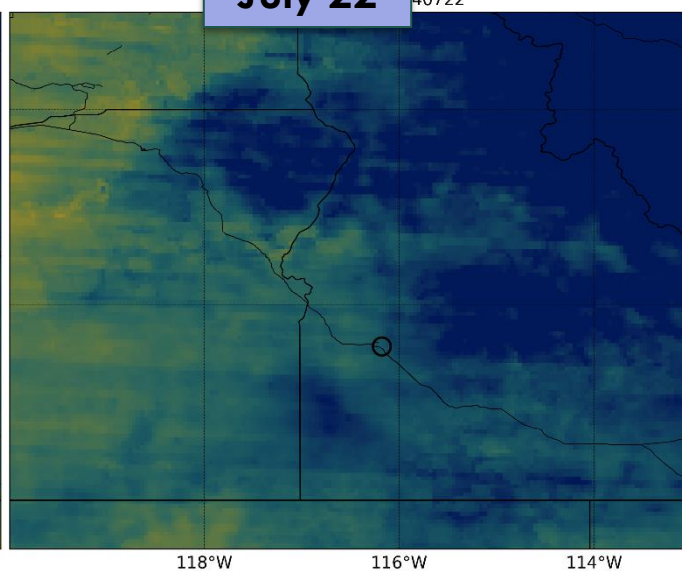
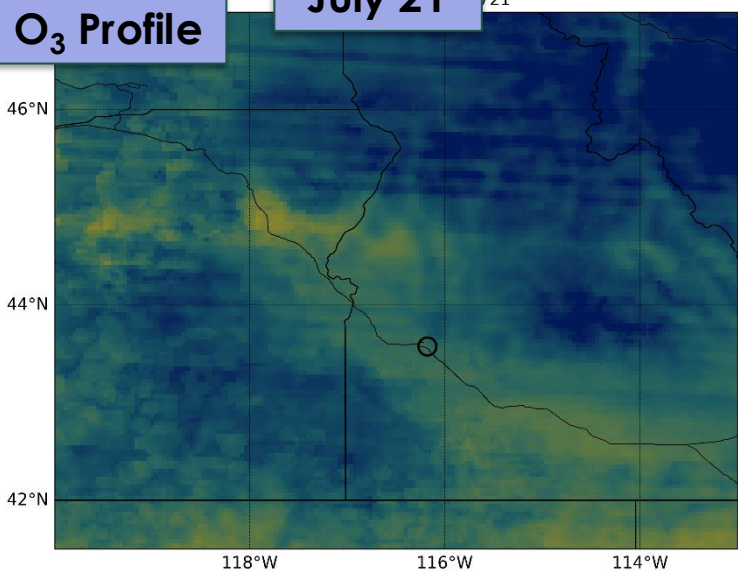


O₃ Profile

July 21

July 22

July 23



O₃ total columns from O₃ profile product are lower than O₃ total product likely due to an underestimation in stratospheric O₃ from O₃ profile retrieval

- O₃ total column retrievals show increase in O₃ across region and over Boise on July 23



TEMPO O₃ Profile - Daily Average



Tropospheric O₃

ospheric O₃ 20240721

TEMPO Tropospheric O₃ 20240722

TEMPO Tropospheric O₃ 20240723

Dobson Units

42
40
38
36
34
32
30
28
26
24

July 21

July 22

July 23

0-2 km O₃

20240721

20240722

20240723

Dobson Units

14
13
12
11
10
9
8
7

- Tropospheric O₃ increases over Boise with some increases in 0-2 km O₃ apparent



Summary



- The newly-available O_3 profile product offers enhanced capabilities to monitor and characterize ozone in the troposphere and add more insight into air quality impacts of the near-surface ozone
- TEMPO NO_2 and HCHO data has larger uncertainties in smoke since aerosols are not explicitly accounted for in the TEMPO retrieval method
 - Qualitative use of NO_2 and HCHO is recommended in wildland fire smoke scenes
 - Less strict cloud fraction threshold is usually required to visualize NO_2 and HCHO plumes in smoke
- Version 4 NO_2 and HCHO changes compared to Version 3 can be large in some cases

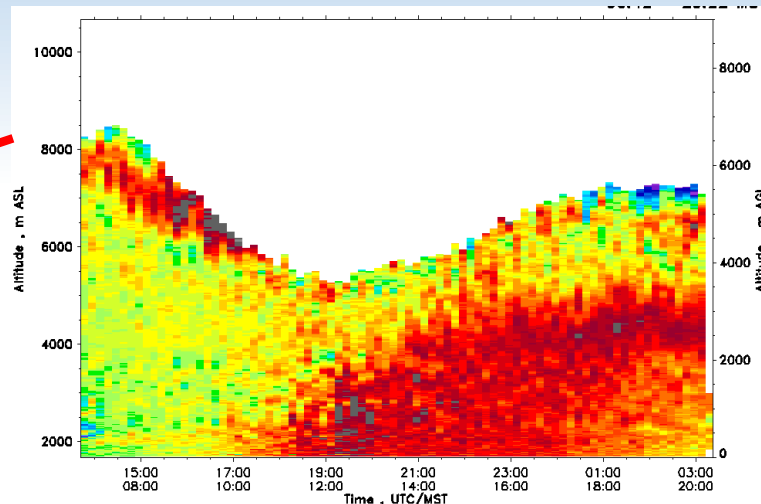
aaron.naeger@nasa.gov



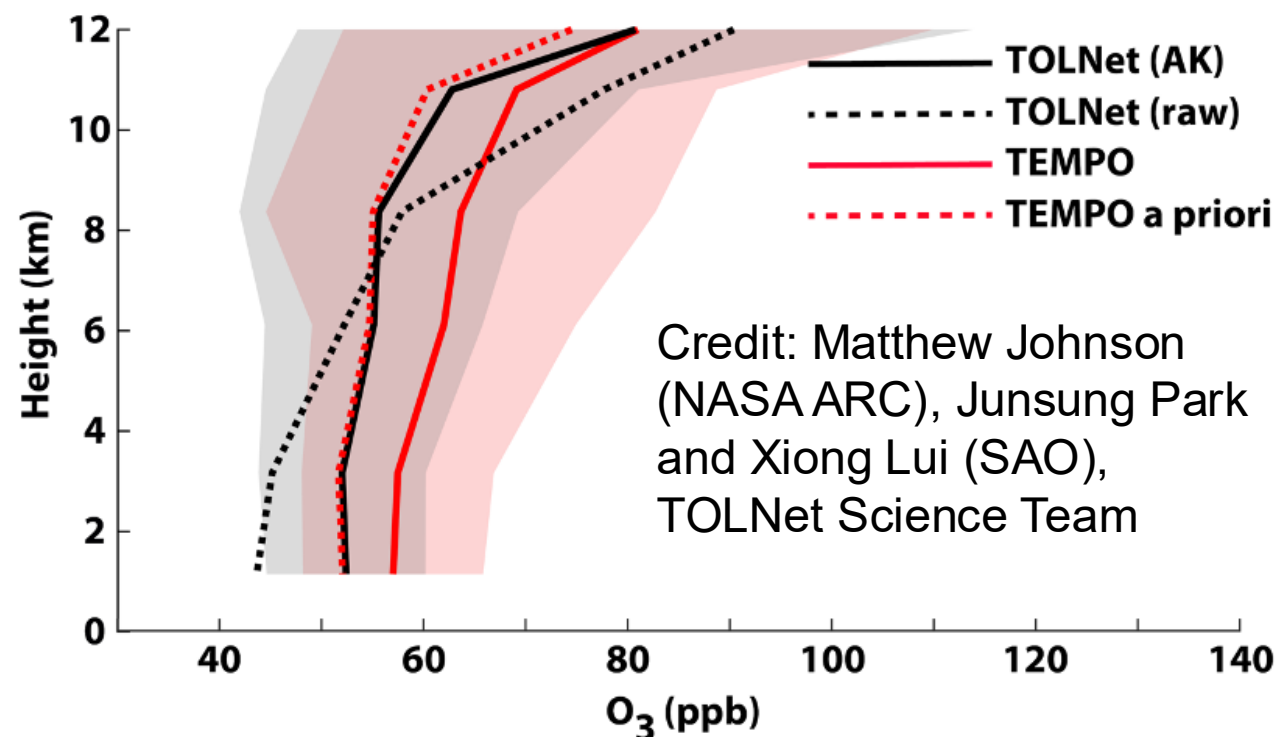
Backup Slides



- Conducted validation of first full season (Sept. – Nov. 2025) of ozone profile product against TOLNet O₃ profiles
- TEMPO's O₃ profiles have low biases and high precision (~7 ppb) in troposphere
- First indication that TEMPO meets its tropospheric O₃ precision requirement (± 10 ppb)



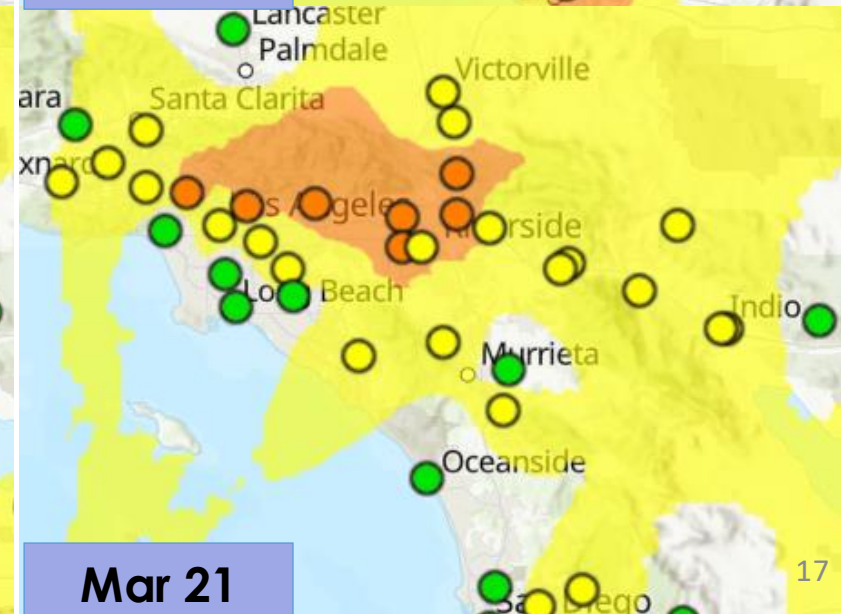
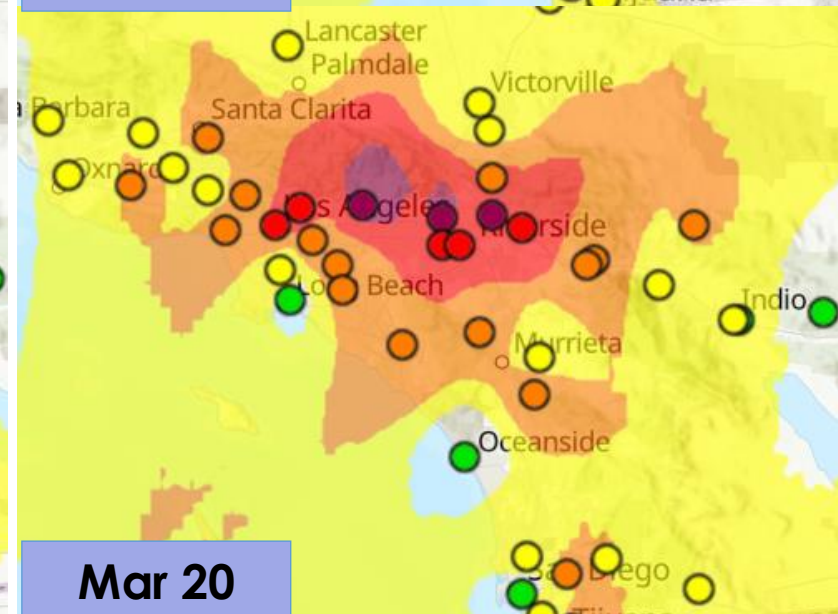
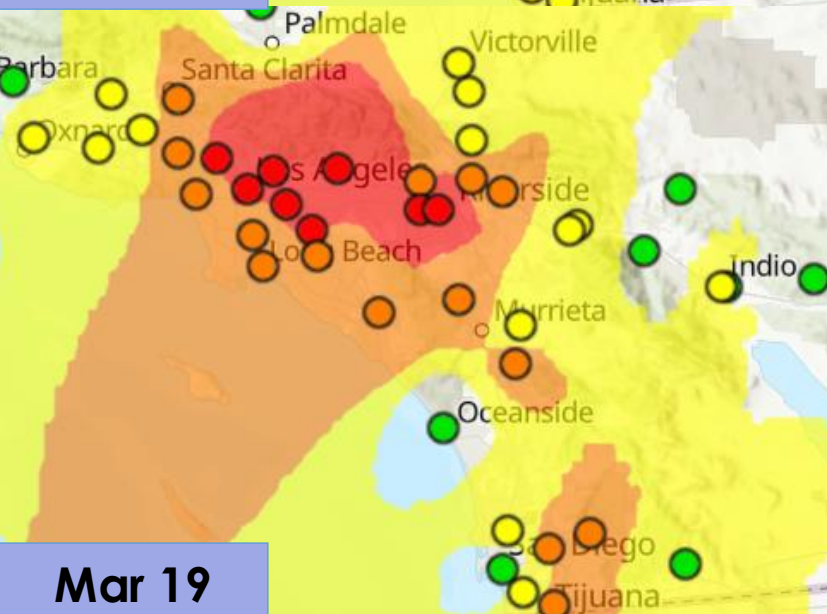
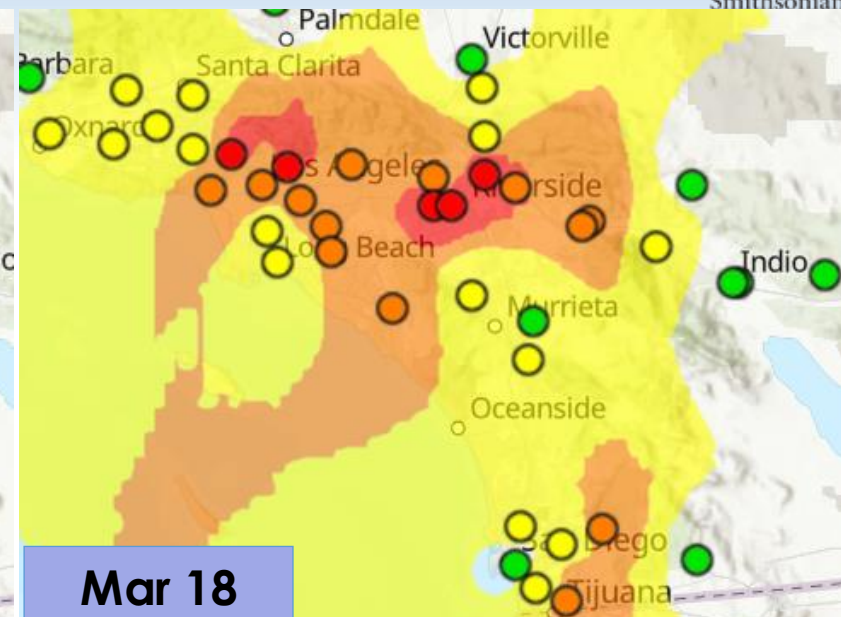
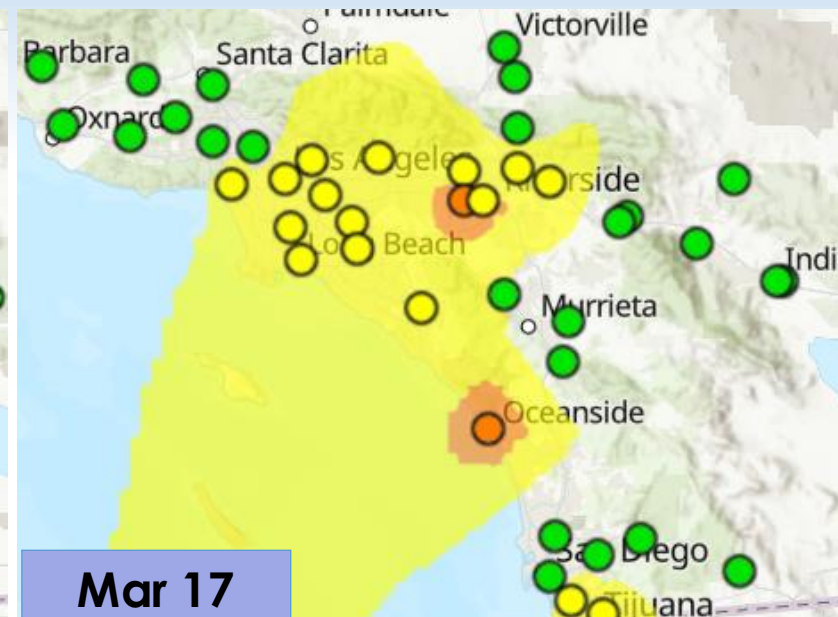
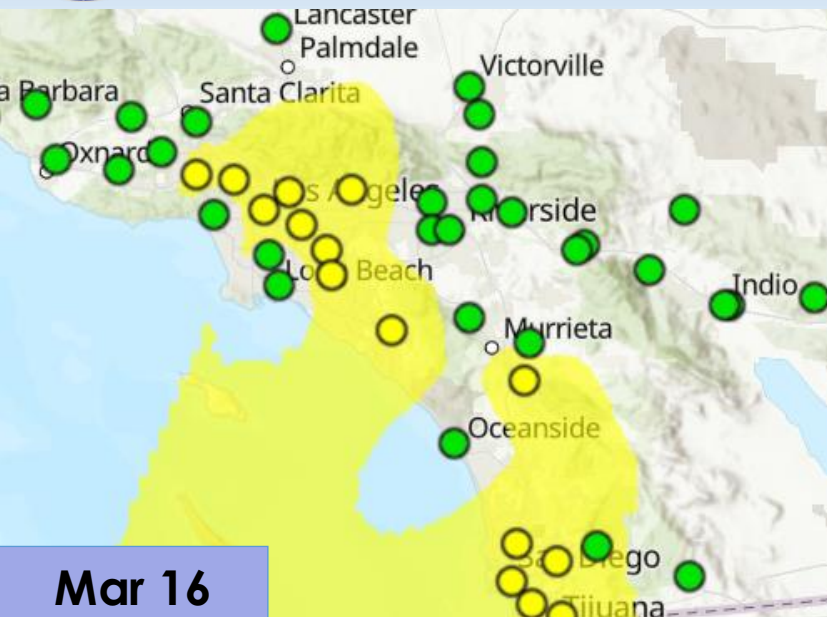
- Ozone profiles from Boulder site, observing a high O₃ day along the CO Front Range



Credit: Matthew Johnson (NASA ARC), Junsung Park and Xiong Lui (SAO), TOLNet Science Team



AirNow O₃ monitors – Daily AQI Maps

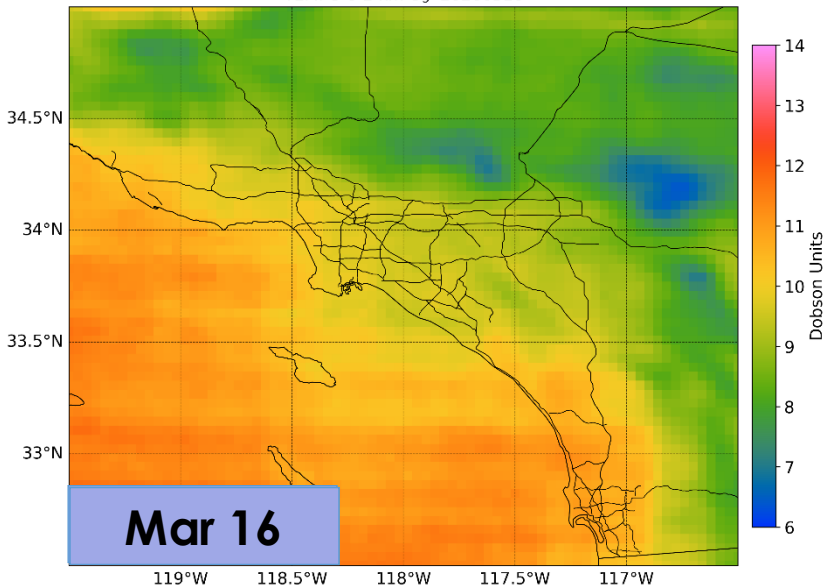




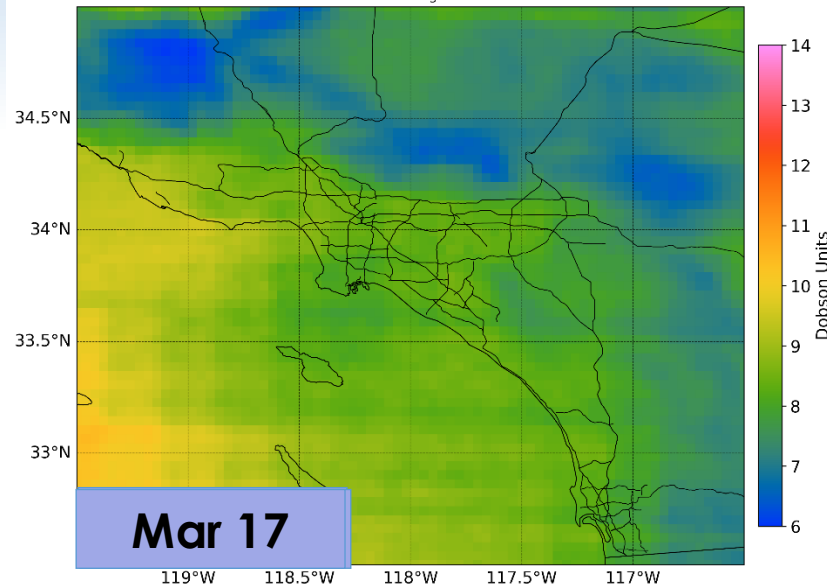
Daily Averaged TEMPO 0-2 km O₃ Columns



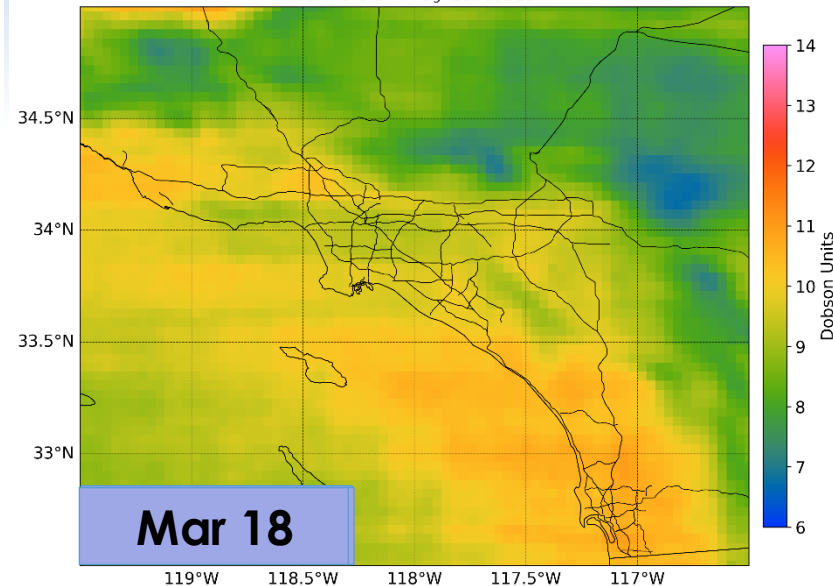
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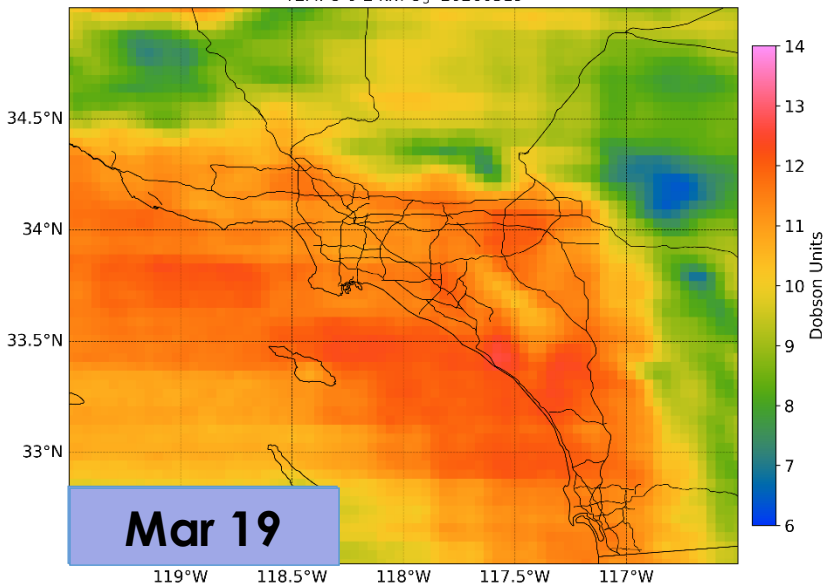
TEMPO 0-2 km O₃ 20260317



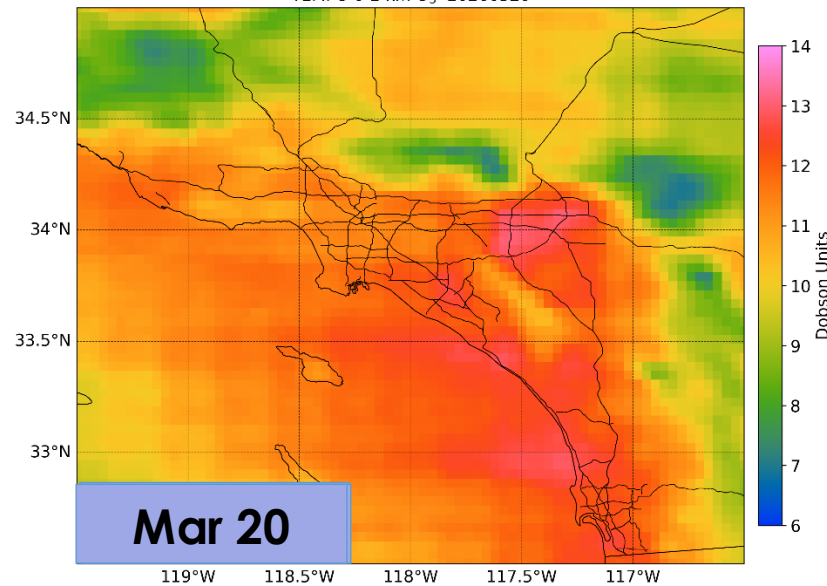
TEMPO 0-2 km O₃ 20260318



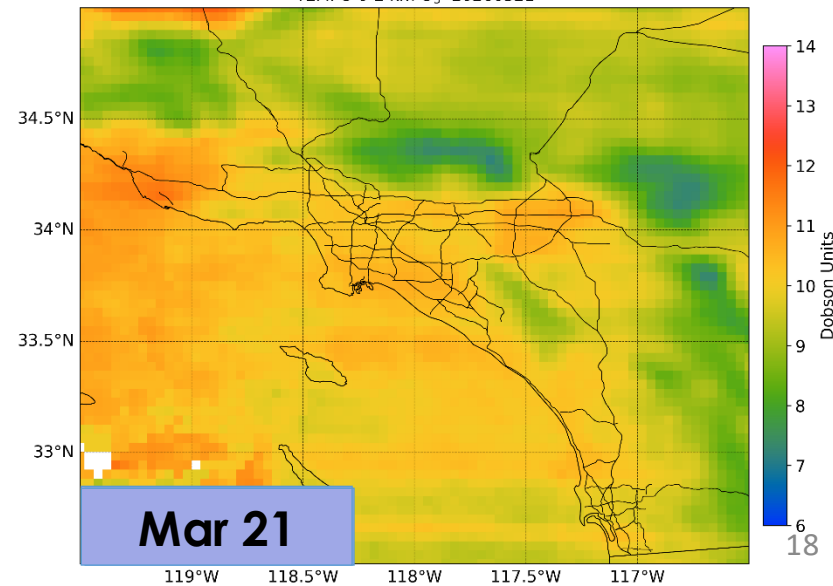
TEMPO 0-2 km O₃ 20260319



TEMPO 0-2 km O₃ 20260320



TEMPO 0-2 km O₃ 20260321

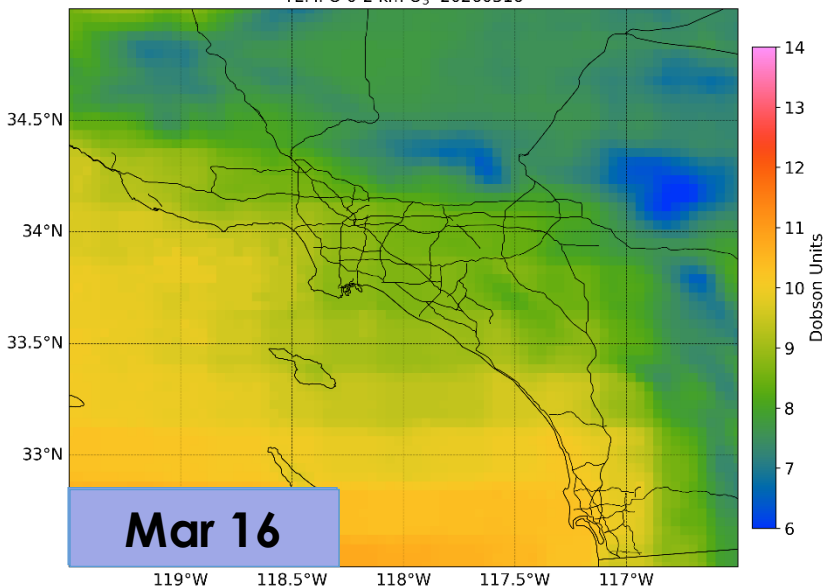




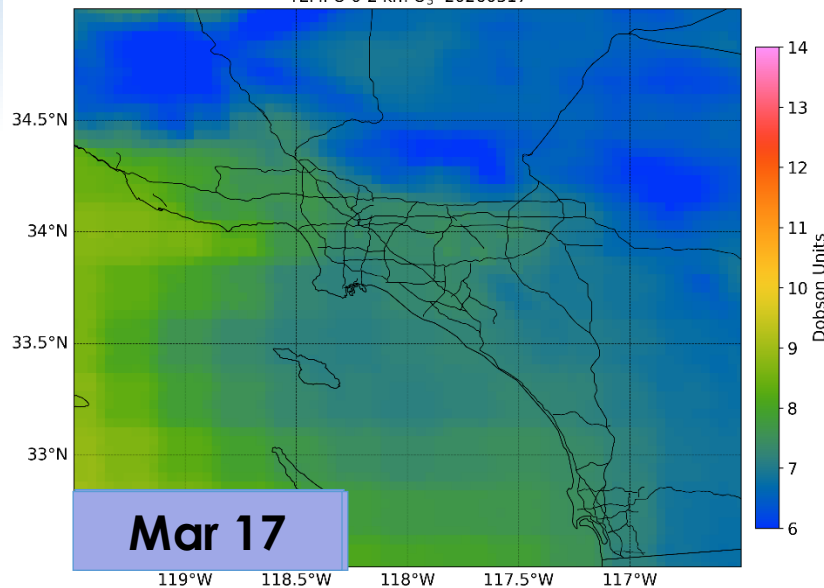
Daily Averaged GEOS-CF 0-2 km O₃ Columns



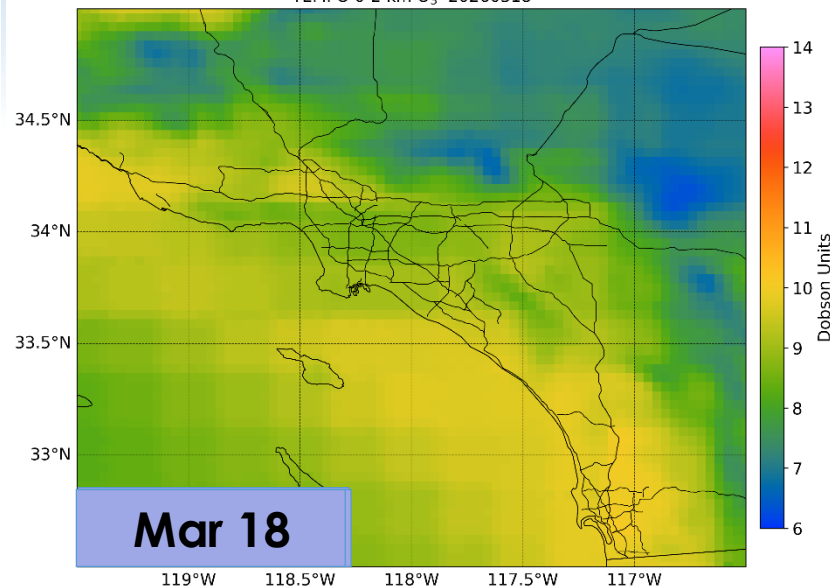
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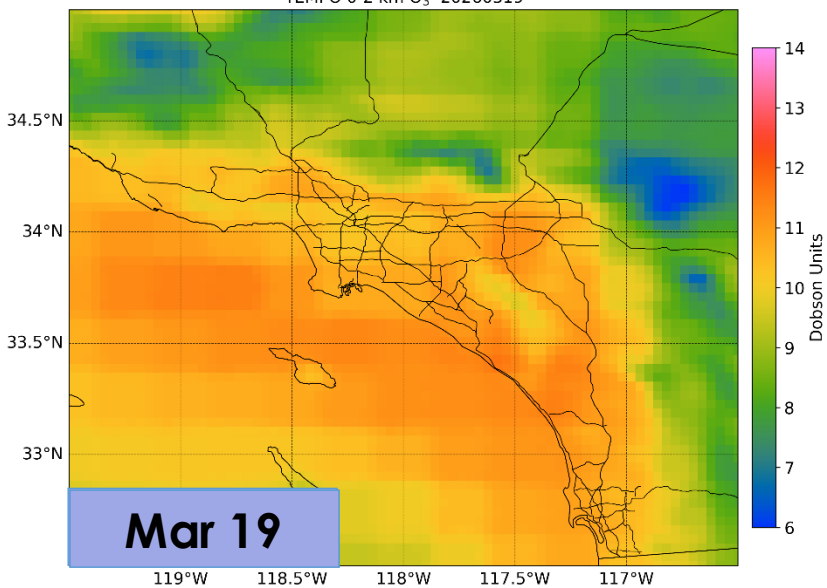
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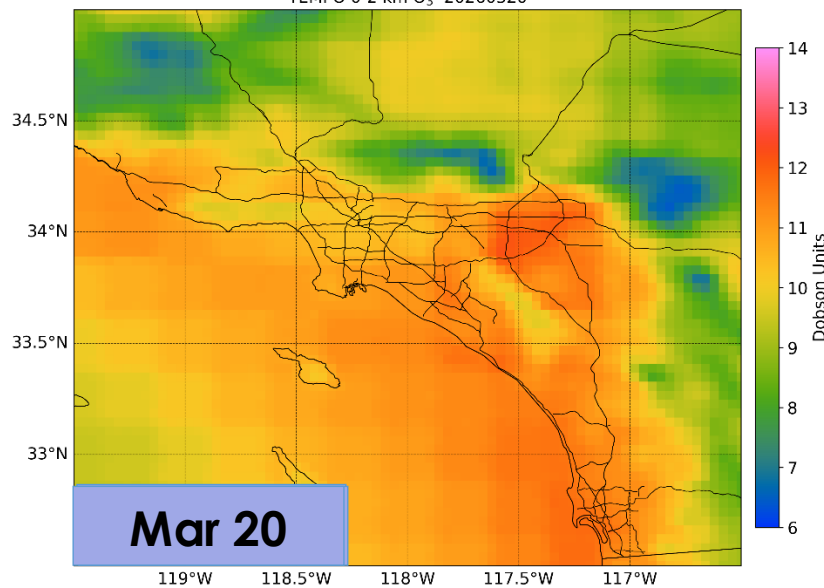
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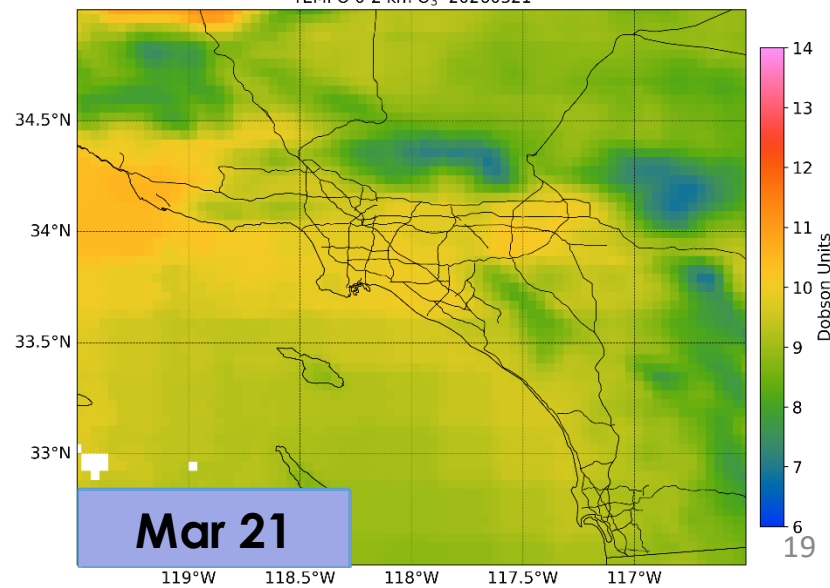
TEMPO 0-2 km O₃ 20260319



TEMPO 0-2 km O₃ 20260320



TEMPO 0-2 km O₃ 20260321





TEMPO vs GEOS-CF Profiles

