

Tropospheric Emissions:
Monitoring of Pollution



TEMPO Nitrogen Dioxide: Product Status

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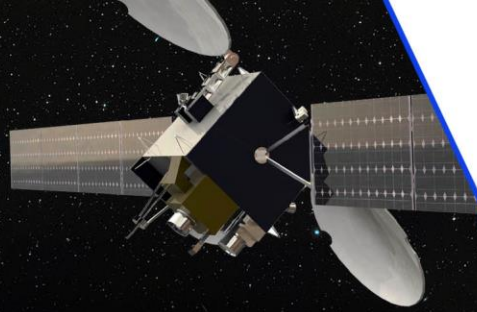
With contributions from:
Gonzalo González Abad
Masoud Ghahremanloo
Joseph Palmo
Xiong Liu
Heesung Chong

TEMPO DART Team Meeting

**University of Iowa
June 15, 2026**

Hourly Measurement of Pollution

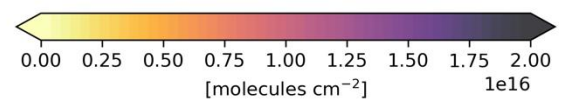
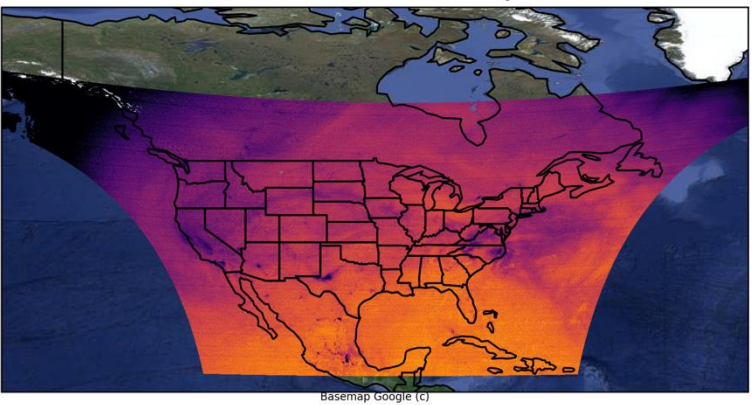
60 minutes



1) Slant column density retrieval (spectral fitting)

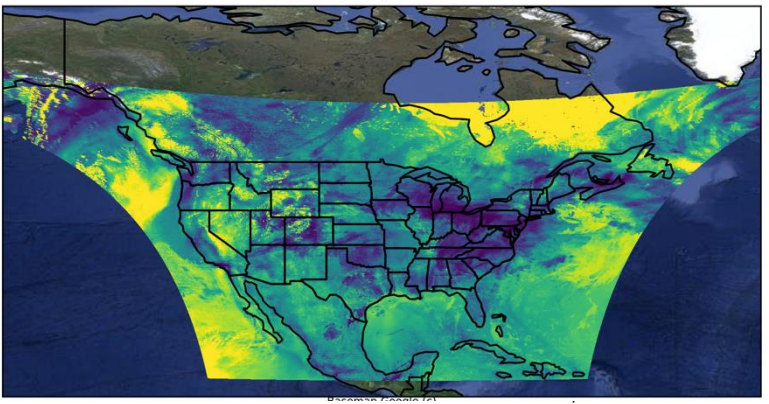
2024-05-09 14:01:32 to 2024-05-09 15:01:13; Scan S006

NO₂ slant column density

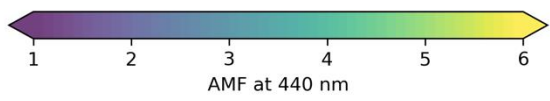
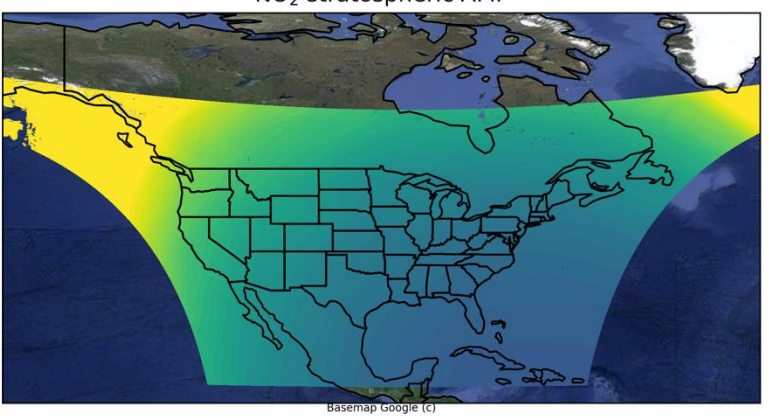


2) Air mass factor (AMF) calculation

NO₂ tropospheric AMF

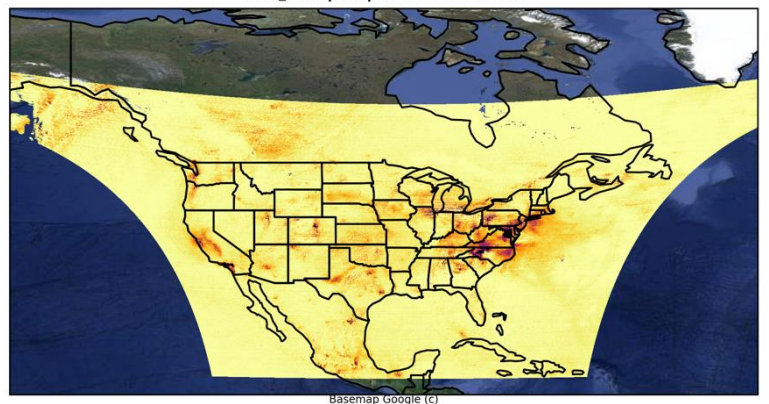


NO₂ stratospheric AMF

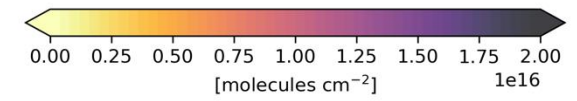
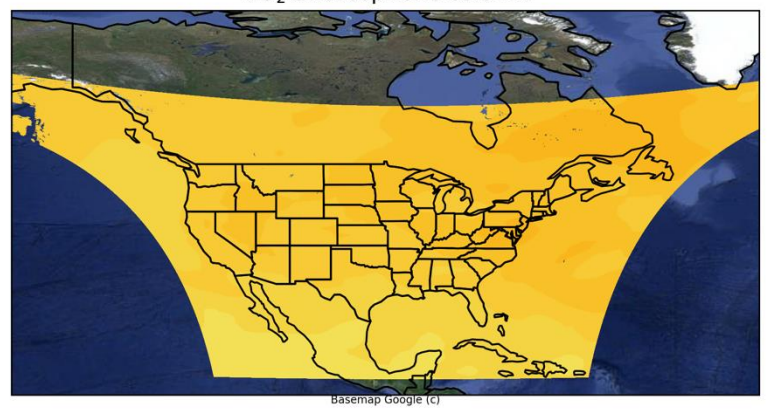


3) Stratosphere/troposphere separation

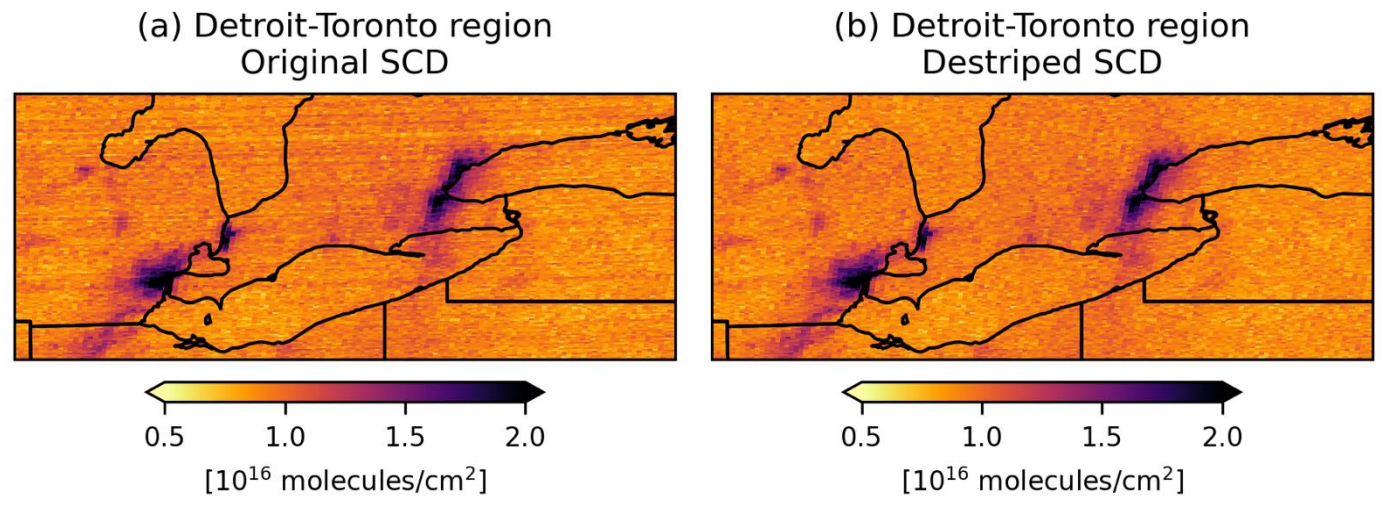
NO₂ tropospheric column



NO₂ stratospheric column



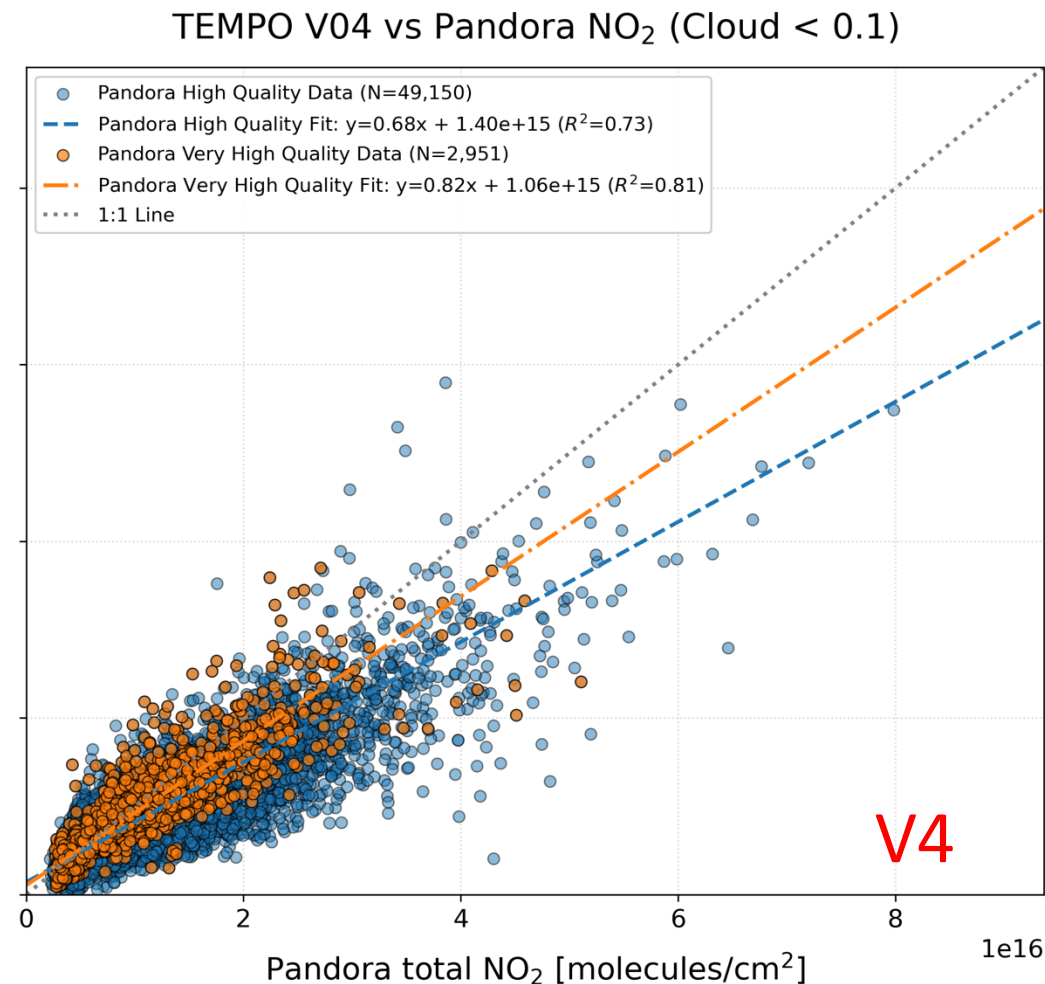
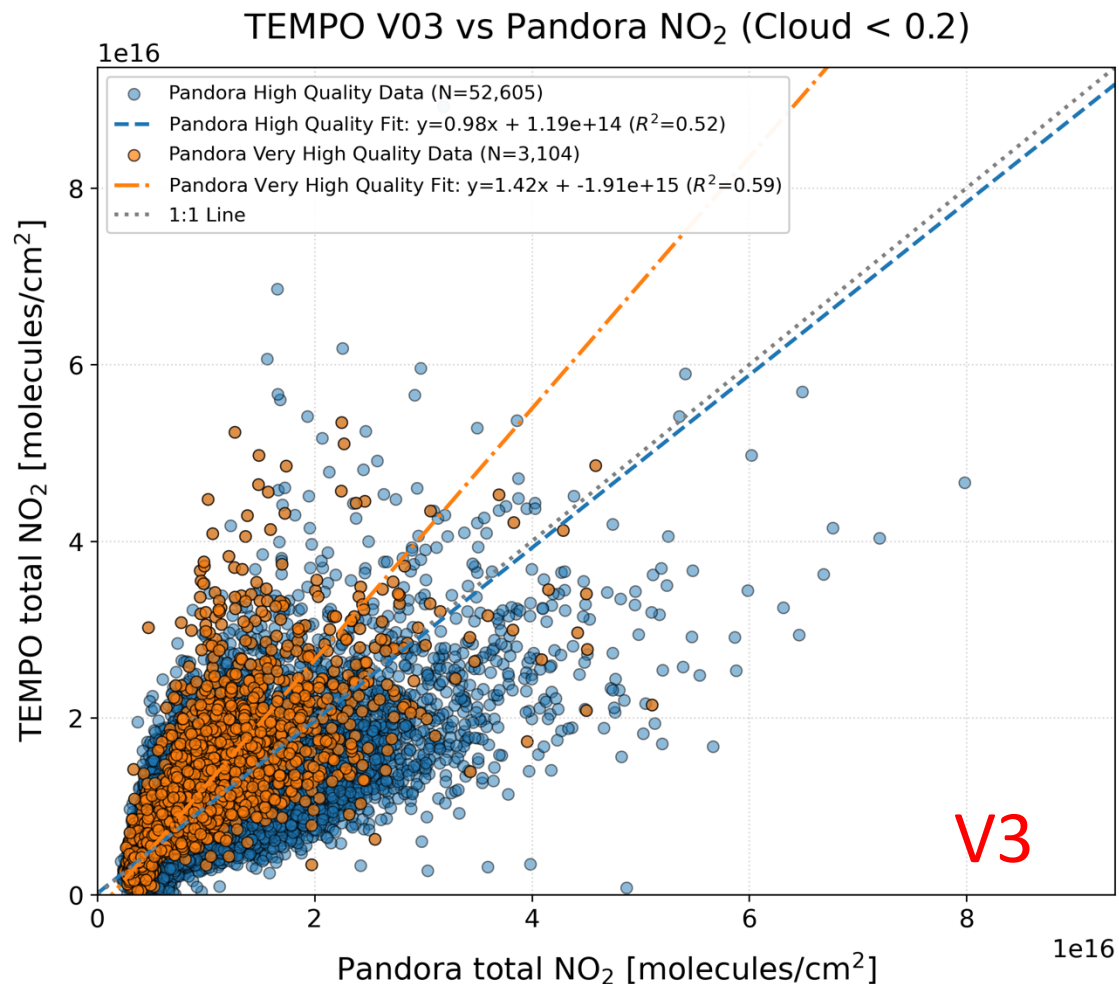
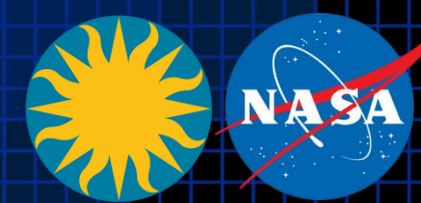
Update	Effect on Tropospheric NO ₂
Level 1B absolute calibration improvement	Cloud fraction bias is reduced; impacts cloud filter and NO ₂ .
GEOS-CF version 2	Variable
Improved surface GLER climatology	Surface reflectance diurnal pattern over land is more accurate.
Fixed surface pressure bug	Large (20-50%) differences in regions of changing terrain
Fixed bug in cloudy scattering weight	Changes in partly cloudy pixels with high clouds
Destriping correction	Nicer images and better statistics!



Tropospheric NO₂ on
October 16, 2025 S008



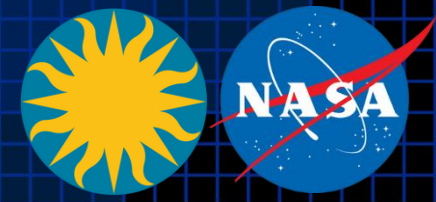
Pandora Comparisons



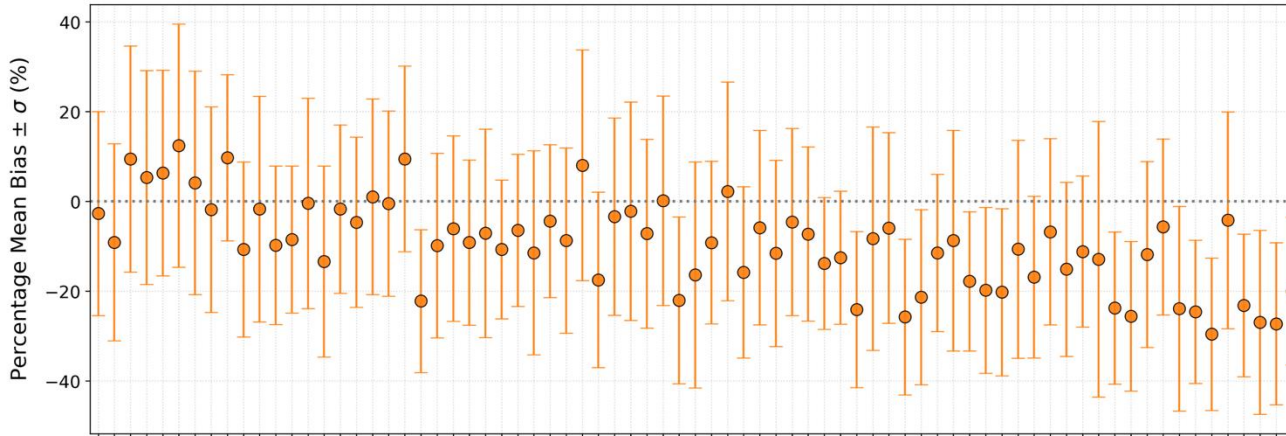
- ODR regression, includes TEMPO total NO₂ (tropospheric + stratospheric) with both V3 and V4 scans processed as of June 13, 2026
- Coincidences within 5 km and 15 minutes
- TEMPO main data quality flag = 0, snow-free



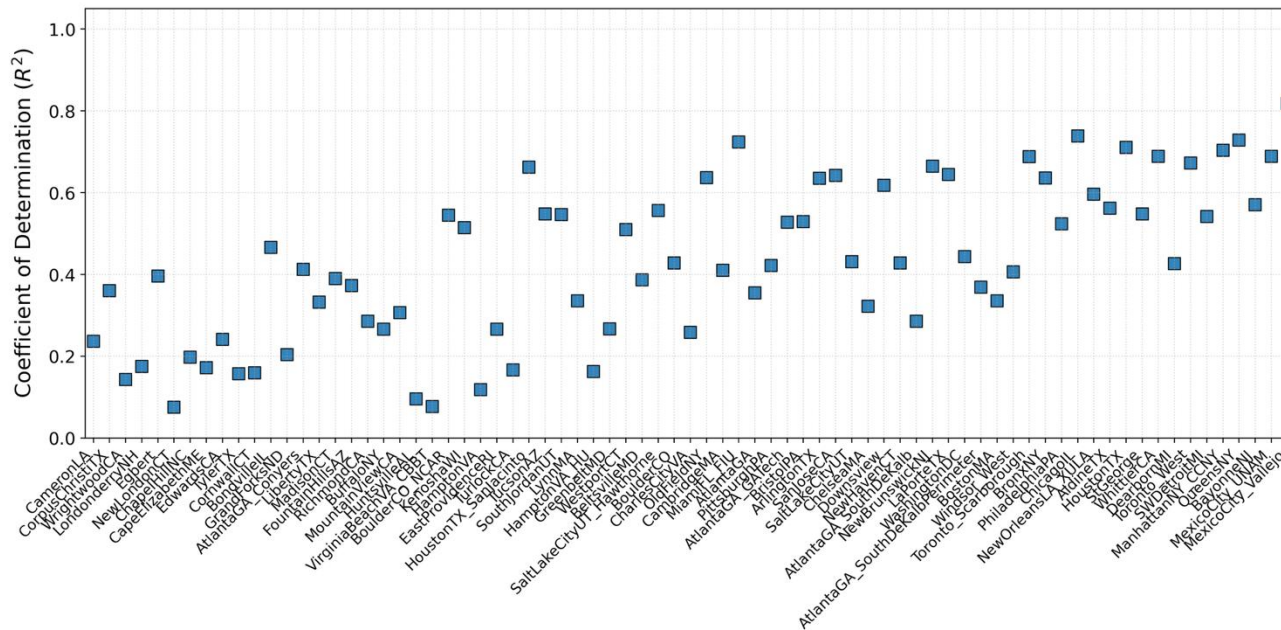
Site-Level Pandora Comparisons



Site-Level TEMPO V04 vs Pandora Percentage Mean Bias



Site-Level TEMPO V04 vs Pandora Coefficient of Determination (R^2)

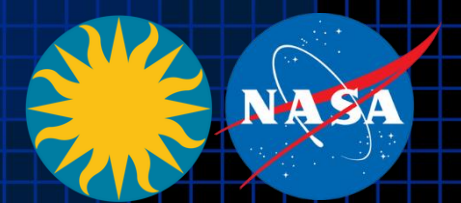


Pandora Ground Station Name (Ordered from lowest to highest mean NO₂ column)

- Overall V4 is lower than V3.
- V4 correlations are significantly better.
- V4 is higher than Pandora at low columns and lower at high columns.
 - Also seen in V3 [Ghahremanloo et al., 2025]
 - Also seen in TROPOMI vs Pandora

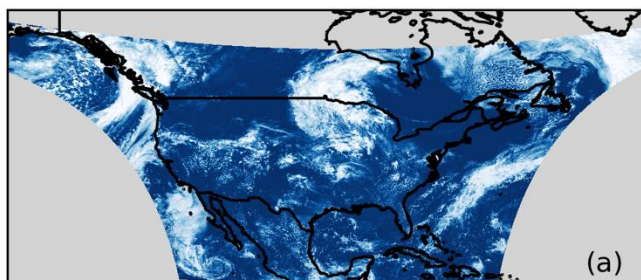


Ongoing Work for Version 5

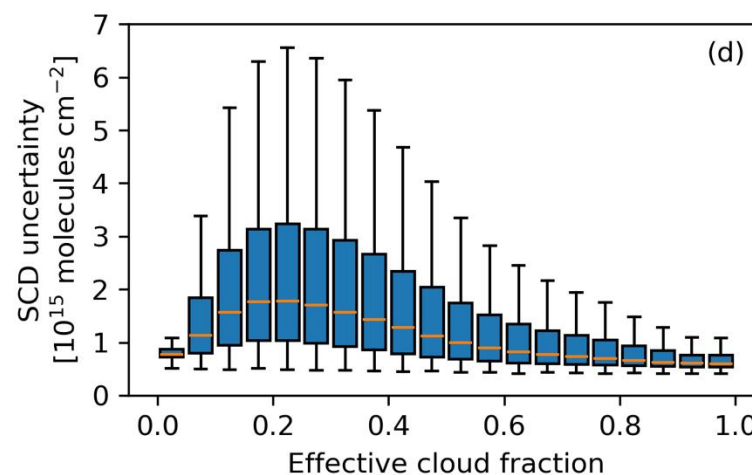
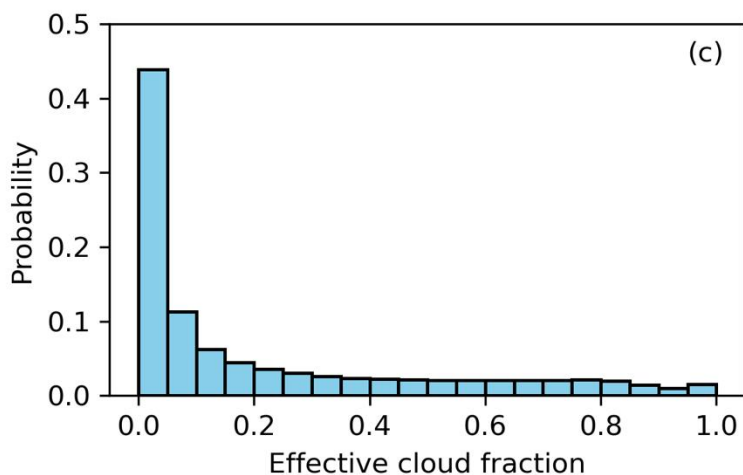
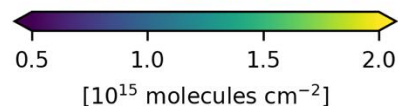
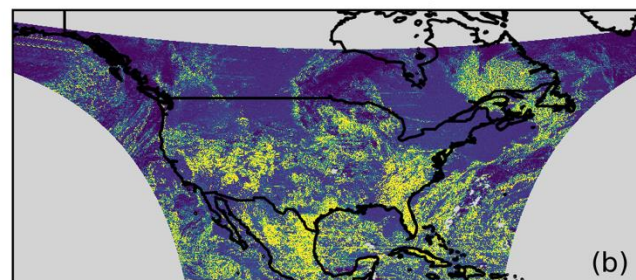


Inhomogeneous filling of instrument slit over partial clouds causes slant column biases and large fitting errors.

Effective cloud fraction



SCD uncertainty

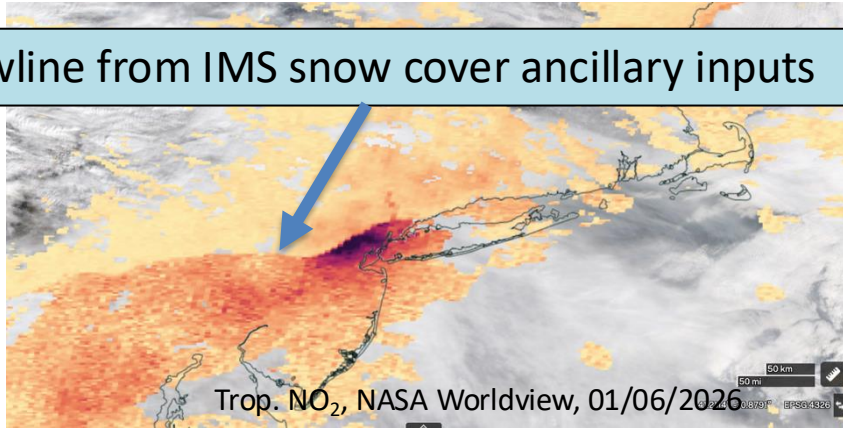


Plan: Use PCA approach to fit pseudo-absorber that represents skewed slit function shape.

Important: As the cloud fraction histogram has shifted to lower values in V4, we now recommend a cloud filter of $ecf < 0.1$ instead of < 0.2 for most users.

Snow and Ice Bias

Snowline from IMS snow cover ancillary inputs



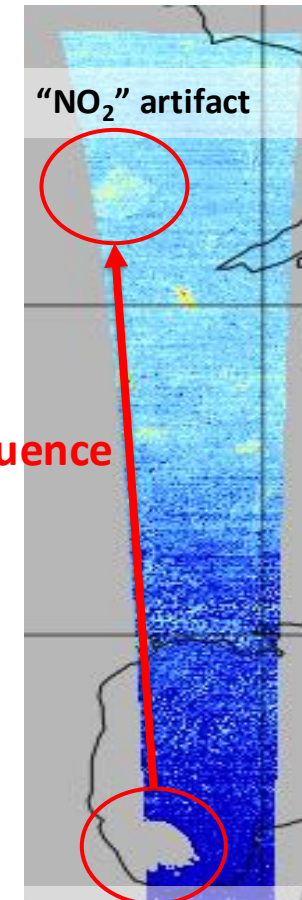
Errors in surface reflectance over pixels flagged as snow/ice lead to artifacts in clouds and trace gas products.

- Low NO₂ bias over snow [Griffin et al., 2026]
- Large northern areas with failed cloud retrievals in winter → missing NO₂

Plan: Improve surface reflectance; use cloud scene albedo over snow.

False NO₂ “Blobs”

Straylight influence



Very bright cloud (NO₂ not retrieved due to saturation)

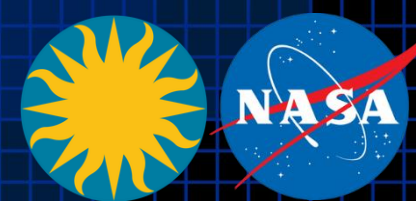
On occasion, artifacts from very bright clouds appear as NO₂ signal due to internal reflection in the spectrometer.

Plan: Improve radiance stray light correction.

[Credit: Heesung Chong, SAO]

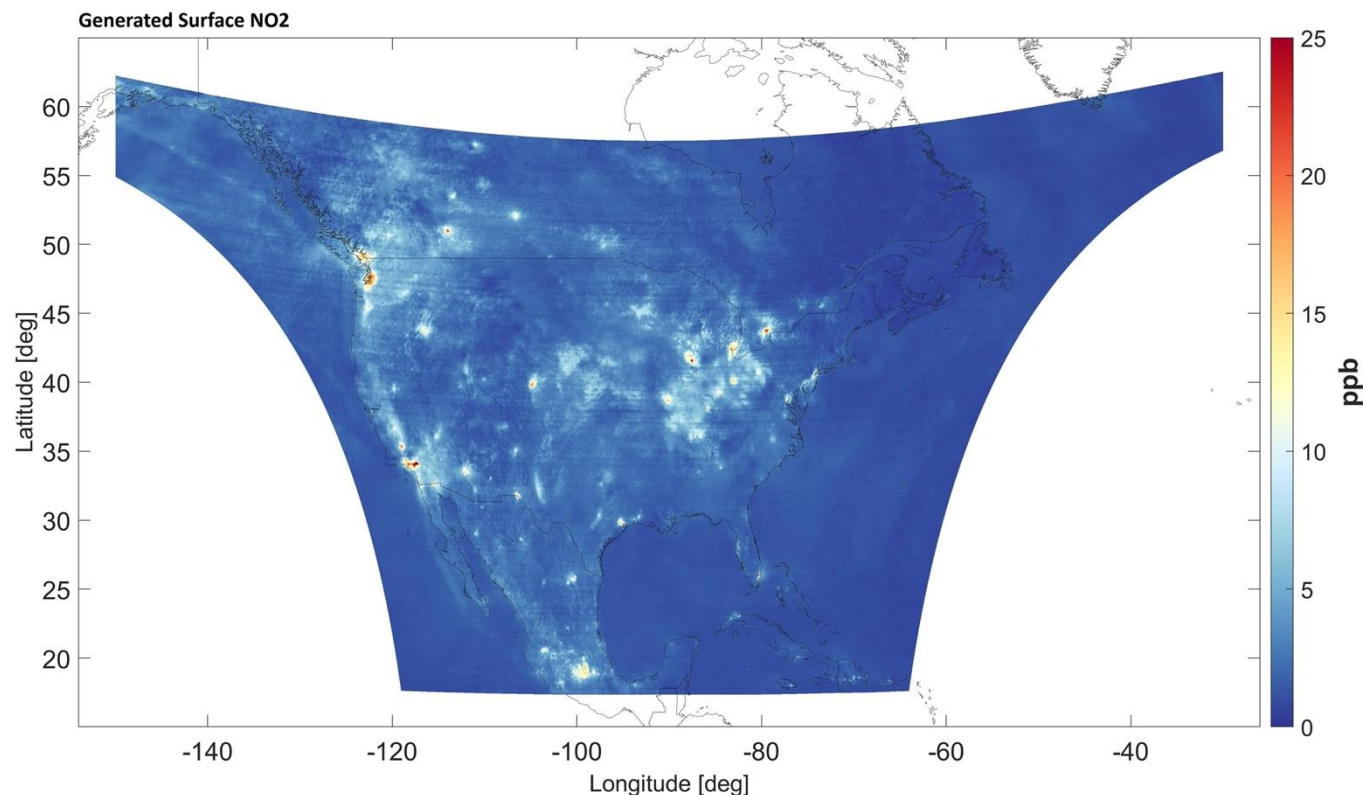


AI-Derived Surface NO₂ Concentrations



Credit: Masoud Ghahremanloo, Smithsonian Astrophysical Observatory

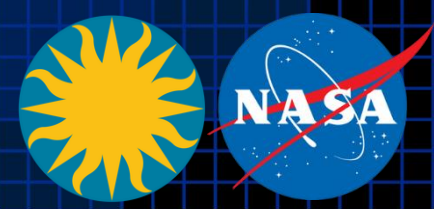
- ***A new 2023-2024 record of gap-free surface NO₂ concentrations at 0.02° × 0.02° is now available from TEMPO.***
- Deep learning model trained on ~750 U.S., Canada and Mexico surface monitors.
- Cross-validation using different methods (ten-fold, spatial, rural-vs-urban, gap-filled) shows excellent performance (R=0.93-0.98, MAB ~1 ppb, MB ~0 ppb).



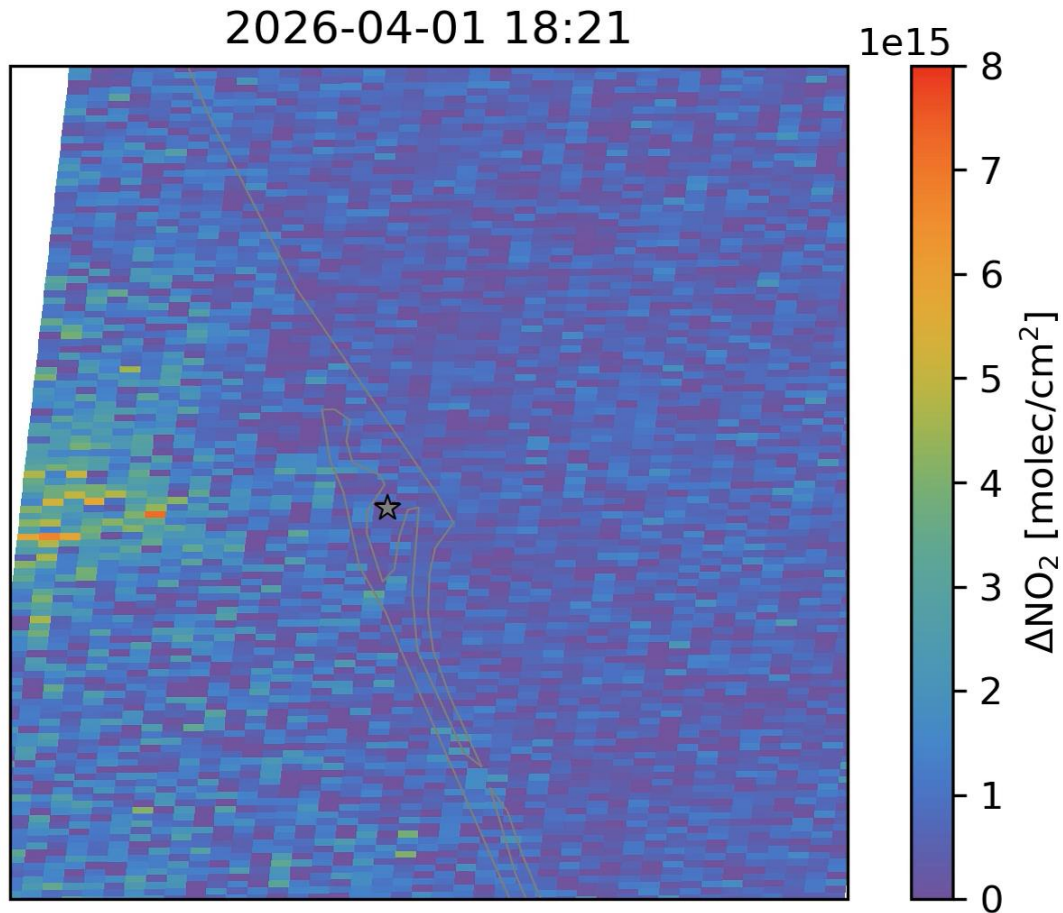
Ghahremanloo et al., "A Next-Generation Deep Learning Framework to Extract Hourly Gap-Free Surface NO₂ Concentrations from TEMPO NO₂ Columns", Submitted to *Remote Sensing of Environment*



Artemis II Launch

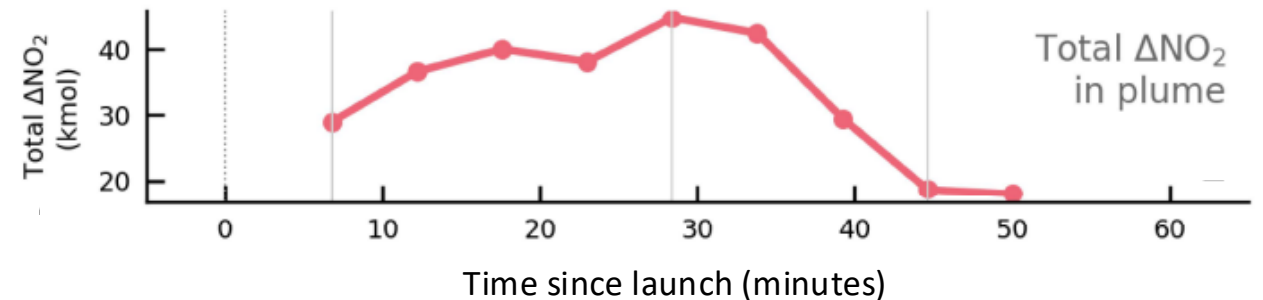


Credit: Joe Palmo, MIT (and TEMPO ops team!)



NO₂ enhancement over background at scan EDT start time.

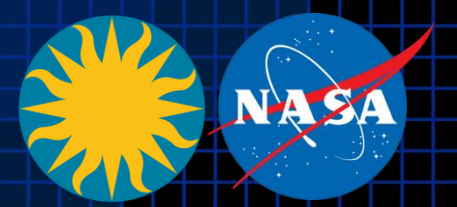
- 6-minute high-frequency observations over Florida on April 1 captured 10 consecutive NO₂ plumes after the Artemis II launch at 18:35 EDT.
- Enables measurement of evolution of rocket-produced NO_x plume.



Palmo et al., "Quantifying Rocket NO_x Emissions Using Geostationary Satellite Observations", Submitted to *GRL*



Summary and Outlook



- Preliminary validation on limited amount of data shows a significant improvement in V4 correlations with Pandora, but TEMPO is consistently lower than Pandora at high NO₂.
- See Madankui Tao's talk for V4 intercomparisons with satellites.
- Future plans:
 - Improve fitting in partly cloudy pixels
 - Improve retrieval approach over snow
 - Use a TEMPO-derived surface reflectance (see Weizhen Hou's poster)
 - Improve latency of the NRT product

