NO_2 Algorithm Development for GeoXO ACX

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NO_2 Algorithm for GeoXO ACX

- Direct Vertical Column Fitting (DVCF) Algorithm for NO_2 Retrievals

$$\ln I_m(\lambda) - \ln I_{TOA}(\lambda) = V \int_0^{\infty} \frac{\partial \ln I_{TOA}(\lambda)}{\partial \tau_z} S_z \sigma(\lambda, T_z)\, dz - \sum_i^m \xi_i \sigma_i(\lambda, T_i) + \sum_{k=0}^{n} \frac{\partial \ln I_{TOA}(\lambda)}{\partial R} \Delta R_k (\lambda - \lambda_0)^k + \varepsilon$$

- λ : wavelength
- I_m : measured radiance
- I_{TOA} : radiative transfer simulation
- σ : gas absorption cross sections
- R : reflectivity or cloud fraction

- NO_2 vertical column : V
- NO_2 Shape factor : S_z
- Gas absorber slant columns : ξ_i
- Aerosol Index : R_1
- Altitude-resolved AMF: $-\frac{\partial \ln I_{TOA}}{\partial \tau_z}$

References:
Yang et al., 2014, DOI: 10.1002/2014GL060136
Huang et al., 2022, DOI: 10.1016/j.atmosenv.2022.11936

NO_2 Algorithm for GeoXO ACX

Advanced Algorithm Features

- Allow accurate algorithm physics: explicit treatment of aerosol and surface BRDF to provide accurate representation of spectral and altitude variations of measurement sensitivities (DOAS's equivalent is the improved AMF).
- Allow more accurate stratosphere-troposphere separation by combining retrievals from UV and VIS spectra
- Allow soft calibration to correct biases in radiometric calibration and instrumental features that interfere with the interpretation of molecular absorptions.

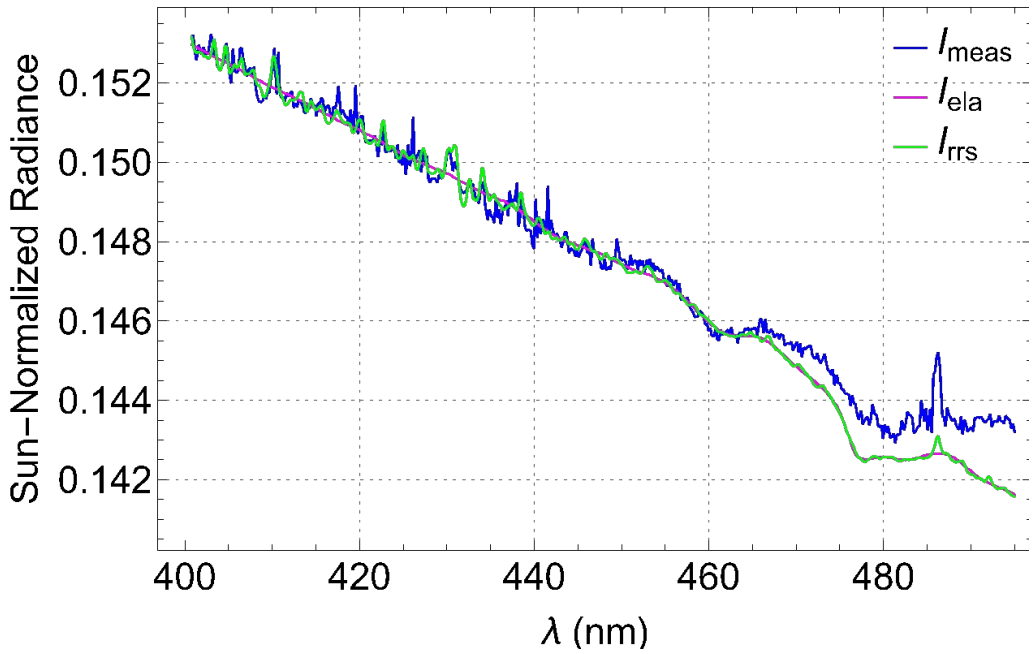
Applications to GEMS and TEMPO

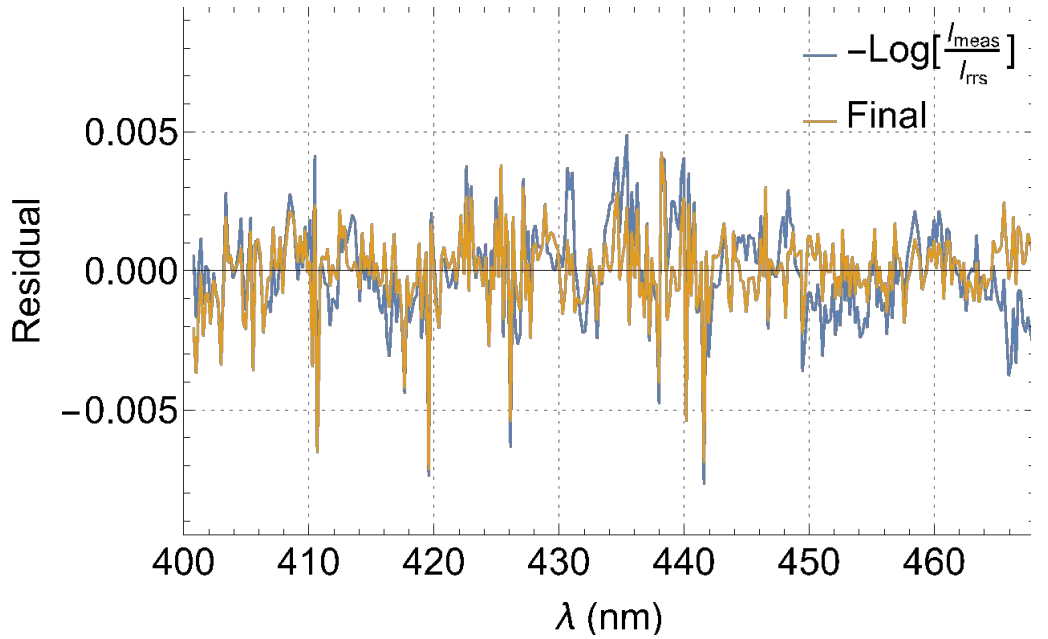
- In preparation for GeoXO ACX, we apply the ACX NO_2 (DVCF) algorithm to proxy data to develop and perfect techniques for handling measurement characteristics:
  - wavelength registrations
  - instrument spectral responses
  - anomalous pixels
  - calibration biases
  - common mode spectra
- Demonstrate accurate and precise retrievals from measurements with various imperfections

Proxy Data

We acknowledge the L1 data providers: US TEMPO team and South Korea's NIER.

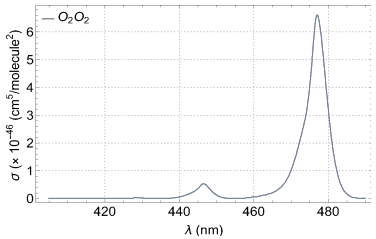
Illustration of ACX NO_2 Retrieval

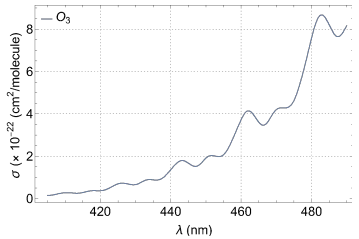


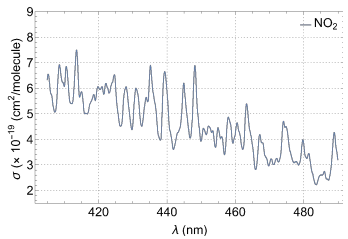


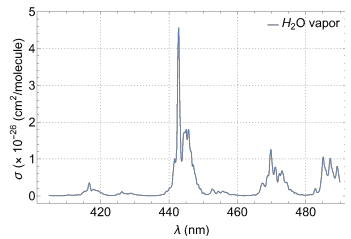
- Information + error are contained in spectral residual: - Log[I_{meas}/I_{rrs}]
- Fitting of residual with reference spectra to extract slant (or vertical) columns

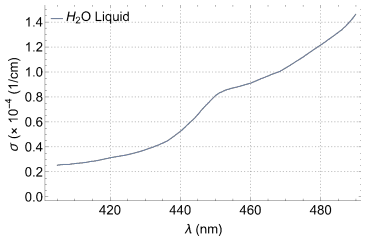
reference spectra



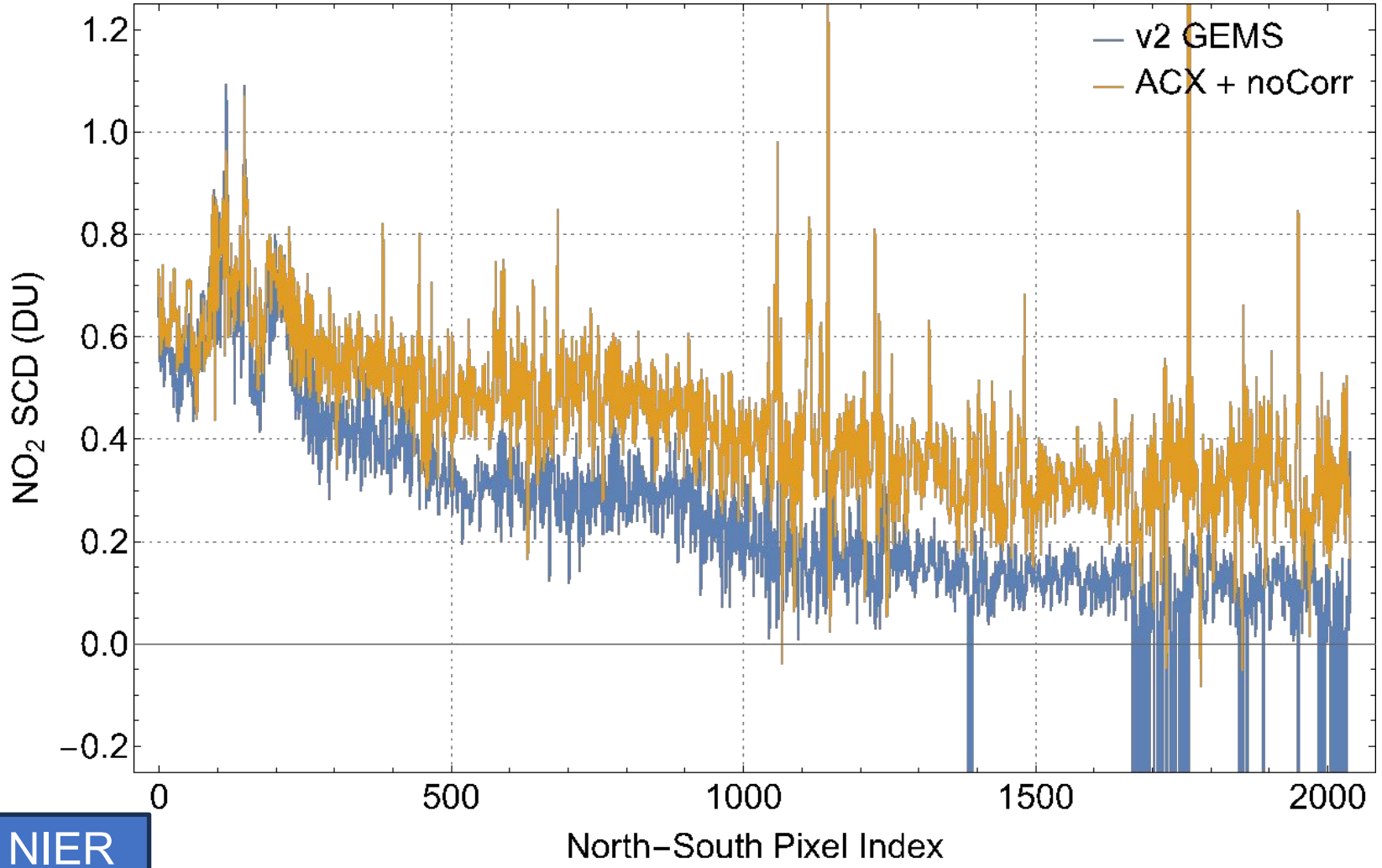








Comparison of GEMS Slant Columns: v2 GEMS vs ACX Algorithm



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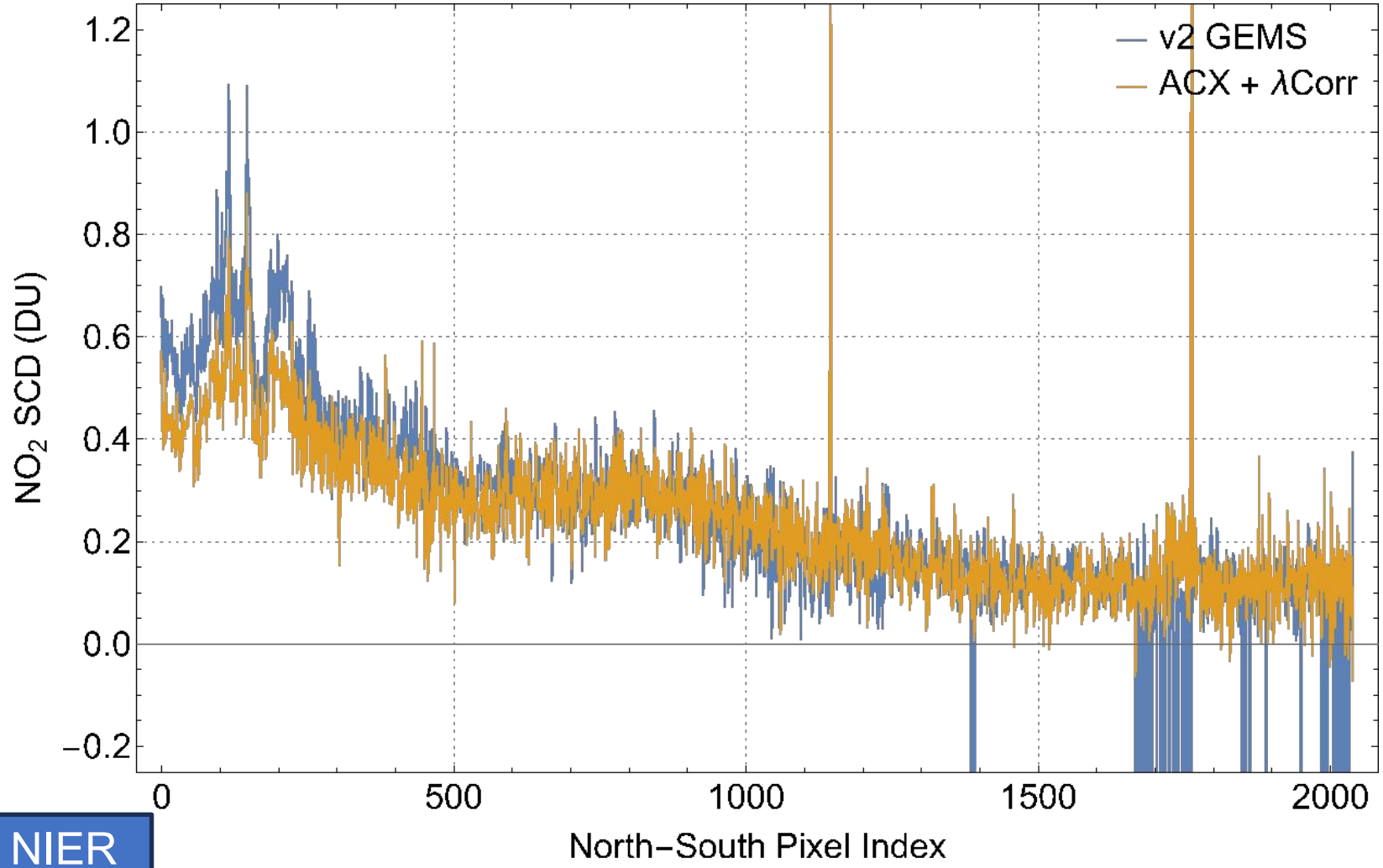
East-West Pixel
Index : 101
Index range 1-695

V2 GEMS is from NIER

Comparison of GEMS Slant Columns: v2 GEMS vs ACX Algorithm



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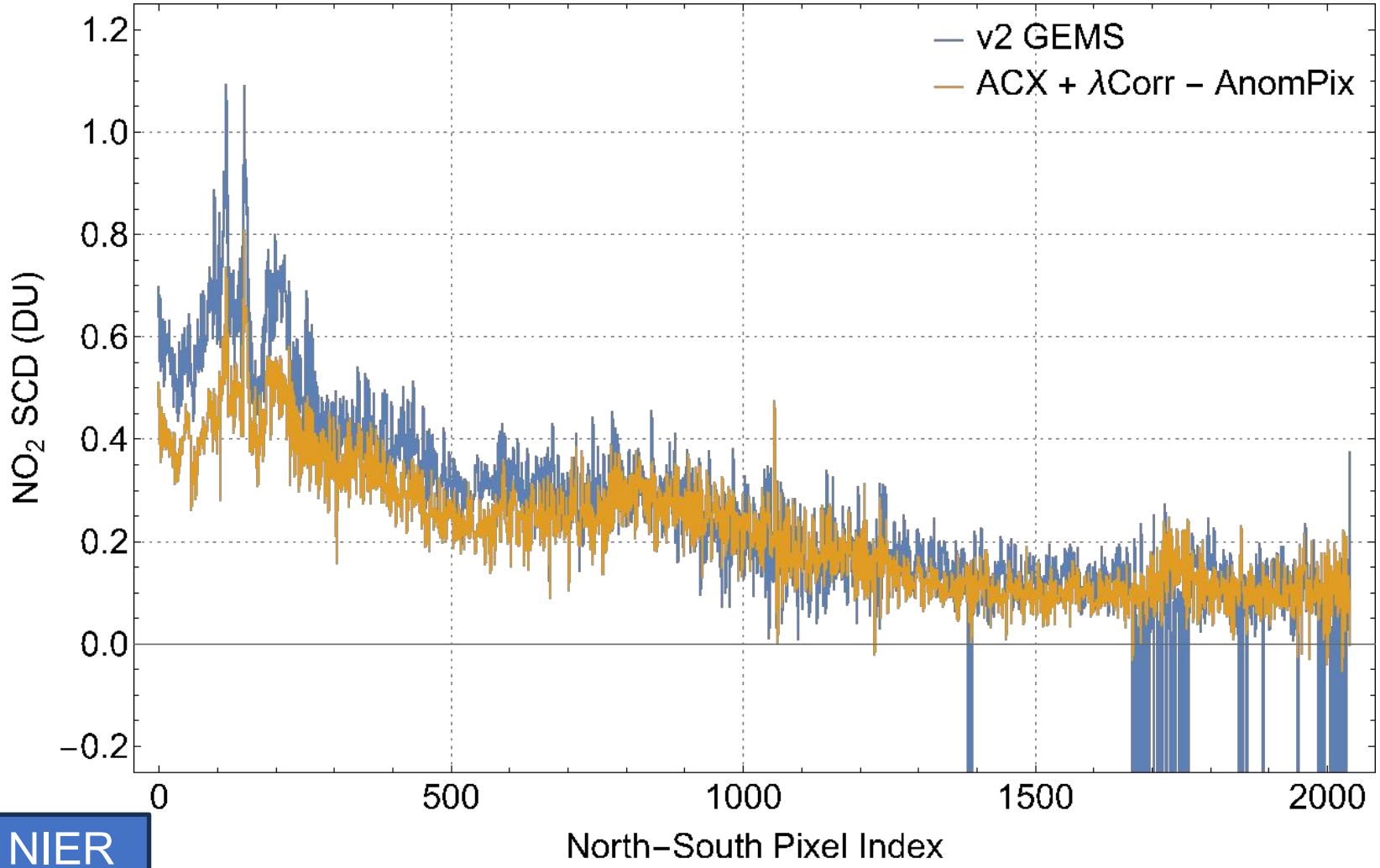
V1 GEMS is from NIER

Comparison of GEMS Slant Columns: v2 GEMS vs ACX Algorithm



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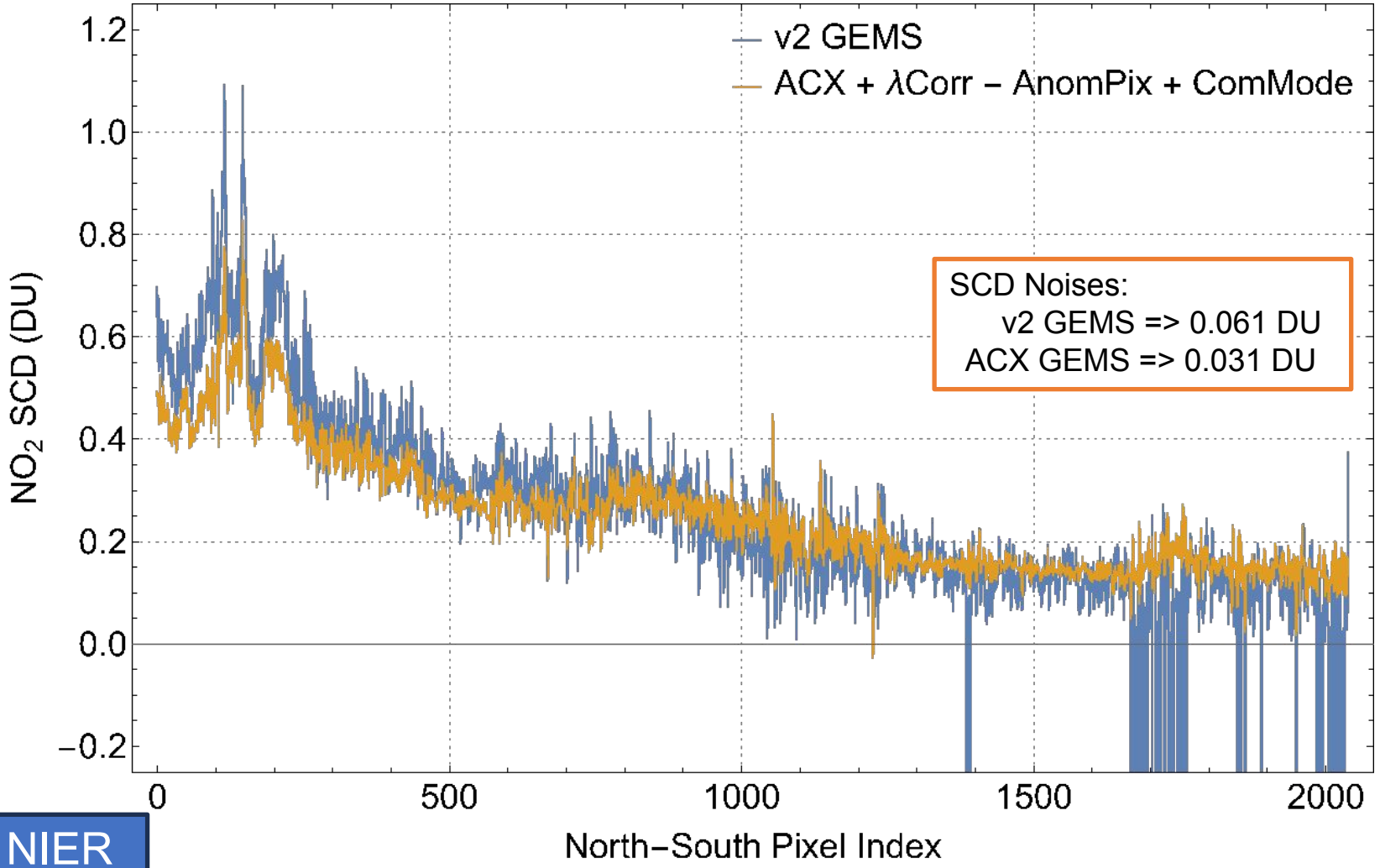
V1 GEMS is from NIER

Comparison of GEMS Slant Columns: v2 GEMS vs ACX Algorithm

Precision improvements means more reliable detections of small NO_2 variations, especially important for regions with low pollution levels, e.g., over US.



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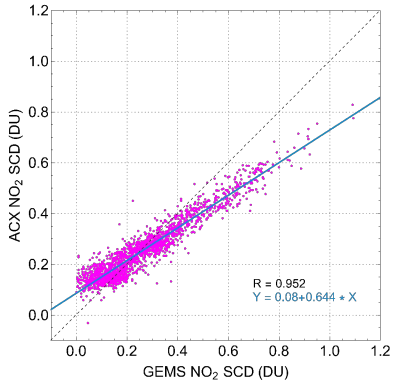
Index : 101
Index range 1-695



V2 GEMS is from NIER

Intercomparisons of Slant Columns: TROPOMI vs GEMS and vs TEMPO

A retrieval algorithm may be separated into two parts

1. Information content quantification => retrieve slant columns
2. Interpretation of Information content => derive vertical columns

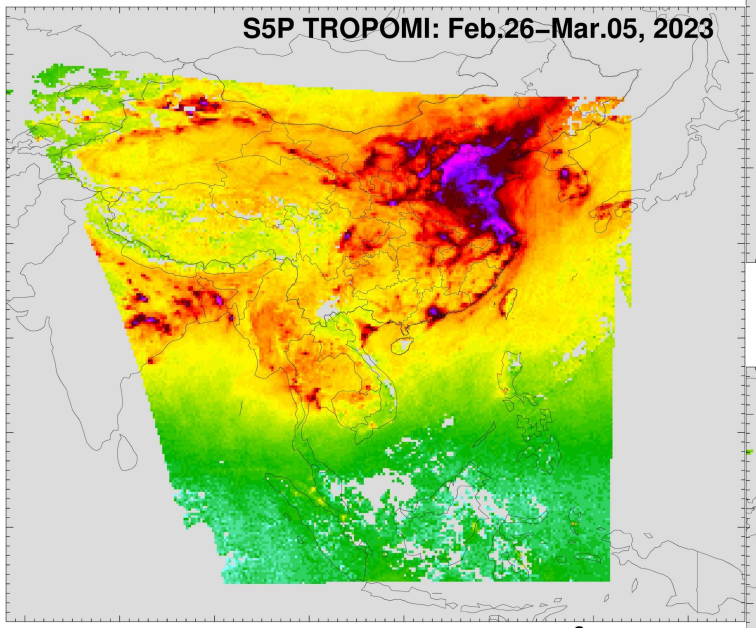
- Slant columns are independent of retrieval assumptions of vertical profiles, surface reflections, and clouds/aerosols, while vertical columns depends on their proper treatments.
- Slant columns are geometry dependent

Sample selection for NO_2 Slant Column Comparisons

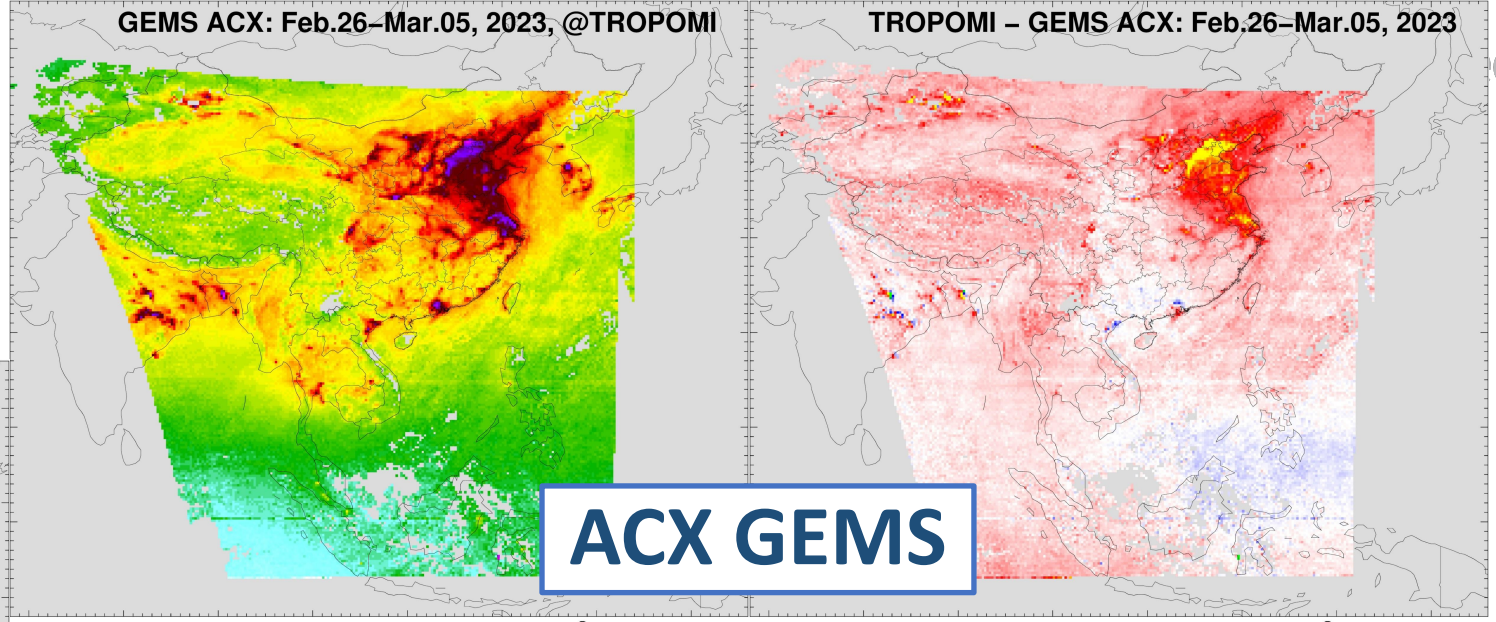
- Near-coincident: same grid cells (0.25° x 0.25°) and ± 30 minutes
- Slant columns are divided by geometric air mass factors (AMF_G) to reduce the impact of path-length difference
- Cloud fraction < 0.2

$$AMF_G = 1/Cos[VZA] + 1/Cos[SZA]$$

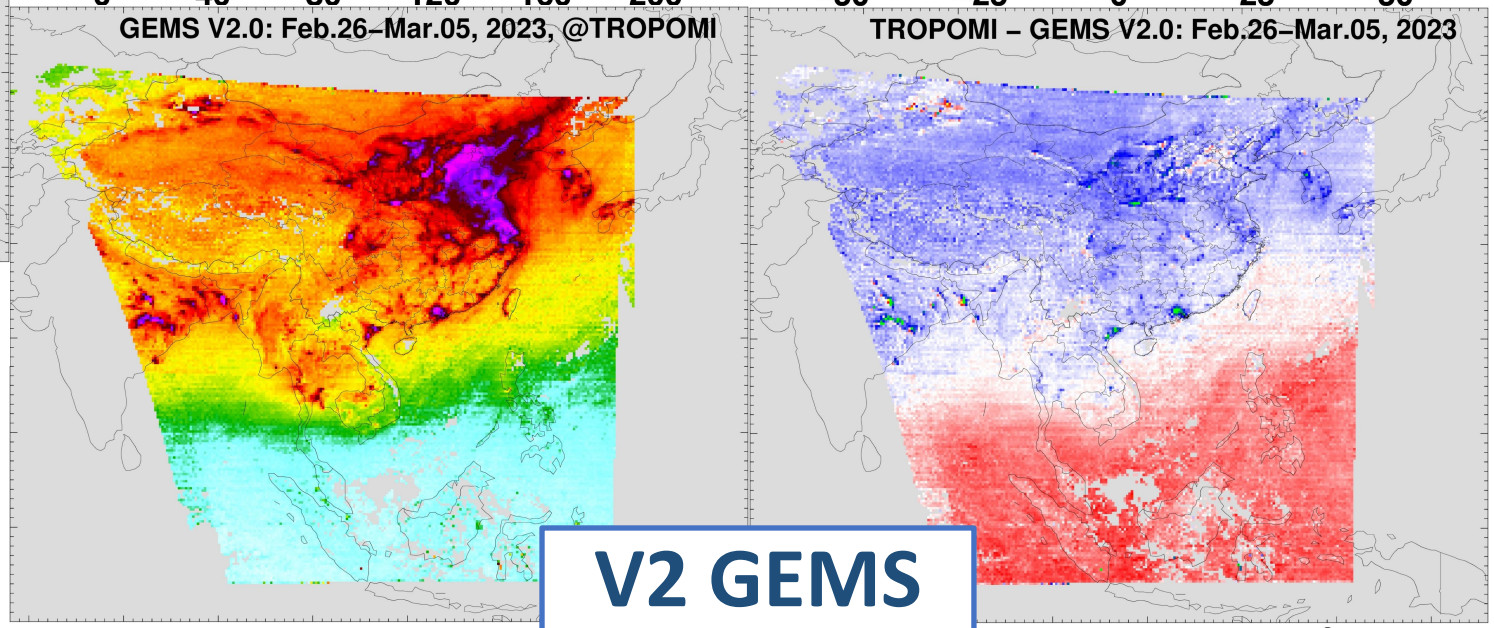
4 days: Feb. 26-27, Mar. 04-05, 2023



TROPOMI

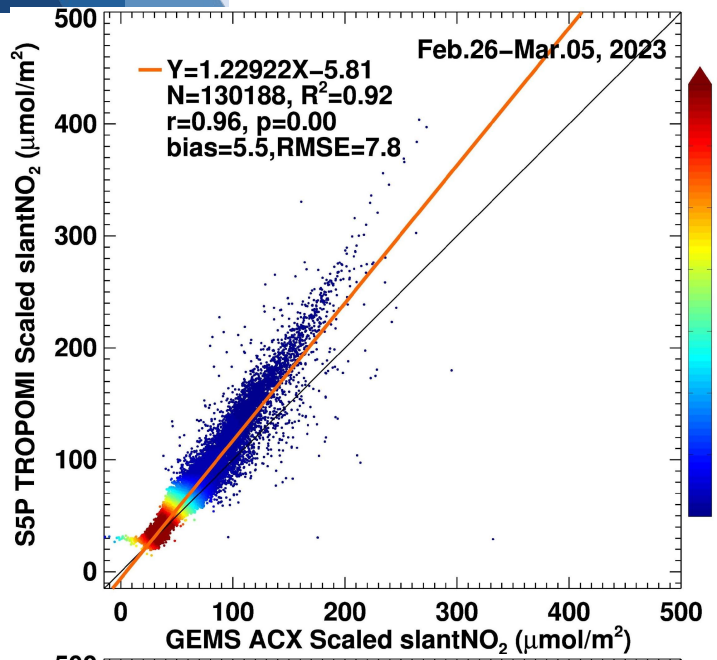


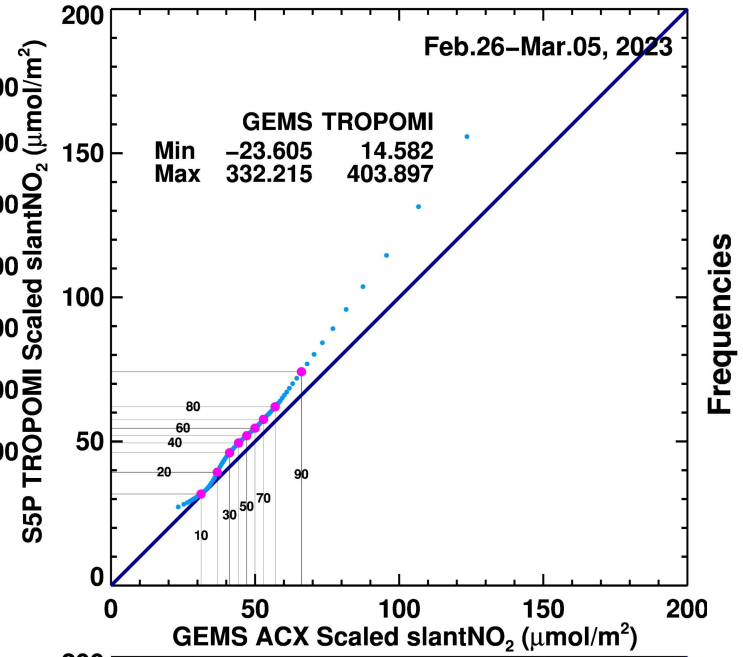
ACX GEMS

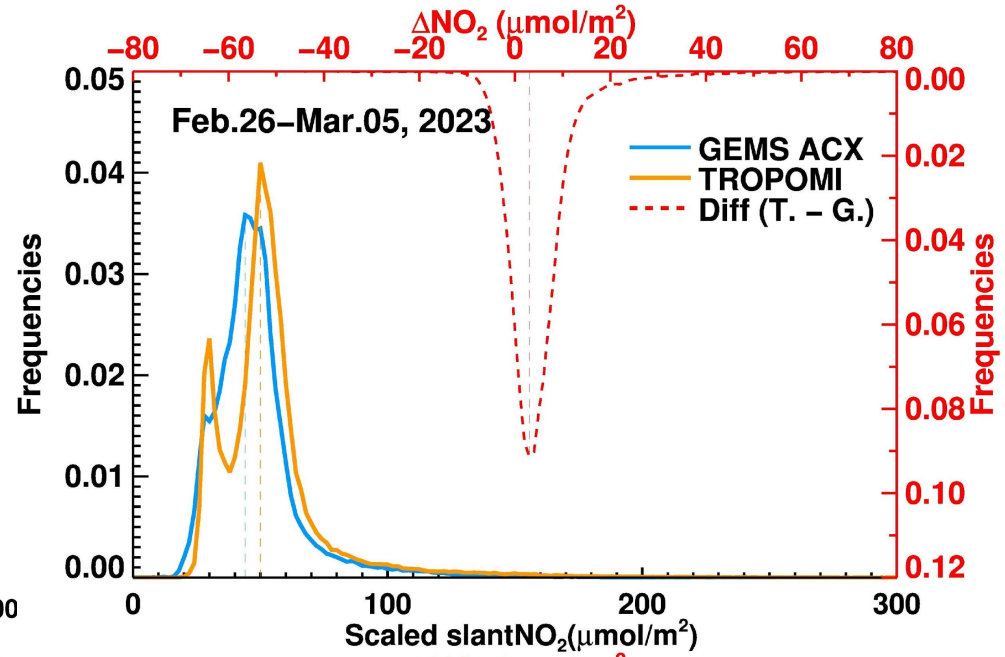


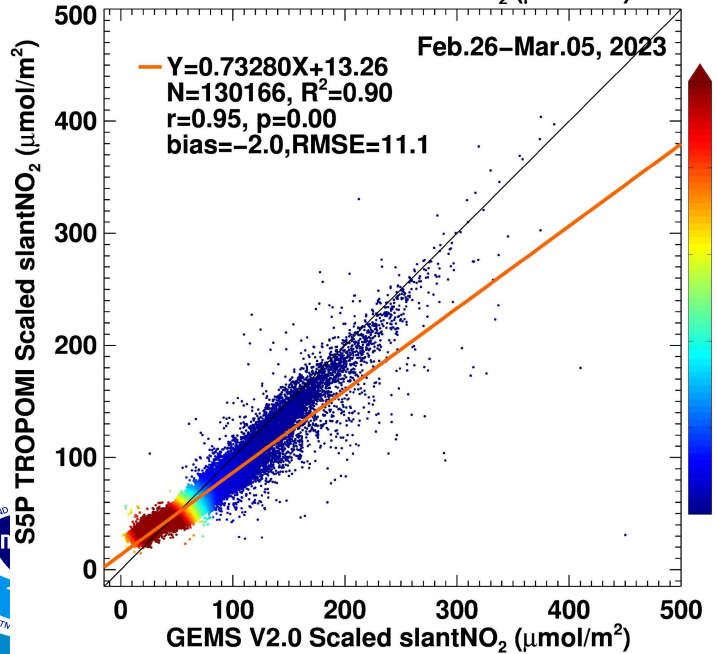
V2 GEMS

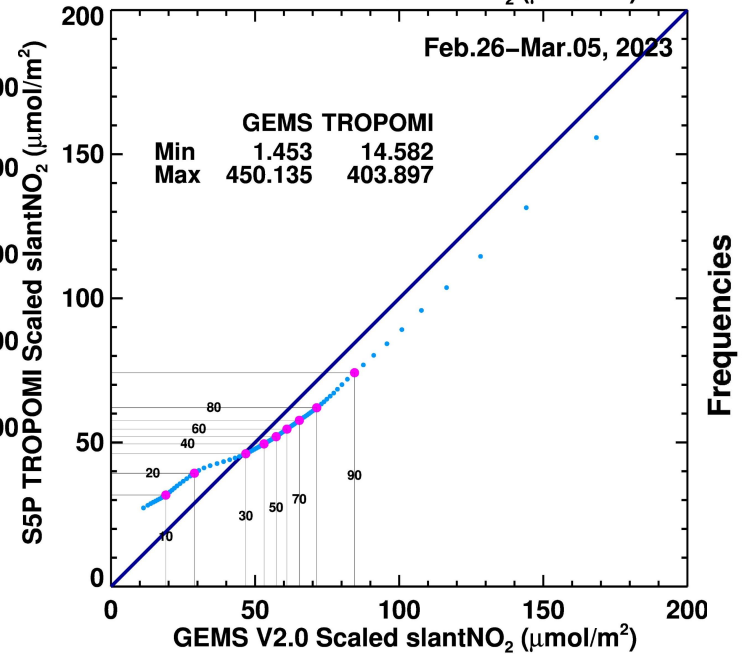
TROPOMI vs ACX and V2 GEMS

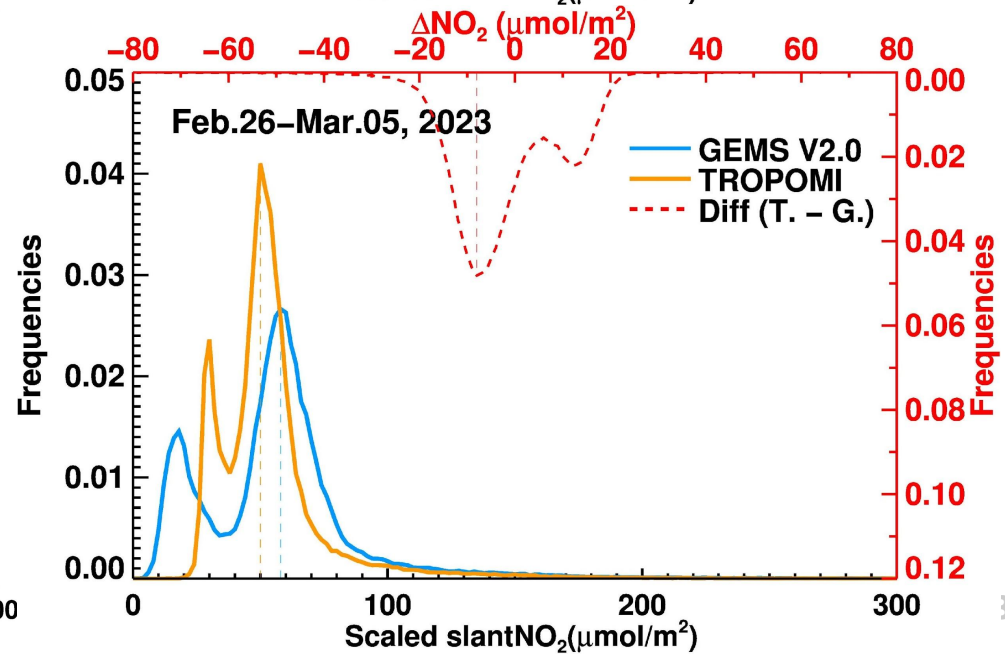




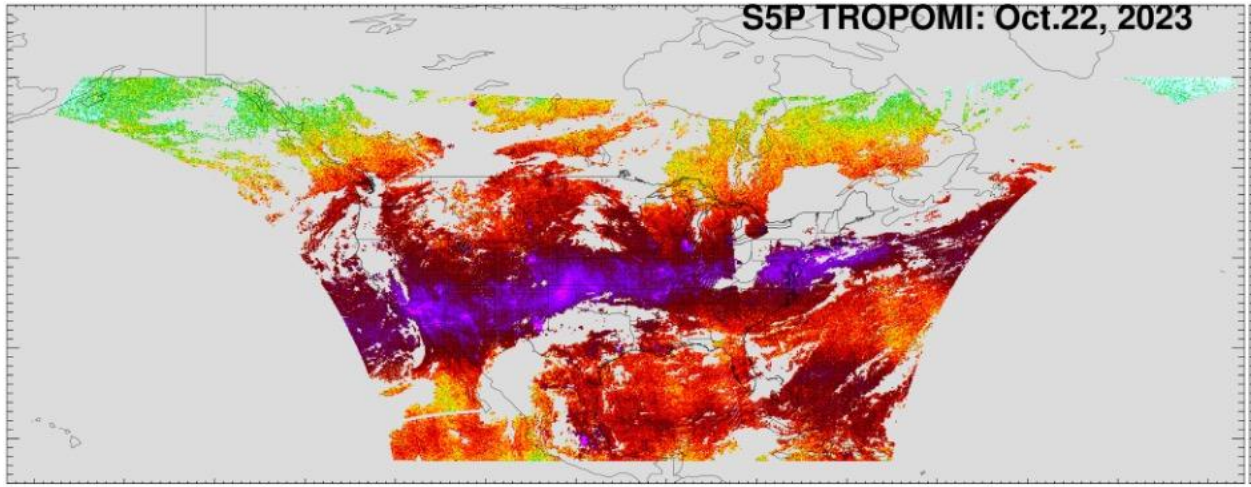


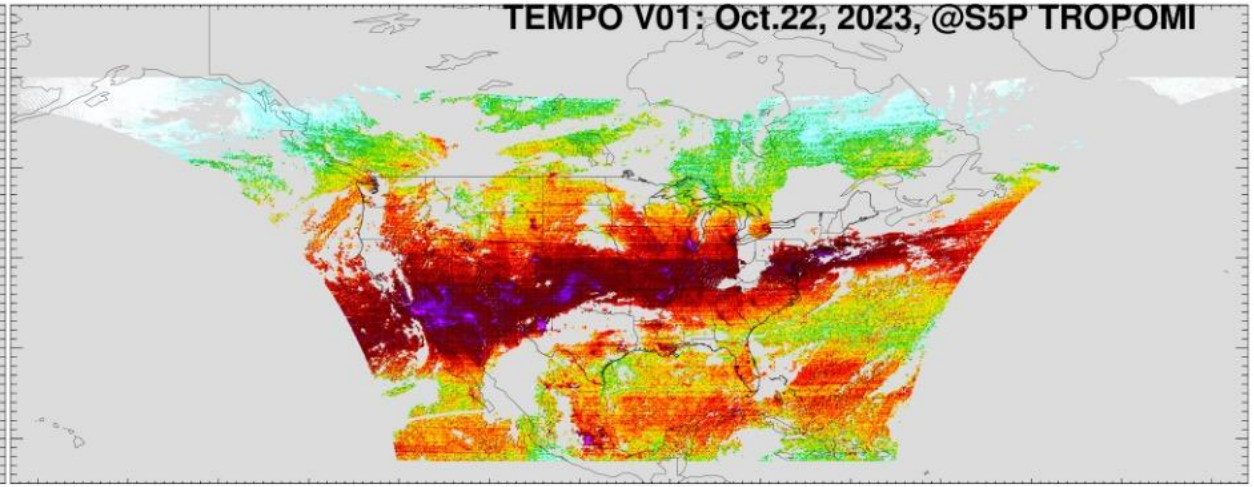






TROPOMI vs V1 TEMPO





Scaled slantNO$_2$ (μmol)/m^2

30 40 50 60 70

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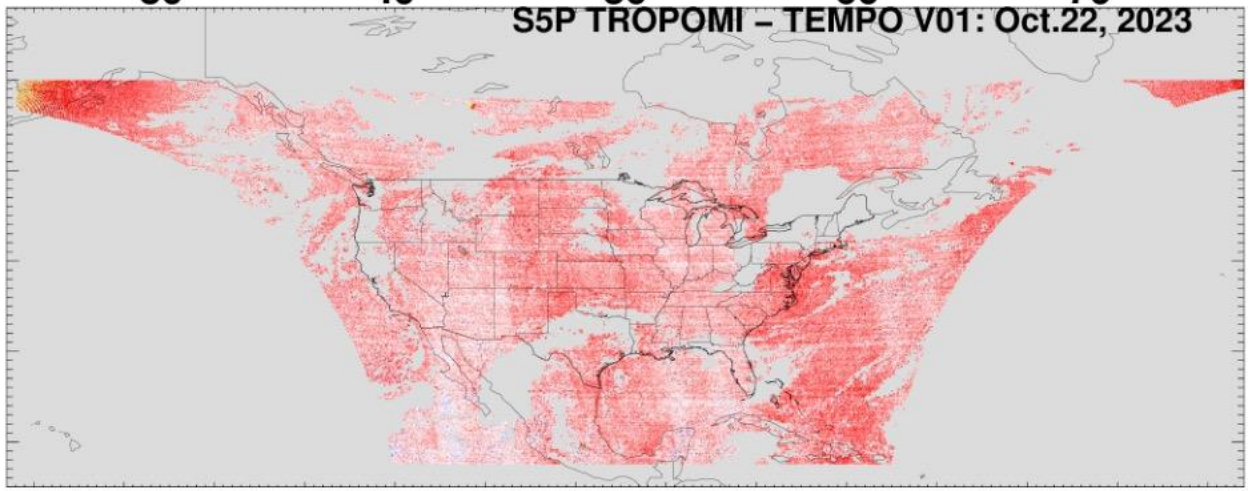
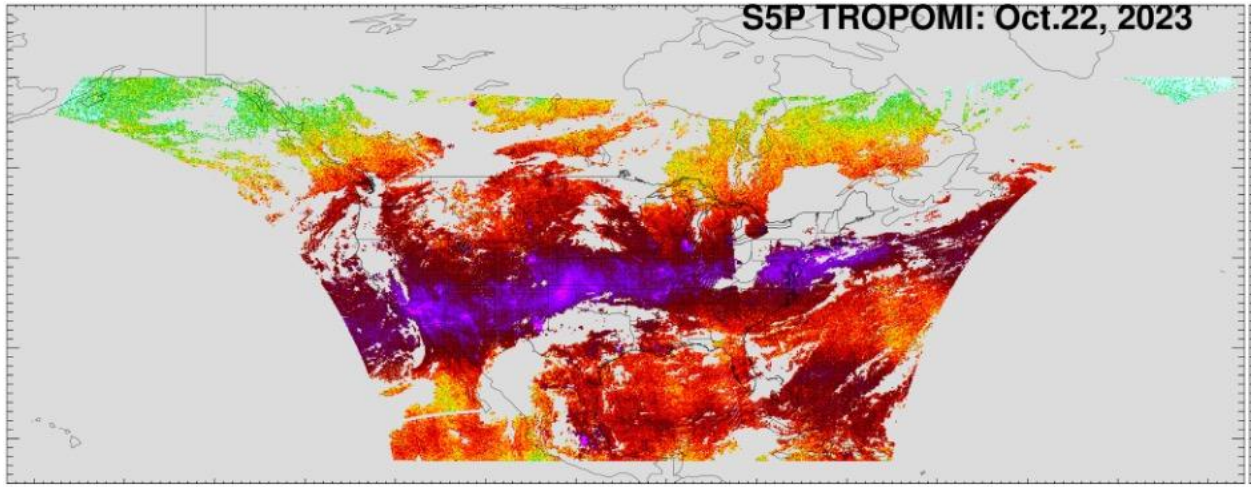
30 40 50 60 70

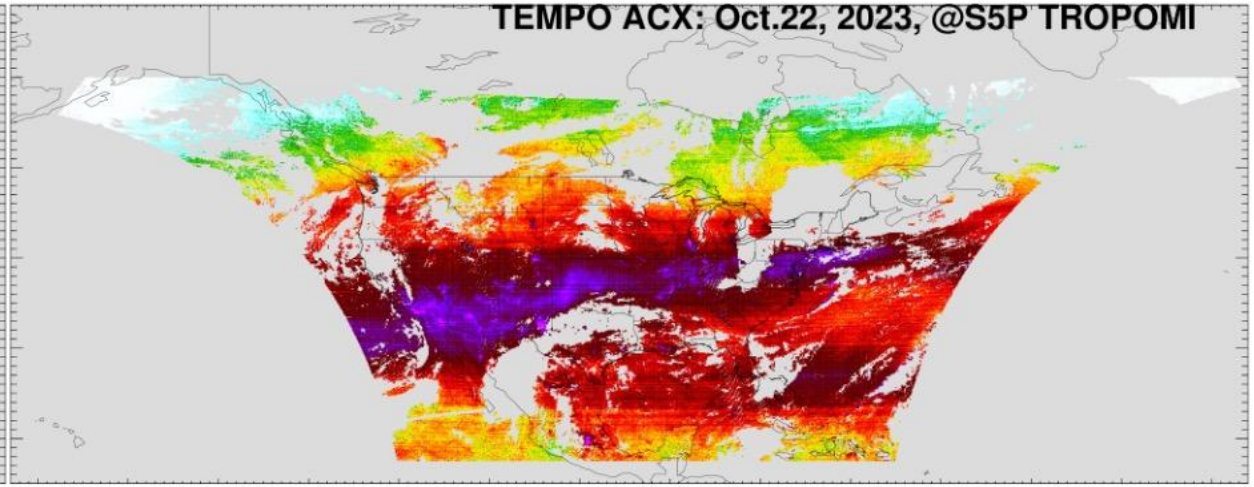


ΔScaled slantNO$_2$ (μmol)/m^2

−30 −20 −10 0 10 20 30

TROPOMI vs ACX TEMPO





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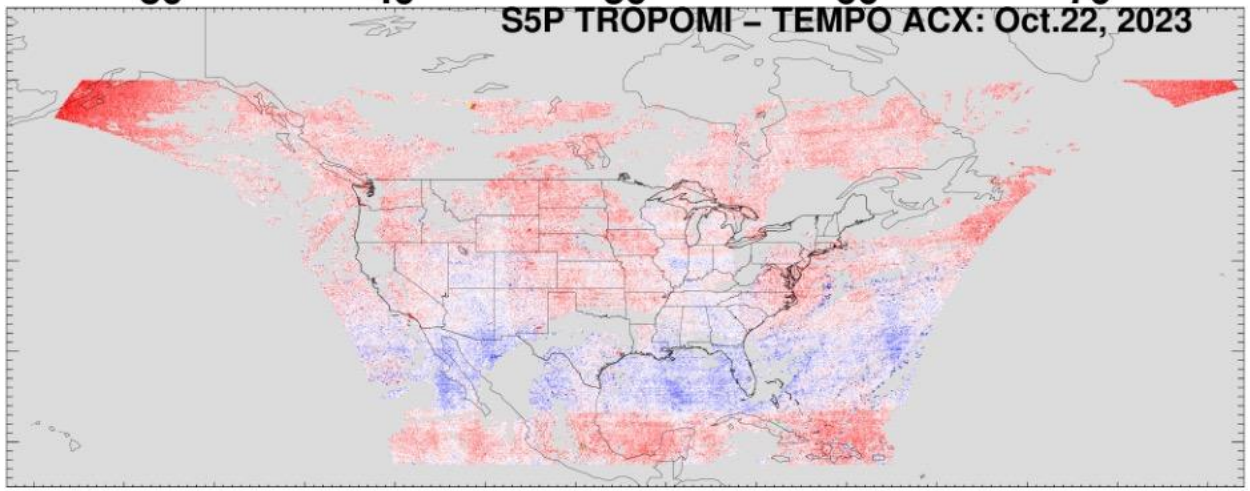
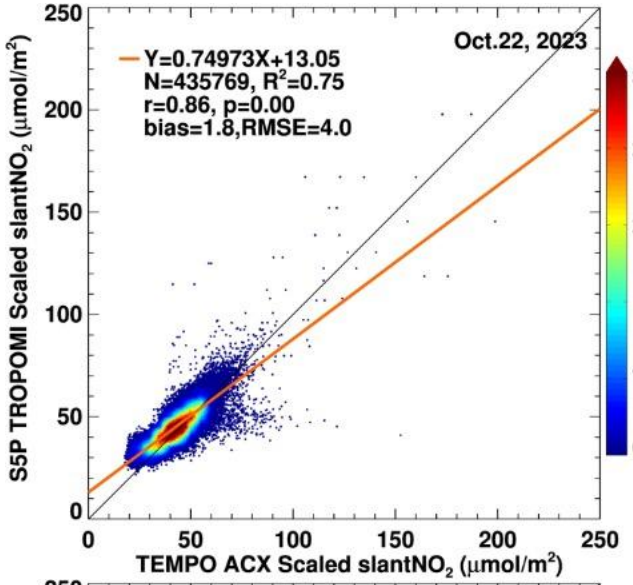
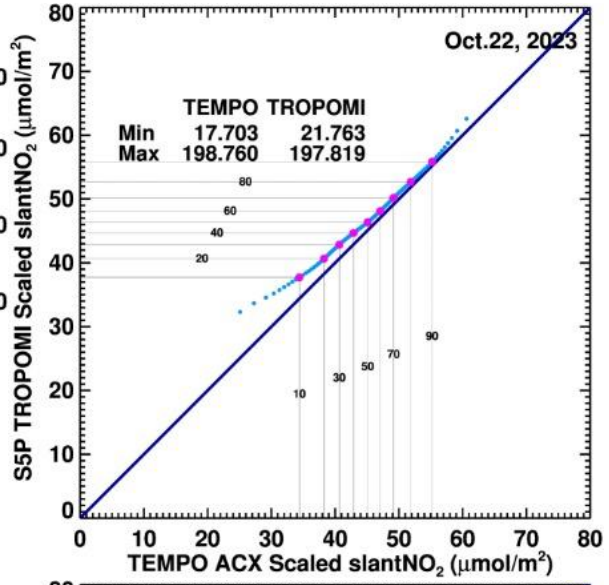


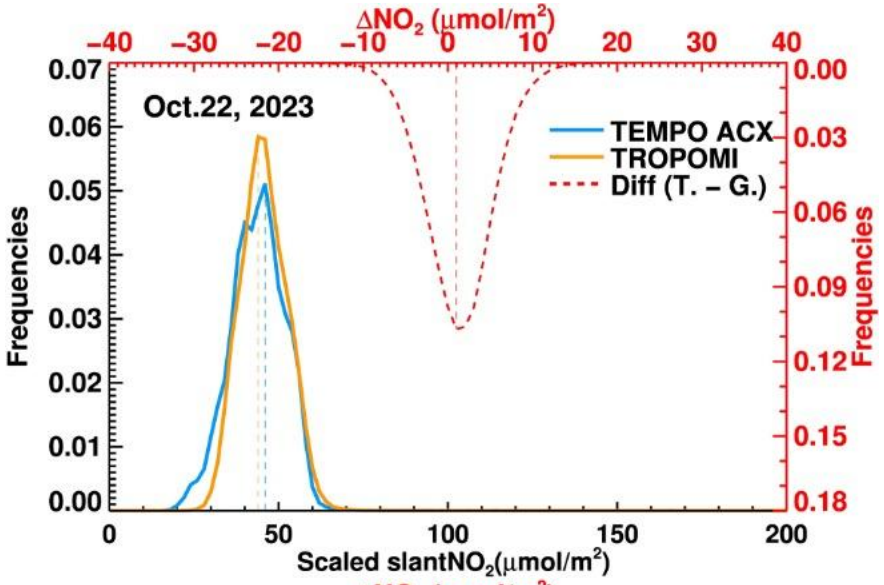
ΔScaled slantNO$_2$ (μmol)/m^2

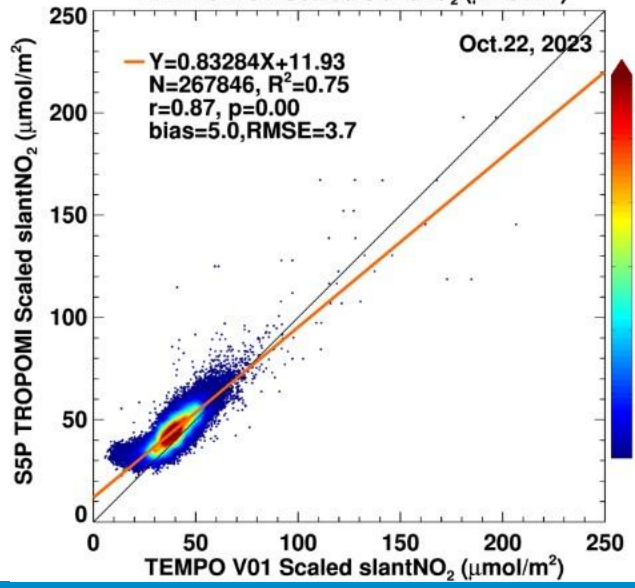
−30 −20 −10 0 10 20 30

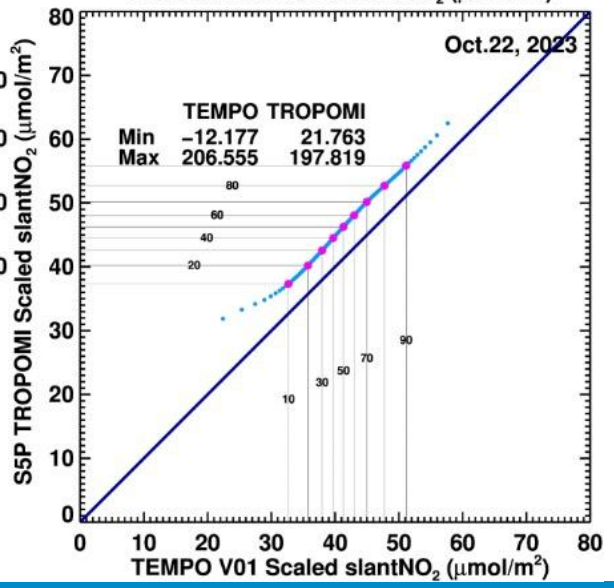
TROPOMI vs ACX and V1 TEMPO

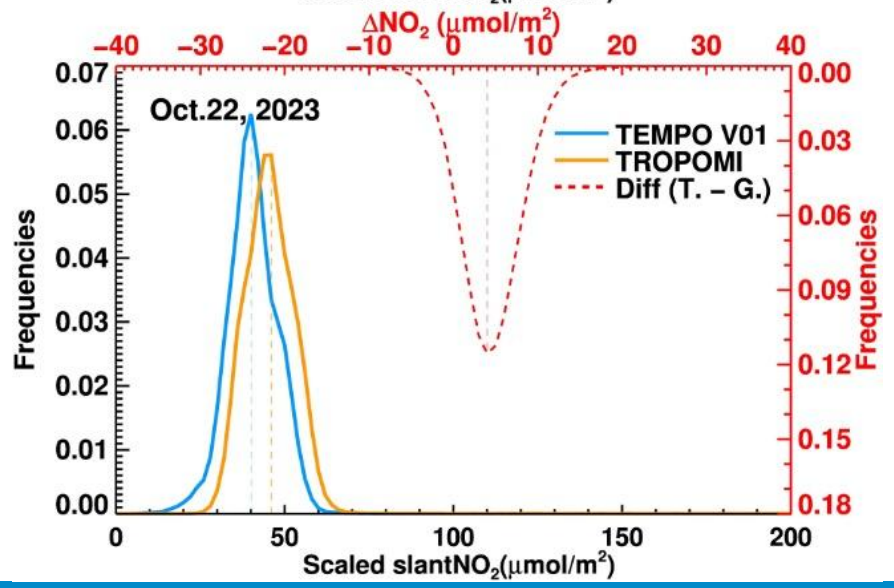










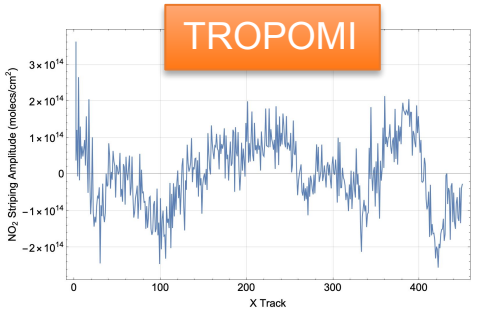


Comparison Summary

- Systematic biases of scaled slant NO_2 columns
  - TROPOMI > ACX TEMPO > v1 TEMPO
  - TROPOMI > ACX GEMS
  - TROPOMI < v2 GEMS at northern latitudes
  - TROPOMI > v2 GEMS at southern latitudes
- ACX TEMPO and ACX GEMS are consistent: bias low similarly against TROPOMI

Source of Biases

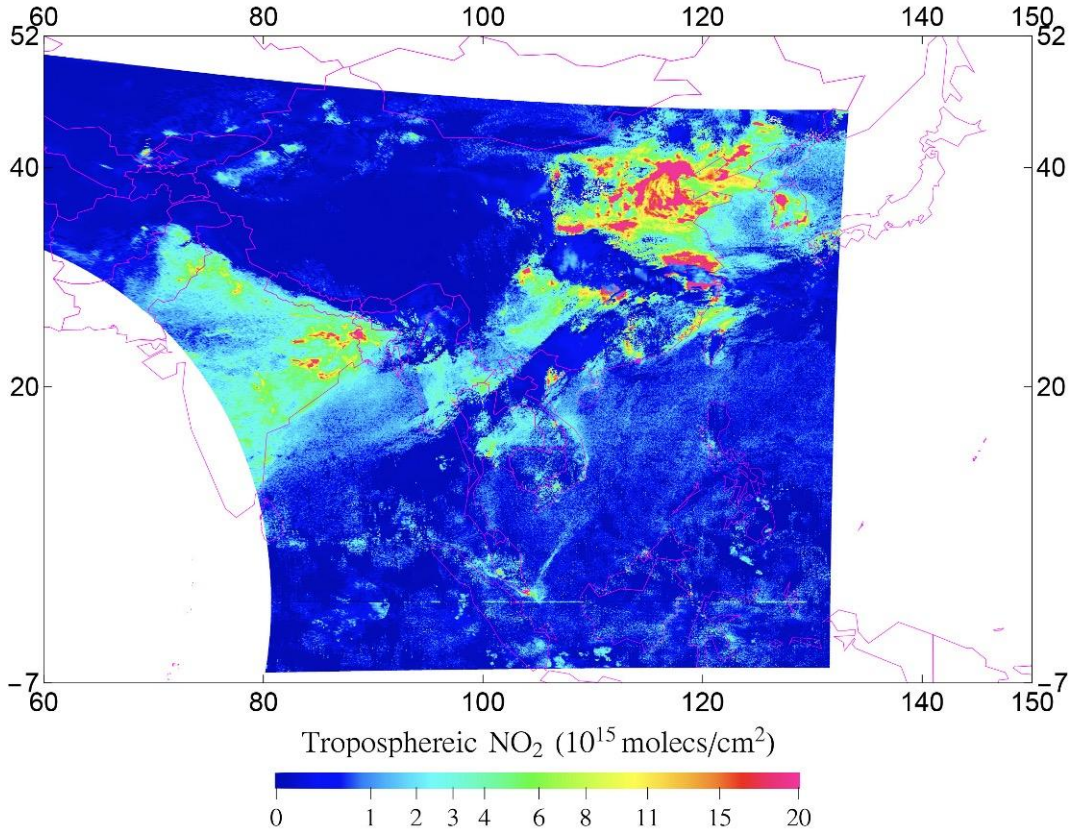
- Systematic biases likely originate from persistent spectral patterns in the sun-normalized radiance spectra, which usually correlate with a molecular absorption spectrum, resulting in biases in the slant columns.
- Corrections (detector dependent)
  - TROPOMI -> Across-track NO_2 slant column stripe offset, 7-day mean, determined over the Pacific Ocean
  - ACX algorithm -> removing common mode spectra derived from residuals over areas with small (< 0.05 DU) tropospheric NO_2 columns.



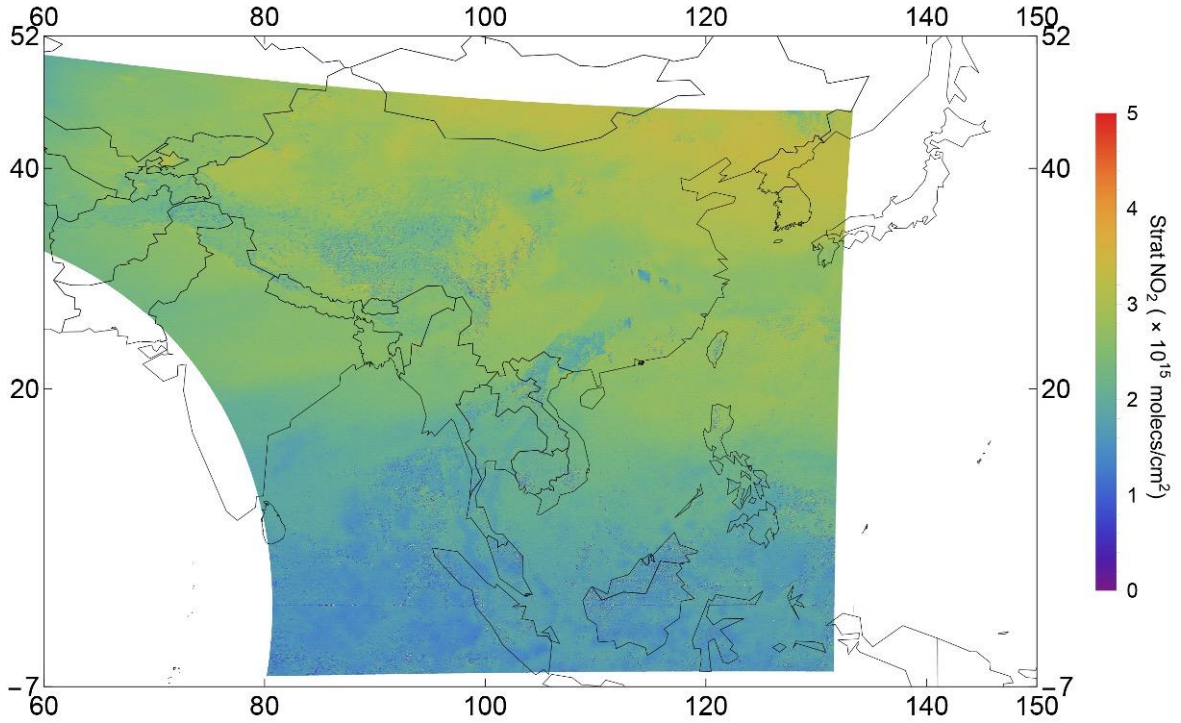
Radiance space corrections work for OMI, OMPS, TROPOMI, GEMS, TEMPO.

ACX Algorithm on GEMS 2021-03-30_0045

Tropospheric NO_2

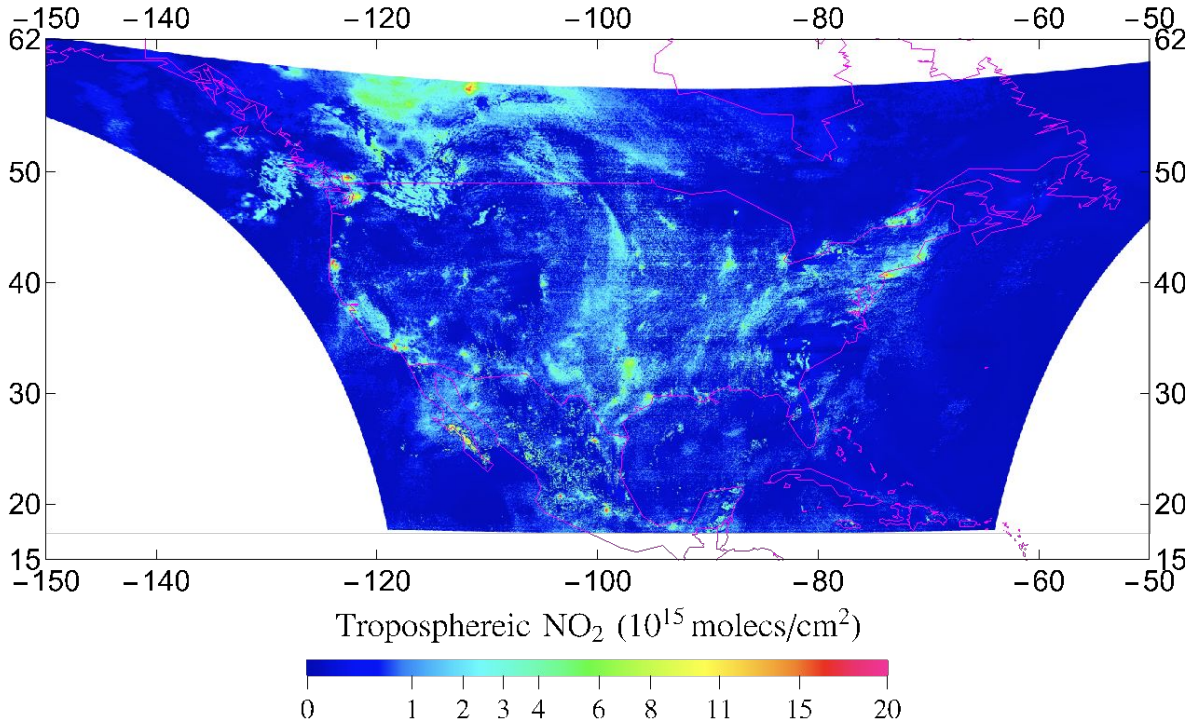


Stratospheric NO_2

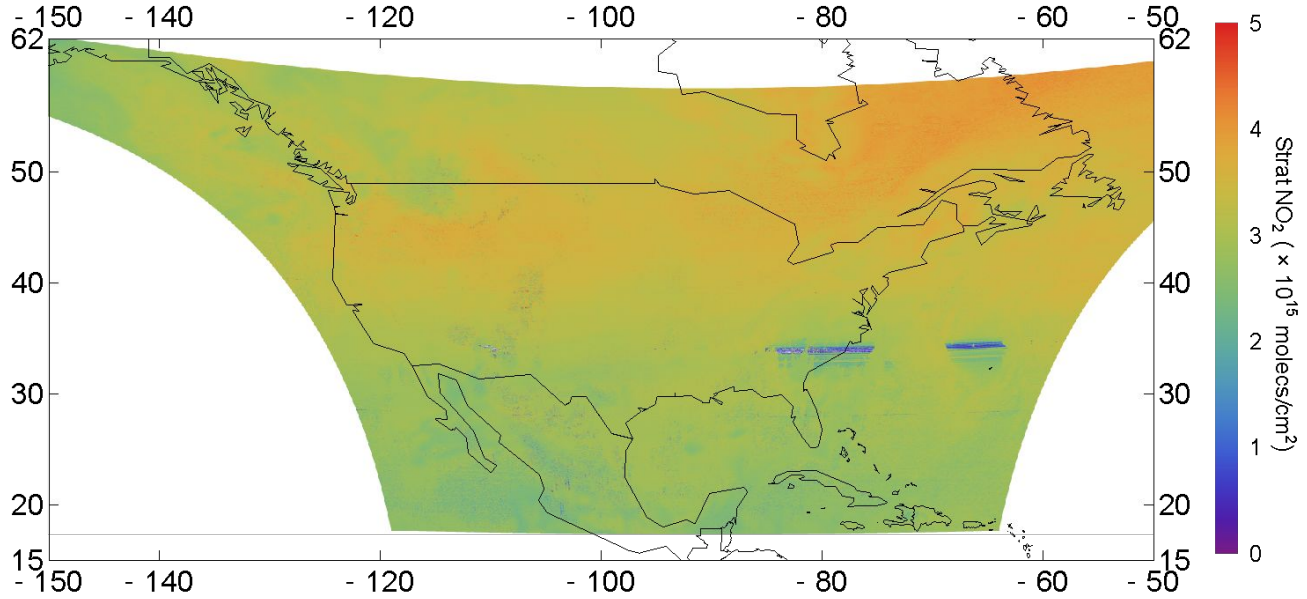


ACX Algorithm on TEMPO 2023-08-30-S010

Tropospheric NO_2



Stratospheric NO_2

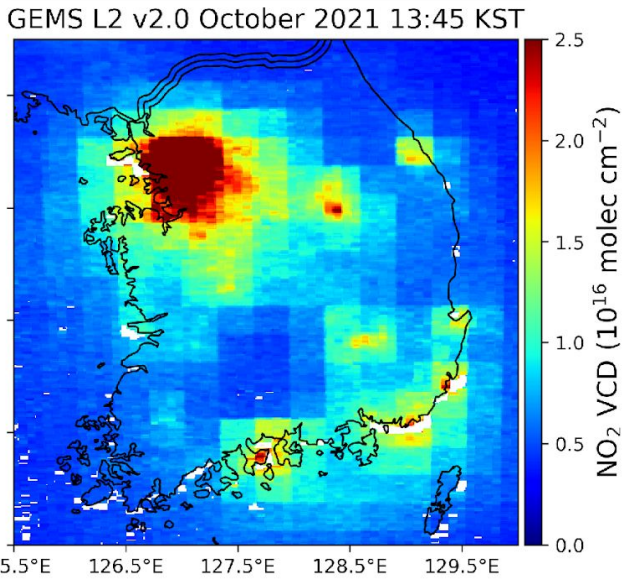


Summary

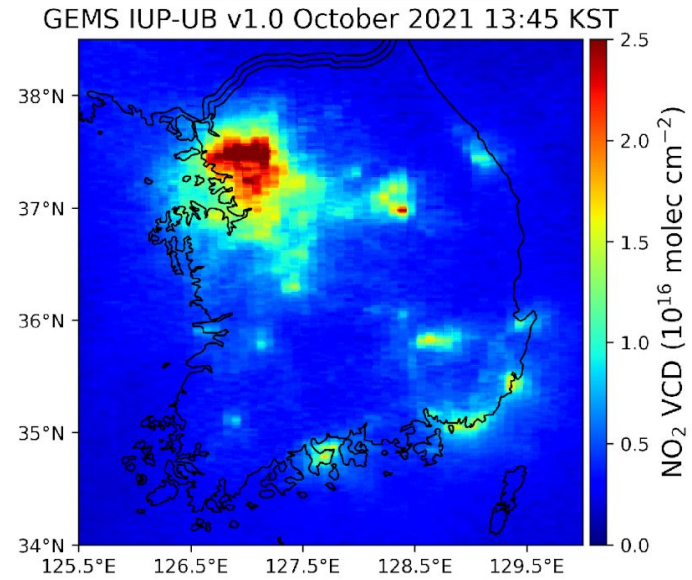
- Applications of the ACX NO_2 algorithm to GEMS and TEMPO yield high-quality (i.e., low noise, few artifacts, and high accuracy) NO_2 products. ACX NO_2 achieved lower noise levels than the corresponding standard products.
- Demonstrate the capability of rapid (near-real-time) production of high quality NO_2 data soon after ACX starts Earth observation

Intercomparisons of Tropospheric NO_2 Monthly Means for October 2021

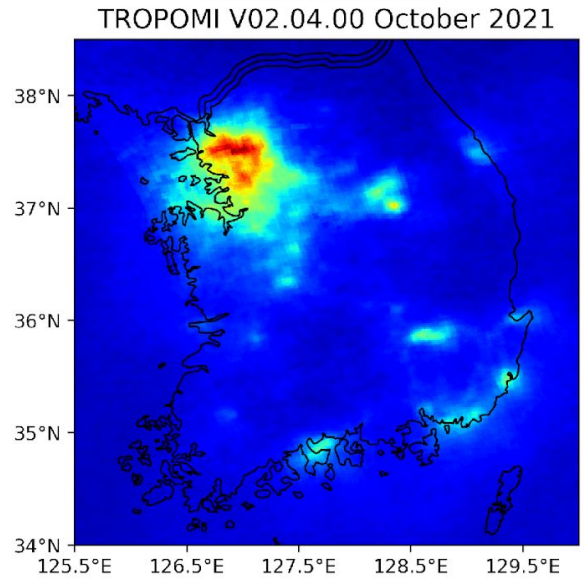
GEMS Standard Product



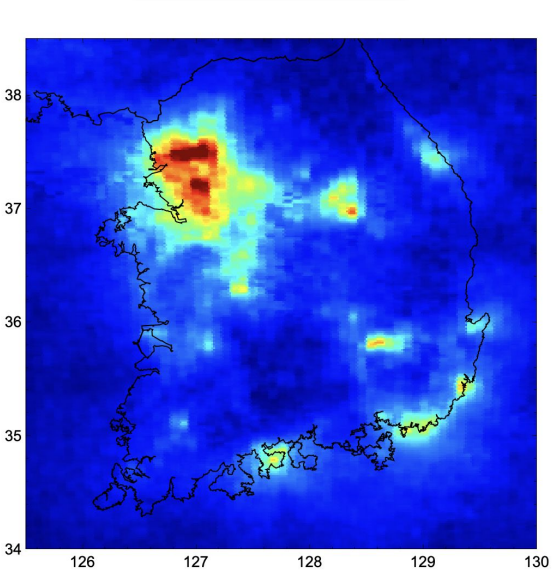
GEMS IUP-UB



TROPOMI



GEMS ACX



Left 3 panels are copied from https://doi.org/10.5194/egusphere-2024-6

Plan

- Algorithm physics improvements: surface reflection (BRDF), aerosol/cloud treatments
- Implementation of joint UV and visible retrievals for NO_2 stratosphere-troposphere separation
- Extensive comparisons and validations to verify the ACX NO_2 accuracy and quantify its uncertainties

Acknowledgement

- We thank the TEMPO science team and the NIER (South Korea's National Institute of Environmental Research) for providing L1 data used in our algorithm development.