Hourly Nitrogen Oxides Emissions Estimated From TEMPO and Comparison With Facility-Level Monitoring Data

Jobaer Ahmed Saju[1], Kang Sun[1,2], Caroline R. Nowlan[3], Gonzalo Gonz´alez Abad[3] and Xiong Liu[3]
[1]Department of Civil, Structural and Environmental Engineering, University at Buffalo, Buffalo, NY, USA
[2]Research and Education in Energy, Environment and Water Institute, University at Buffalo, Buffalo, NY, USA
[3]Atomic and Molecular Physics Division, Center for Astrophysics | Harvard & Smithsonian, Cambridge, MA, USA

Acknowledgement:
KS and JAS
- NSF CAREER
- NASA FINESST (2025-2028 Cohort)
CRN, GGA, and XL
- NASA TEMPO Mission

Introduction

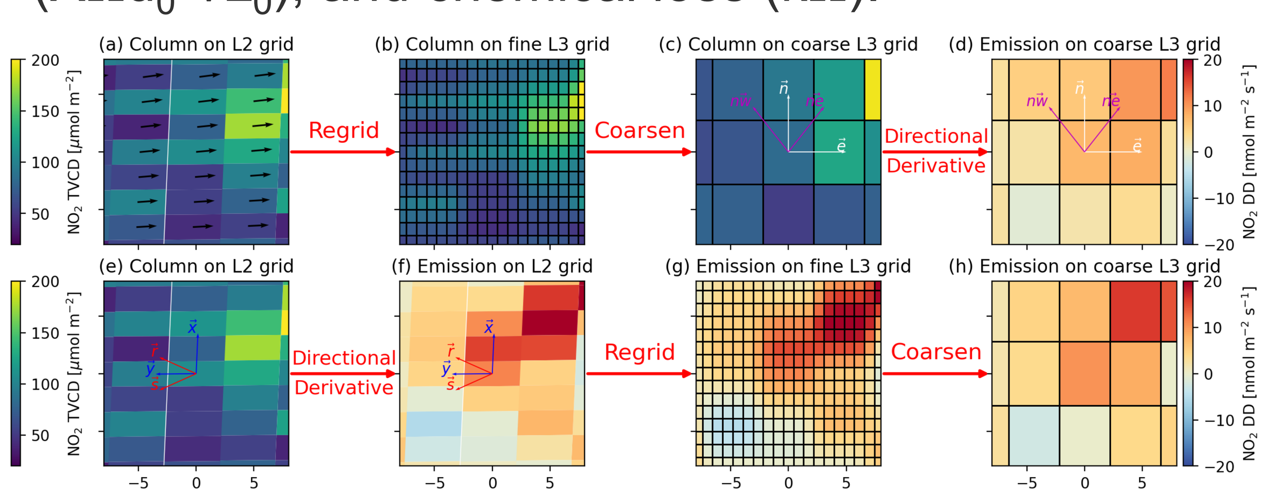
- Nitrogen oxides (NOx) play a critical role in air quality and human health.
- TEMPO provides hourly NO_2 measurements over North America from geostationary orbit.
- Emissions can be estimated from satellite-observed column amounts (Ω), while the existing methods rely on steady-state assumption.
- This study demonstrates hourly NOx emission estimation using TEMPO produced NO_2 Tropospheric vertical column amounts (TCVDs).

Methods

- The directional derivative approach (DDA) is applied to L2 hourly NO_2 TVCDs from TEMPO, incorporating the column tendency term to relax the steady-state assumption.

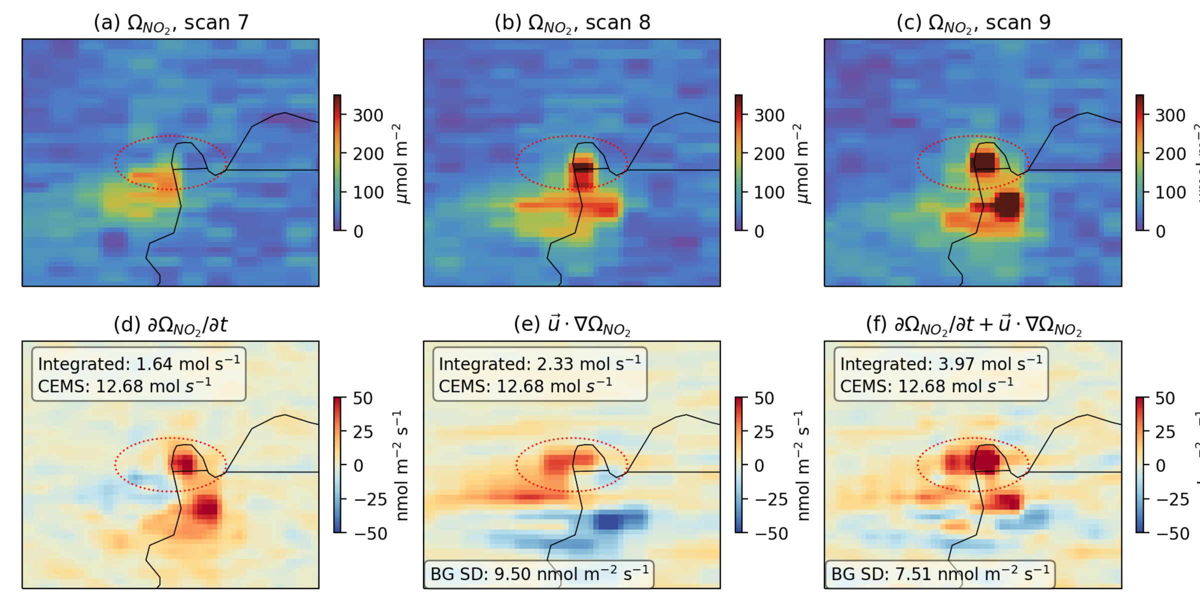
$$E = \underbrace{\underbrace{\overbrace{\frac{\partial\Omega}{\partial t} + \underbrace{\vec{u}\cdot(\nabla\Omega)}_{DD}}^{DD'} + X\Omega\vec{u_0}\cdot(\nabla z_0)}_{DD\_topo} + k\Omega}_{DD\_chem} \qquad (1)$$

Emissions (E) are derived from the tendency ($\partial\Omega/\partial t$), advection ($u\cdot\nabla\Omega$), topographic effects ($X\Omega u_0\cdot\nabla z_0$), and chemical loss ($k\Omega$).

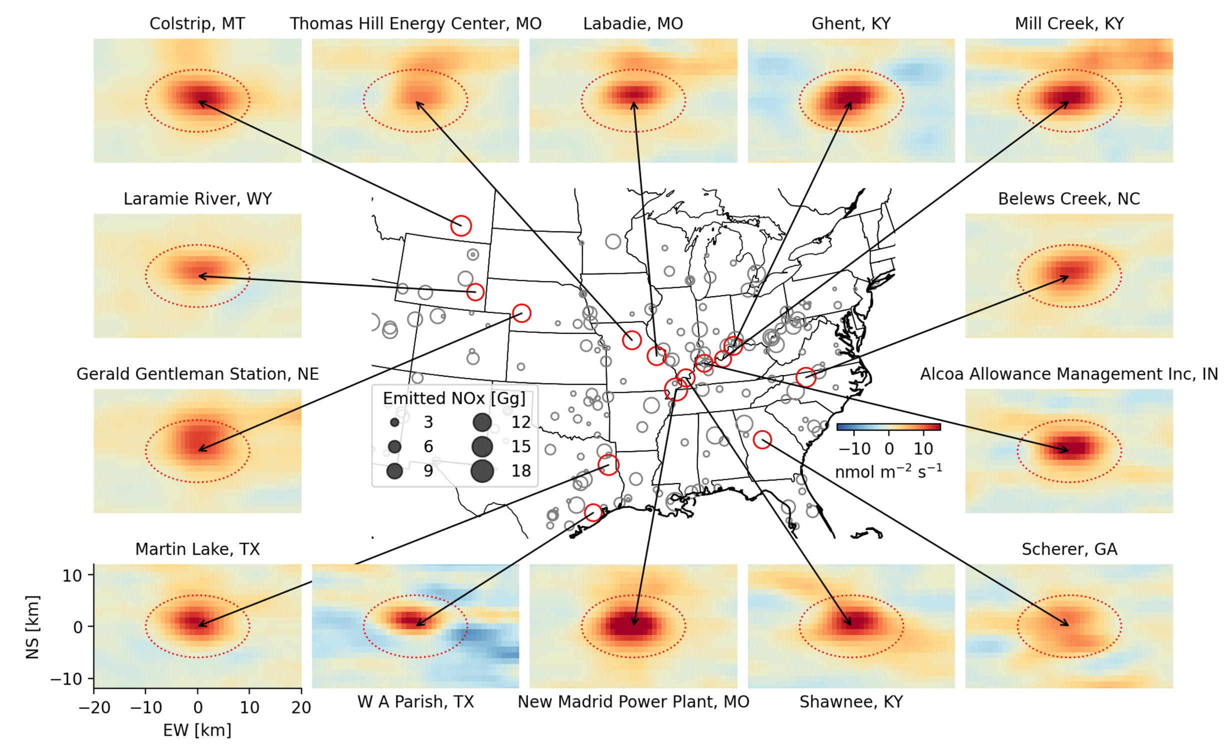


- The L3→4 (top row) method re-grids L2 NO_2 TVCDs to a finer L3 grid, then coarsens and estimate emissions, but loses spatial detail due to pixel coarsening.
- We use L2→4 (bottom row) method that computes emission directly on native L2 pixel coordinates, preserving TEMPO's resolution for detailed emission mapping.

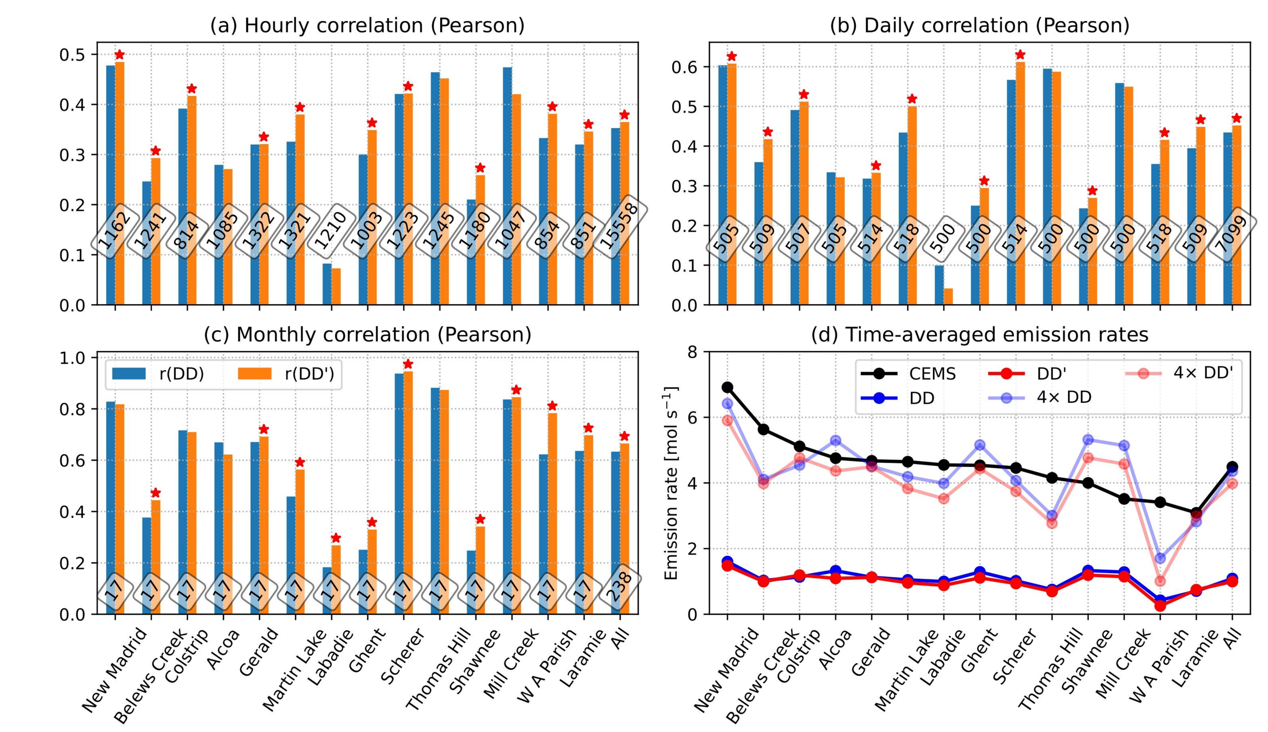
Results



- The tendency term contributes 40% to the DD′-based emission rate over the New Madrid Power Plant on 1 November 2023 (Scan 8 at 12:00 local time), and the southeast negative anomaly (e) is compensated when tendency is added to DD (f).

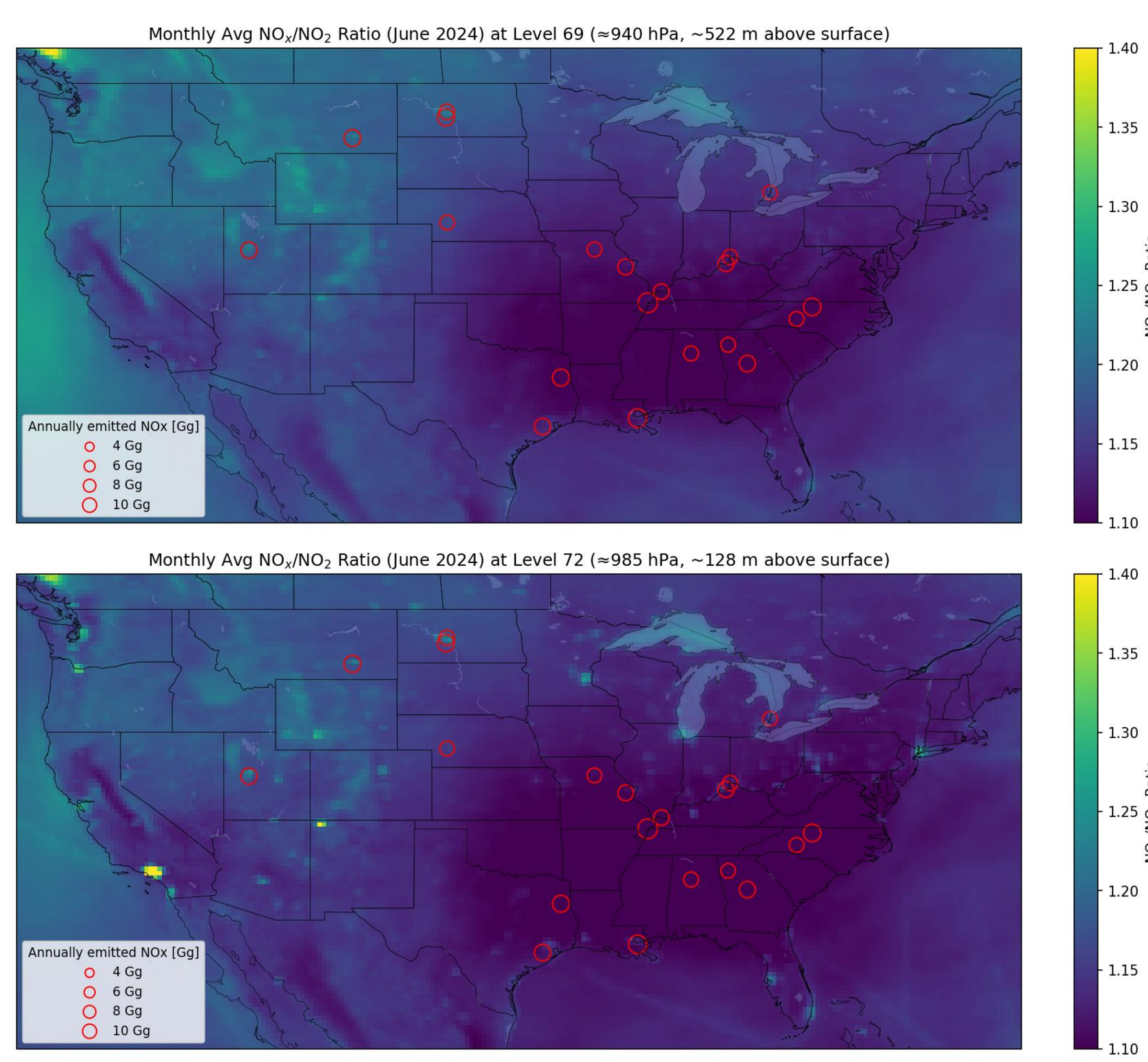


- The DD′ estimator from the L2→4 method near 14 power plants, calculated on 0.01° grids, resembles a 2D Gaussian kernel elongated east–west, matching theoretical point spread function of DDA emission estimator.

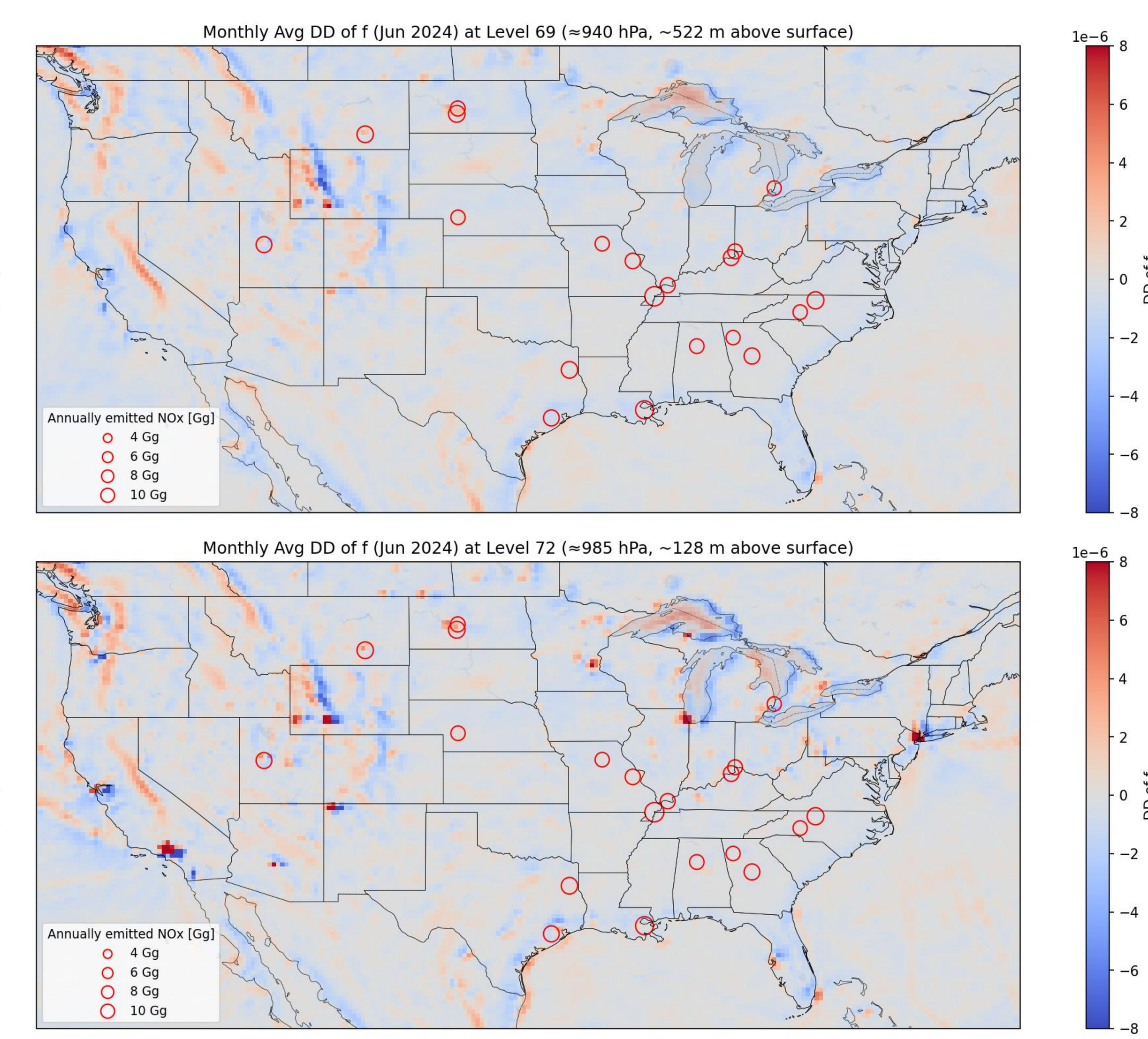


- In 10 of the 14 individual cases and in the combined analysis, DD′ shows a higher correlation with CEMS emissions than DD.
- The fourfold low bias (d) is likely caused by underestimated NOx/NO_2 ratio near the stack.

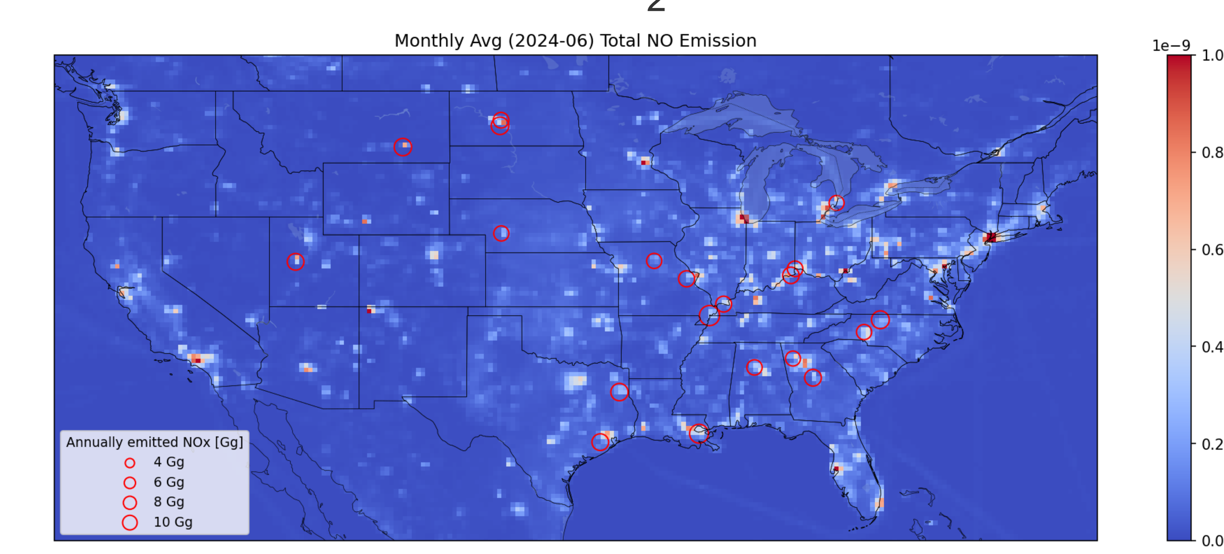
NOx/NO_2 Climatology from GEOS-CF



- GEOS-CF NO and NO_2 data were used to derive $f=NOx/NO_2$ climatology for scaling TEMPO NO_2-based emissions, reducing low bias near high-NO/NO_2 sources.



- The DD of $f=NOx/NO_2$ from GEOS-CF shows spatial patterns that align with major NOx sources.
- This DD of f is essential for applying the climatological f in emission estimation method.

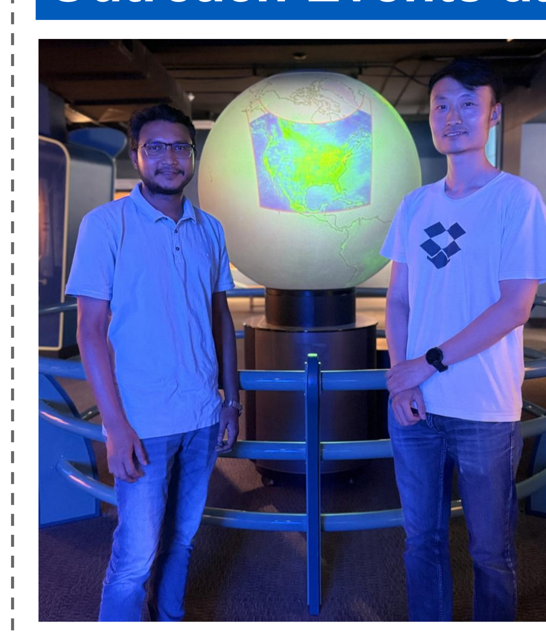


- GEOS-CF total NO emissions reveal strong hotspots at CEMS-monitored power plants.

Conclusions

- Incorporating the tendency term of NO_2 TVCDs into DDA improves correlation with CEMS emissions.
- The L2→4 approach enables detailed emission mapping while preserving TEMPO's native resolution.
- Including NOx/NO_2 climatology from GEOS-CF data in DDA can further improve emission estimates.

Outreach Events at Buffalo Museum of Science



- TROPOMI-based NO_2 TVCDs world map with TEMPO field of regard is displayed on the Museum's Omniglobe.

- Our Pandora instrument was showcased on the Museum rooftop during Juneteenth 2025 for public outreach.

University at Buffalo The State University of New York

Department of Civil, Structural and Environmental Engineering
Email: jobaerah@buffalo.edu
ORCID: https://orcid.org/0000-0002-6358-8871