

Satellite-Based Estimates of NO_x Pollution and Emissions at High Resolutions

基于卫星遥感的氮氧化物大气浓度和排放精细反演

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NOx as Key Constituent for Environment & Climate



- Lifetime: hours, hard to measure
- Known sources: combustion, soil, lightning



NOx

NH₃, SO₂

PM_{2.5}

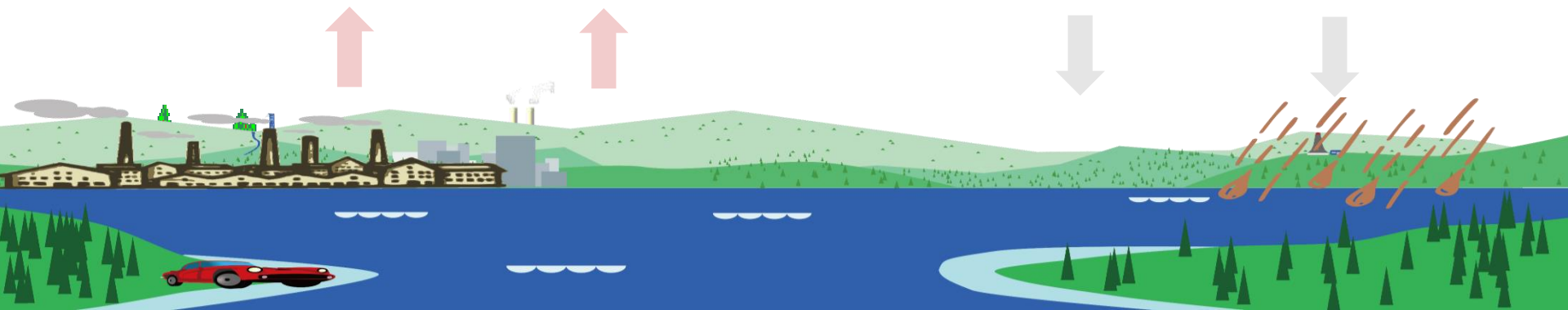
O₃

NMVOC, CO

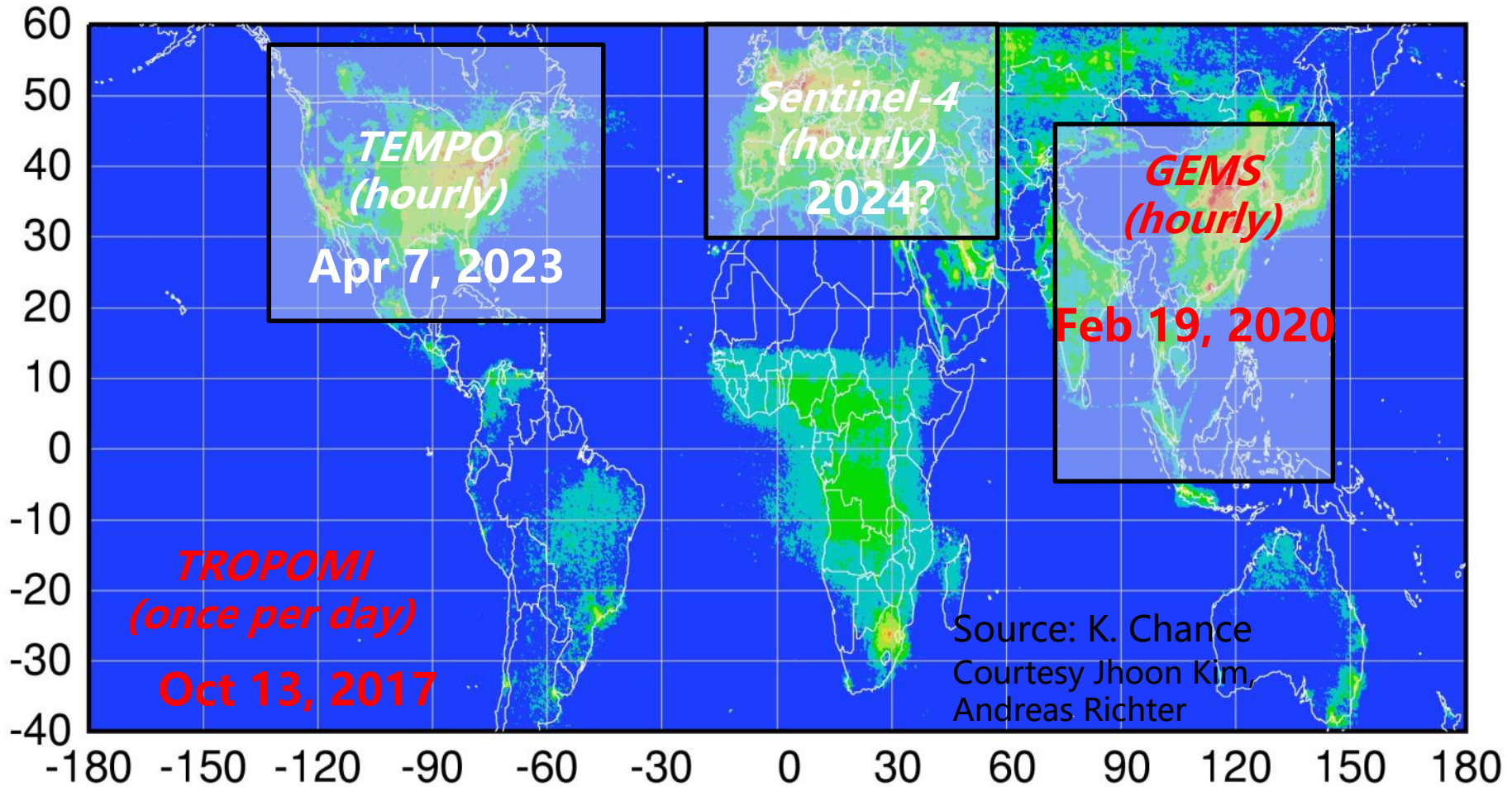
CH₄

Health

Climate



High-Resolution Geostationary and Polar Orbiting Satellite Measurements of NO₂ and Other Tracers

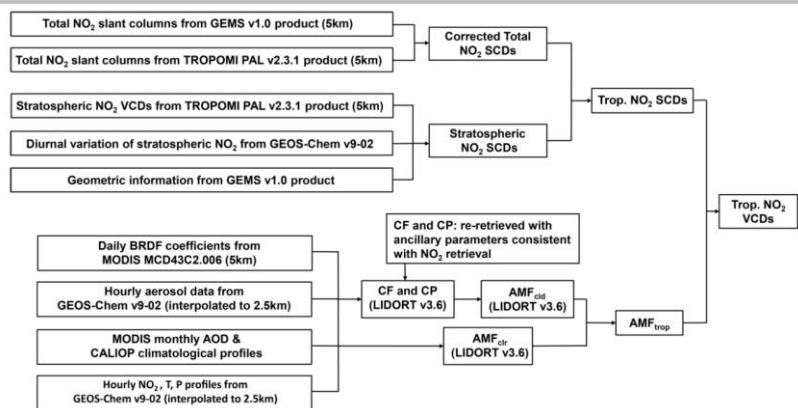


NO₂ sensors: GOME, SCIAMACHY, **OMI**, GOME-2A/B, OMPS, **TROPOMI**, **GEMS**...

From Radiance to NO₂ Concentrations and then to NO_x Emis: Physical-Chemical Approach Based on Governing Equations

POMINO

First aerosol-explicit NO₂ algorithm



PHLET

Fast, NL chemistry-explicit algorithm

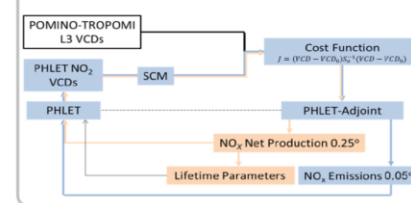
Resolution: ≤ 5 km

Peking University High-Resolution Lifetime-Emission-Transport Model:

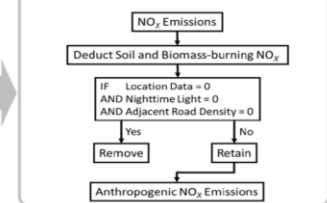
$$\frac{\partial C(x, y)}{\partial t} = r(x, y) \cdot L(x, y) - \nabla \cdot (V(x, y) \cdot C(x, y)) + \nabla \cdot (\alpha \cdot K(x, y) \cdot \nabla C(x, y)) = 0$$

Net local source Mean advection Effective diffusion

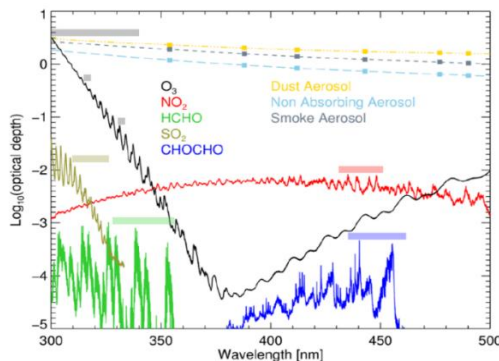
Total Surface Emission Retrieval



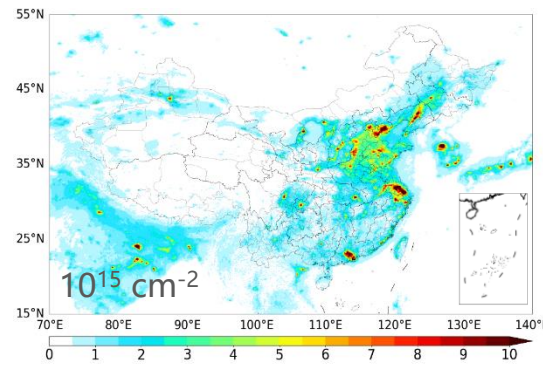
Filtering for Anthro. Sources



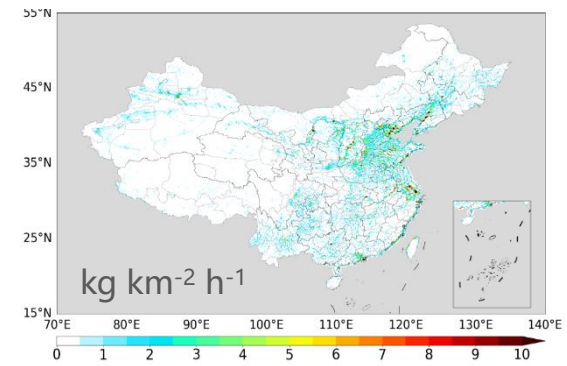
Radiance



Trop. NO₂ VCD



NO_x emission

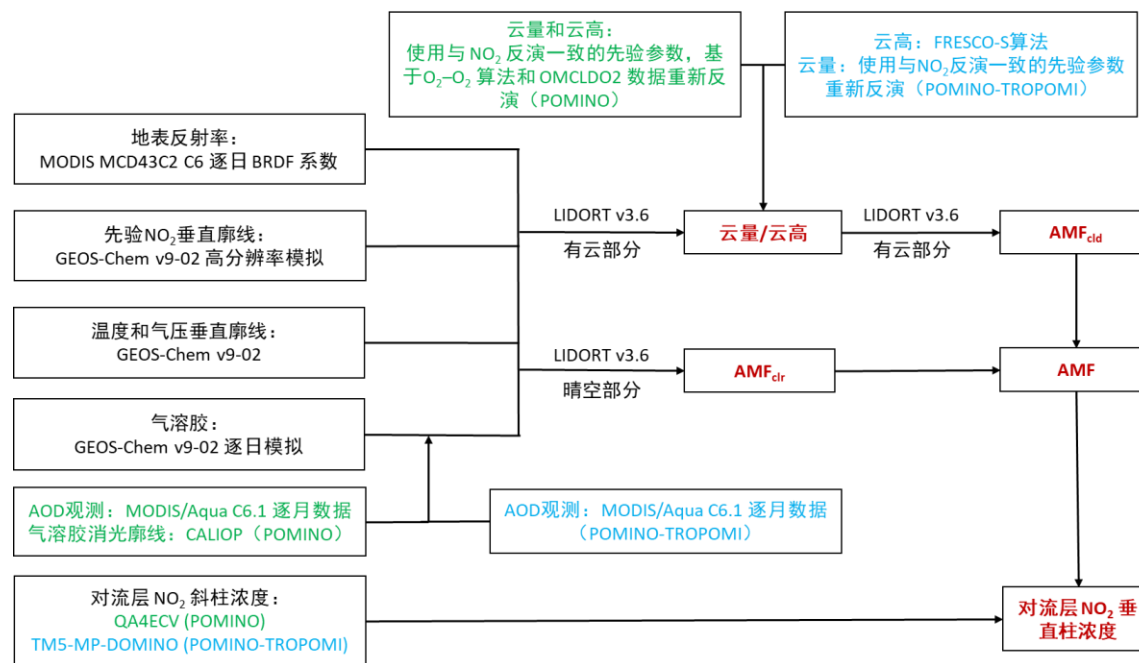


POMINO: An Improved Algorithm to Retrieve Trop. NO₂

POMINO-GEMS

- ✓ Explicit aerosols
- ✓ Surface BRDF
- ✓ High-res NO₂ profiles
- ✓ Coherent cloud retrieval

$$VCD_{trop} = \frac{SCD_{trop}}{AMF_{trop}} = \frac{SCD_{total} - SCD_{trop}}{AMF_{trop}}$$



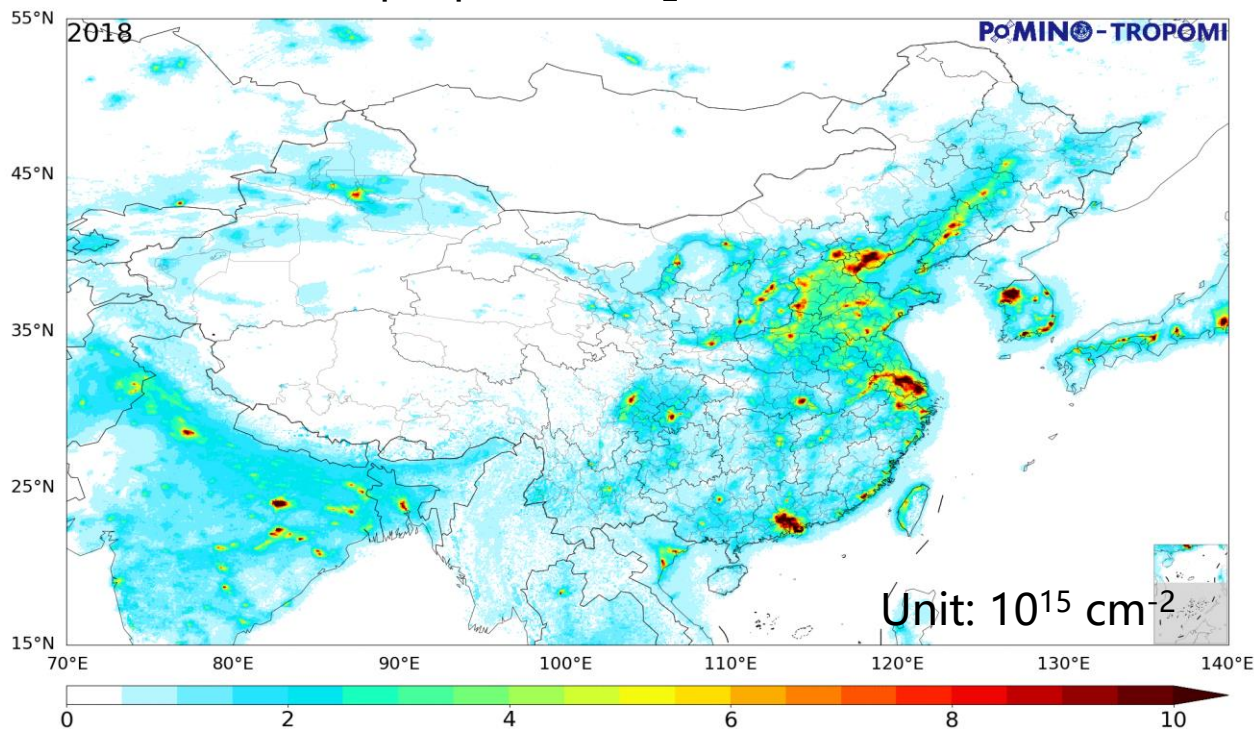
Lin et al., ACP, 2014; Lin et al., ACP, 2015;
Liu et al., AMT, 2019; Zhang et al., NRSB, 2022; Zhang et al., AMT, 2023

POMINO NO₂ VCD Products for OMI, TROPOMI & GEMS

<http://www.pku-atmos-acm.org/acmProduct.php>

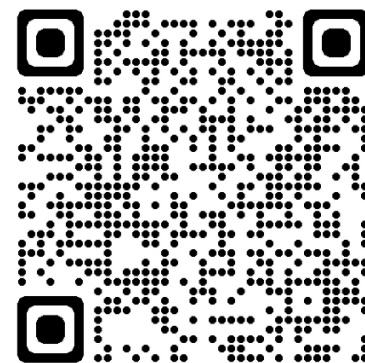
All Level-2 and Level-3 data are freely available (2004-present)

5 km-res Tropospheric NO₂ VCDs in JJA 2018–2022



Lin et al., ACP, 2014;
Lin et al., ACP, 2015;
Liu et al., AMT, 2019;
Liu et al., AMT, 2020;
Zhang et al., NRSB, 2022
Zhang et al., AMT, 2023

500+ registered users from ~200 institutes in 25 countries

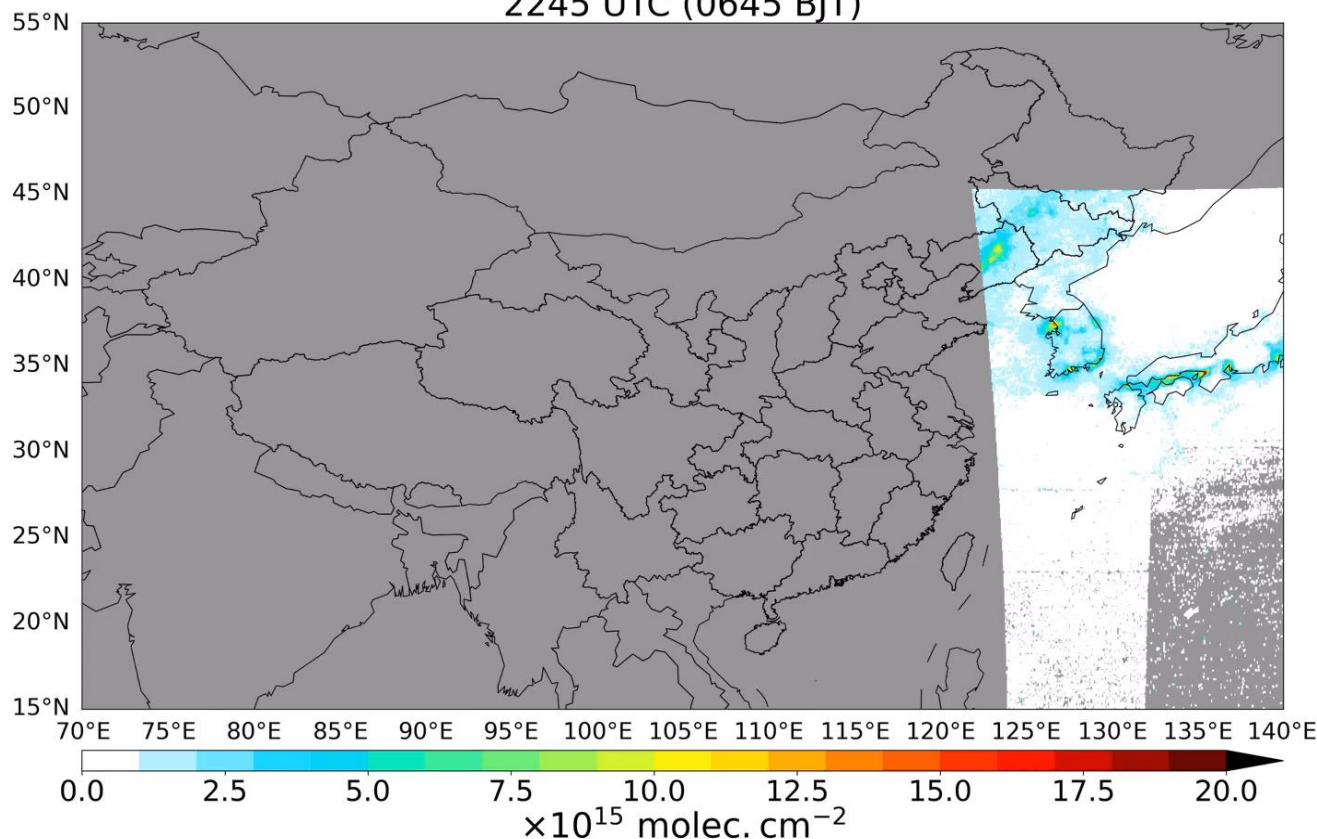


POMINO-GEMS NO₂ VCD Product

<http://www.pku-atmos-acm.org/acmProduct.php>
All Level-2 and Level-3 data are available (2021-present)

POMINO-GEMS NO₂ VCDs for JJA 2021

2245 UTC (0645 BJT)



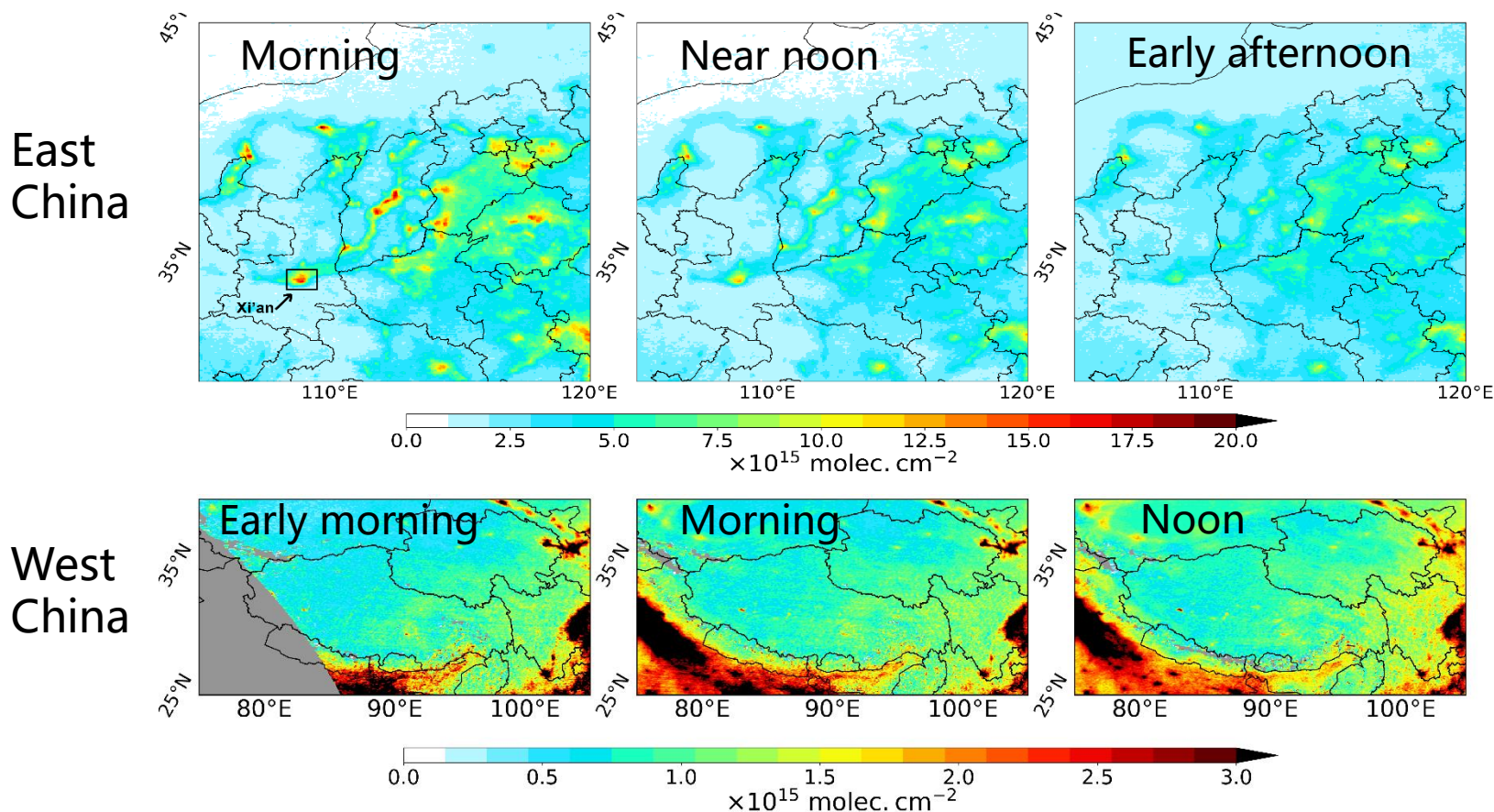
Lin et al., ACP, 2014; Lin et al., ACP, 2015; Liu et al., AMT, 2019; Liu et al., AMT, 2020;
Zhang et al., NRSB, 2022; Zhang et al., AMT, 2023

POMINO-GEMS NO₂ VCD Product

<http://www.pku-atmos-acm.org/acmProduct.php>

All Level-2 and Level-3 data are available (2021-present)

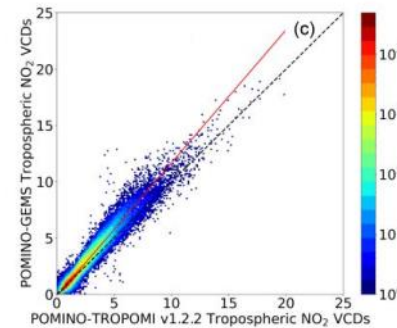
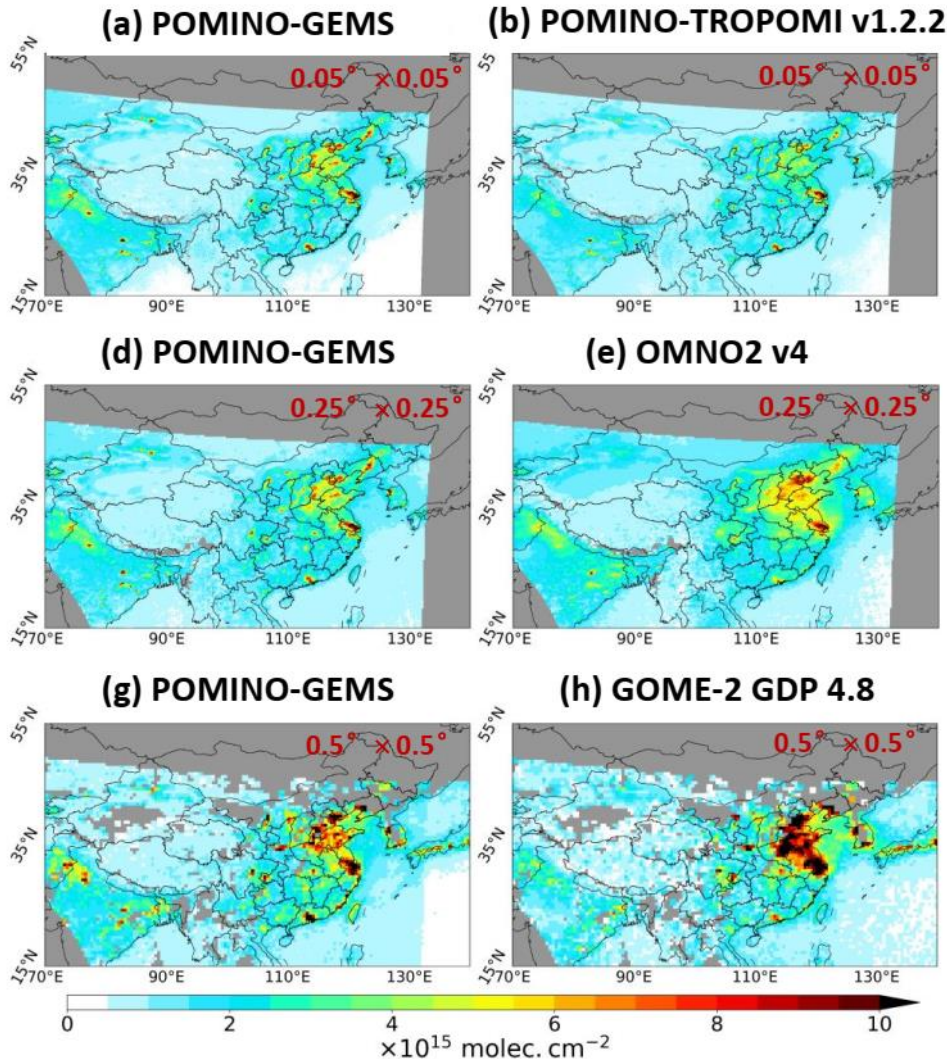
POMINO-GEMS NO₂ VCDs for JJA 2021



Lin et al., ACP, 2014; Lin et al., ACP, 2015; Liu et al., AMT, 2019; Liu et al., AMT, 2020;
Zhang et al., NRSB, 2022; Zhang et al., AMT, 2023

Comparison between Multiple NO₂ Products

JJA 2021

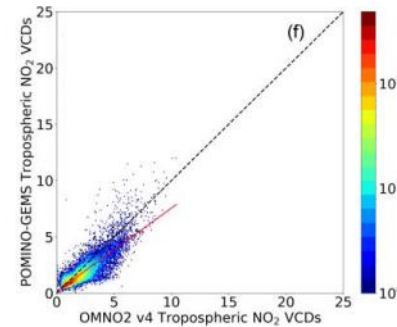


$$Y = 1.18 X - 0.16$$

$$R = 0.98$$

$$\text{NMB} = 4.9\%$$

$$N = 758568$$

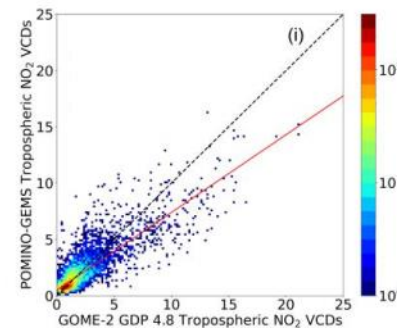


$$Y = 0.74 X + 0.16$$

$$R = 0.87$$

$$\text{NMB} = -16.8\%$$

$$N = 30540$$



$$Y = 0.69 X + 0.49$$

$$R = 0.83$$

$$\text{NMB} = -1.5\%$$

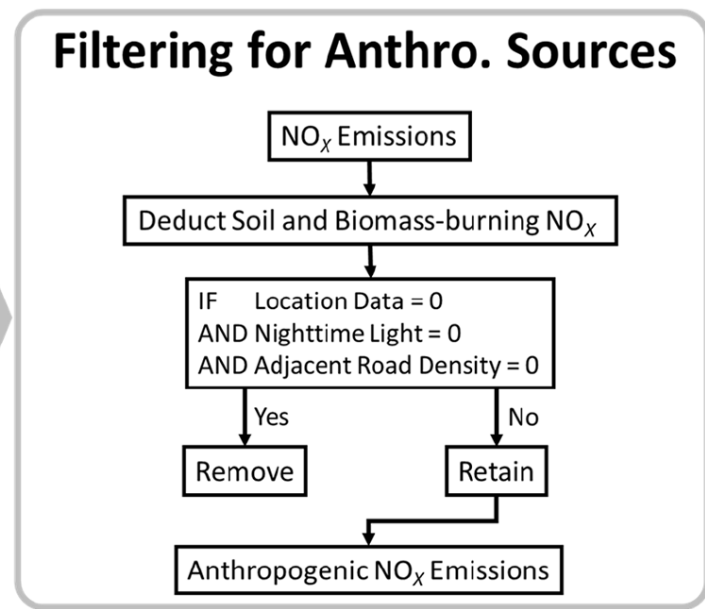
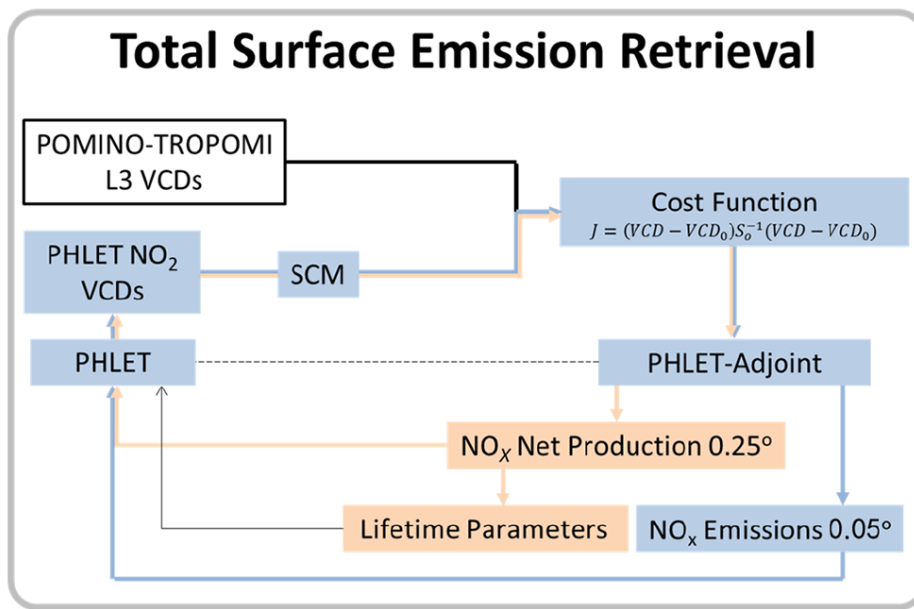
$$N = 7515$$

High-Resolution NO_x Emission Estimate Based on PHLET

- **Fast convergence; High resolution (≤ 5 km)**
- **Horizontal transport; Non-linear chemistry; Proper pixel matching**

Peking University **H**igh-Resolution **L**ifetime-**E**mission-**T**ransport Model

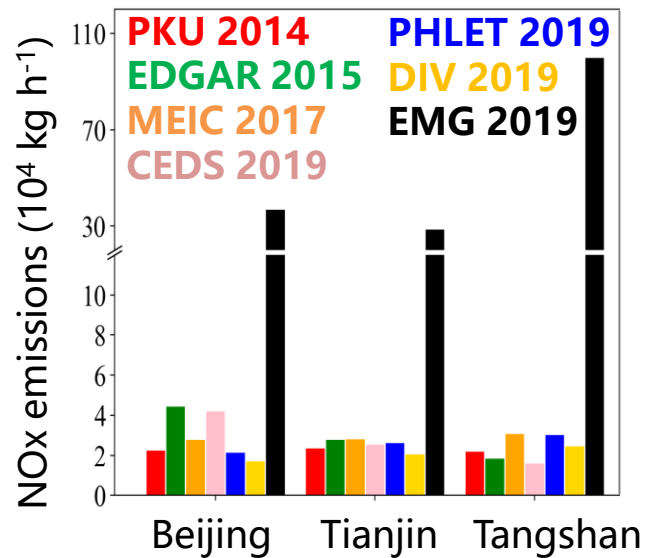
$$\frac{\partial C(x,y)}{\partial t} = \underbrace{r(x,y) \cdot L(x,y)}_{\text{Net local source}} - \underbrace{\nabla \cdot (V(x,y) \cdot C(x,y))}_{\text{Mean advection}} + \underbrace{\nabla \cdot (\alpha \cdot K(x,y) \cdot \nabla C(x,y))}_{\text{Effective diffusion}} = 0$$



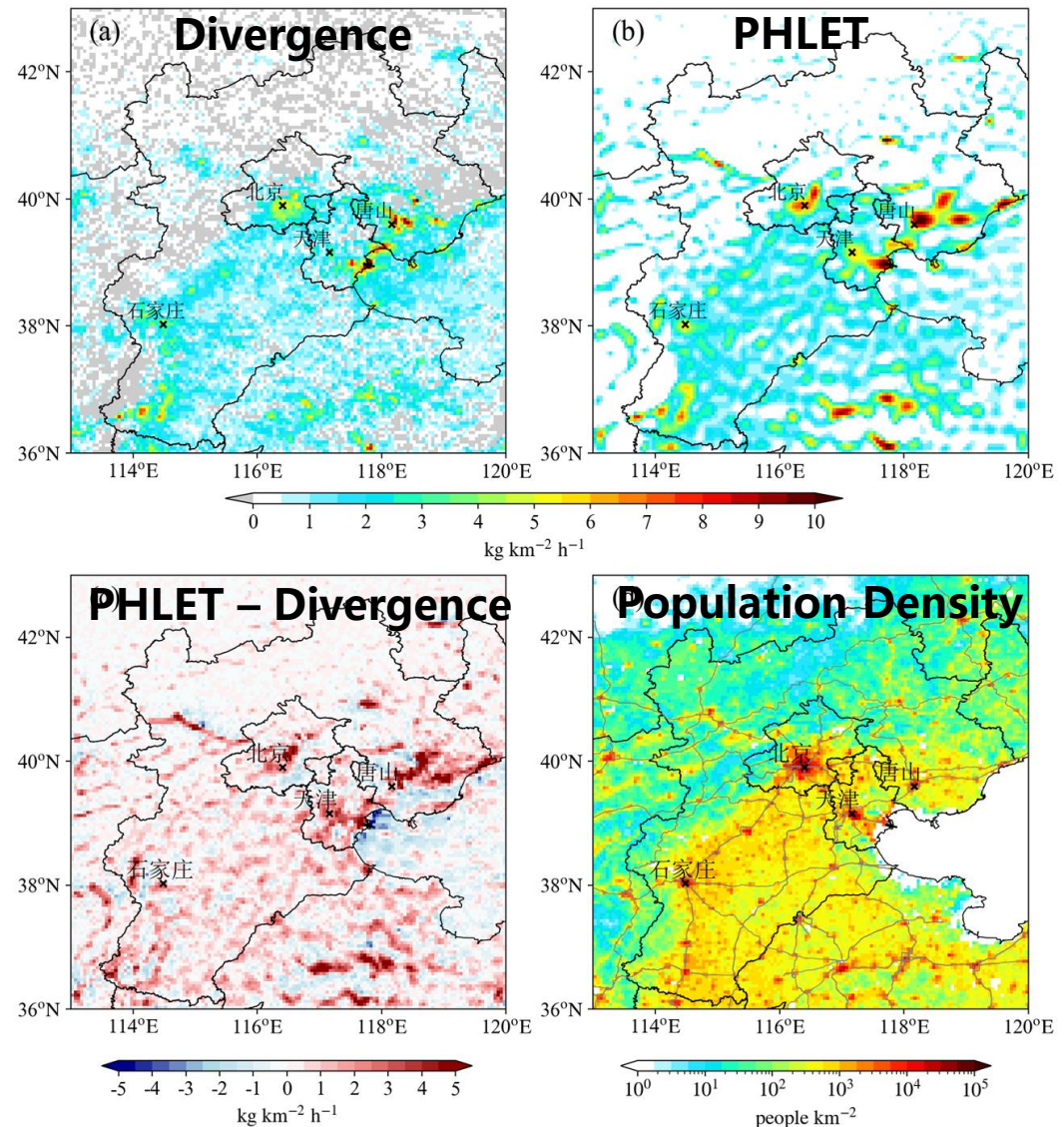
Kong et al., ACP, 2019; Kong et al., EST, 2022

PHLET is Much More Accurate Than Other Methods

Top-down and bottom-up emissions for JJA 2019

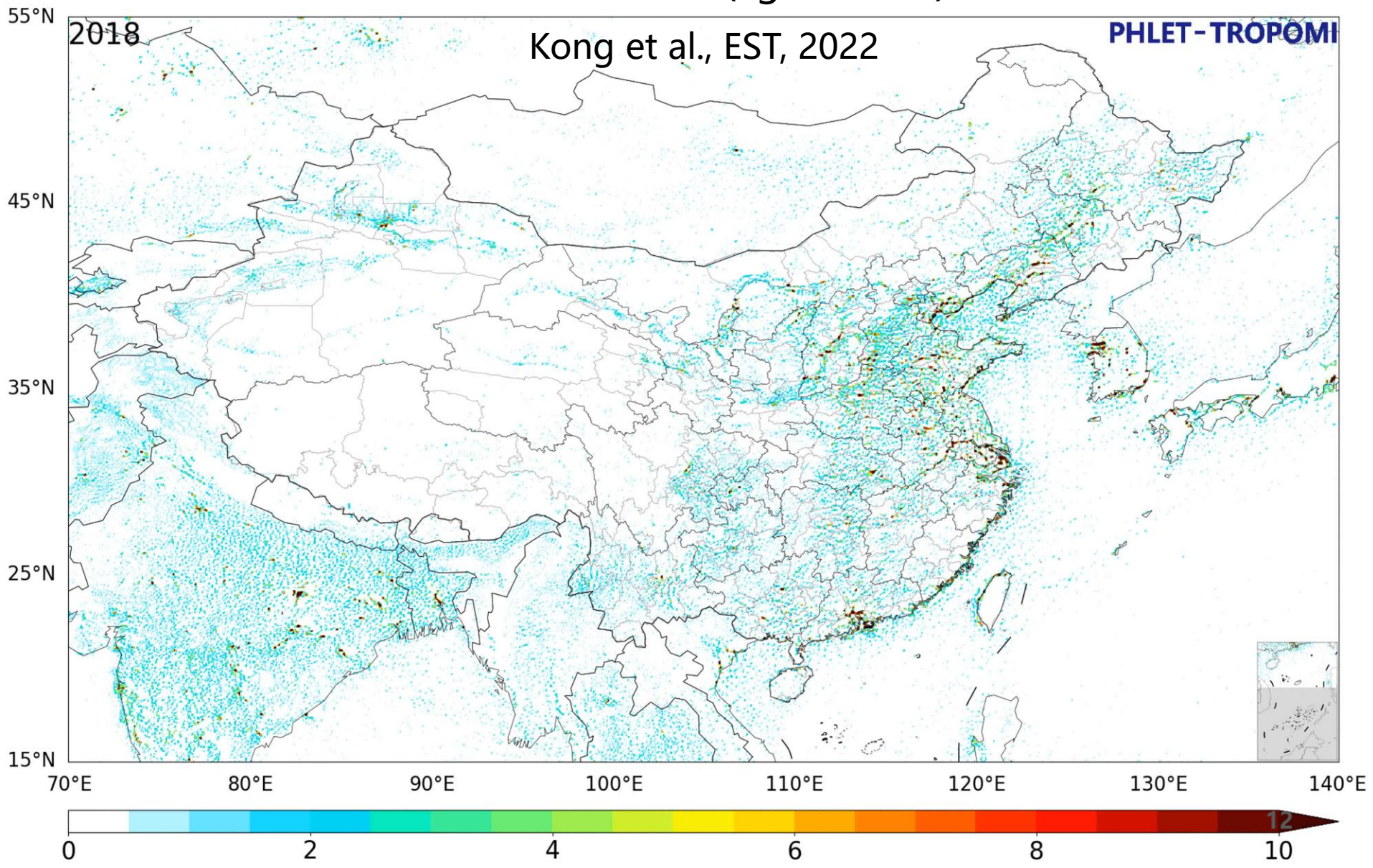


王思杰等, 地球科学学报, 2024

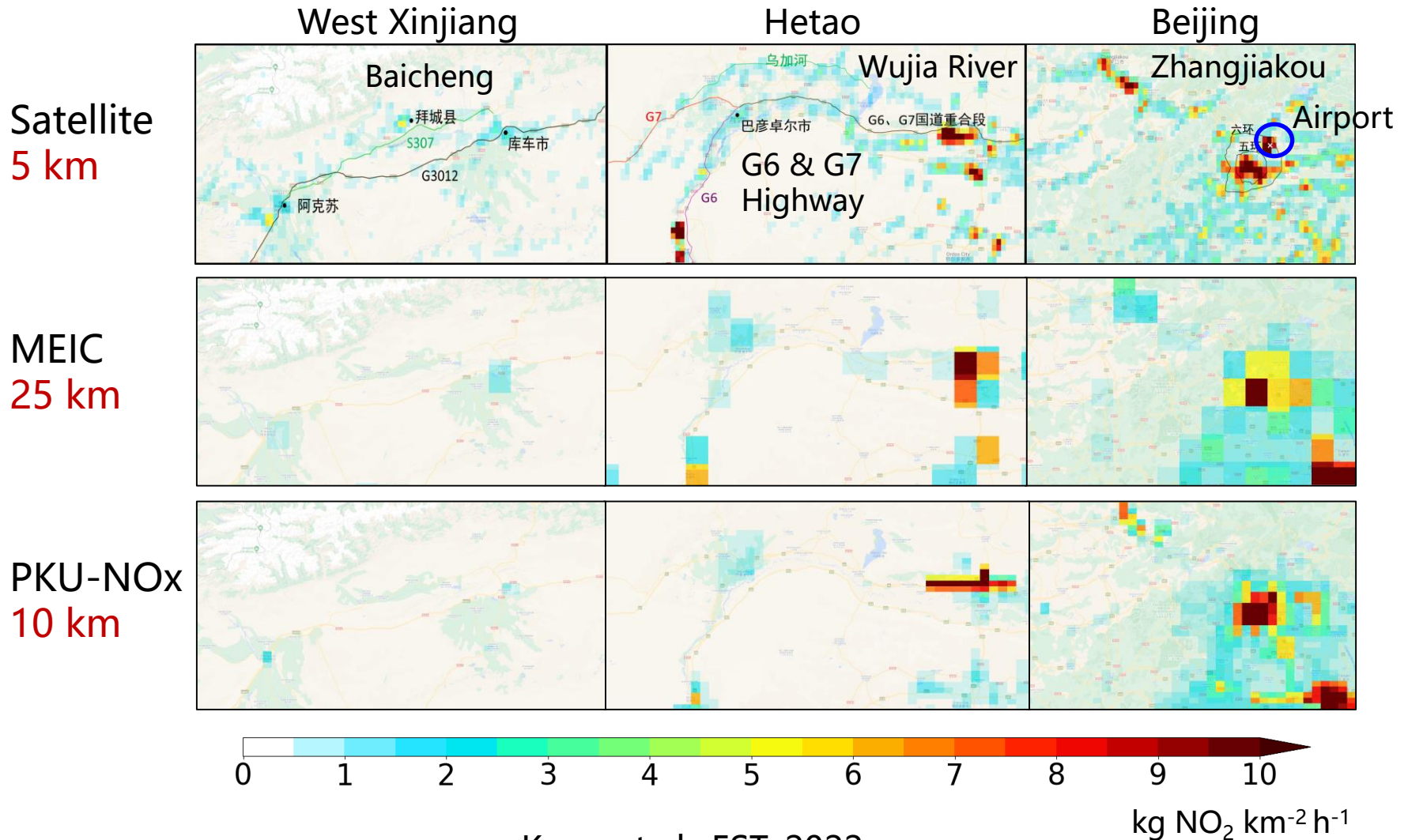


5 km-Res NO_x Emissions Reveal Fine Scale Features

JJA emissions ($\text{kg km}^{-2} \text{h}^{-1}$)



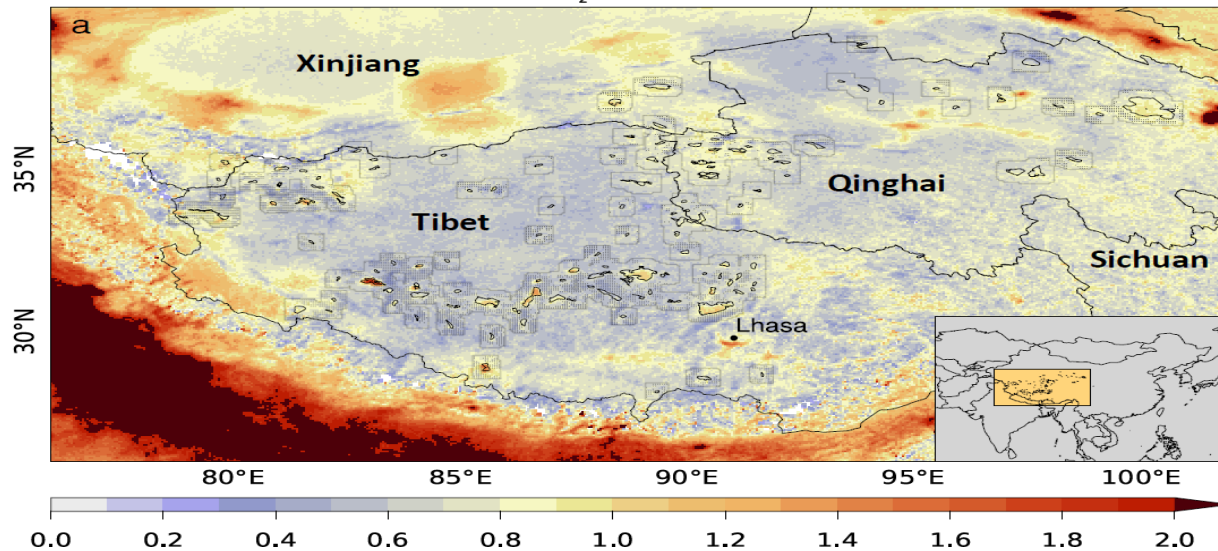
High-Resolution NO_x Emission Retrieval Data Reveal Anthropogenic Sources Missing in Inventories



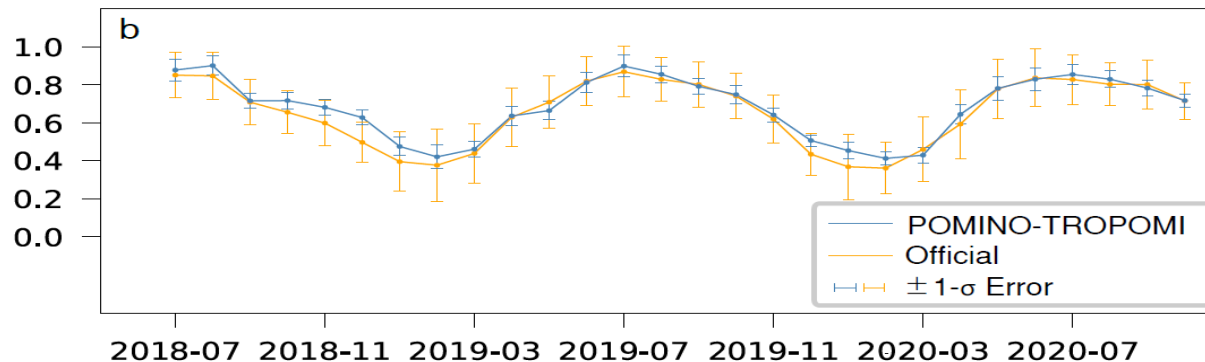
Kong et al., EST, 2022

Unexpected High NO₂ VCDs over Tibetan Plateau Lakes

POMINO-TROPOMI NO₂ VCDs in JJA 2019 (10^{15} cm⁻²)



NO₂ VCDs in 2018/07–2020/07 (10^{15} cm⁻²)

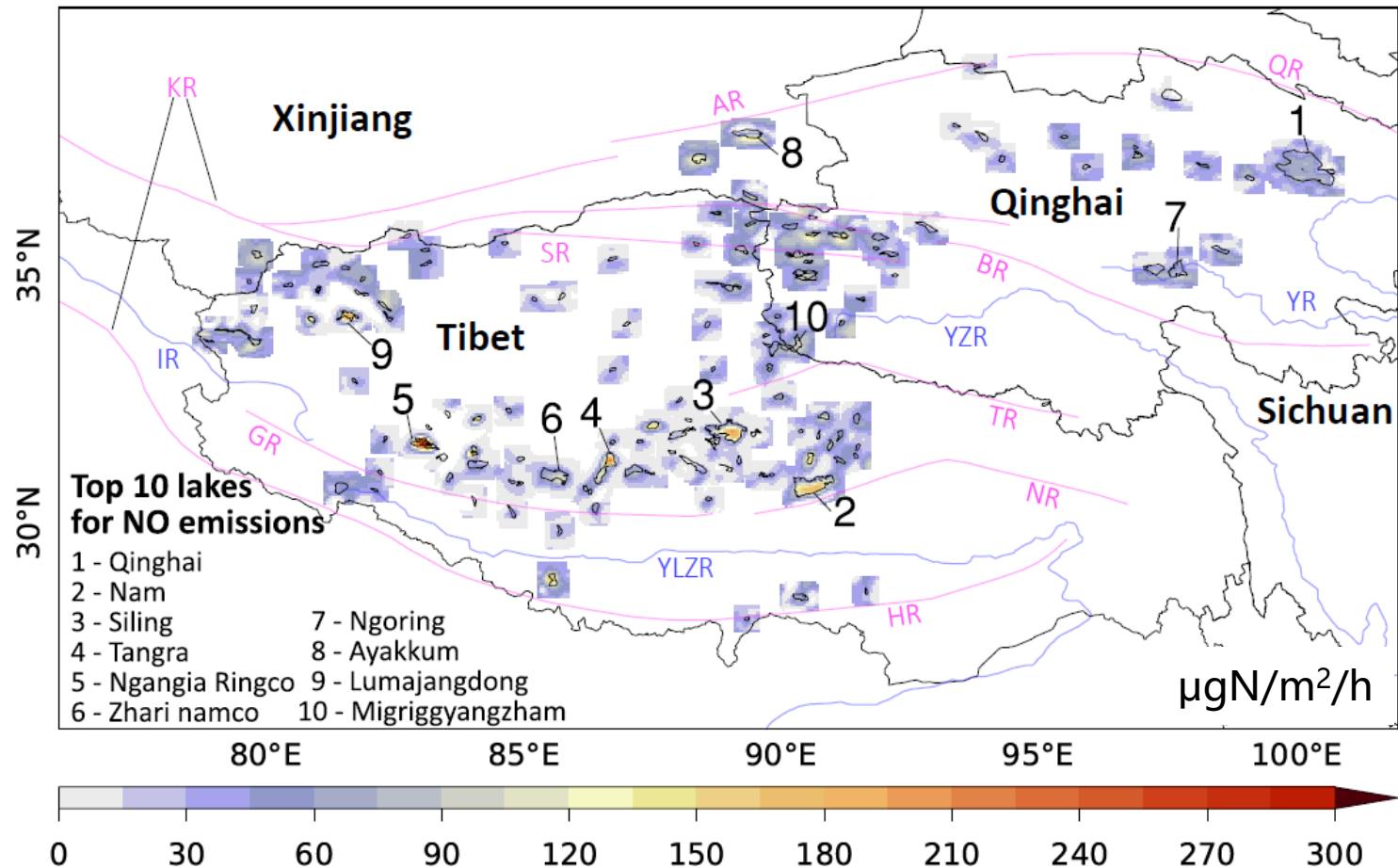


Kong et al., *Nature Geoscience*, 2023; *Nature Research Highlight*

High-Resolution NO_x Emission Retrieval Data

Discover Unknown High Natural Emissions from TP Lakes

- Total lake emissions are comparable to megacities

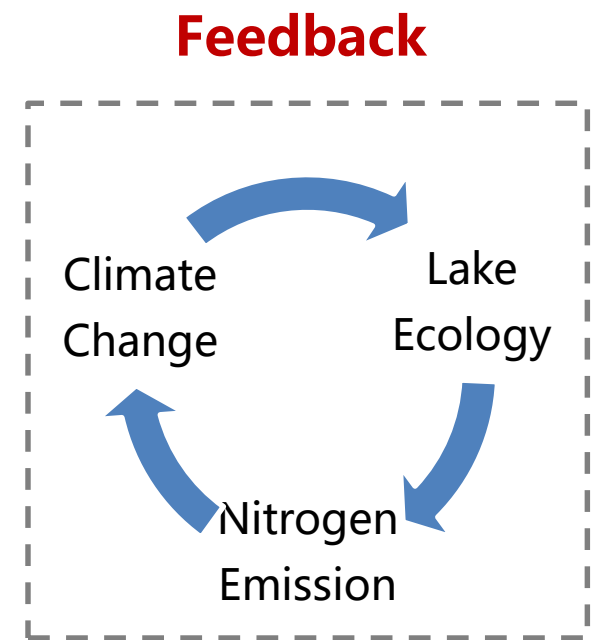
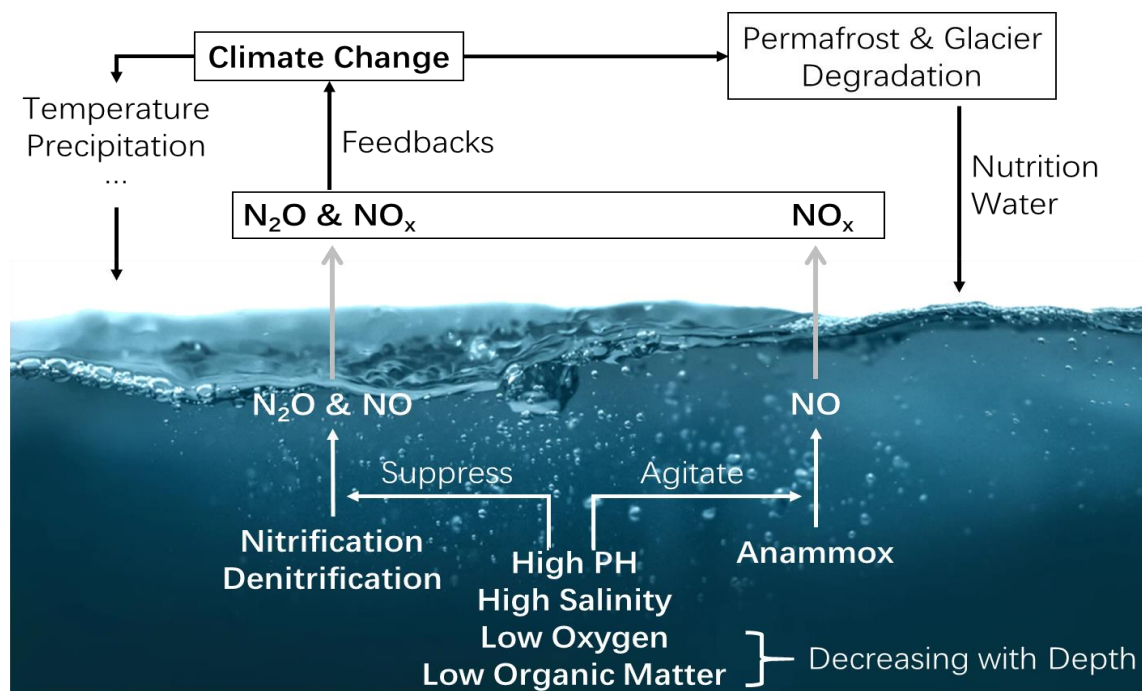


Kong et al., *Nature Geoscience*, 2023; *Nature Research Highlight*

Microbial Mechanisms of NO_x Emissions under Rapid Warming

Anammox, nitrification-denitrification, and/or other mechanisms?

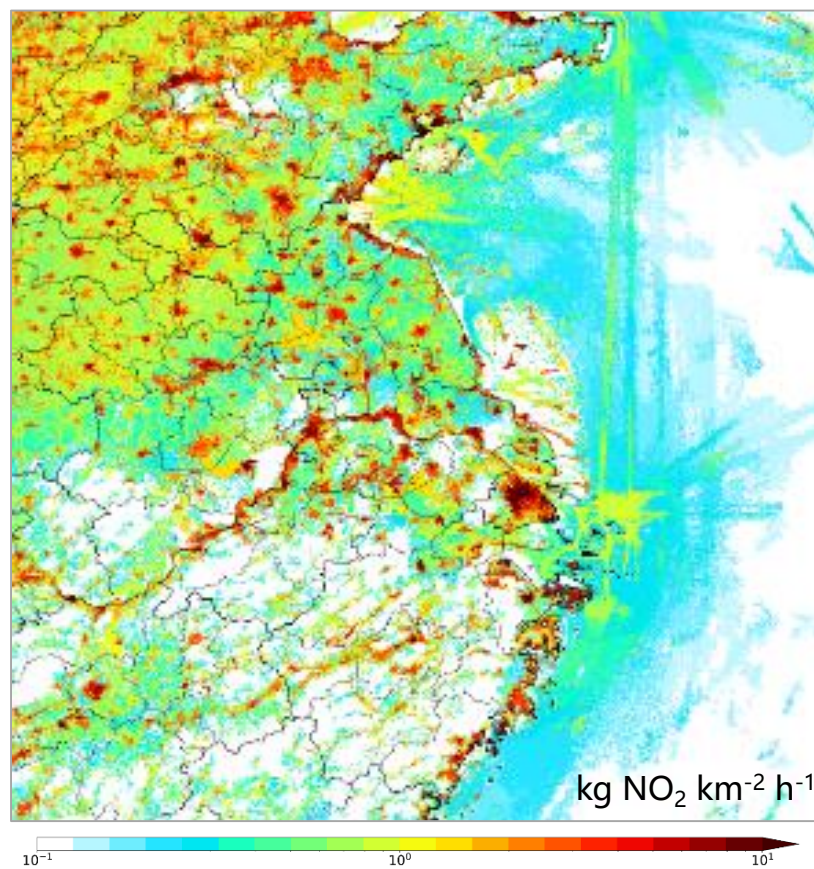
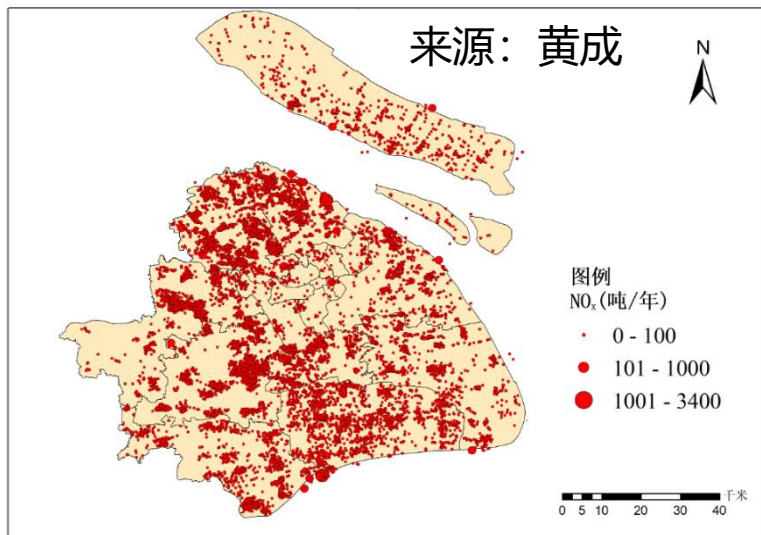
- Nitrogen input from melting glaciers/permafrost?
- Closed lake, low-oxygen, low-organic, saline, alkaline
- Formed in bottom water and sediment? in surface water?



Kong et al., *Nature Geoscience*, 2023; *Nature Research Highlight*

Towards NO_x Emission Retrieval at 1 km Resolution: Combining Physical and AI Methods

NO_x emissions in JJA 2019 at 1 km resolution: Preliminary results



Kong et al., in prep

Summary

- Satellite measurements offer an unprecedented opportunity to monitor worldwide NO_x pollution and emissions at km resolution.
- Our **fast, fine, reliable** emission retrieval reveals considerable previously unaccounted anthropogenic and natural sources.
- Our satellite data are freely available, and we look forward to collaborating with AI experts and other colleagues.



Group photo on 2024/06/13



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