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Mapping Carbon Emissions in Space and Time to Support Attribution and Mitigation

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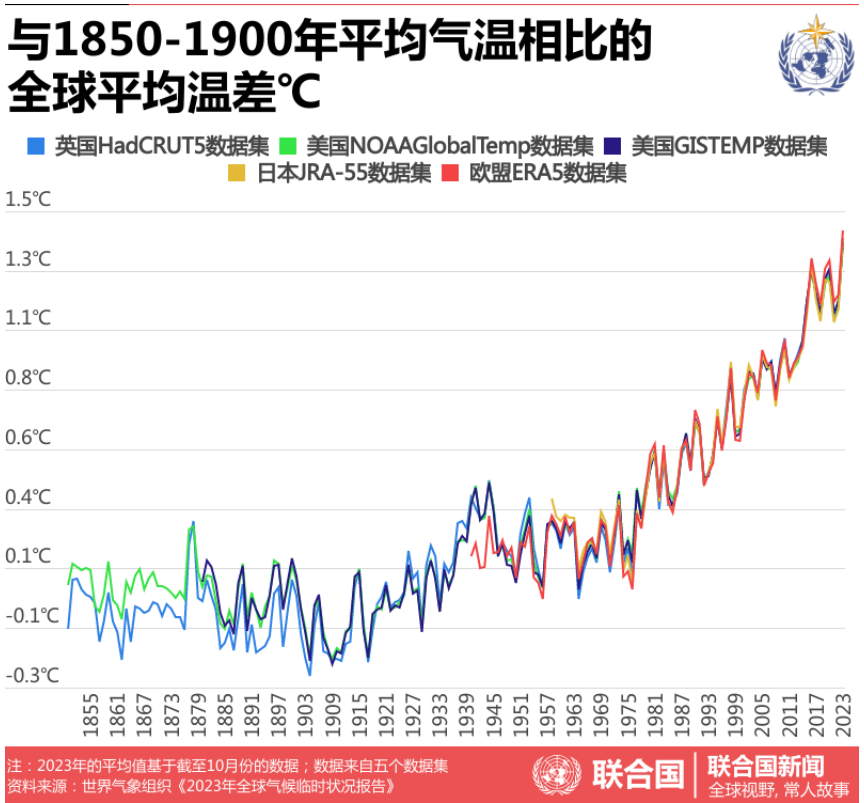
China University of Mining and Technology

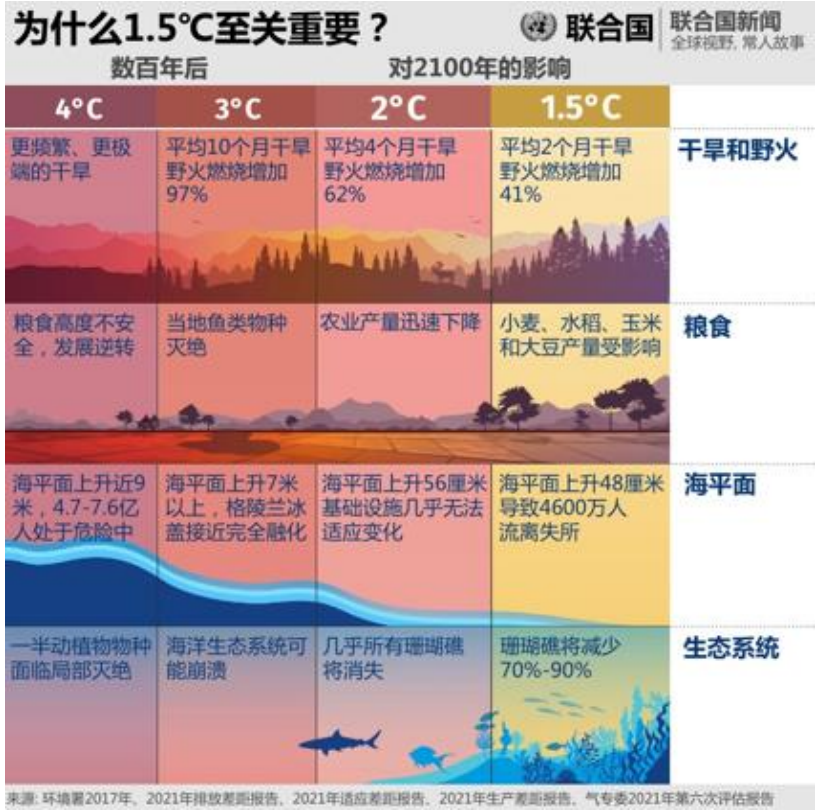
Background

	Global Mean Radiative Forcing (W m^{-2})					ERF (W m^{-2})
	SAR (1750–1993)	TAR (1750–1998)	AR4 (1750–2005)	AR5 (1750–2011)	Comment	AR5
Well-mixed greenhouse gases (CO_2, CH_4, N_2O, and halocarbons)	2.45 (2.08 to 2.82)	2.43 (2.19 to 2.67)	2.63 (2.37 to 2.89)	2.83 (2.54 to 3.12)	Change due to increase in concentrations	2.83 (2.26 to 3.40)
Tropospheric ozone	+0.40 (0.20 to 0.60)	+0.35 (0.20 to 0.50)	+0.35 (0.25 to 0.65)	+0.40 (0.20 to 0.60)	Slightly modified estimate	
Aerosol–radiation interactions	Not estimated	Not estimated	–0.50 (–0.90 to –0.10)	–0.35 (–0.85 to +0.15)	Re-evaluated to be smaller in magnitude	–0.45 (–0.95 to +0.05)

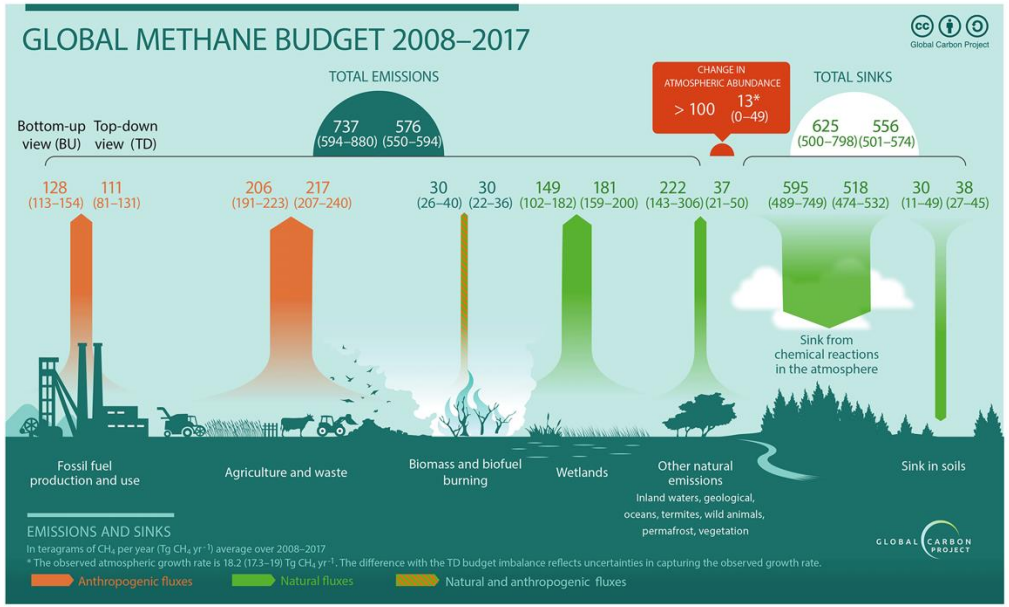


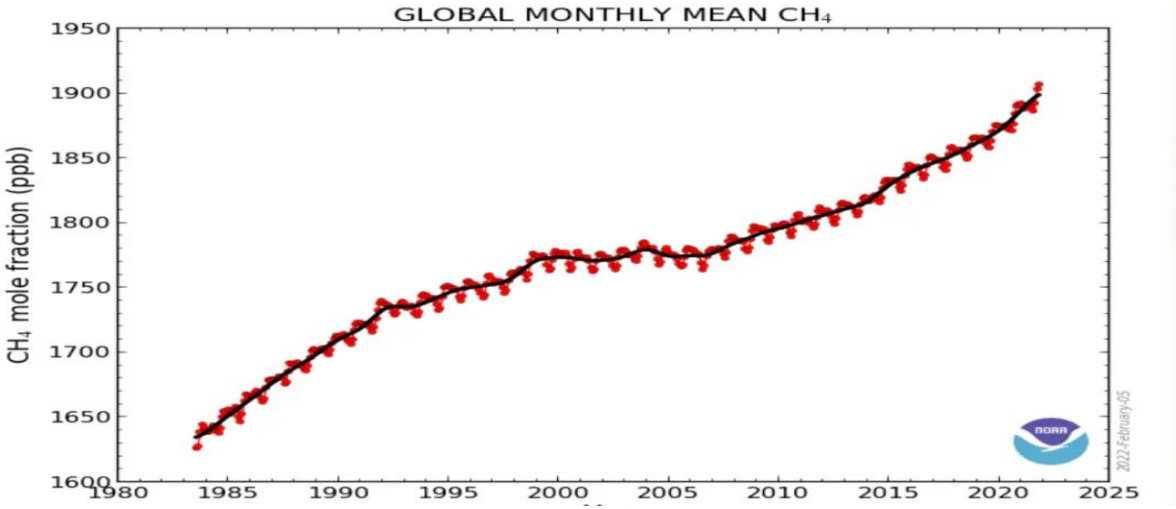
“Long-Lived” GHGs (CO_2,CH_4) 2.5-3.1W/m^2

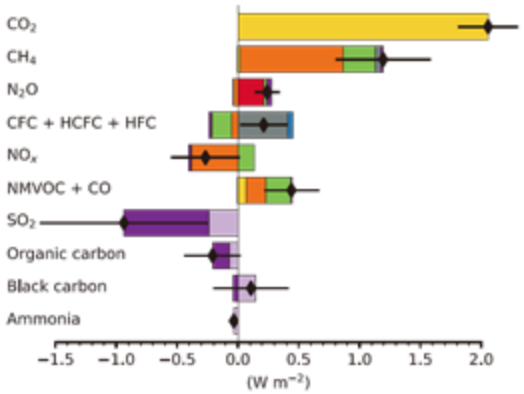
“Short-Lived” Climate Forcers (BC,CO,NO_x). Locally powerful: 10-50W/m^2



Background

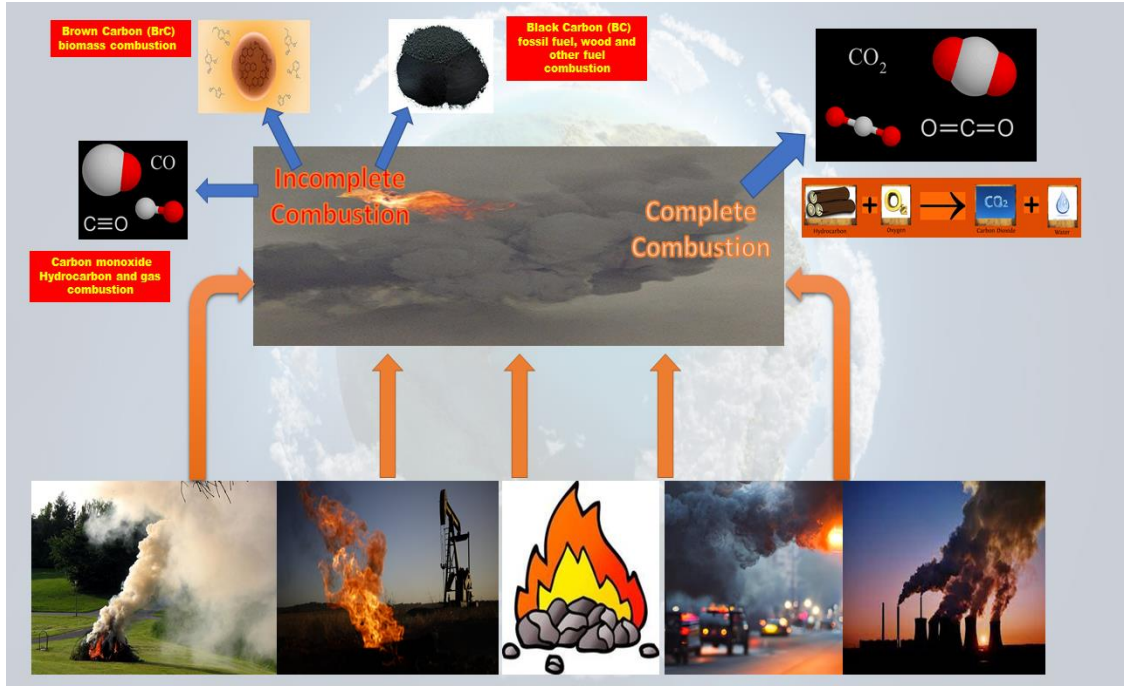






Radiative Forcing of Methane Continues to Increase Globally

Black Carbon (BC) is a short-lived climate pollutant (SLCP) produced by incomplete combustion of fossil fuels and biomass.



《地球大数据支撑可持续发展目标报告——SDGs十周年特别报告》

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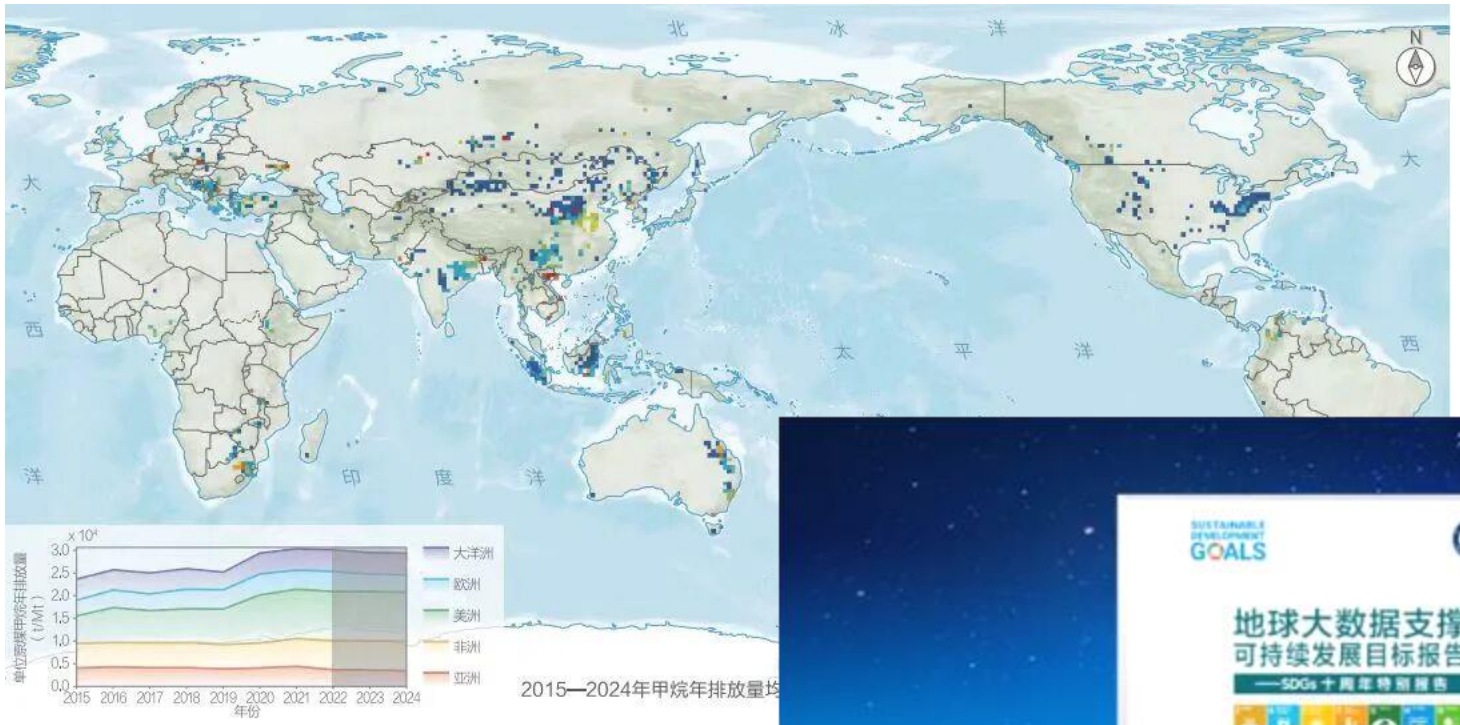

2015—2024年甲烷年排放量均

9月27日，在第80届联合国大会期间，《地球大数据支撑可持续发展目标报告——SDGs十周年特别报告》（以下简称“《报告》”）在联合国官网正式发布。

我校环境与测绘学院碳排放与空气质量遥感团队的秦凯教授、Jason Cohen教授、胡玮博士生等负责完成了《报告》的“减缓：温室气体排放”部分有关甲烷排放量的内容

What + Where + When → Why

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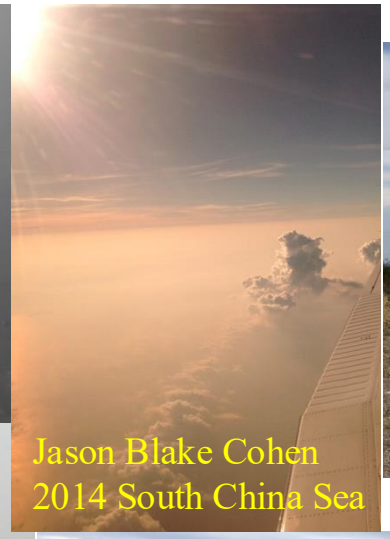
We must use measurements to constrain and understand emissions! Models do not match Satellite and surface observations in tandem, biases with extreme events.

Jason Blake Cohen (Oregon, USA) 2012


Jason Blake Cohen 2014 South China Sea

Jason Blake Cohen 2021，银川

Jason Blake Cohen (Singapore) 2013

Jason Blake Cohen (Arctic) 2014

Jason Blake Cohen 2003 Wuhan

Jason Cohen, August 2017, Malaysia

Jason Blake Cohen, Mar 2020, Thailand

Jason Blake Cohen (Guangdong) 2018

What + Where + When → Why
Chinese Coal Mine Methane

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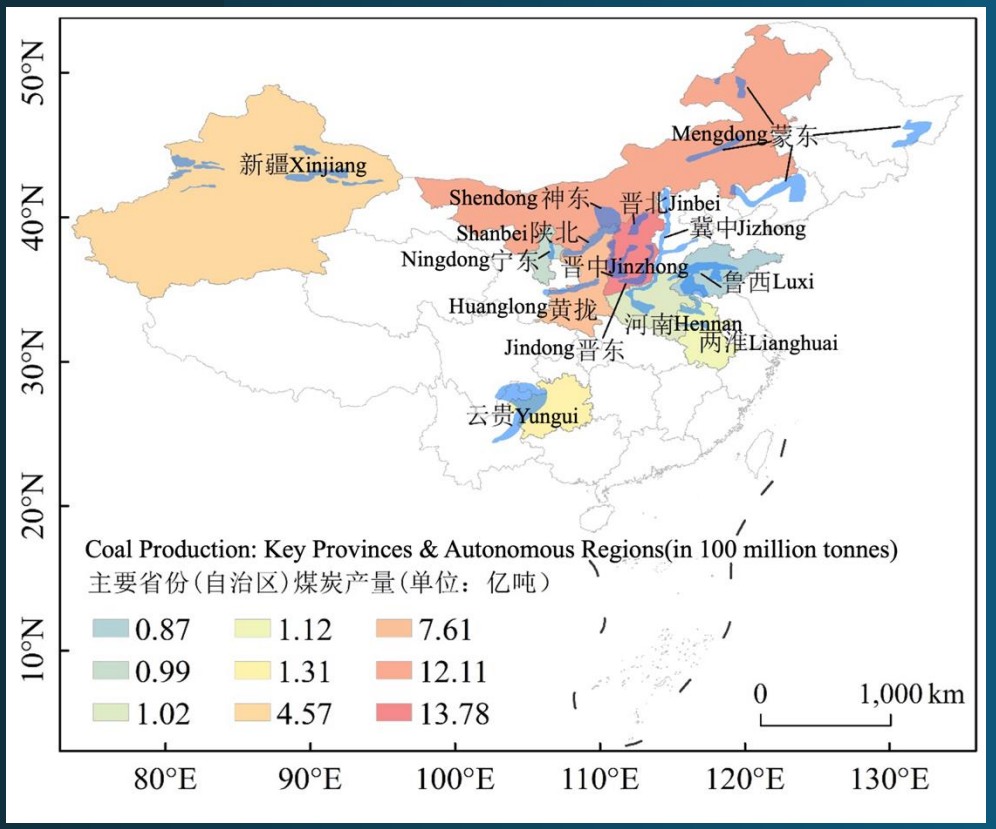
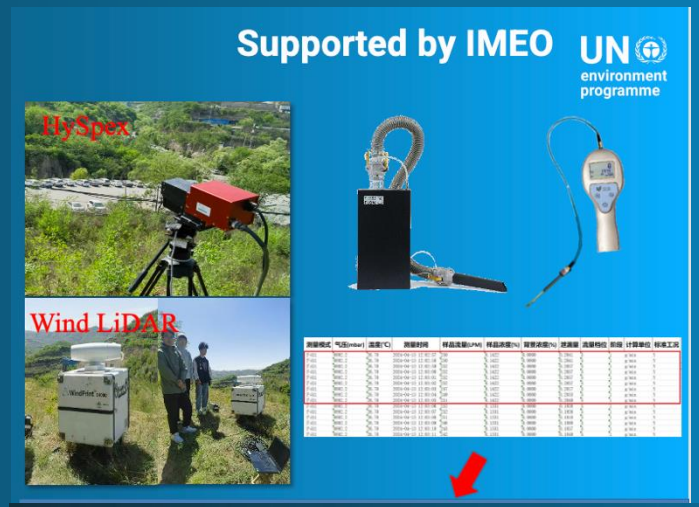
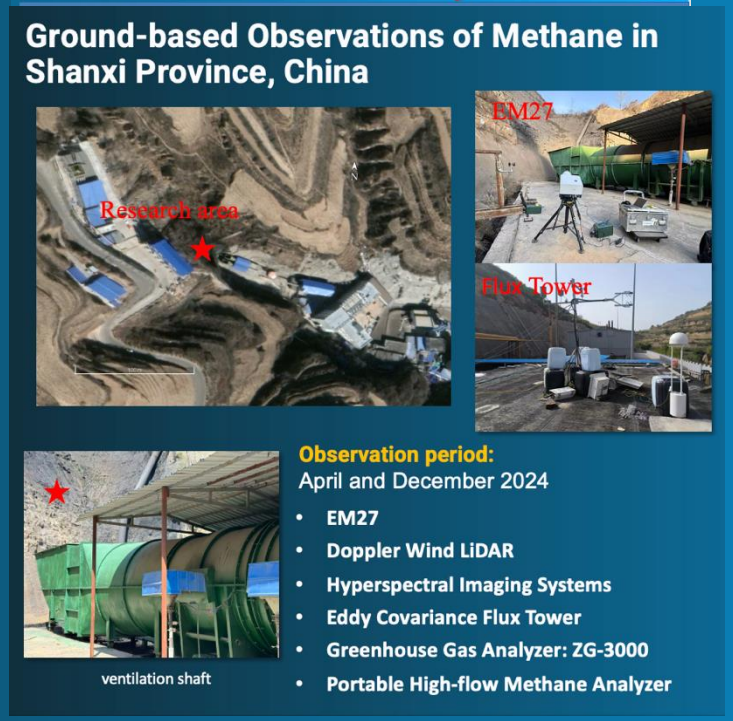
96.6% of coal production in 2020. From 2021-2023, production up 530MTon in western China and down 30MTon elsewhere.







What + Where + When → Why
Building Fast, Flexible, & Open Physical Models

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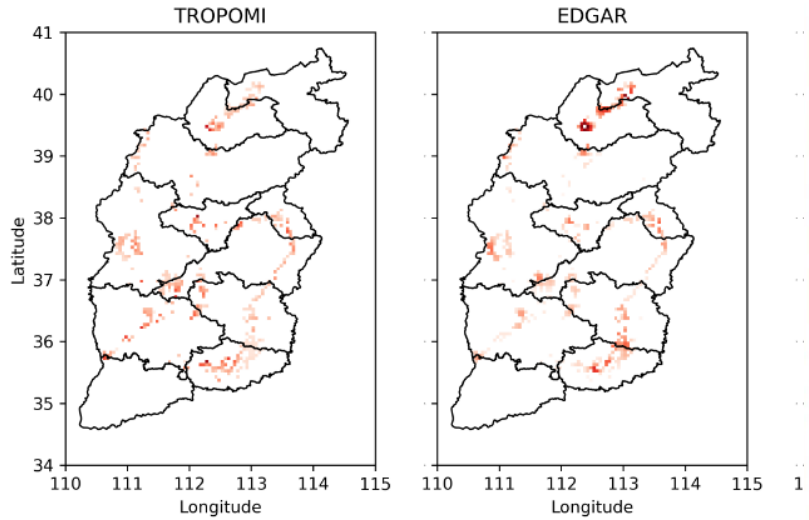

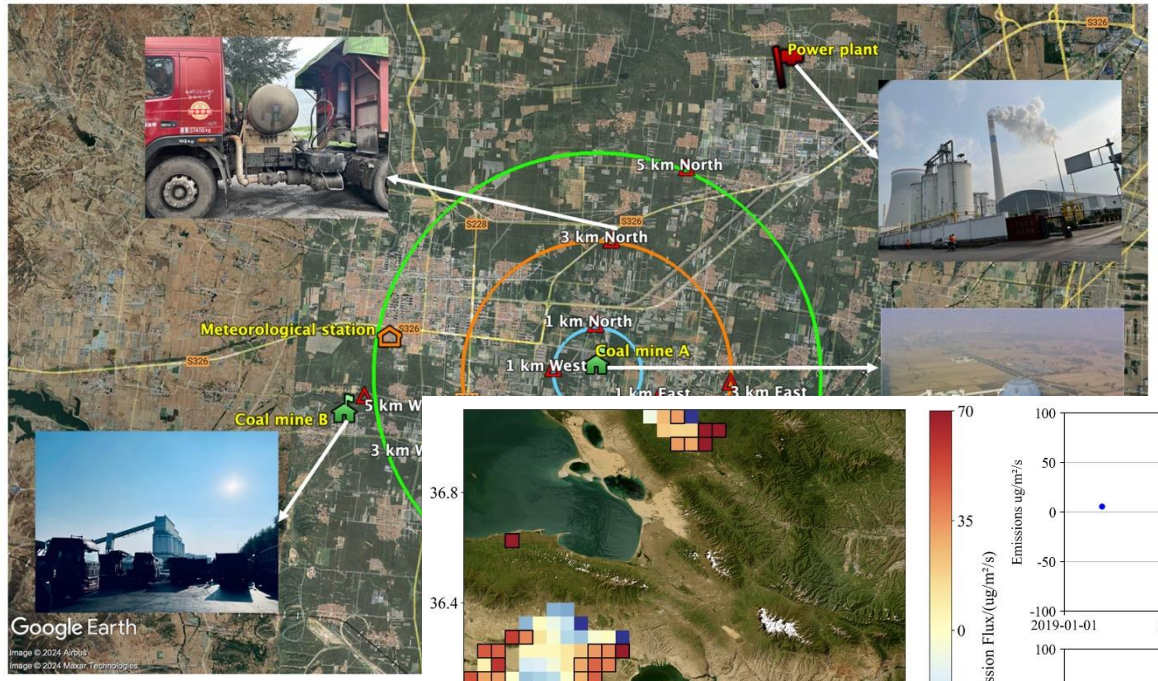

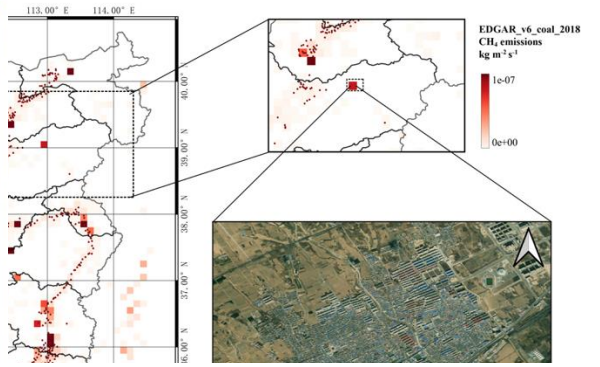

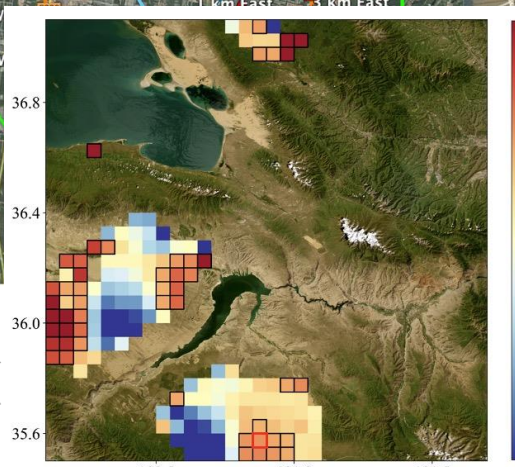

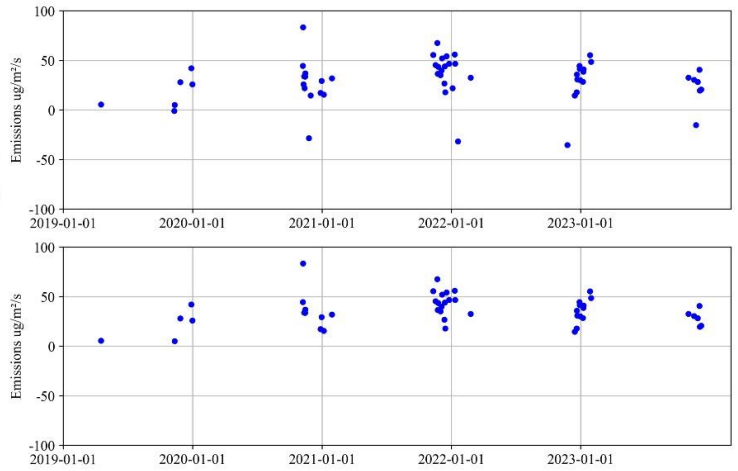

TROPOMI Satellite yields 5km daily emissions product. Explicit uncertainty analysis makes results useful for attribution.

CH_4 emissions (kg h^{-1})

	Mean ± SE				Median	Max
CM-A	6860 ± 3520	102	3070	19 000	2130	24 900
CM-B	[illegible]	[illegible]	[illegible]	[illegible]	1450	37 300

Home > International Journal of Coal Science & Technology > Article

Merging TROPOMI and eddy covariance observations to quantify 5-years of daily CH_4 emissions over coal-mine dominated region

Research | Open access | Published: 09 July 2024
Volume 11, article number 56, (2024) Cite this article

Download PDF

Wei Hu, Kai Qin, Fan Lu, Ding Li & Jason B. Cohen

EGU European Geosciences Union — Atmospheric Chemistry and Physics

Article

Surface-observation-constrained high-frequency coal mine methane emissions in Shanxi, China, reveal more emissions than inventories, consistent with satellite inversion

Fan Lu, Kai Qin, Jason Blake Cohen, Qin He, Pravash Tiwari, Wei Hu, Chang Ye, Yanan Shan, Qing Xu, Shuo Wang, and Qiansi Tu

EGU European Geosciences Union — Atmospheric Chemistry and Physics

Article

Individual coal mine methane emissions constrained by eddy covariance measurements: low bias and missing sources

Kai Qin, Wei Hu, Qin He, Fan Lu, and Jason Blake Cohen

How can we trust TROPOMI based Methane Emissions Estimation: Calculating Emissions over Unidentified Source Regions

Bo Zheng, Jason Blake Cohen, Lingxiao Lu, Wei Hu, Pravash Tiwari, Simone Lolli, Andrea Garzelli, Hui Su, and Kai Qin

Abstract. We propose a novel method for computing the effects of TROPOMI observational uncertainties on emissions calculation arising from the nonlinearity of the gradient terms and non-biased filtering in space and time. Application using TROPOMI XCH_4 data in clean areas of Western China with long-term WMO background observations quantifies a minimum detectable emission threshold of 1.8 $\mu g/m^2/s$, lower than existing community thresholds using TROPOMI. By combining threshold-based and stochastic approaches that incorporates pixel-by-pixel and day-by-day XCH_4 uncertainties, we identify and filter physically unrealistic emission values in both space and time. The resulting emissions reveal both missing sources and a 5 % emission bias caused by the nonlinearity of the gradient term. Validation was performed by applying the method to the Permian Basin, where comparisons with airborne observations demonstrate the method's ability to align with independent datasets. The importance and implications of our results are related to this being a new methodology for methane emissions estimate from TROPOMI which enables precise identification of emission sources and improved handling of observational noise, offering a more accurate framework for methane emission monitoring across diverse regions using existing satellite platforms. Our results yield a non-negative emissions dataset using an objective selection and filtration method, which include a lower minimum emissions threshold on all grids and reduction of false positives. Finally, the new approach can be adopted to other satellite platforms to provide a more robust and reliable quantification of emissions under data uncertainty that moves beyond traditional plume identification and background subtraction.

How to cite. Zheng, B., Cohen, J. B., Lu, L., Hu, W., Tiwari, P., Lolli, S., Garzelli, A., Su, H., and Qin, K.: How can we trust TROPOMI based Methane Emissions Estimation: Calculating Emissions over Unidentified Source Regions, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-1446, 2025.

What + Where + When → Why
Transport of Coal Mine Methane to Agricultural Areas

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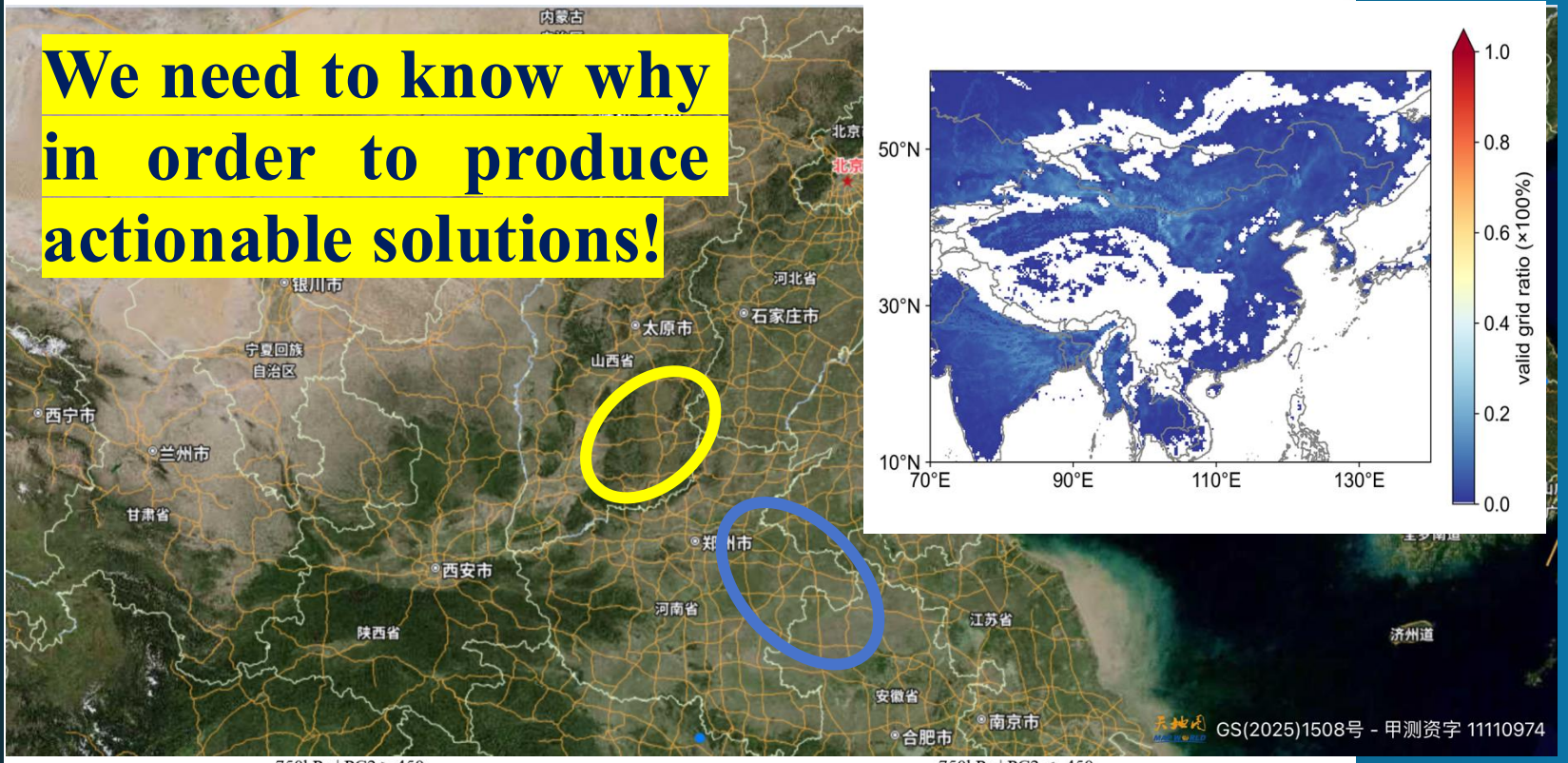
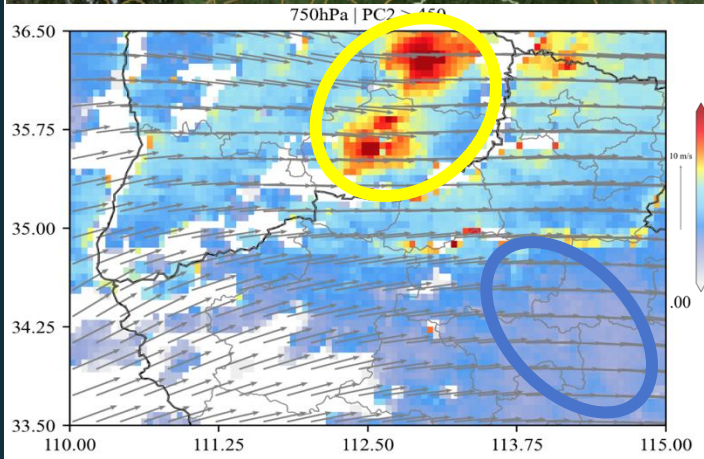
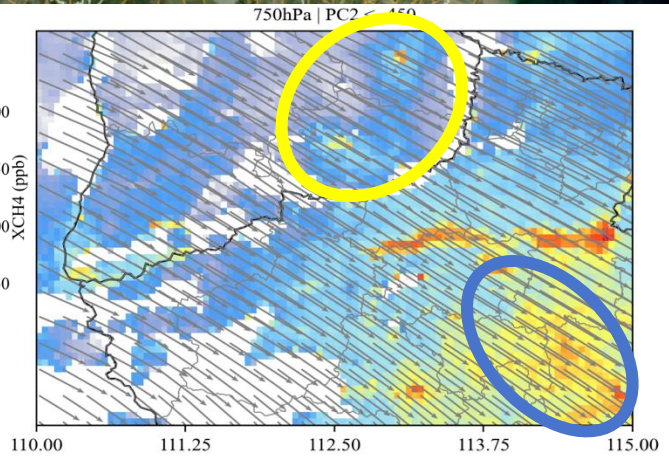
We need to know why in order to produce actionable solutions!

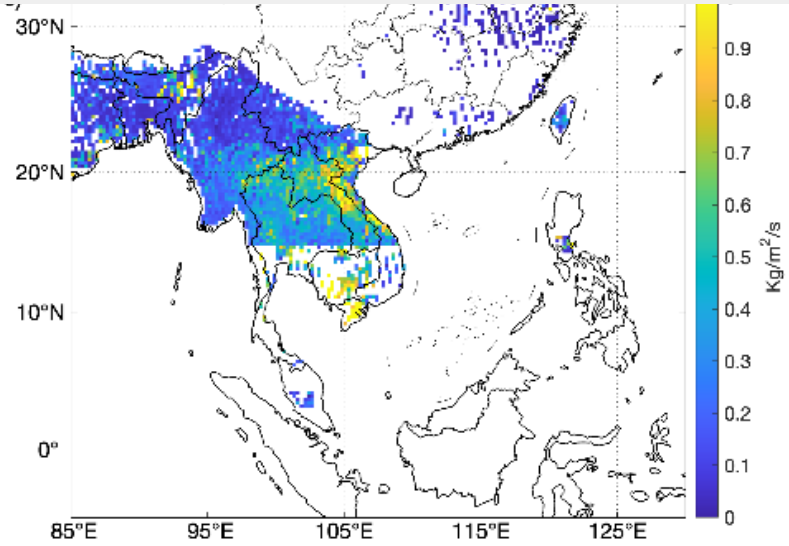


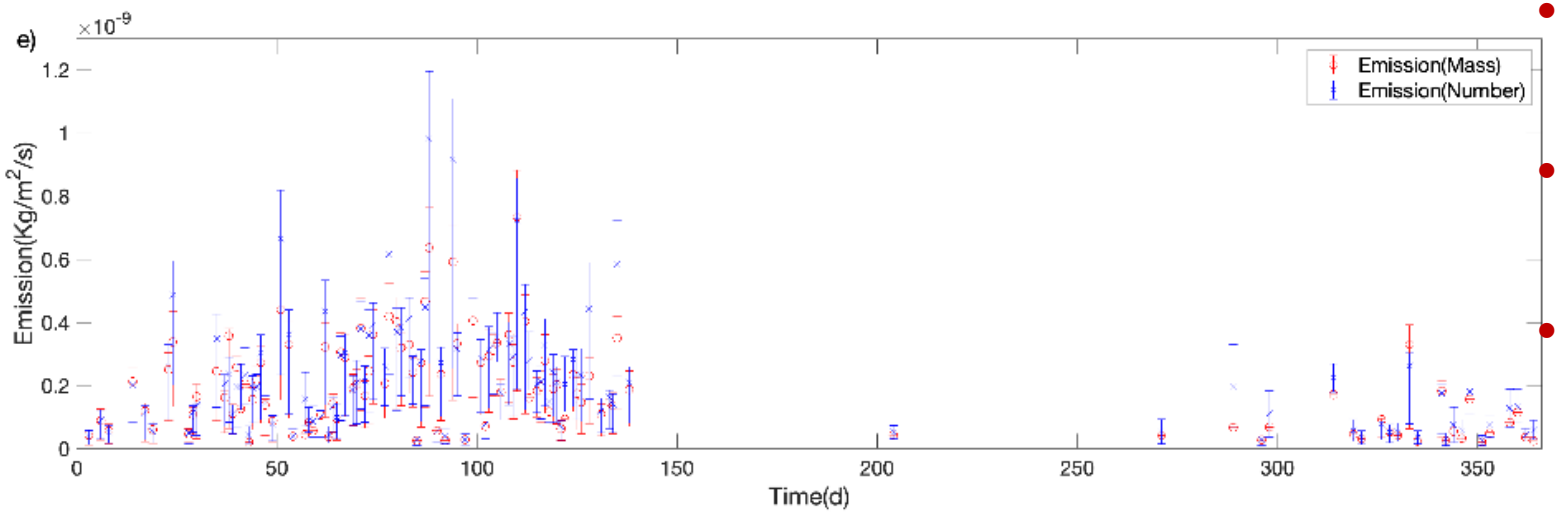




- 40% of data demonstrates global methane increase.
- 5.3% of data demonstrates long-range transport of coal mine methane from Shanxi to Agricultural regions in Henan.

What + Where + When → Why
Black Carbon from Forest Fires





- **Emissions of BC (247Gg) are higher than inventories, similar to Cohen 2014.**
- **High emission found in rapidly developing areas & Biomass Burning.**
- **Uncertainty ranges from 23.3–62.3%**

Liu and Cohen* et al. (2025) RSE ; Cohen (2014) ERL; Liu and Cohen* et al. (2025) ESTL; Cohen and Wang (2014) JGR

What + Where + When → Why
Black Carbon And Air Pollution Control: Success!

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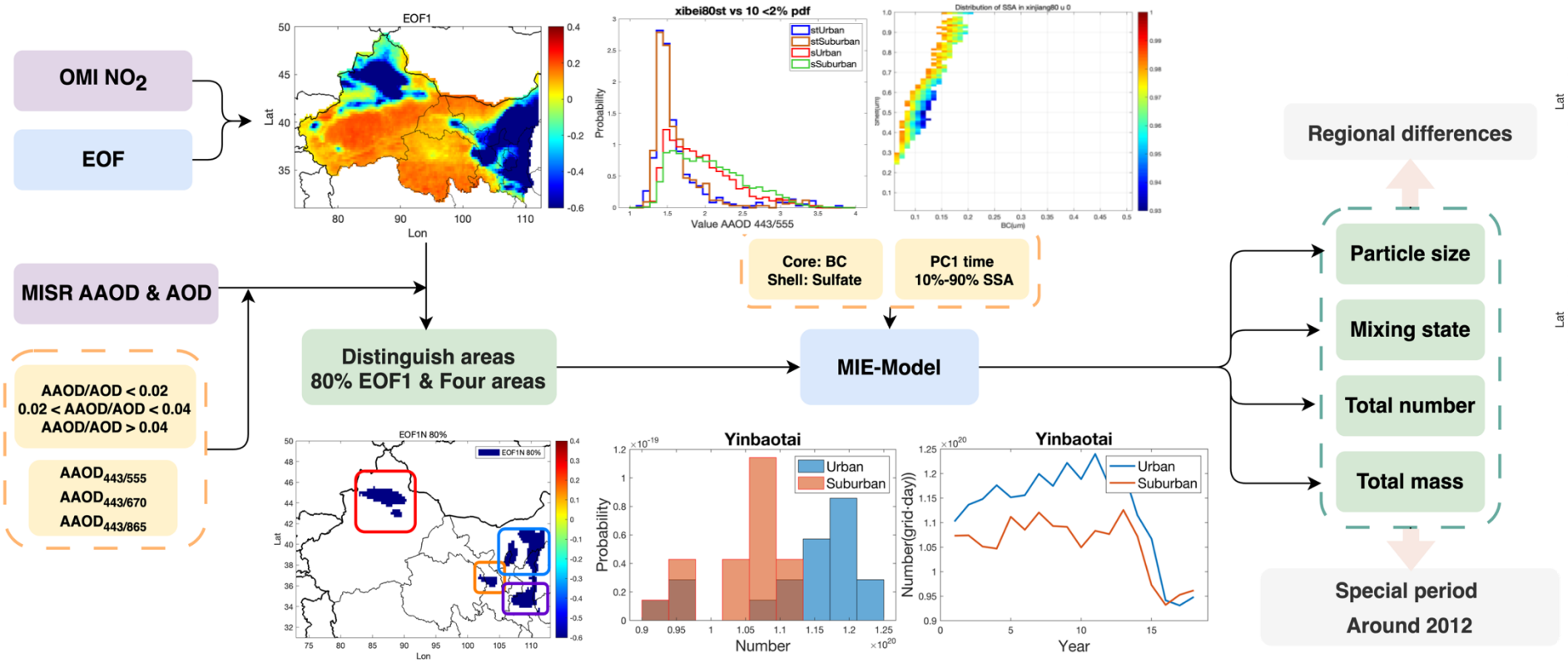

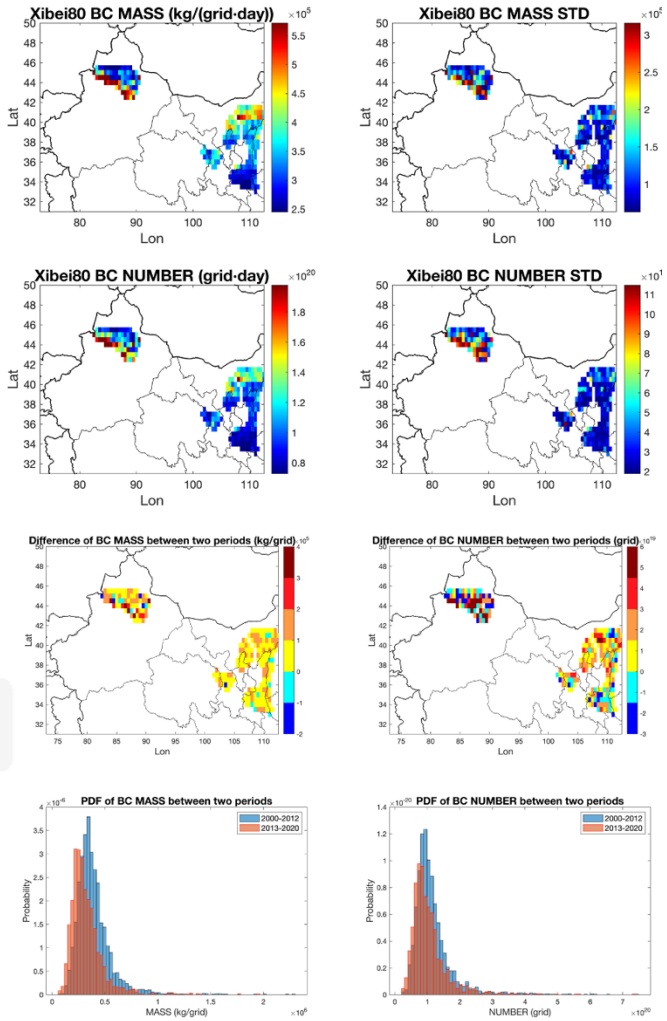

- **Objectively determine the high NO_2 source areas**
- **Policy implementation starting in 2013, BC size in Urban areas decreased, while they did not in suburban areas**
- **Two substantial decreases were observed: the first uniquely in 2008 (Beijing Olympics) and the second starting in 2013.**

Liu, Cohen, et al., 2024; https://doi.org/10.1038/s41612-024-00663-9

Western China BC mass and number

What + Where + When → Why
Black Carbon Global & Regional Data

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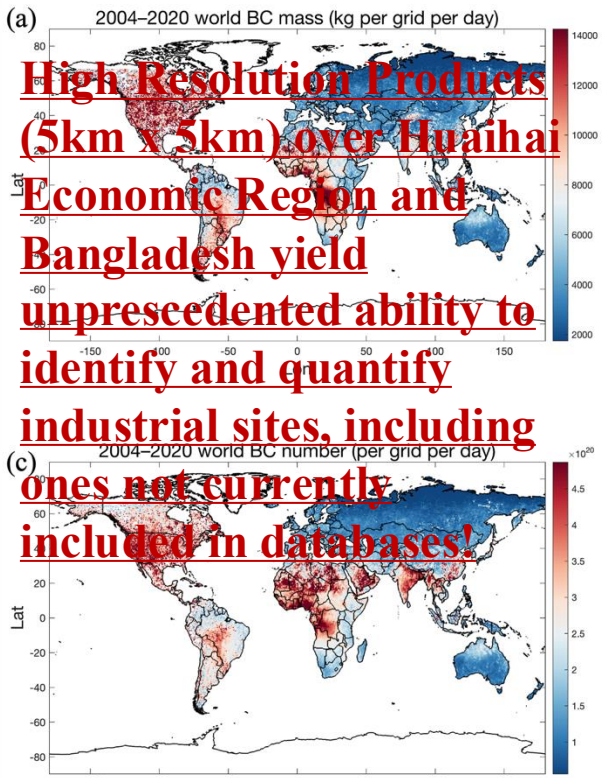
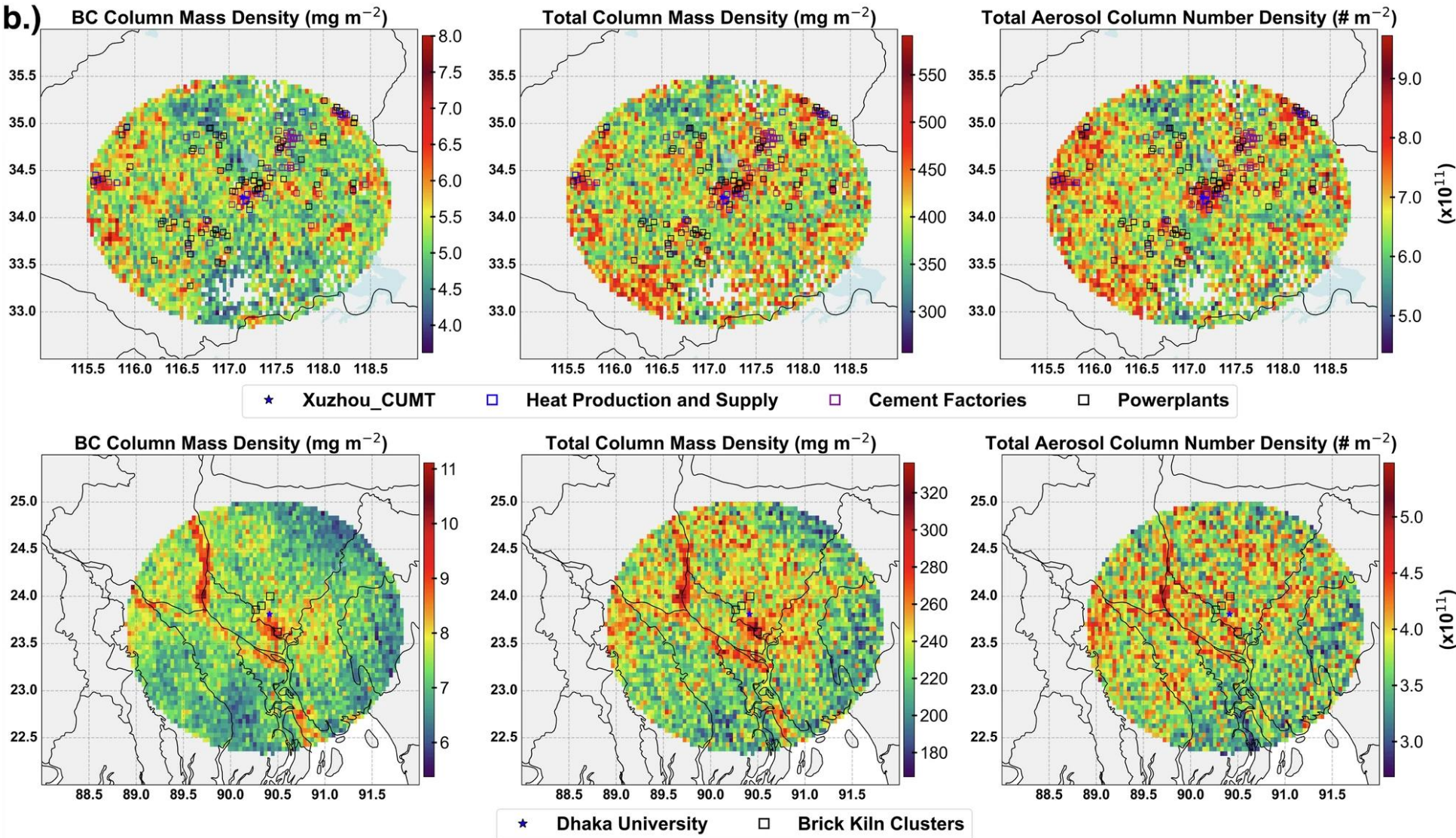


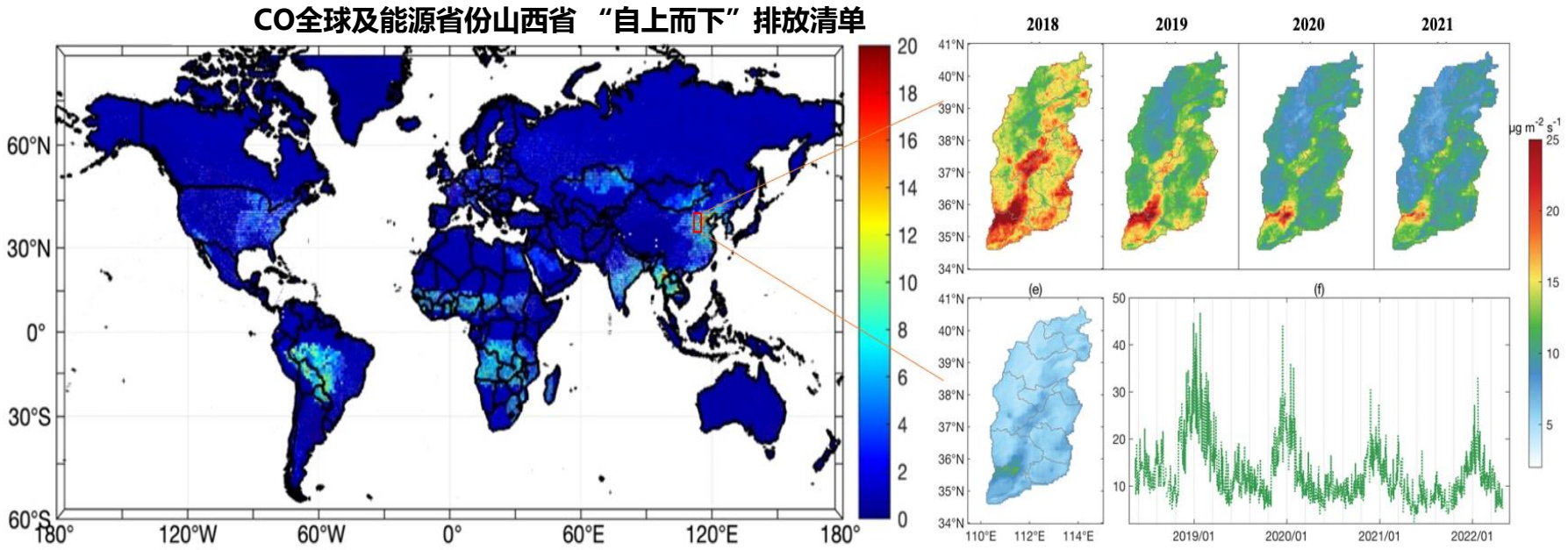
High Resolution Products (5km x 5km) over Huaihai Economic Region and Bangladesh yield unprescedented ability to identify and quantify industrial sites, including ones not currently included in databases!

Satellite and Ground Remote sensing observation



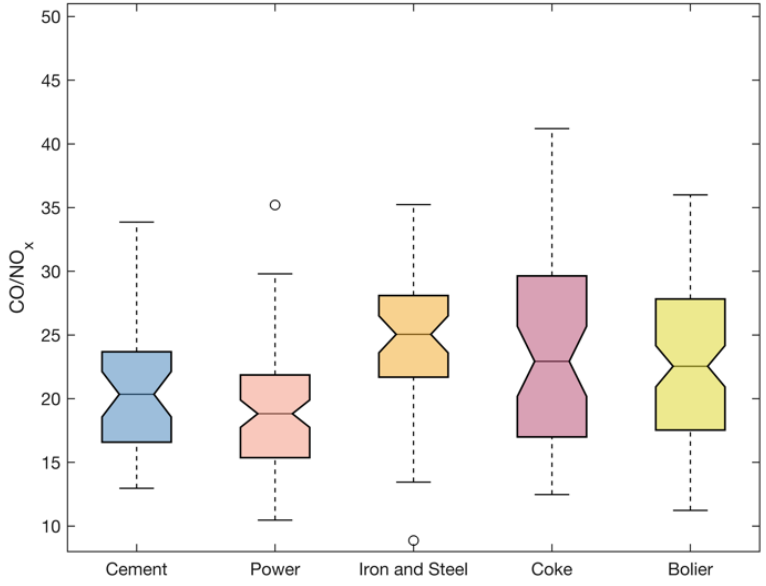
Liu J; Cohen et al (2024, 2025) ; Tiwari, P; Cohen, J.B (2025) ; Liu, Cohen, et al., 2025; https://doi.org/10.5194/essd-2025-593

What + Where + When → Why
Carbon Monoxide (an indirect GHG)



Carbon Monoxide is substantial in Shanxi, up to 7% of the total CO_2 emissions. Although Emissions are decreasing, they are not accounted for in the current Carbon Accounting Framework.

Most of this is attributed to Iron/Steel and Coke, necessary components for the Green Energy Transition!



Li and Cohen* et al. (2023) ACP; Li and Cohen* et al. (2025) CEE; Wang, Cohen* et al., (2025) NPJ

What + Where + When → Why
NOx (Air Pollutant and Emissions Tracer)

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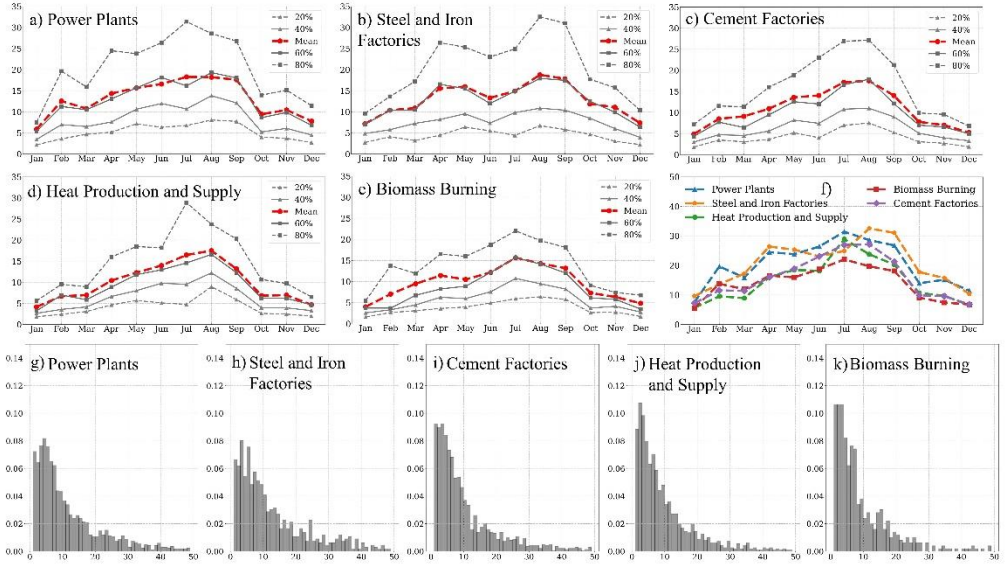
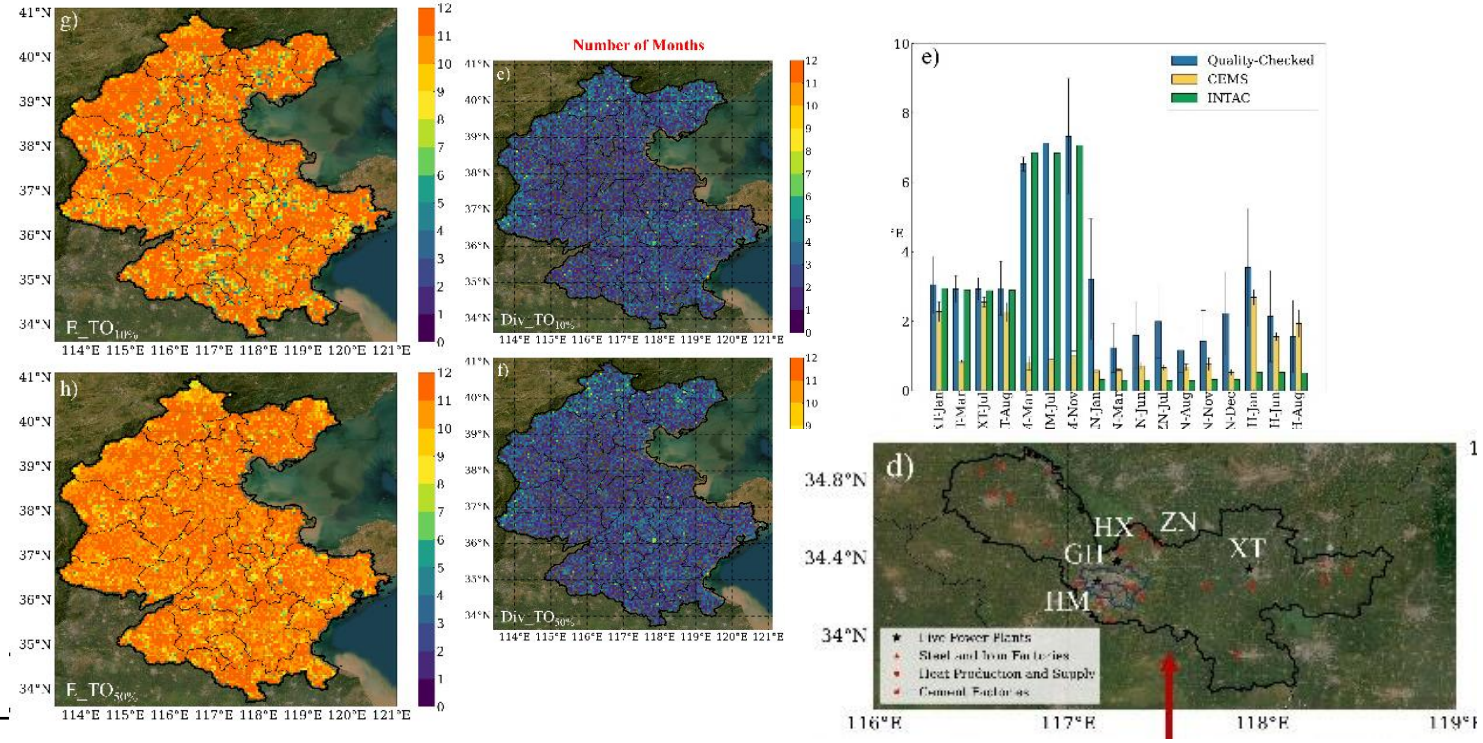
- **TROPOMI**
- **Mass balance equation**

1. Sources Attribution (NO_x/NO_2)



Industrial Source Types	50%	hl ratio	Attribution Factors
Power Plants	8.02	6.15	[M,L]
Steel and Iron Factories	9.21	6.16	[H,L]
Cement Factories	7.14	8.93	[L,H]
Heat Production and Supply	6.93	7.94	[L,M]
Biomass Burning	6.50	5.96	[L,L]

2. Quality-checked NO_x Emissions (Using Observational Uncertainty)



Lu, Cohen* et al. (2025) ACP; Lu, Cohen* et al. (2025) TGRS

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CO2 Indirect Calculation

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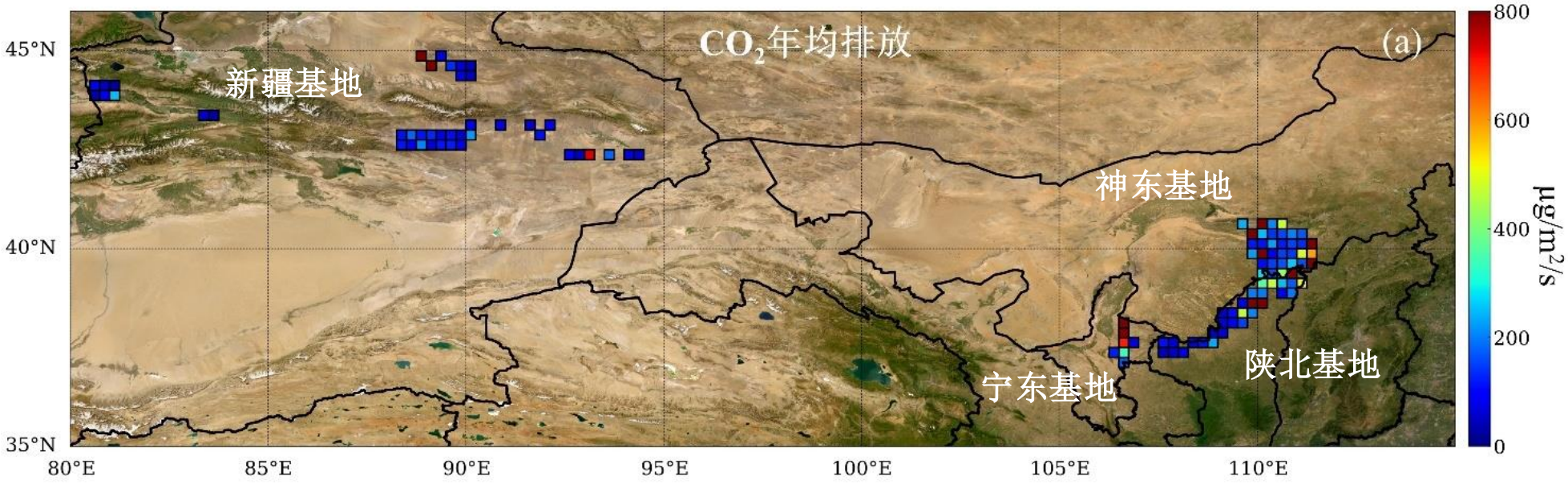
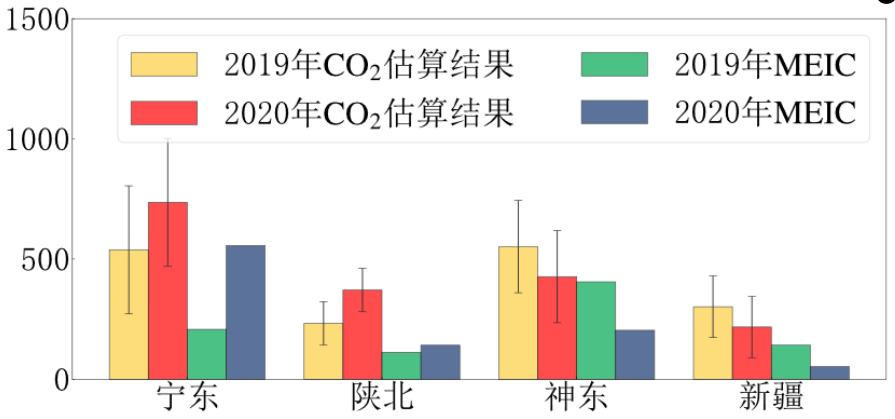
We use 3 different satellite products: TROPOMI NO_2, CO and SO_2 VCDs



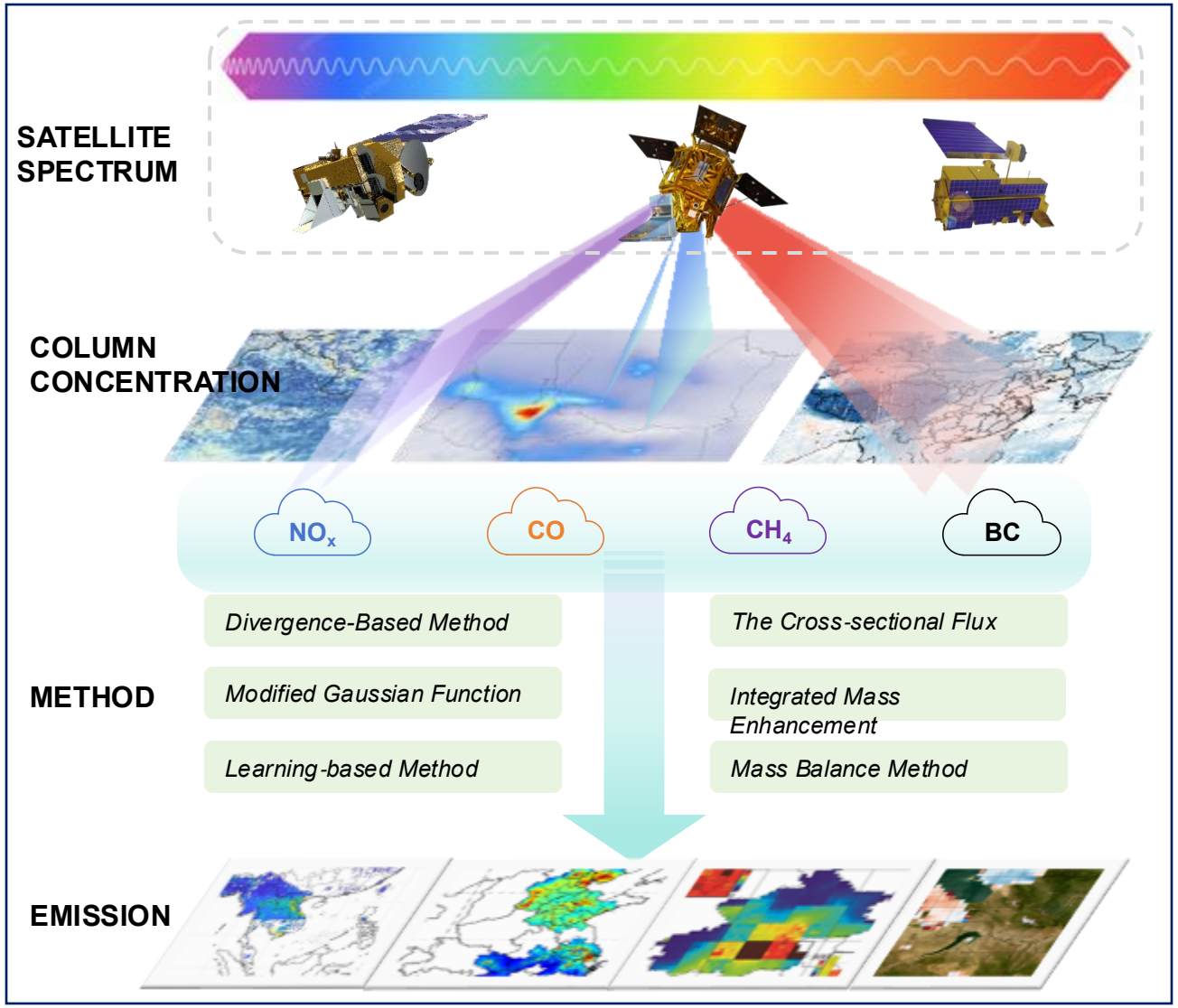
Compared to MEIC data, 87% of grid cells exhibit higher emission estimates, underscoring the necessity of improving **GEOSPATIALLY DISTRIBUTED** emission inventory accuracy.

μg/m²/s	宁东基地	陕北基地	神东基地	新疆基地
CO_2-2019	538.2±266.3	232.1±90.5	551.6±191.8	301.5±127.6
CO_2-2020	735.5±202.0	371.2±144.8	416.7±146.8	217.3±119.8



https://doi.org/10.1016/j.rse.2023.113720
https://doi.org/10.5194/acp-23-8001-2023
https://doi.org/10.5194/acp-25-2291-2025
https://doi.org/10.1038/s43247-025-02301-5

What is my Scientific Idea? 我的科学理念



- Observation Based Approaches
- Model Based Approaches

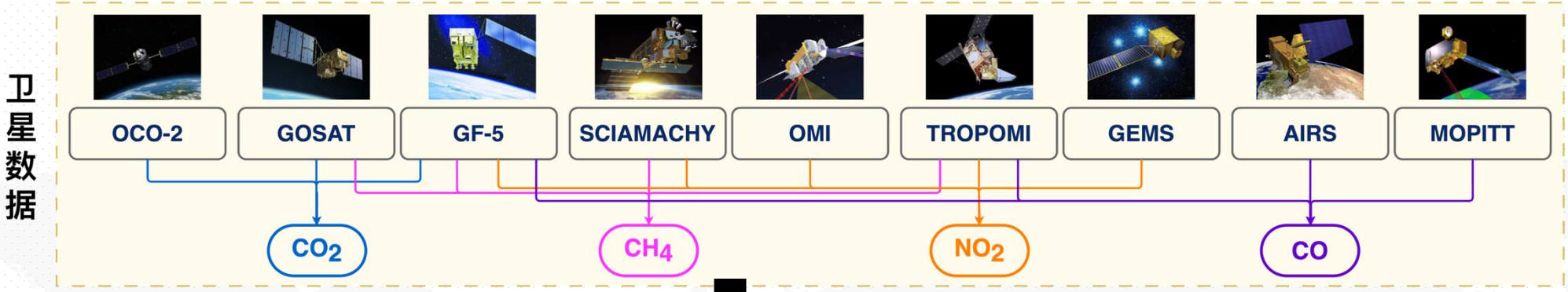
Flexible Inclusion of Atmospheric Thermodynamics, Dynamics, and Chemistry to Quantify Emissions of NO_x, CO and CH_4

Considering Explicit Observational Uncertainty and Cross-Species Source Consistency to Quantify Attribution and Anomalous Events

Addressing Realistic Optical and Microphysical Assumptions Impact on Quantifying Absorbing Aerosol Emissions

如何发展一个物理约束的轻量级排放遥感反演方法体系?

Emissions: Fast, Attributable, Physical, Open, Accessible



Thermodynamics of combustion

Chemical Production

Atmospheric Diffusion

先验清单

$$E_{NOx} = \frac{d}{dt}(\alpha_1 V_{NO_2}) + \frac{1}{\alpha_2}(\alpha_1 V_{NO_2}) + \frac{1}{\alpha_3}\cdot\nabla(\boldsymbol{u}\cdot\alpha_1 V_{NO_2}) \quad \text{(MFIEE-NO}_x\text{)}$$

$$E_{CO} = \frac{d}{dt}(V_{CO}) + \frac{1}{\alpha_{2a}}(V_{CO}) - \frac{1}{\alpha_{2b}}(V_{HCHO}) + \frac{1}{\alpha_3}\cdot\nabla(\boldsymbol{u}\cdot V_{CO}) \quad \text{(MFIEE-CO)}$$

$$E_{CH4} = \frac{d}{dt}(V_{CH4}) + \frac{1}{\alpha_3}\cdot\nabla(\boldsymbol{u}\cdot V_{Ch4}) + \frac{1}{\alpha_5}\cdot\nabla^2(V_{CH4}) \quad \text{(MFIEE-CH}_4\text{)}$$

$$E_{BC} = \frac{d}{dt}(V_{BC}) + \frac{1}{\alpha_{4a}}|Rain|(V_{BC}) + \frac{1}{\alpha_{4b}}|\boldsymbol{u}|(V_{BC}) + \frac{1}{\alpha_3}\cdot\nabla(\boldsymbol{u}\cdot V_{BC}) \quad \text{(MFIEE-BC)}$$

Chemical Decay

Wet and Dry Deposition

Atmospheric Transport: pressure induced and gradient induced

Li, **Cohen**, et al., 2025 CEE; Liu, **Cohen**, et al., 2024 CEE; Hu…**Cohen**, 2024 CS&T;
Lu, **Cohen**, et al., 2025 ACP; Qin, … **Cohen**, 2023 RSE; Li, **Cohen**, et al. 2023 ACP; Wang, **Cohen**, et al., 2025 NPJ

Shortening the Path From Remote Sensing Observations to Real-World Emissions

感谢聆听！

Thank you for your time!

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