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Quantifying sectoral methane emissions with multi-species analysis

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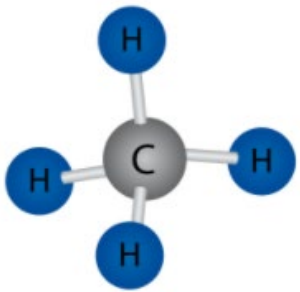
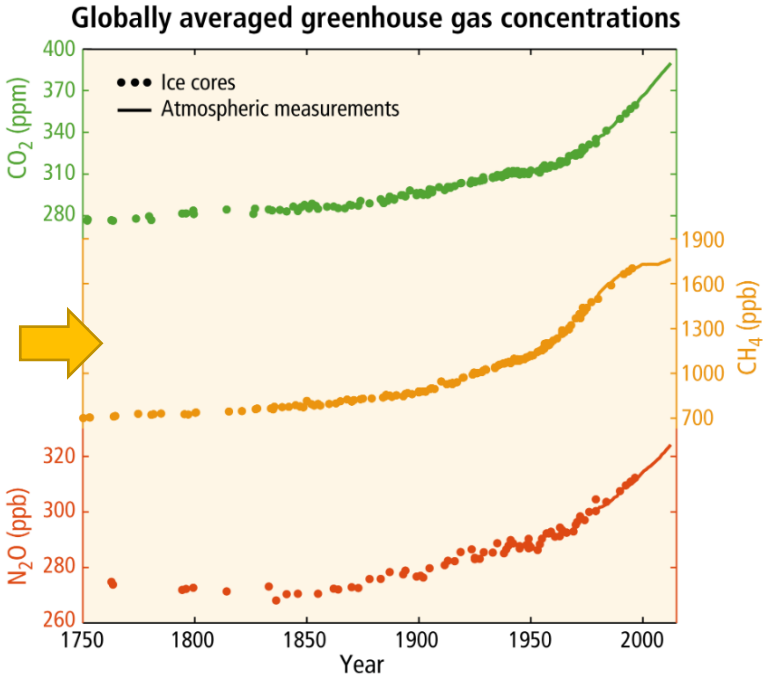
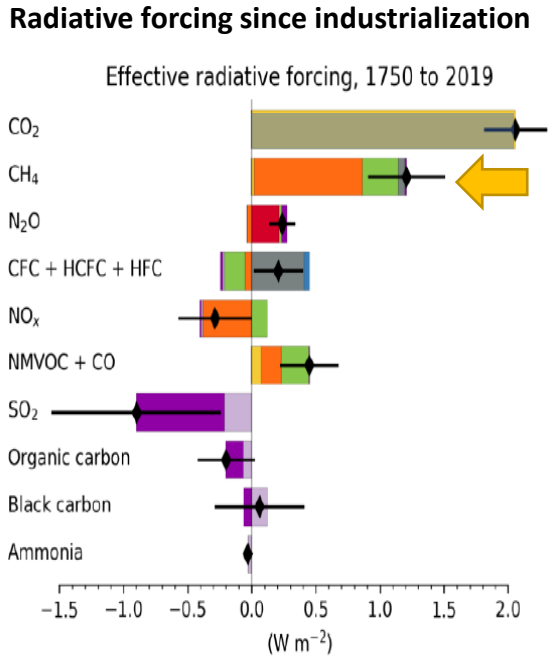


September 22, 2025

Methane (CH_4): the second greenhouse gas





Global Warming Potential

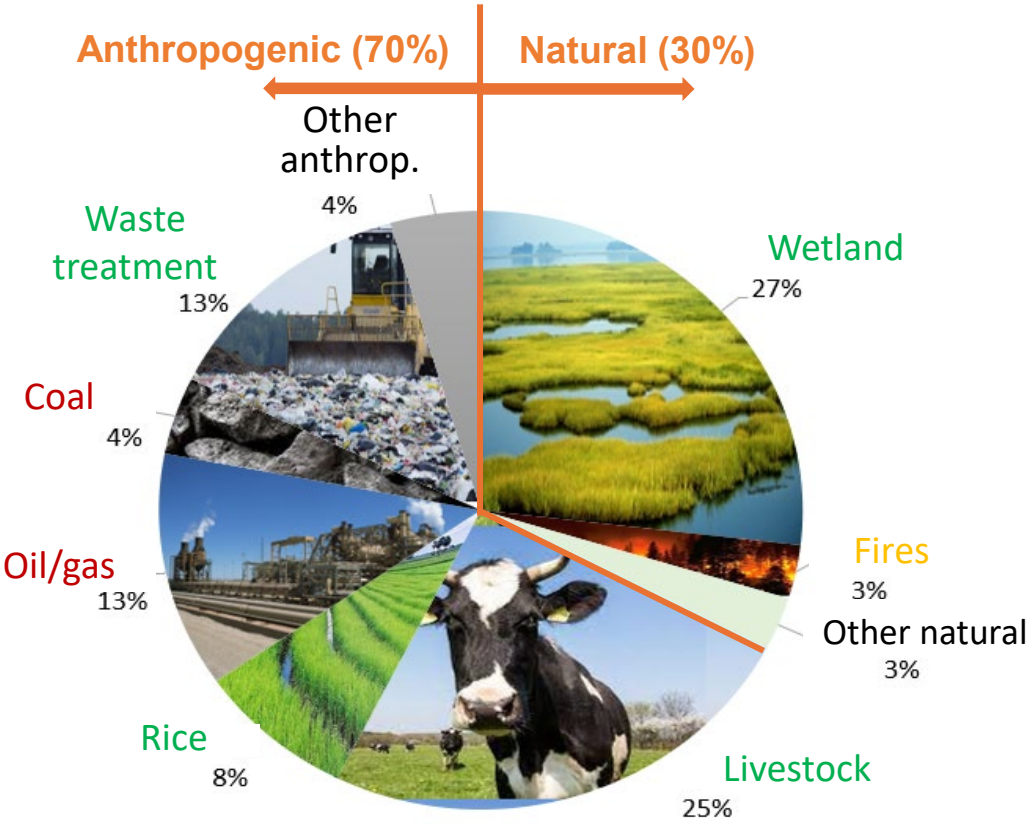
Capacity of unit mass to trap heat relative to CO_2

30 times to CO_2 (100-yr horizon)

80 times to CO_2 (20-yr horizon)

IPCC AR6 2021

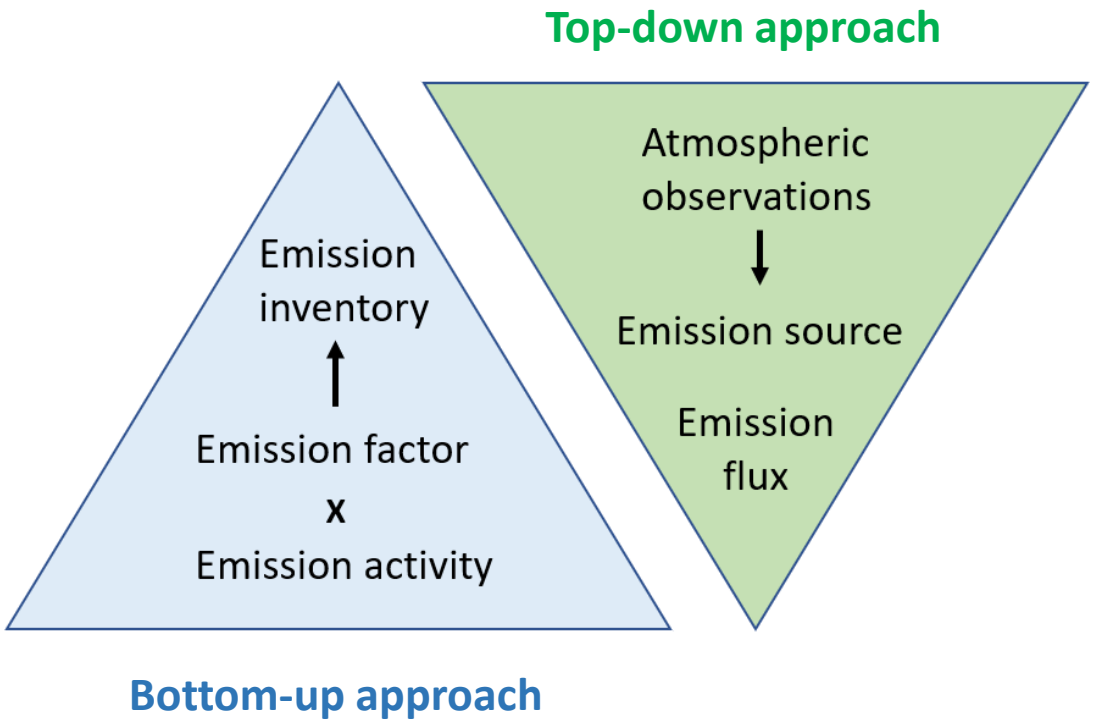
Methane sources to the atmosphere



Close ties with important issues

- Energy security
- Food production
- Urban management
- Ecosystem feedback

Greenhouse gas monitoring



Complex sources

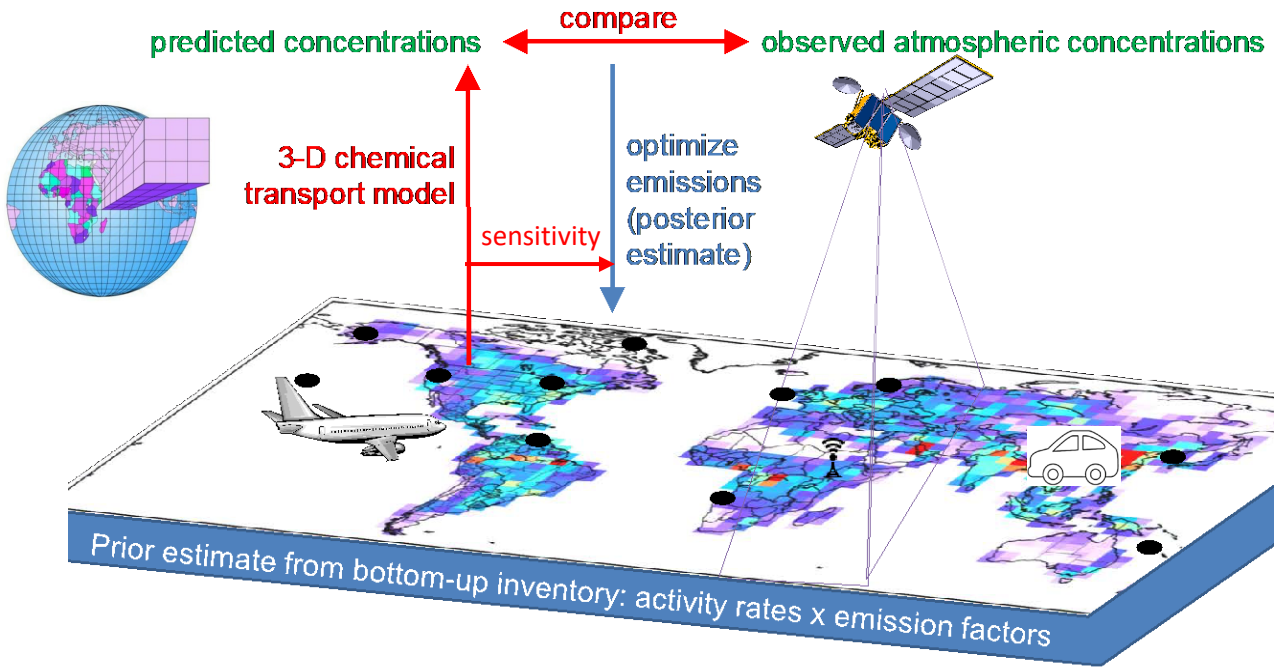
- Fugitive emissions
- Dependence on environmental conditions
- Large spatial-temporal variation

Large uncertainties in bottom-up estimates

Underscore importance of top-down approach

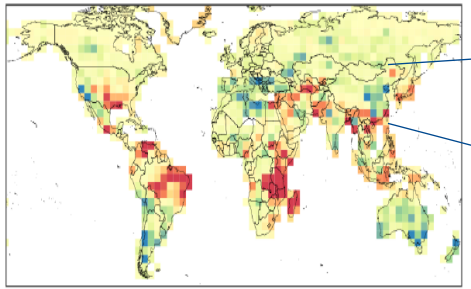
Methane emission inverse modeling

Satellite, surface sites, airplane, mobile



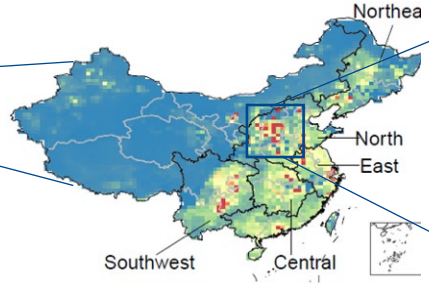
A multi-scale, multi-platform monitoring system

Global



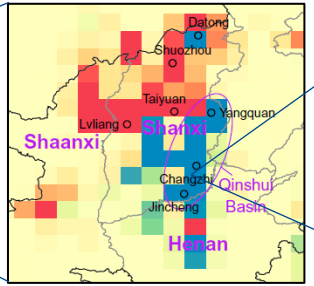
Zhang et al., ACP, 2021
Lu et al., ACP, 2021
Luo et al., ACP, 2022
Chen et al., NSR, 2025

National



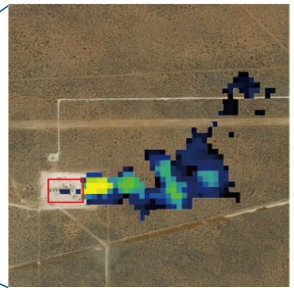
Zhang et al., PNAS, 2022
Liang et al., ACP, 2023

Regional



Zhang et al., Sci. Adv., 2020
Liang et al., EST, 2024

Facility



Zhao et al., ACP, 2025
Zhao et al., JGR-A, 2025

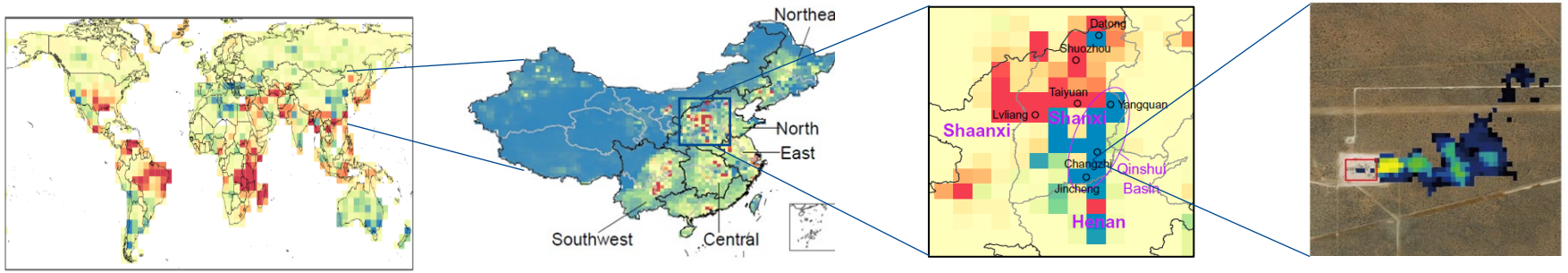
A multi-scale, multi-platform monitoring system

Global

National

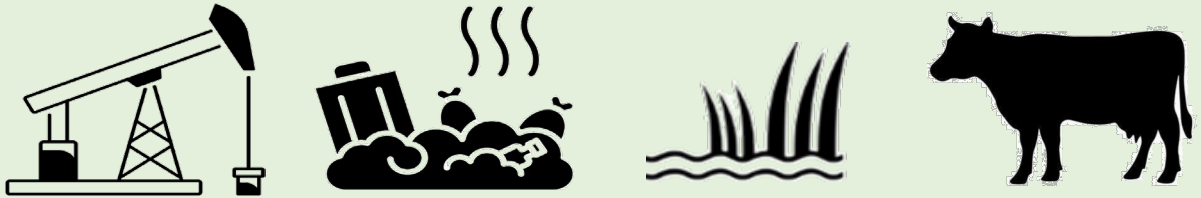
Regional

Facility



Limited capability to distinguish different sources

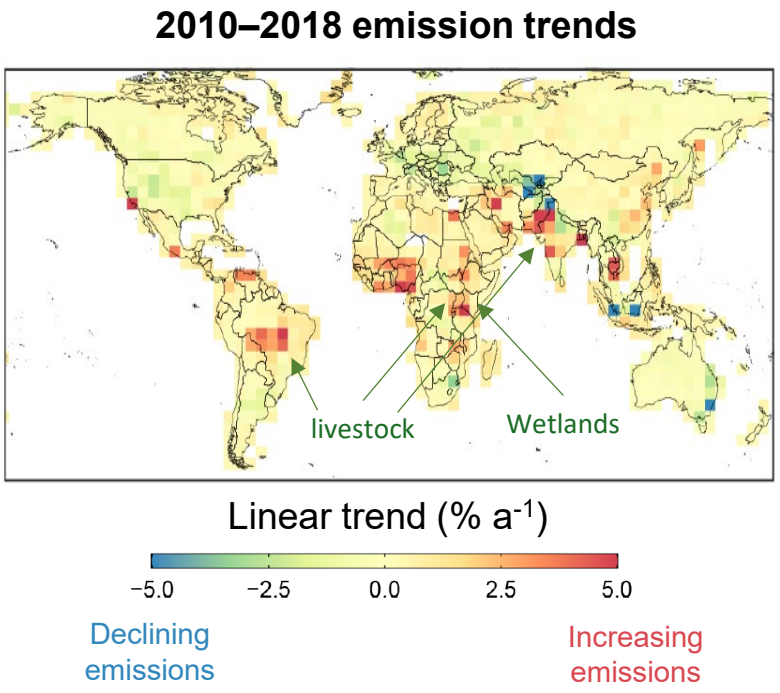
CH_4



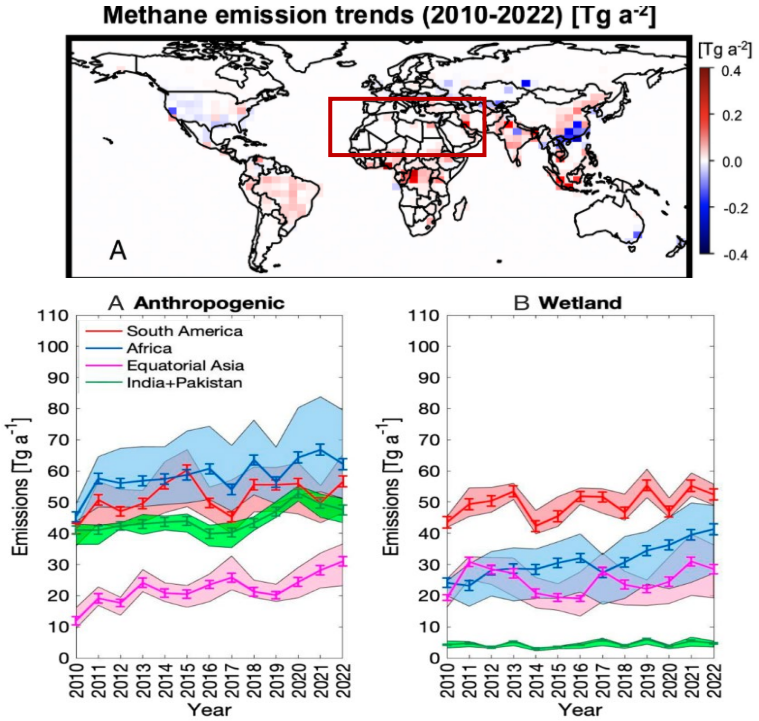
Joint NH_3-CH_4 analysis

Global methane emissions 2010–2018

How to separate contributions of livestock to the positive trend?



Zhang et al., ACP, 2021



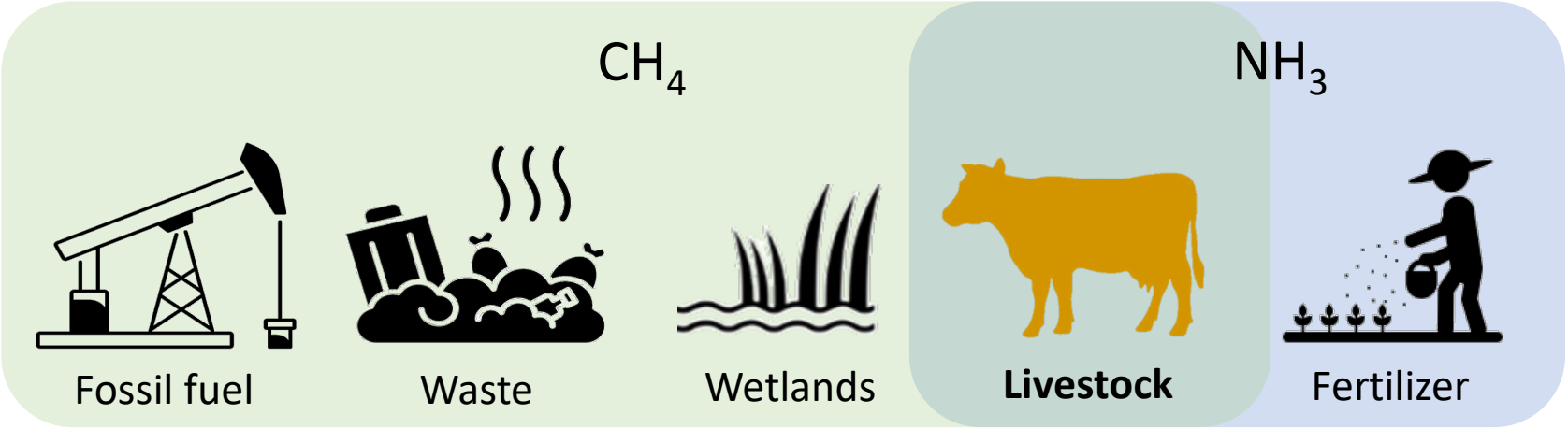
Qu et al., PNAS, 2024

Is the increase due to livestock or wetlands?

Wetlands in Sezibwa and Akweng River, Uganda

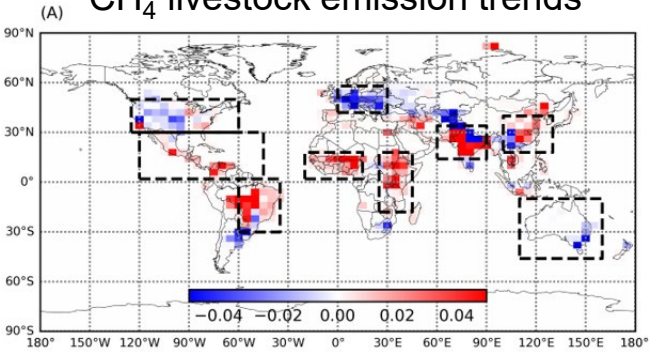
A multi-scale, multi-platform, multi-species monitoring system

- CH_4 and NH_3 are both emitted from livestock activities
- Better livestock attribution with joint analysis of CH_4 and NH_3 observations

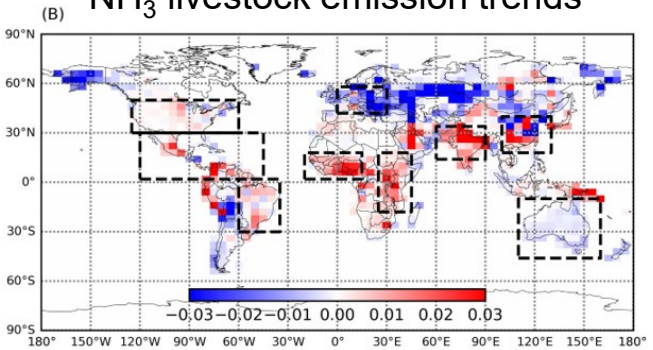


Joint NH_3-CH_4 analysis

CH_4 livestock emission trends

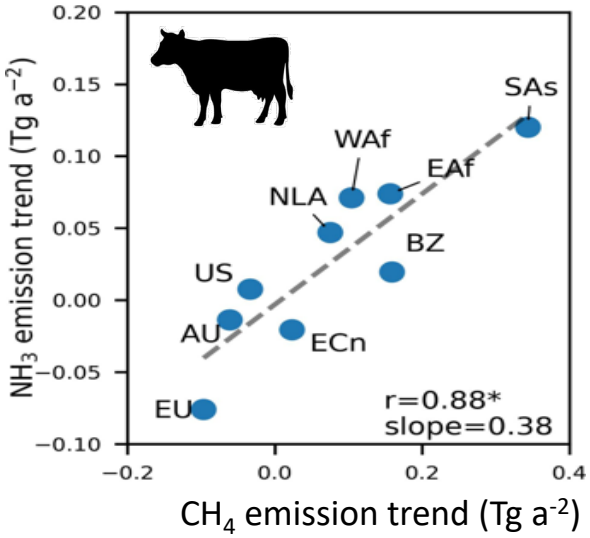


NH_3 livestock emission trends



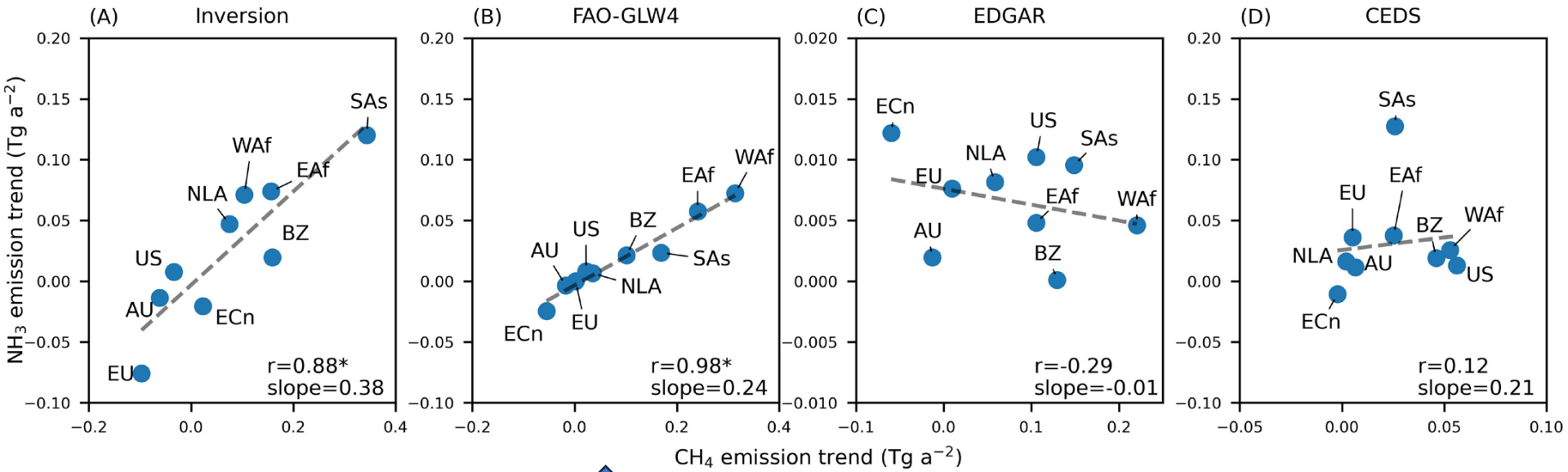
Strong correlation between NH_3 and CH_4

→ **livestock as common driver**



Luo et al., Atmos. Chem. Phys.,2022;
Tang et al., Envir. Res. Lett., 2025

NH_3-CH_4 trend correlation not captured by inventories

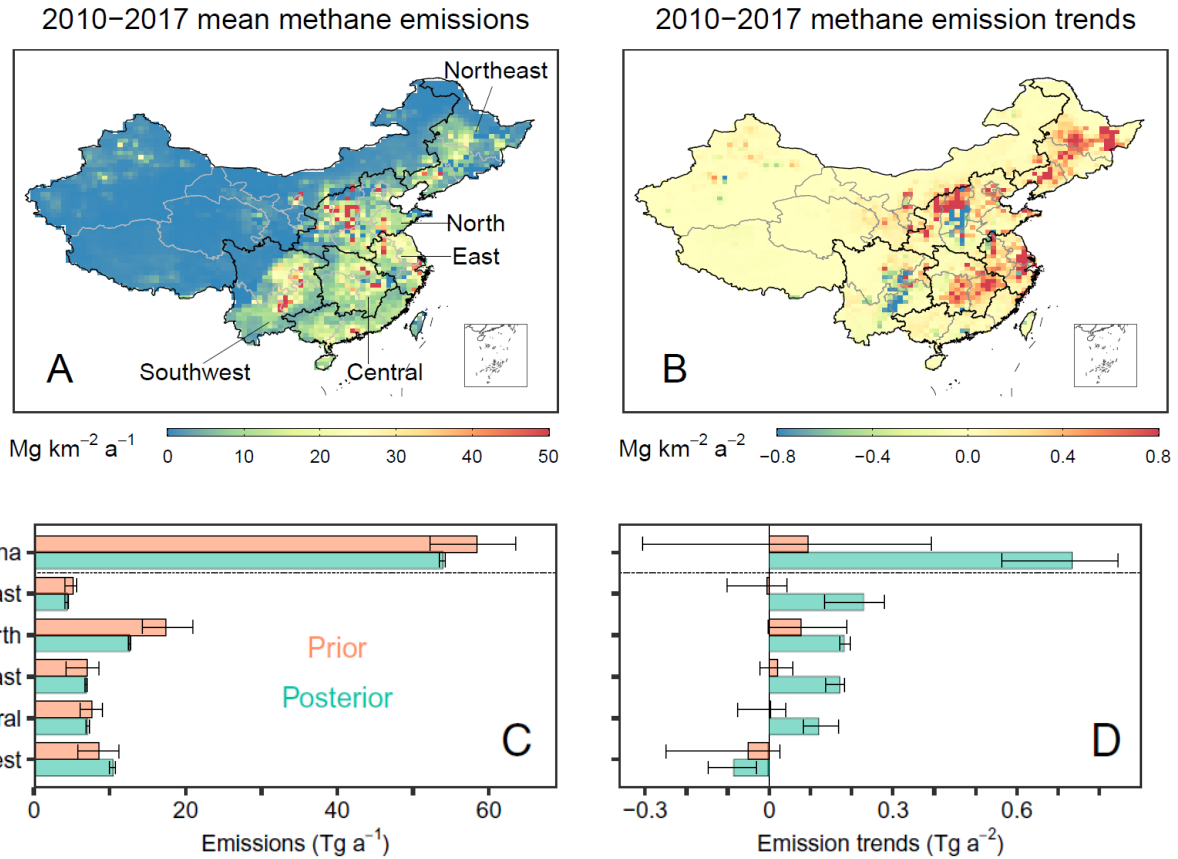


Largely explained by livestock population growth

Inconsistent methods or data for GHG and air pollutant inventories

Joint C_2H_6-CH_4 analysis

High resolution methane emissions & trends

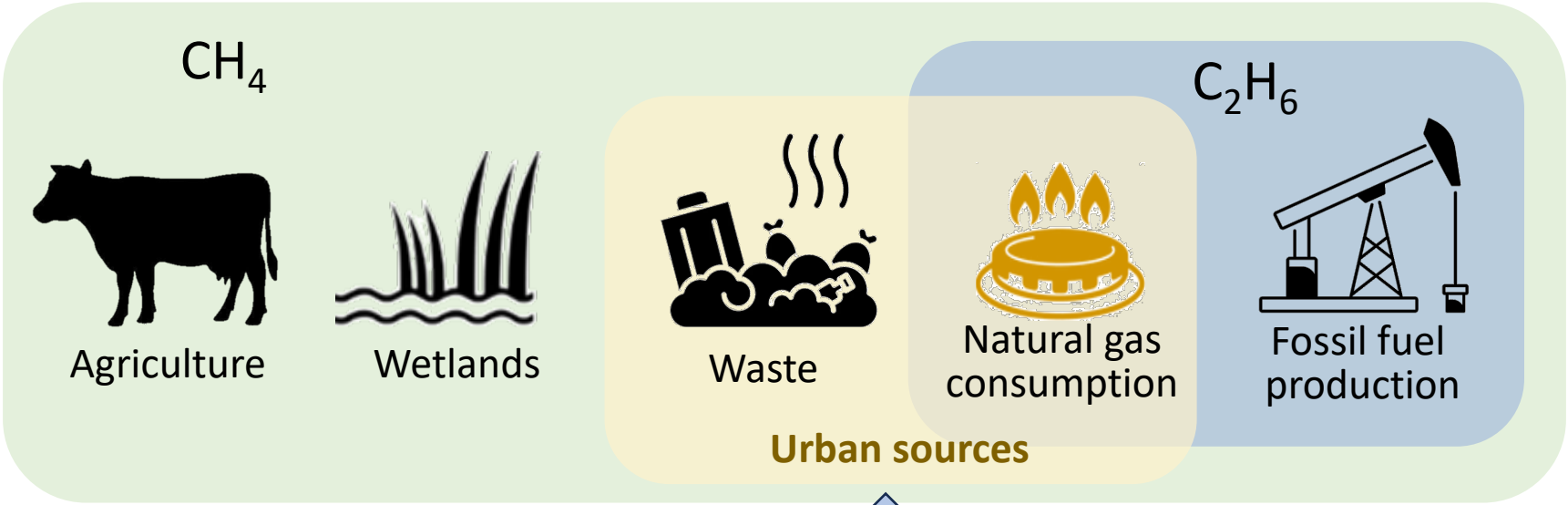


- Reference point for future progress
- Understand regional distribution, trends, and drivers

Zhang et al., PNAS, 2022

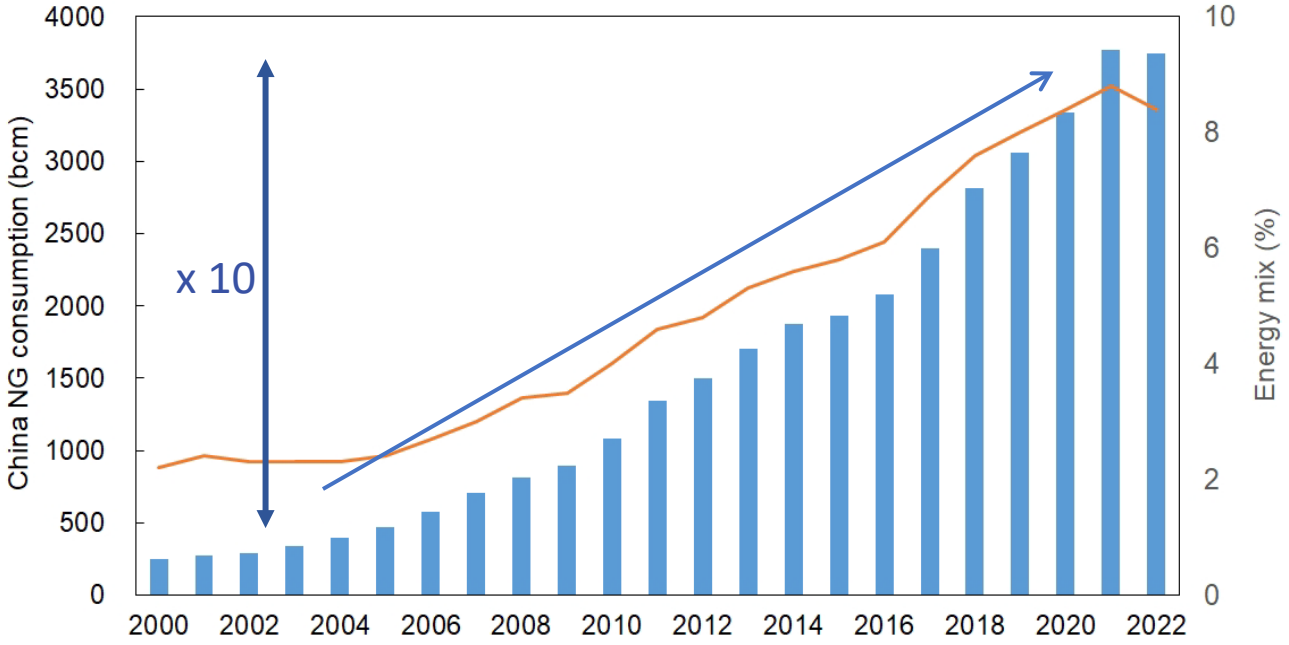
Which is the main sector in Chinese cities, waste or natural gas?

- Better natural gas attribution with joint analysis of CH_4 and C_2H_6 observations



Trend of natural gas consumption in China

Rapidly increasing consumption of natural gas since the 2000s



National Bureau of Statistics of China

What is the leakage rate?

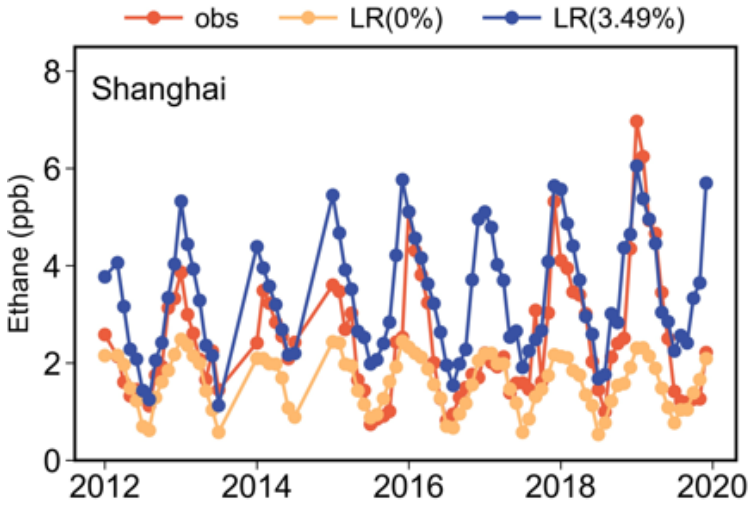
- **~0.2%** default inventory guideline
- **~2%** reported in some North American cities

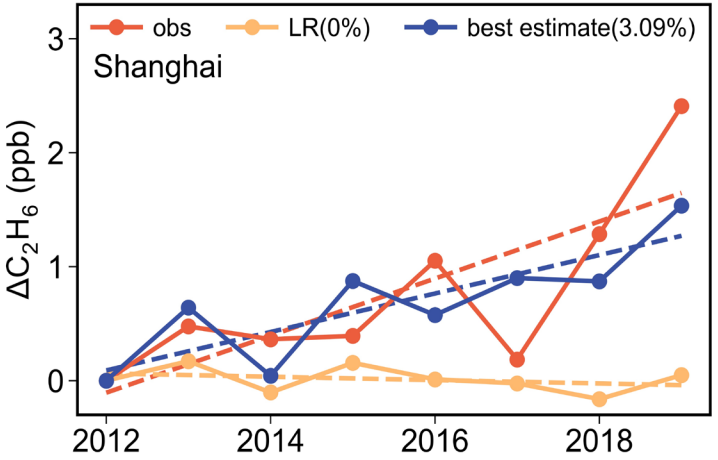
Los Angeles: Wennberg 2012; Wunch 2016; He 2019; Zeng 2023

Boston: Mckain 2014

Contribution of NG consumption is severely underestimated

Ethane observations in Yangtze-River Delta



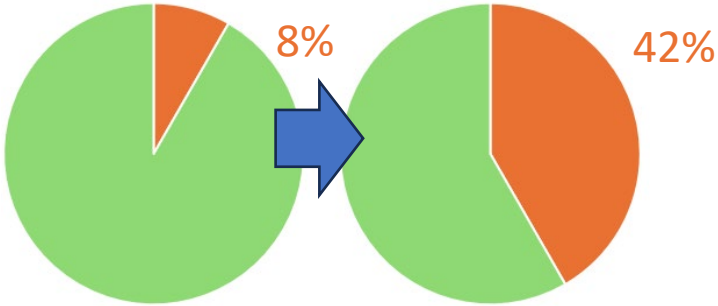


A leakage rate of 3.5% is needed to reproduce ethane observations

Zhao et al., in prep

Implications for China's urban methane emissions

Natural gas consumption to methane emissions in Yangtze-River Delta cities

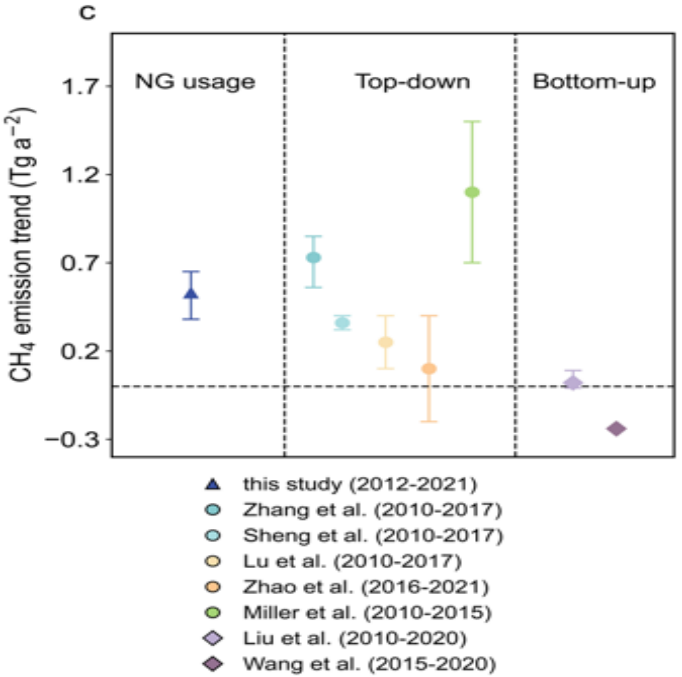


Zhang et al. (2022) Updated with ethane data

Natural gas consumption

Non-Natural gas consumption (e.g., wastewater, landfills)

Important contributor to national trend



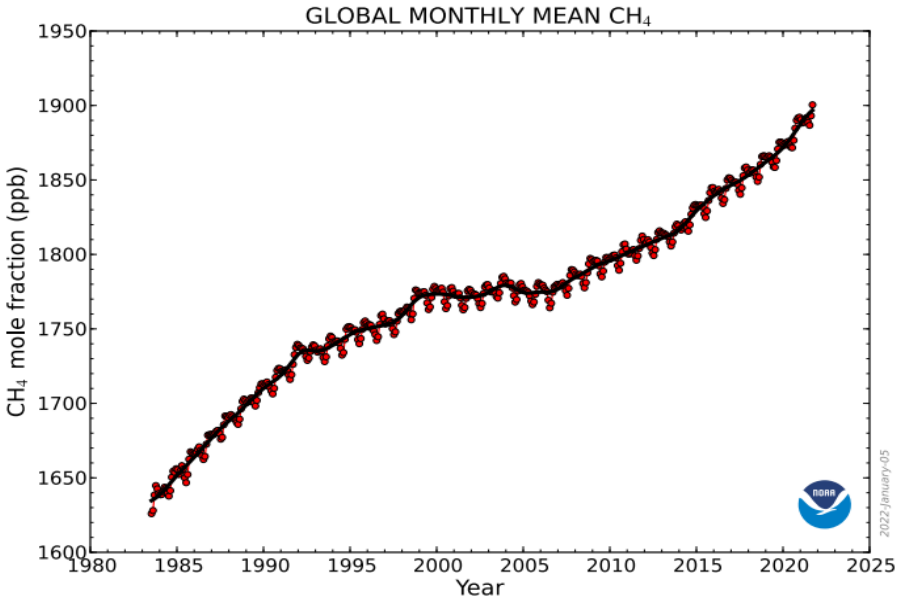
Zhao et al., in prep

Satellite CO to infer latitudinal distribution of global OH variations

More than emissions …

Mass balance of CH_4

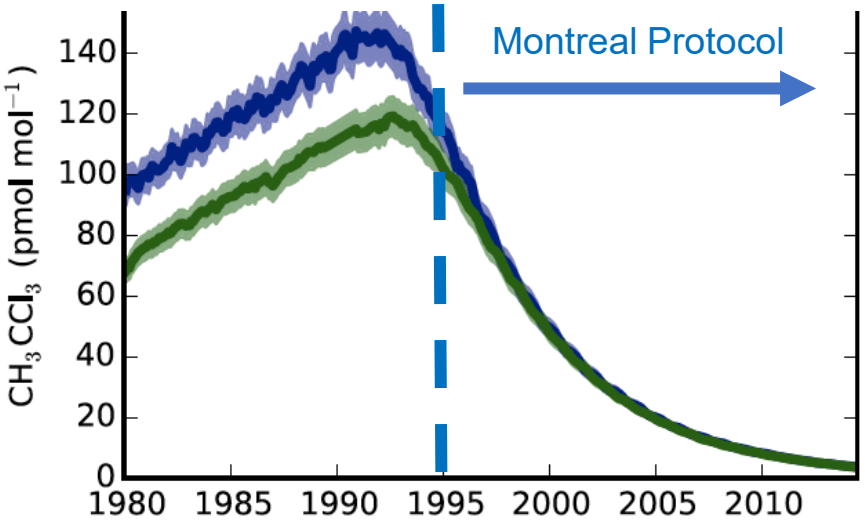
Δ CH_4 mass = Emission – Sink



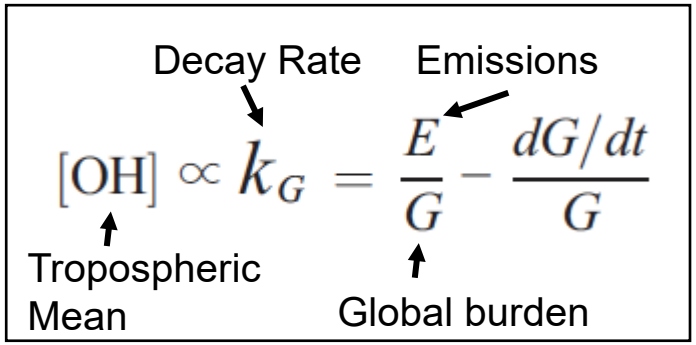
A complete understanding is impossible if **sink** is treated as **constant**, or as **a black box**!

How to monitor changes in global mean OH concentration?

Conventional method:
Methyl chloroform (MCF) proxy



Turner et al., 2017



CHALLENGE

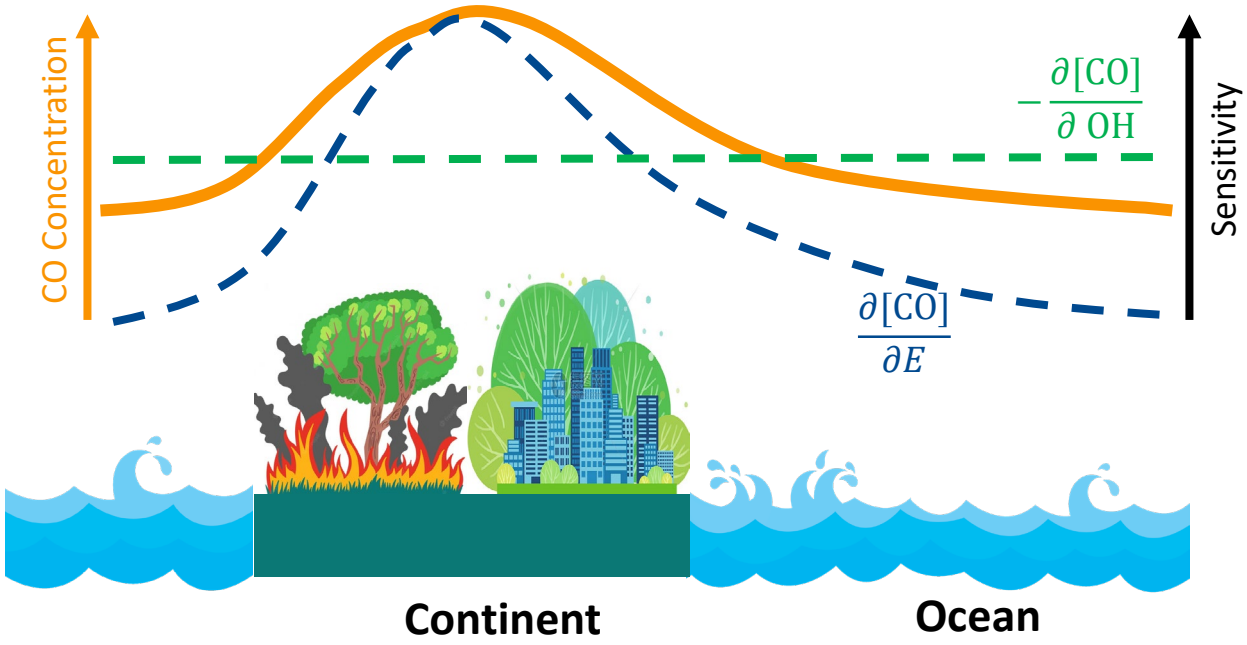
Challenges

- Approach to detection limit
- Provides no spatial information

A new method using satellite CO observations

$$\frac{dn_{CO}}{dt} = -\nabla \boldsymbol{u} \cdot n_{CO} + E + \sum_i \gamma_i E_i - \left(k_{CO} n_{CO} - k_{CH_4} n_{CH_4}\right) n_{OH}$$

Transport Emission OH-dependent Loss



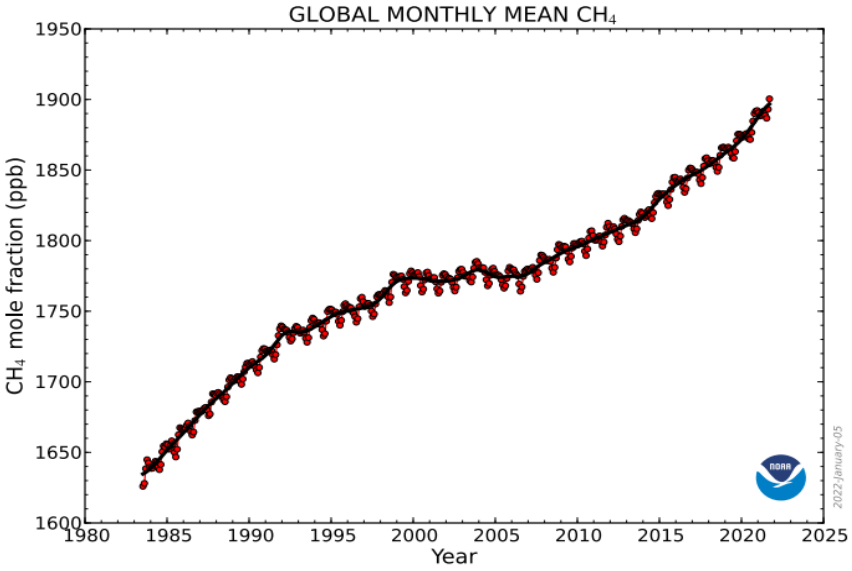
Spatial coverage
+
Shorter lifetime

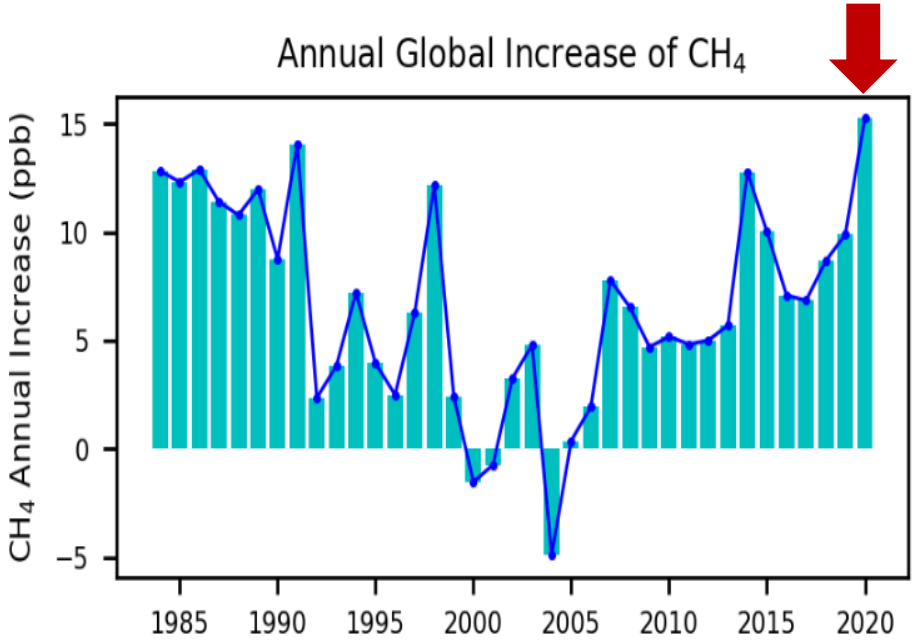
Latitudinal & seasonal distribution

Chen et al., National Science Review, 2025

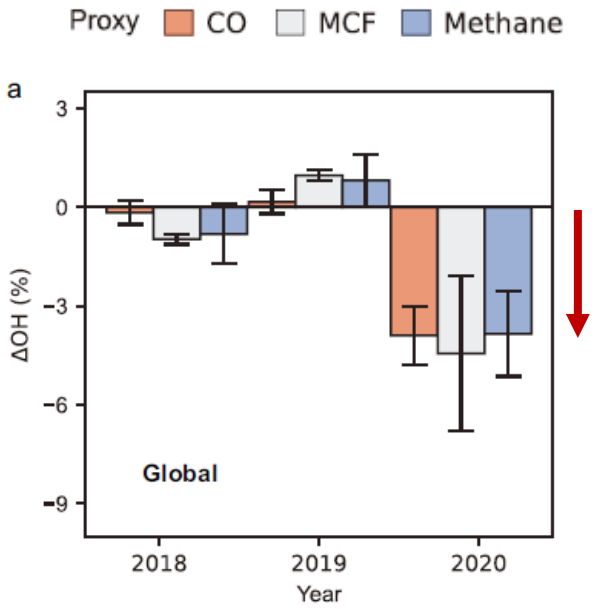
Rapid increase during 2020

What causes the record high growth of methane in 2020?



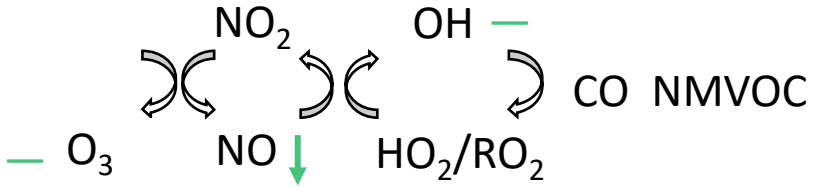


Reduced global OH in 2020

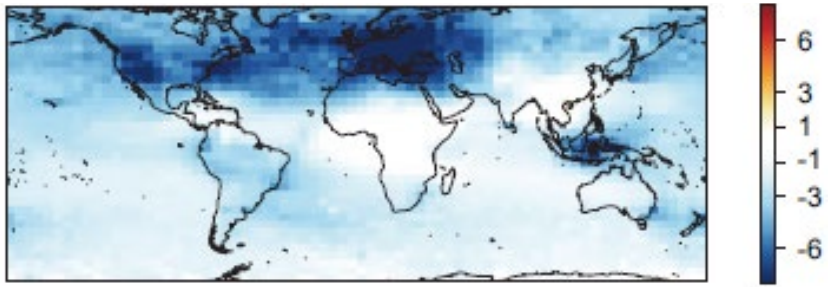


Peng et al., Nature, 2022
Laughner et al., PNAS, 2021
Miyazaki et al., Sci. Adv, 2021

Decreased NO_x emissions due to COVID-19 lockdowns



OH reduction mainly in Northern Hemisphere

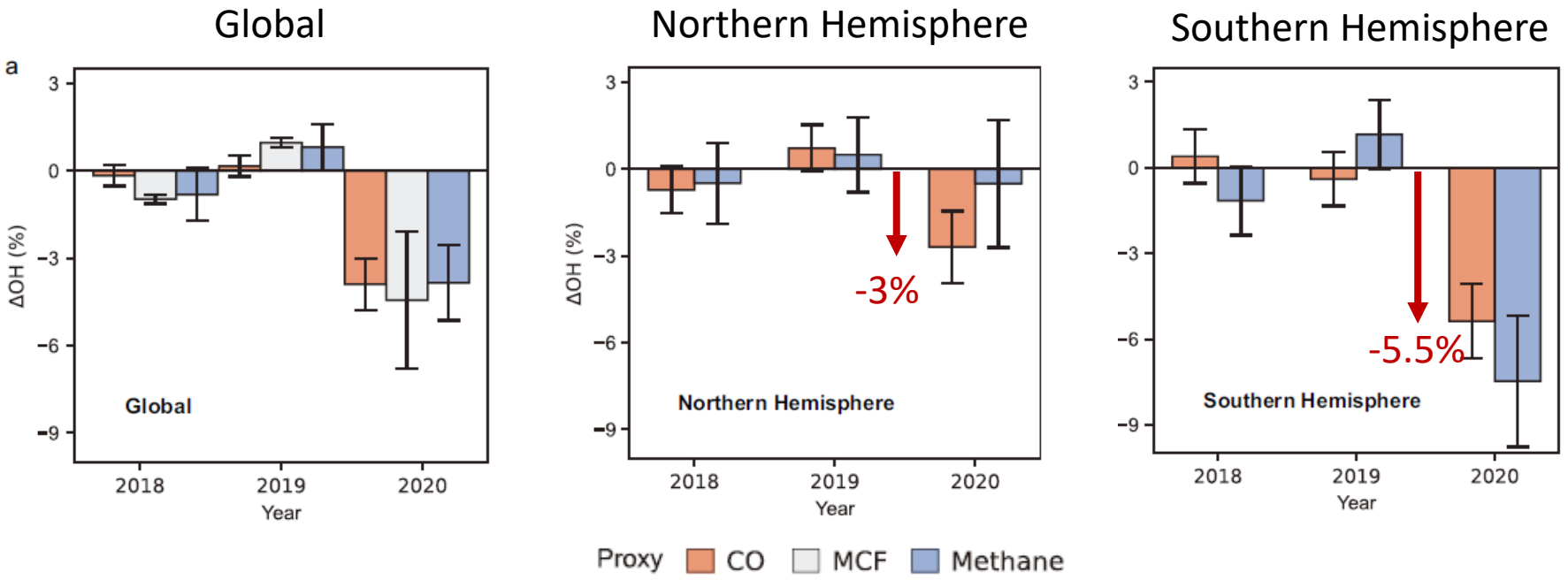


Simulated change due to COVID-19

Chen et al., NSR, 2025

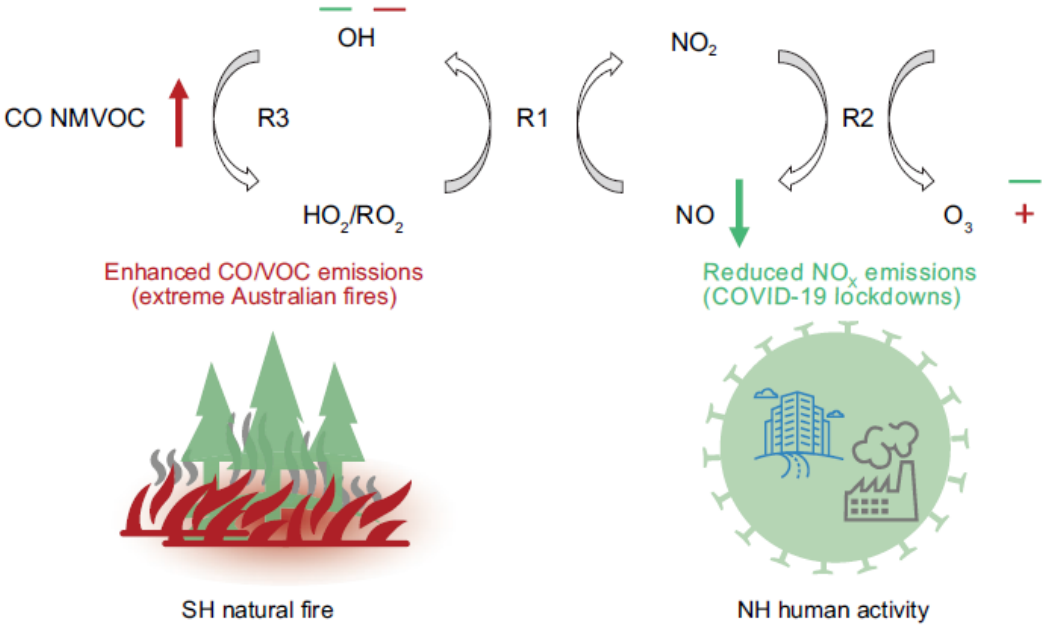
Reduced OH in both hemispheres

Greater reduction in Southern Hemisphere → COVID-19 was NOT the only driver

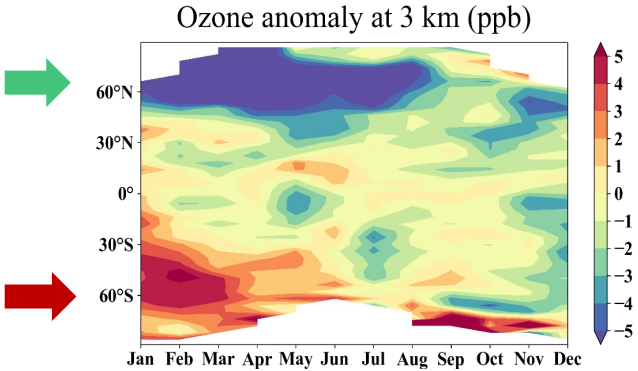


Chen et al., NSR, 2025

Extreme wildfires in Australia also contribute



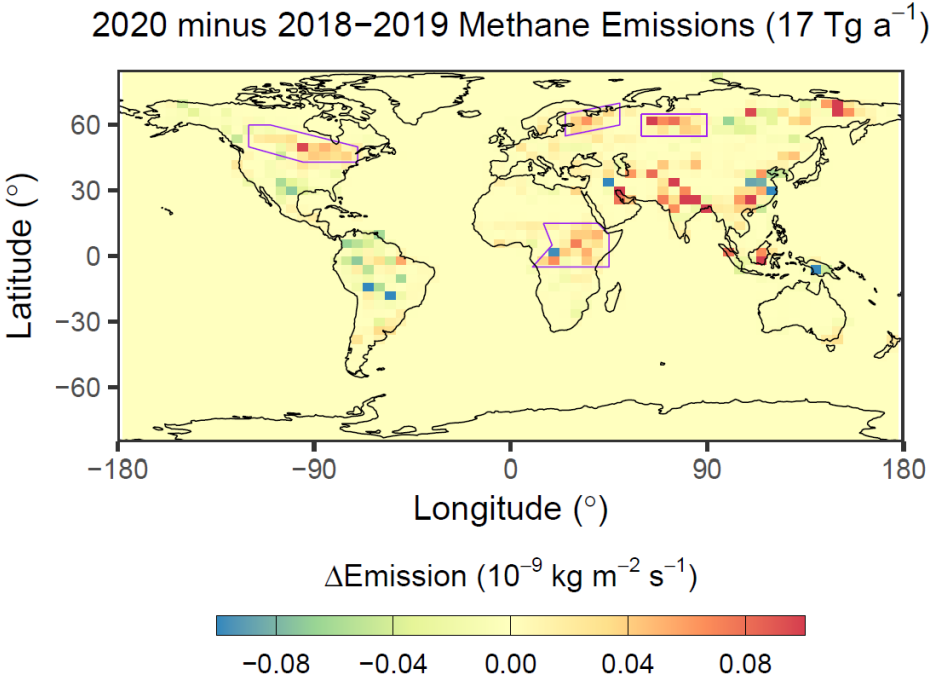
Satellite observed ozone anomaly
(2020 minus 2018-19)

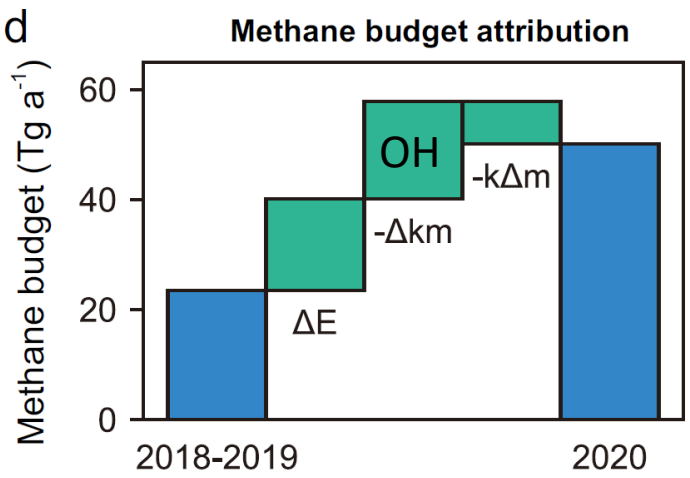


Chen et al., NSR, 2025

Global budget analysis for 2020

Enhanced 2020 growth driven by increased CH_4 emissions and reduced OH





Chen et al., NSR, 2025

Summary

- NH_3 observations are useful for constraining livestock methane emissions and their changes at the continental scale
- Ethane observations are useful for quantifying methane emissions from natural gas consumption in cities, therefore separate their contributions from waste emissions.
- Satellite CO observations are useful for detecting latitudinal changes in OH concentrations