Distinct Efficacy of Regional Emissions in Affecting Global Methane Concentrations: A Modeling Study with Interactive Methane Chemistry and Emission Tags

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Methane Emission Driven CESM2 modeling system

Simulations[1]	Time	Chemistry	Methane Emission	Emission Scale	Tags
Baseline	2014-2019	SLH[2]	GCP[3]	100%	Total, Asia, Europe, North America
No Emission	2014-2019	SLH	GCP	0%	Total

1. Simulations using set up by **Mirrezaei**, et al. (to be submitted). Following previous presentation by Dr. **Gaubert**.

2. SLH: improved short lived halogen chemistry representation in CESMv2.2 (**Fernandez**, et al., to be submitted);

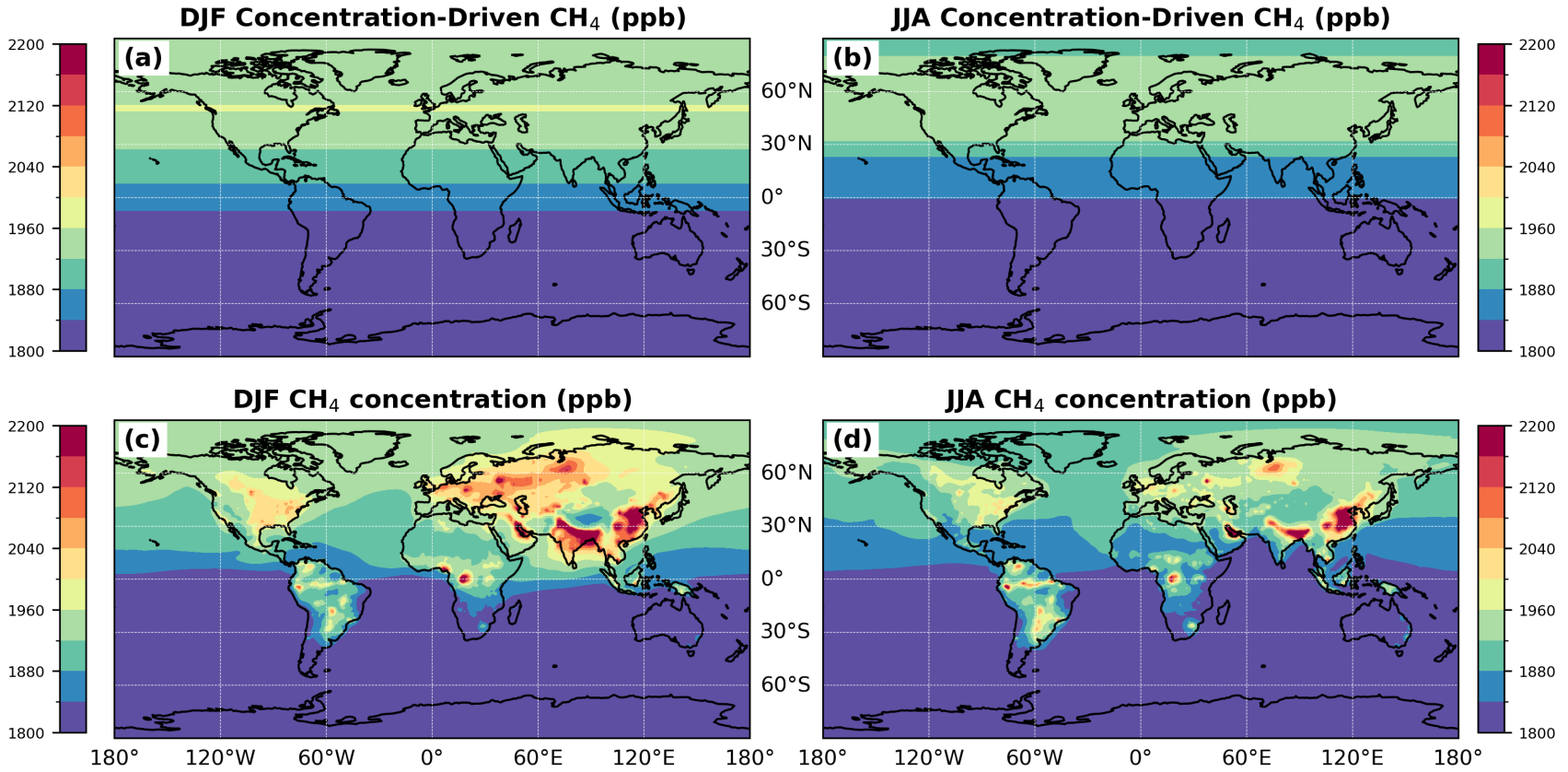
3. GCP: Global Carbon Project 2020 (**Saunois**, et al., 2020);

Methane Emission Driven CESM2 modeling system

Prescribed concentration in CAM-chem

Emission driven:

Local Emission → Concentration



Model simulations
vs
Observations

- Good agreement with global in-situ observation network;

NOAA CH4 GLOBALVIEWplus v7.0 ObsPack data (Schuldt et al., 1981, 2024)

Implementing the tagging technique

- This technique draws inspiration from studies on aerosol and CO transport and chemistry (e.g., Gaubert et al., 2016; Wu et al., 2023) and **enables the attributing CH_4 to different emission sectors and regions**.

- By tracking each CH_4 tag, our approach provides insights into **the contribution to the atmospheric burden at specific locations and times from each tag**, accounting for spatial and temporal characteristics of related chemical processes.

- Specifically, in addition to the baseline simulation with total CH_4 emissions from all regions, we **implement regional emission tags for Asia, Europe, and North America** to quantify CH_4 concentrations attributable to each source region.

Total Emission

Assign to regions

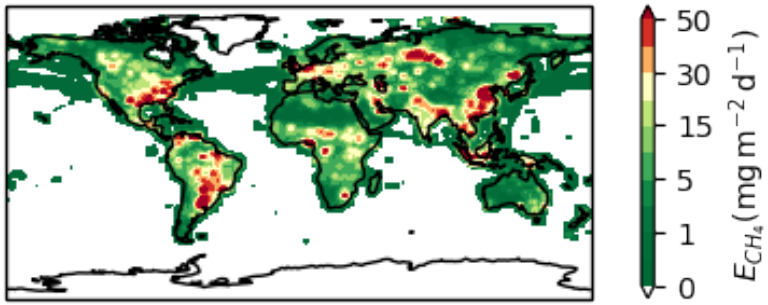
Emission of Tags

Transport

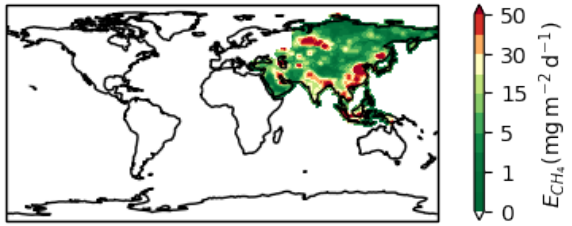
Reactions

Concentration of Tags

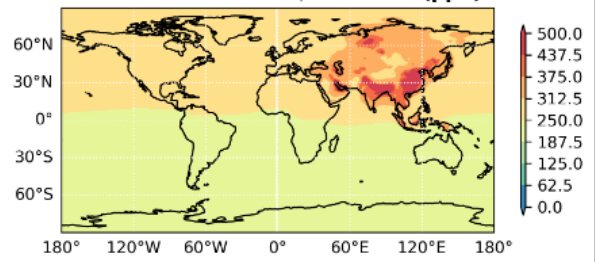
Global Emissions



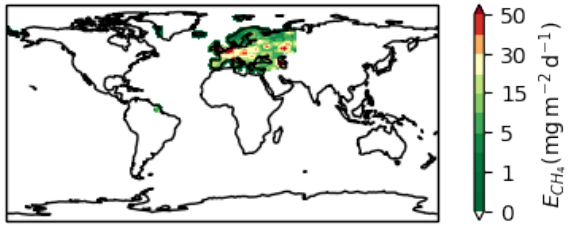
Emissions from Asia



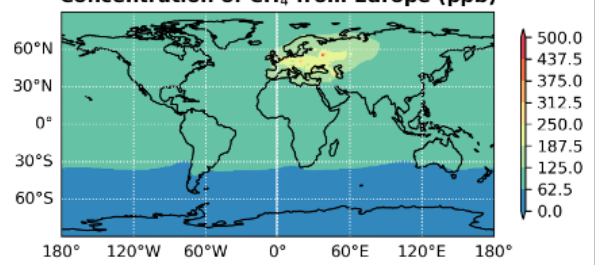
Concentration of CH_4 from Asia (ppb)



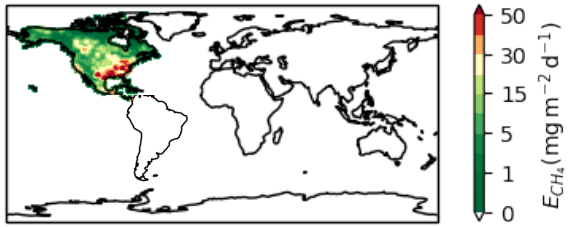
Emissions from Europe



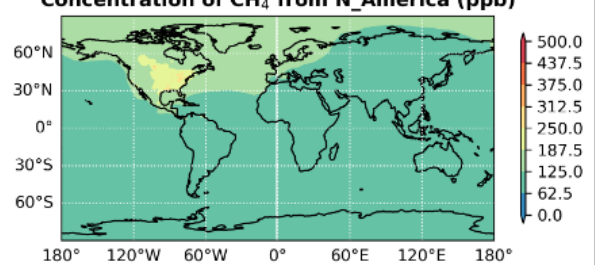
Concentration of CH_4 from Europe (ppb)



Emissions from North America

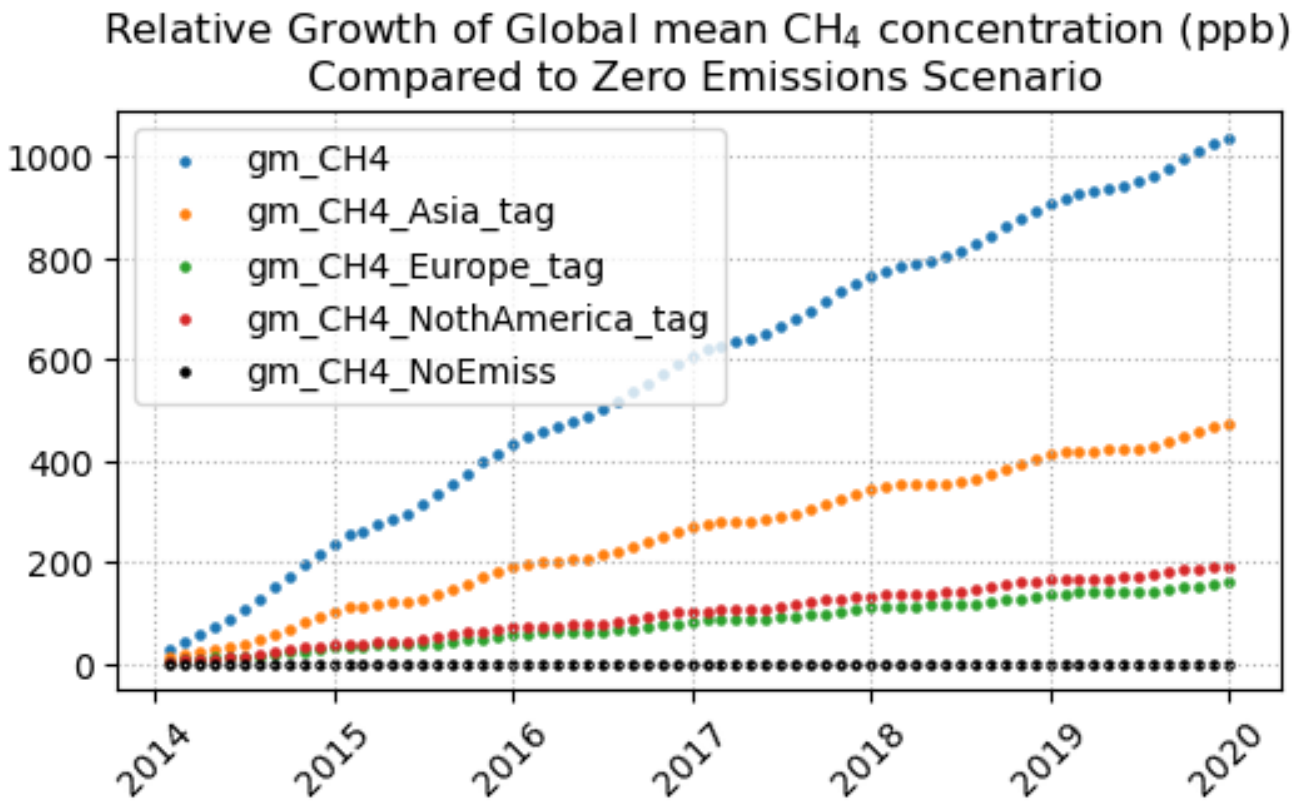


Concentration of CH_4 from N_America (ppb)



Emissions from other regions (or sectors)

CH_4 originated from other regions (or sectors)

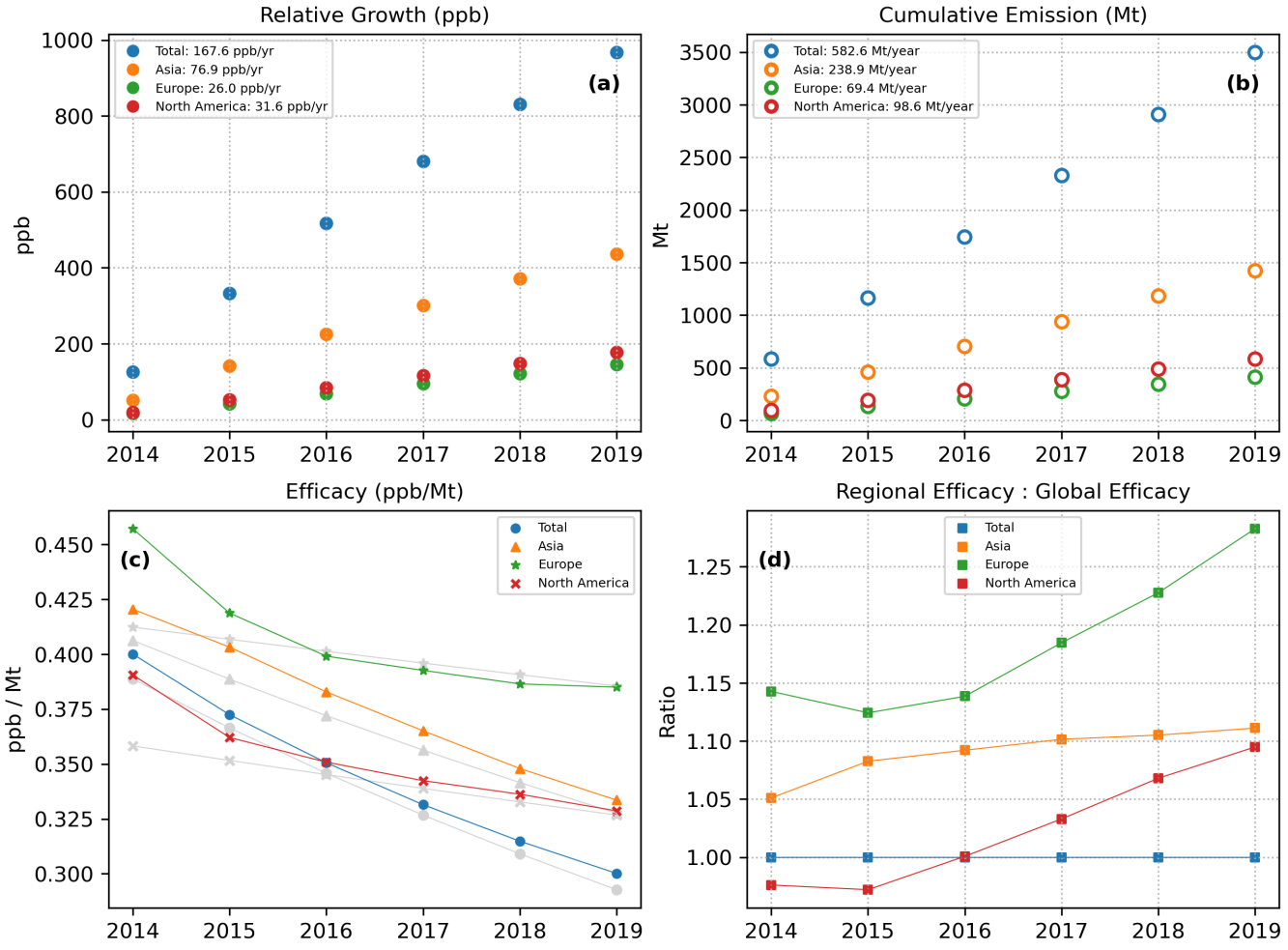


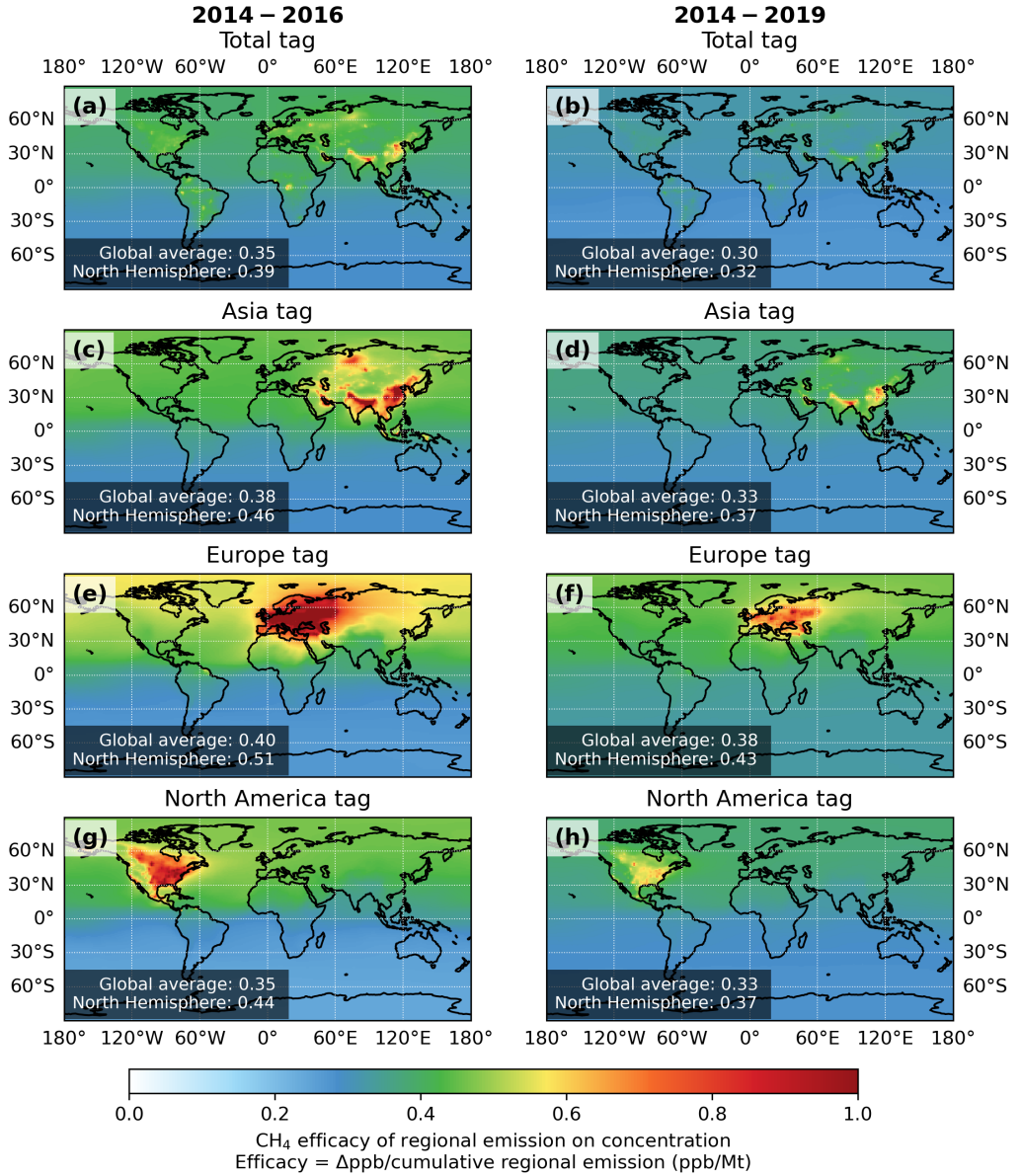
The **efficacy** of methane emission (Eff): the increase in atmospheric CH_4 concentration per unit cumulative methane emissions since January 2014.

$$\mathrm{Eff_{tag}(t, lat, lon)} = \frac{\mathrm{C_{tag}(t, lat, lon)} - \mathrm{C_0(t, lat, lon)}}{\int_{t_0}^{t} \mathrm{E_{tag}(t)}dt}$$

, in ppb/Mt of methane. C_0 is the no emission run.

$$\mathrm{Eff}_{\mathrm{tag}}(t, lat, lon) = \frac{\mathrm{C}_{\mathrm{tag}}(t, lat, lon) - \mathrm{C}_0(t, lat, lon)}{\int_{t_0}^{t} \mathrm{E}_{\mathrm{tag}}(t)\,dt}$$





Methane concentration following exponential decay:

$$C_{tag}(t) = C_0(t) + \left(f \cdot E_{tag} \cdot \tau_{tag}\right) \cdot \left(1 - e^{-\frac{t}{\tau_{tag}}}\right)$$

ppb

- The location and pathway of European methane concentration impacts the high latitudes over NH.

Summary

- Utilizing the CESM2.2 with **emission-driven methane feature, short-lived halogen chemistry, and a tagging technique** tracking three representative regions, we conducted a 6-year simulation (2014-2019).
- **The simulated concentration shows reasonable agreement** with surface observations in terms of long-term trends and seasonal variations.
- **We estimated the methane lifetime** and found that the lifetime closely **reflects the OH concentration along the transport pathway** after emission.
- **European emissions have the greatest efficacy** in increasing the global methane level, mainly due to their prolonged lifetime over the polar region. However, the **radiative forcing from Europe is not necessarily higher** due to the weak solar radiation over high latitudes.

Future Plan

- Diagnostics of radiative forcing
- Longer simulations

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