The Global Methane Budget :
Emerging climate feedbacks

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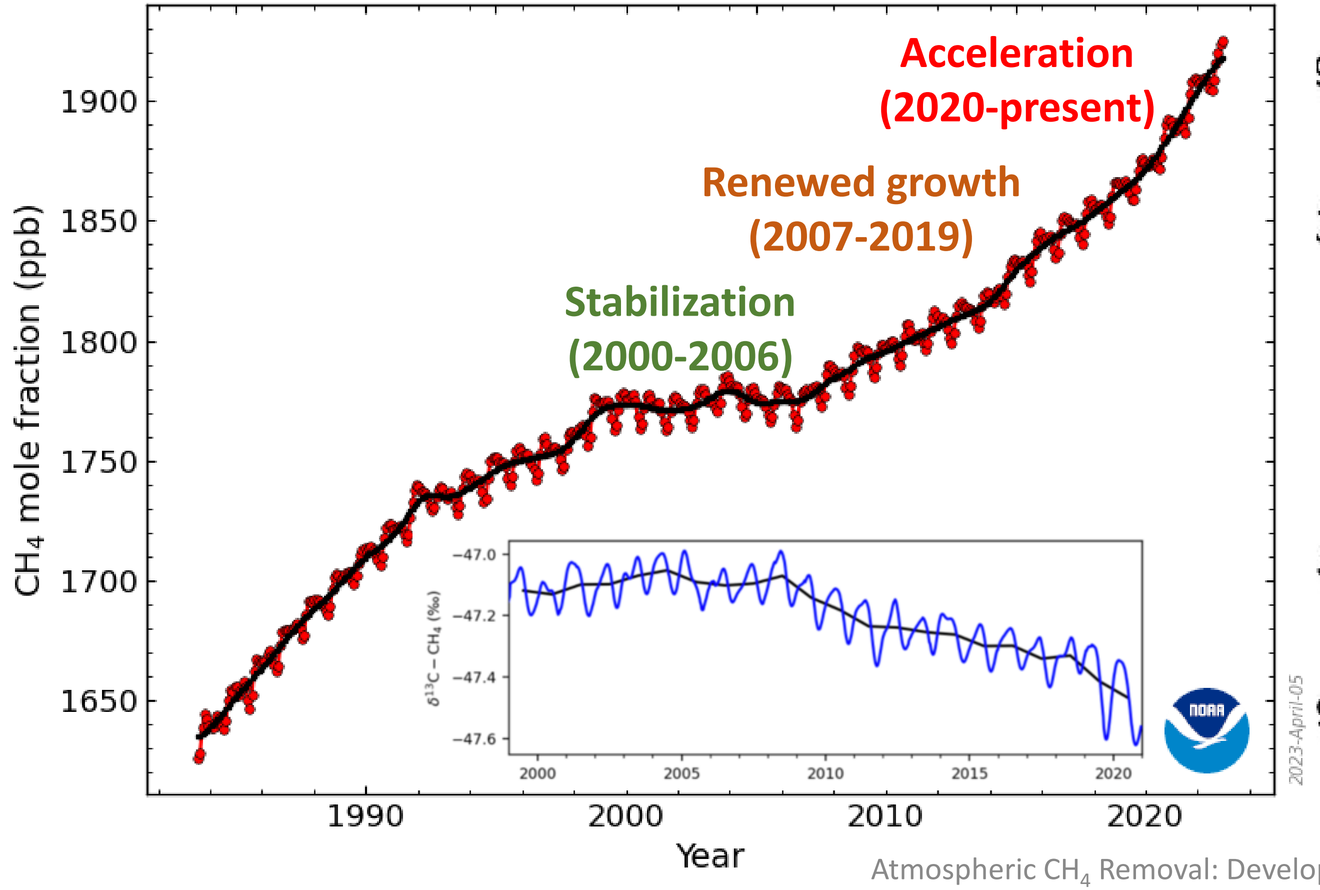
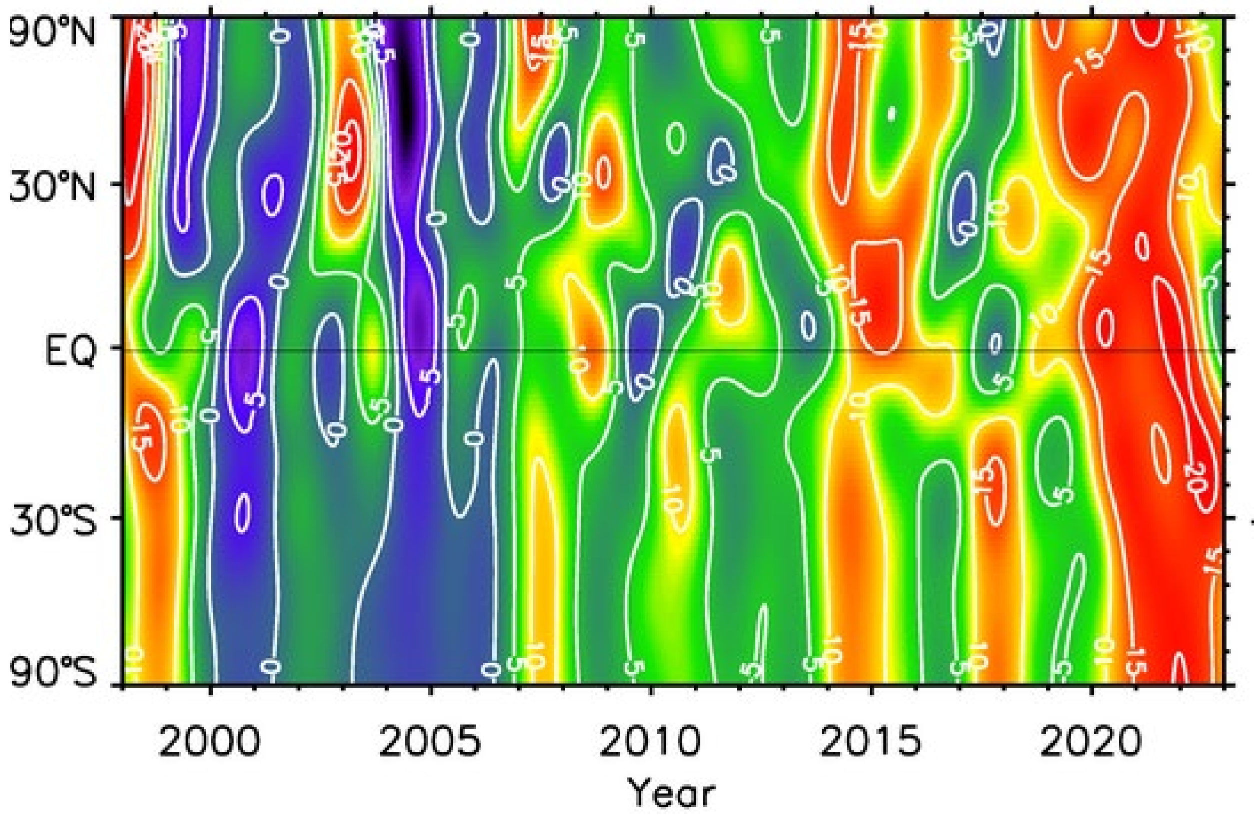
Atmospheric CH_4 Removal: Development of a Research Agenda
(NASEM 2023)

Accelerating growth of atmospheric CH_4

- Methane concentrations are is ~170% higher than pre-industrial levels
- Responsible for around one third of warming since 1850
- Growth rate anomalies vary year-to-year in latitudinal position





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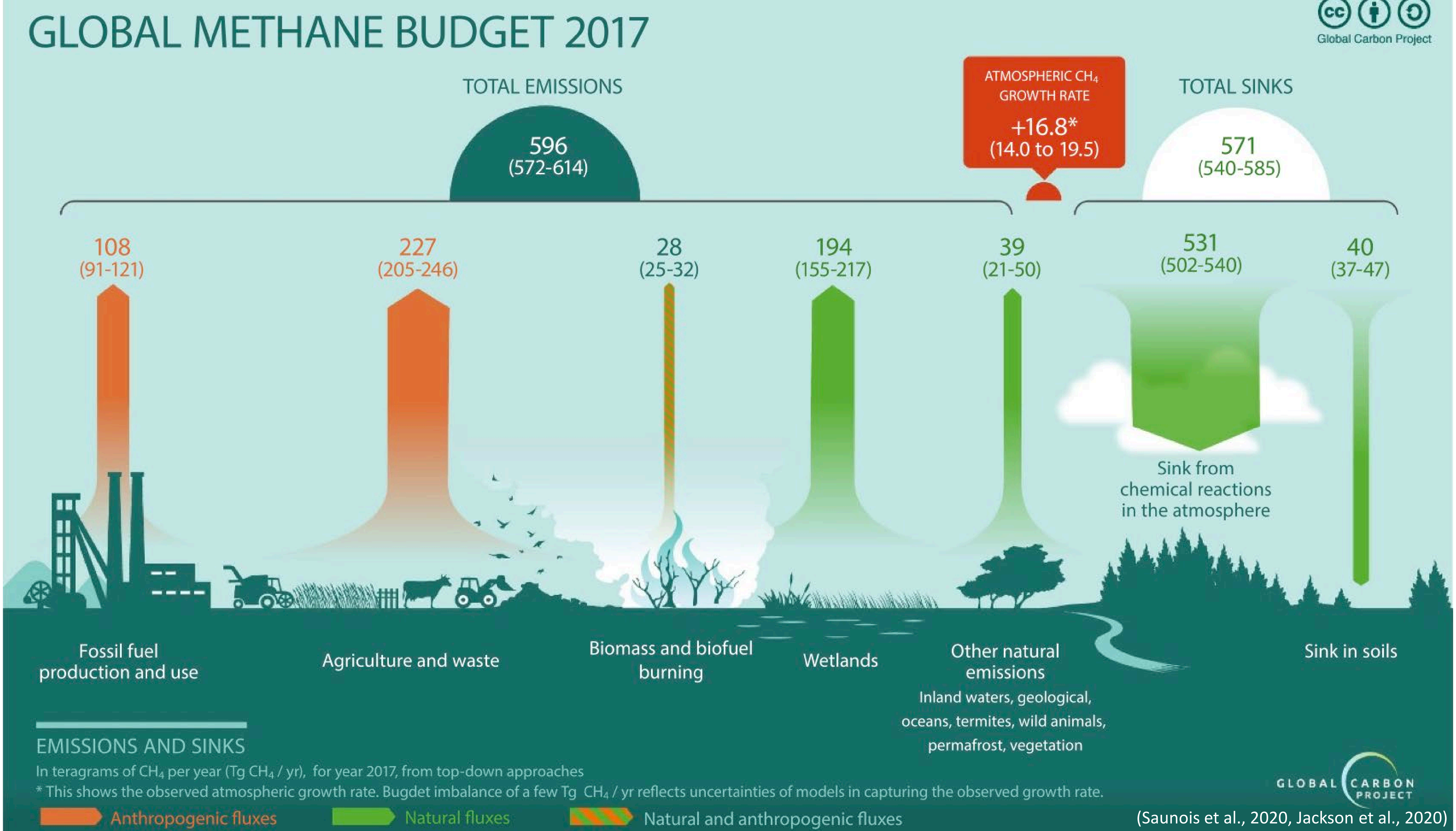
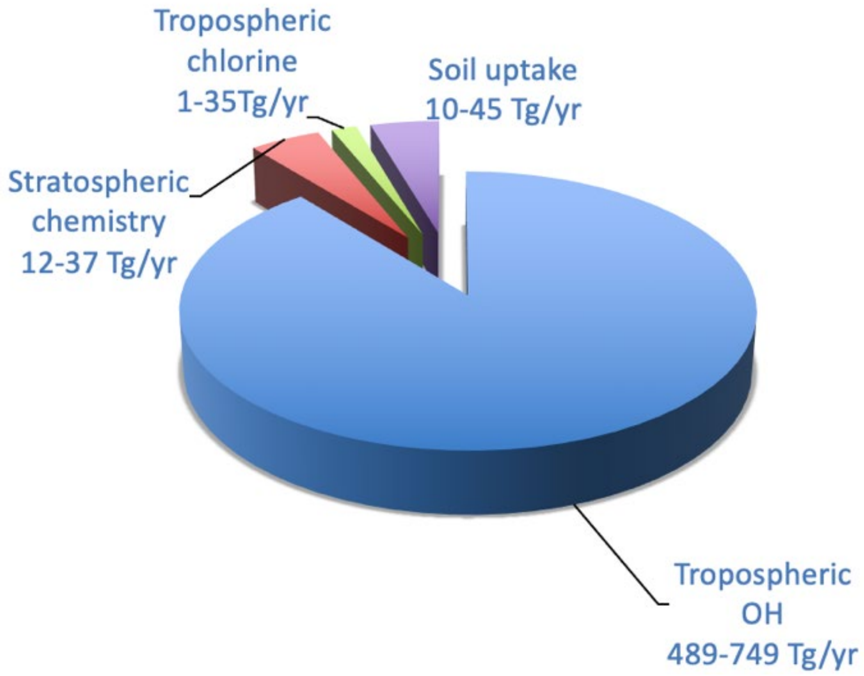
Xin (Lindsay) Lan / NOAA



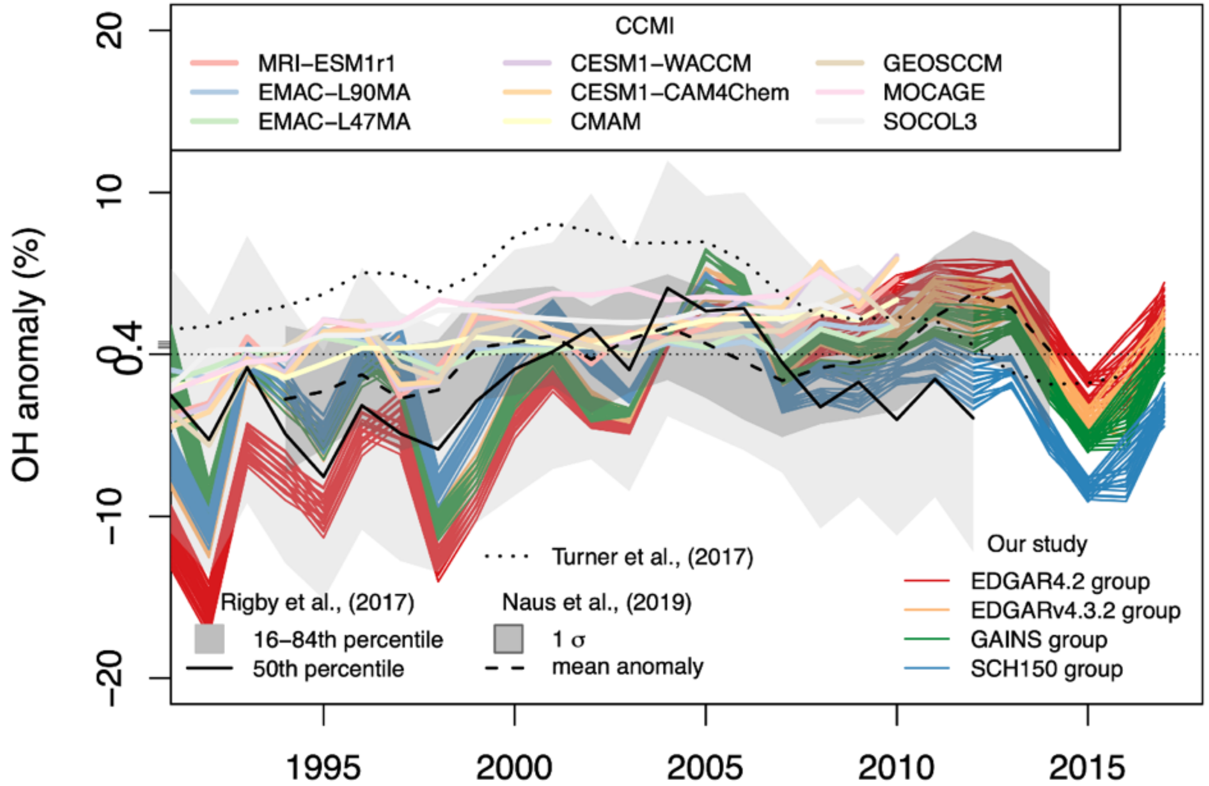
(Saunois et al., 2020, Jackson et al., 2020)

Atmospheric CH_4 removals: Chemical Sink

- Hydroxyl radical, OH, is main oxidant of CH_4, responsible for 90% of methane removal in atmosphere.
- Three approaches derive estimates of OH quantity in the atmosphere:
    1. Chemistry climate models that includes hundreds chemical reactions between numerous species
    2. Box-modeling based on methyl-chloroform (MCF) observations
    3. Isotopic box-models, matching atmospheric growth with emission ensembles
- Large (10-15%) uncertainty on global OH mean concentrations, no discernable trend



GCP 2020



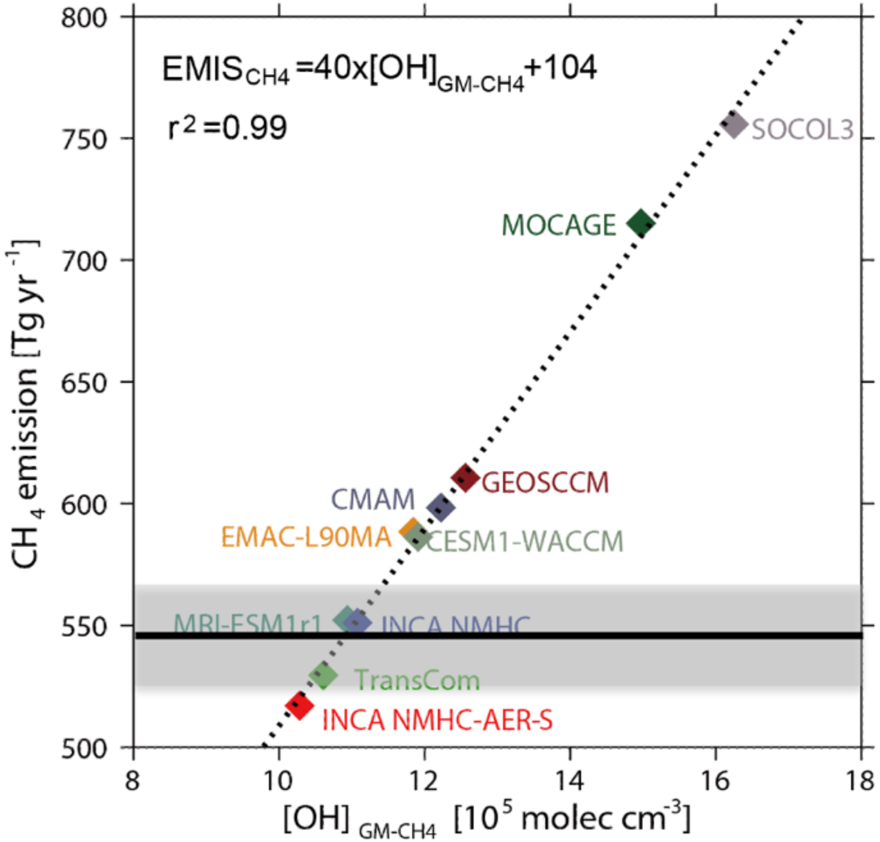
(Zhang et al., 2021)

(Zhao et al., 2019)

Atmospheric CH_4 removals: Chemical Sink

- Methane emissions derived by top-down systems are OH dependent
- Uncertainty in OH data from chemistry-climate models used in atmospheric inversions yields larger emission uncertainties that model ensembles
- Uncertainty in global total methane emissions is probably underestimated in the Global Methane Budget

Emissions uncertainty from OH fields

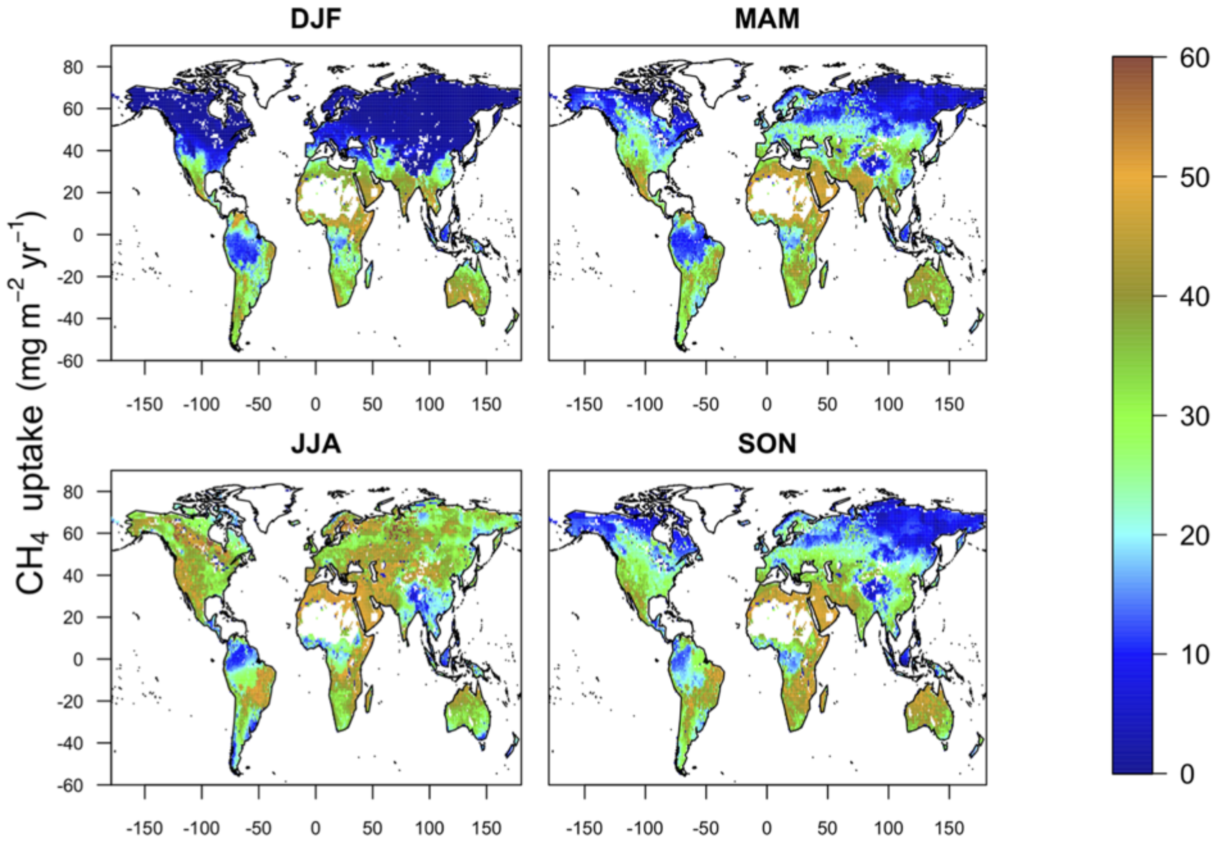


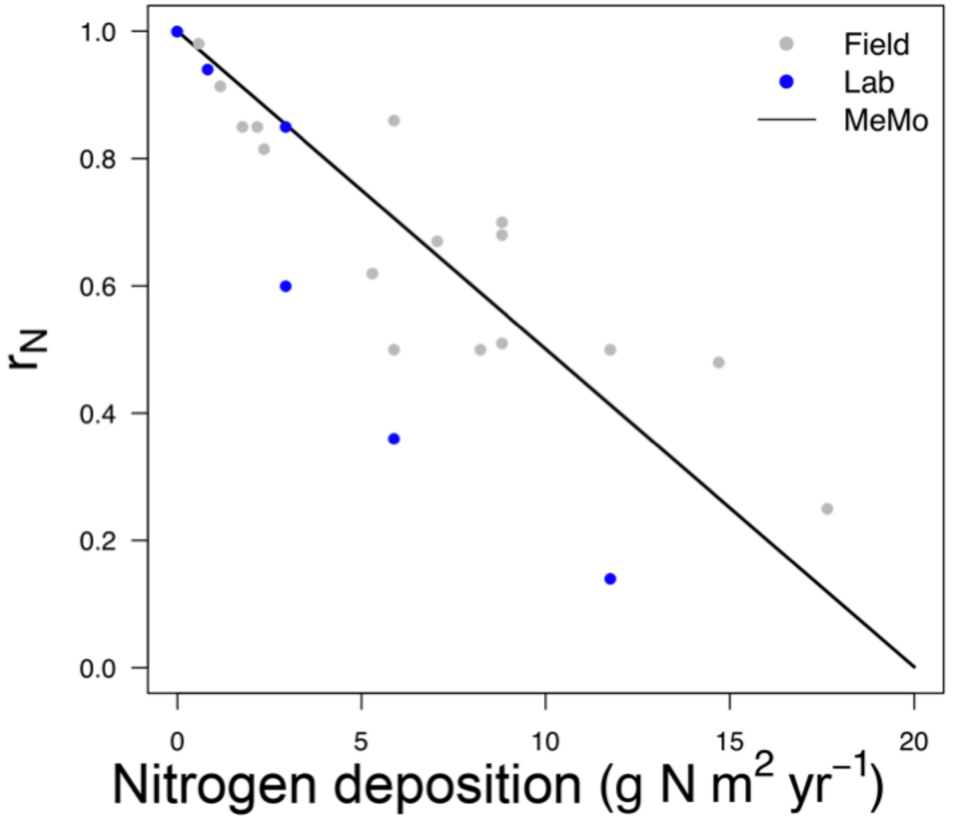
Top-Down estimates for 2000-2009 Saunois et al. (2020)

(Zhao et al., 2020)

Atmospheric CH_4 removals: Natural Sink

- Unsaturated oxic soils, with presence of methanotrophs, remove around 11-49 Tg CH_4 yr^{-1}
- Soil methane removal is affected by soil moisture, soil temperature, pH, and different microbial communities
- Changes in microbial communities, due to nitrogen deposition, can weaken soil methanotrophy





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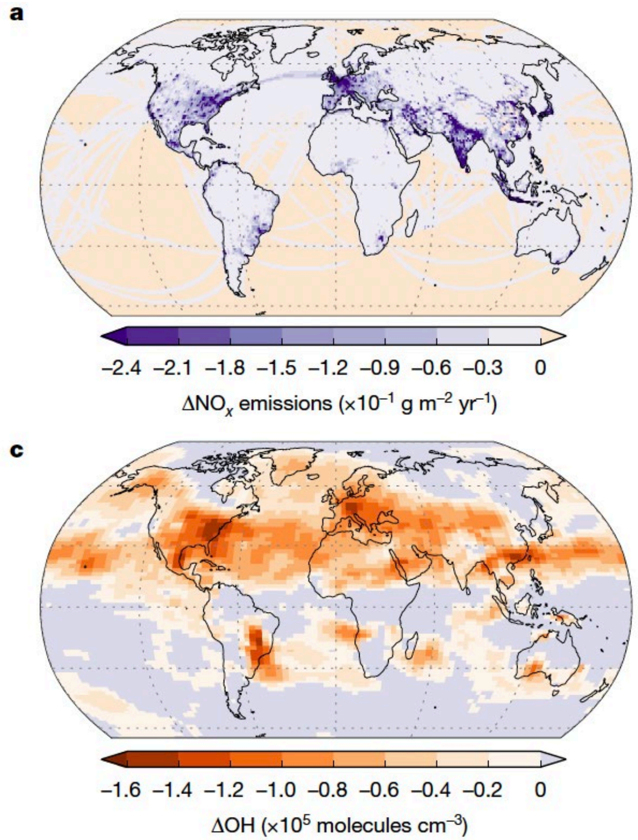
(Murguia-Flores et al., 2018)

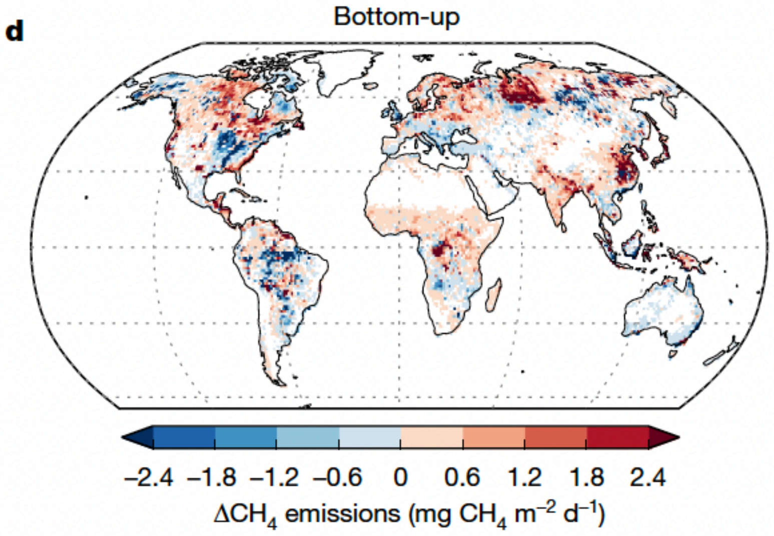
COVID-19 as case for Earth system feedbacks

- In 2020, largest observed increase in atmospheric CH_4 (15.2 ppb)
- COVID-19 lockdowns triggered trace gas chain reaction that increased CH_4 lifetime
- Northern hemisphere temperature extremes led to higher wetland emissions

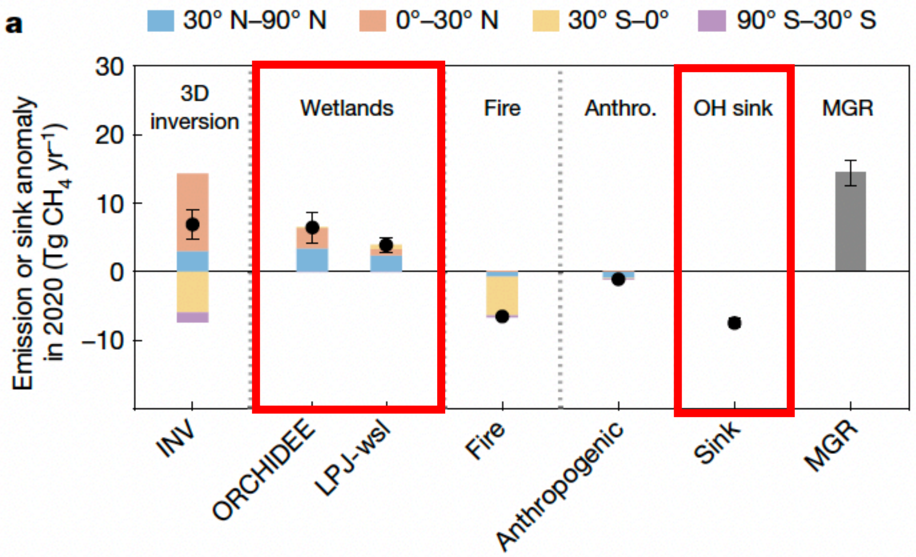
Reductions in atm. OH



Increased wetland emissions



2020 methane budget



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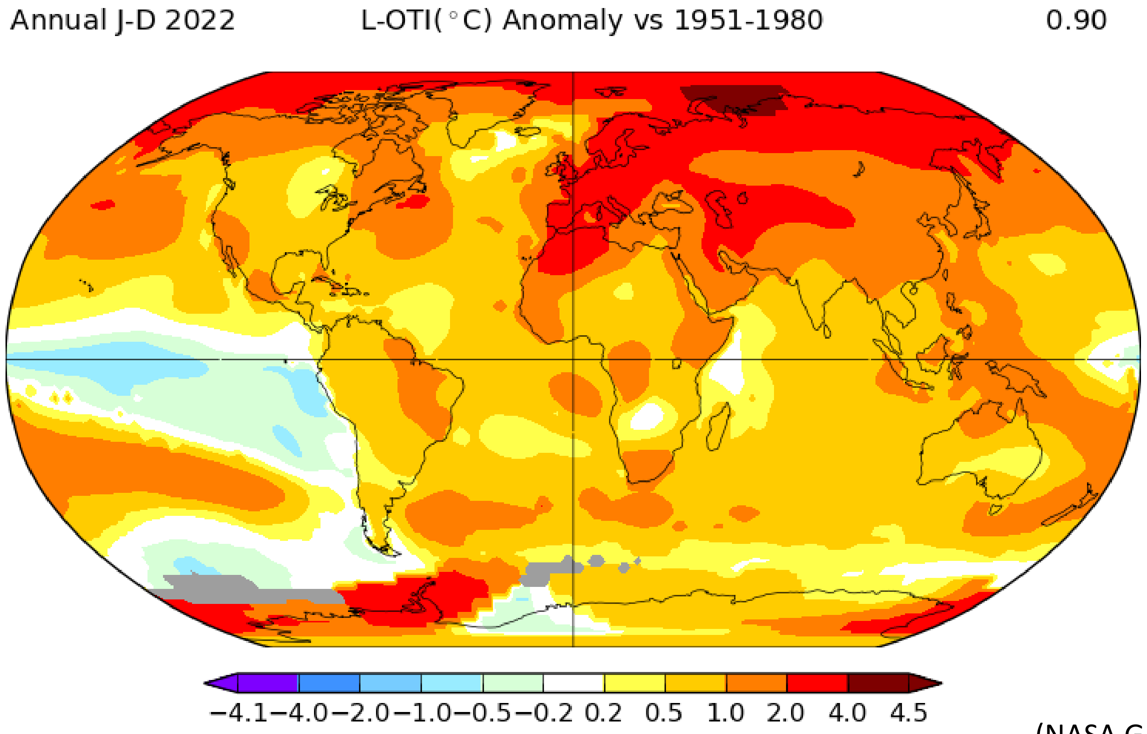
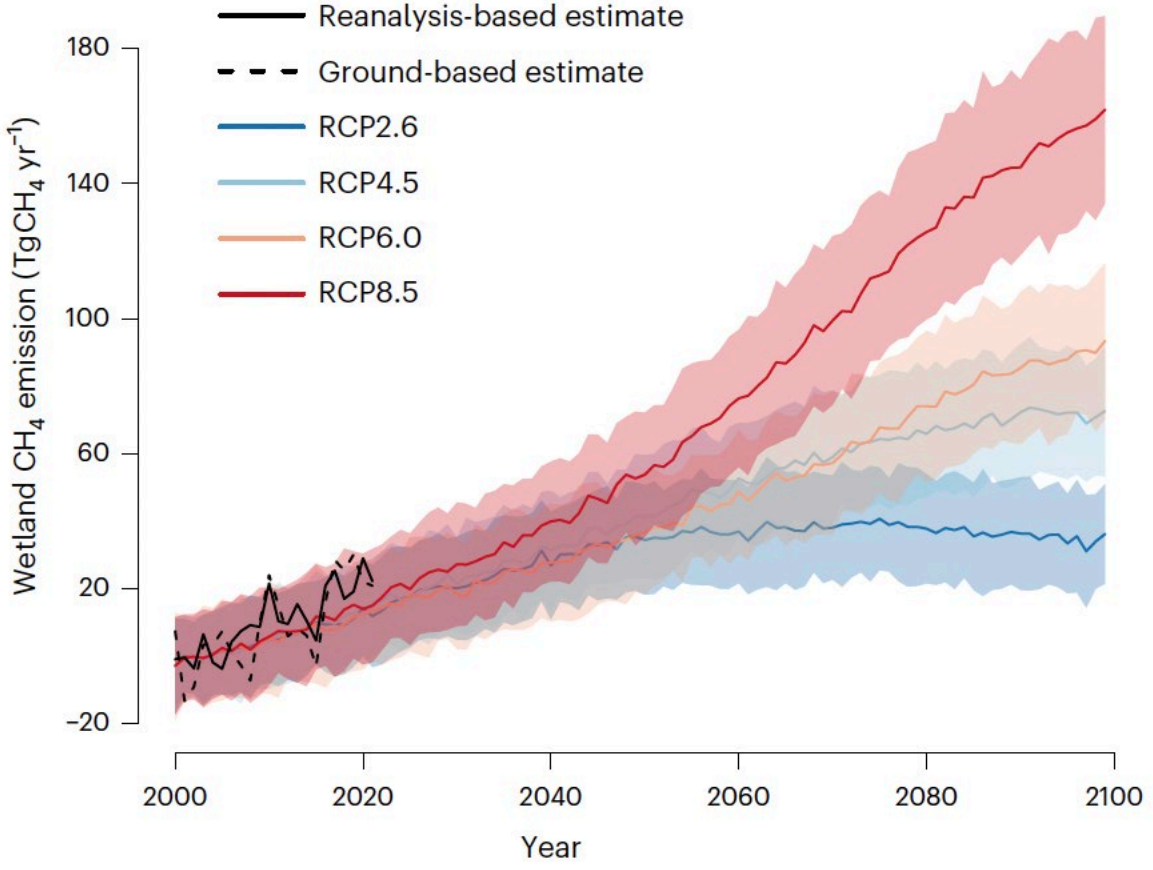
(Laughner et al., 2021, Peng et al., 2022)

Emergence of wetland CH_4 climate feedbacks

- Past eight years were warmest on record, with 2021 and 2022 5th and 6th warmest
- Approaching 1.5°C warming within next 10-years at current rates of CO_2 emissions
- Wetland methane trend now emerging from high-interannual variability, driven by tropical wetland methane emissions



(NASA GISS)



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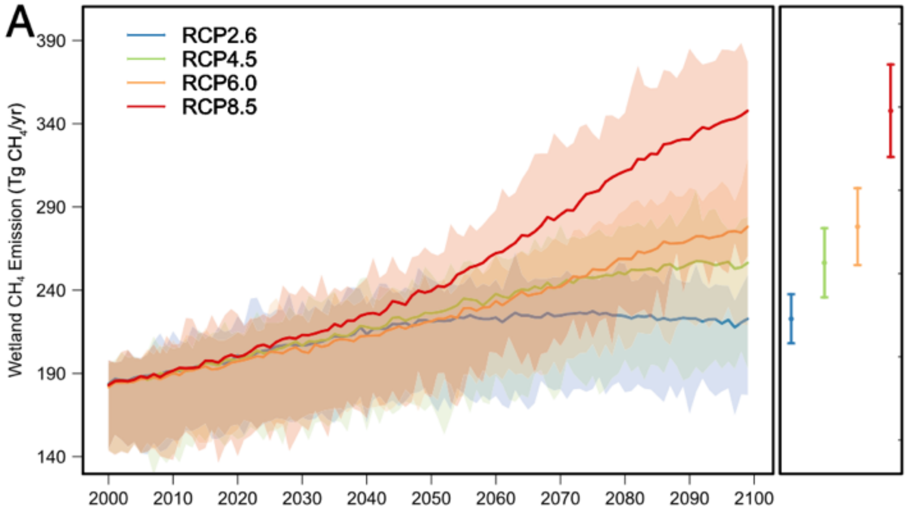
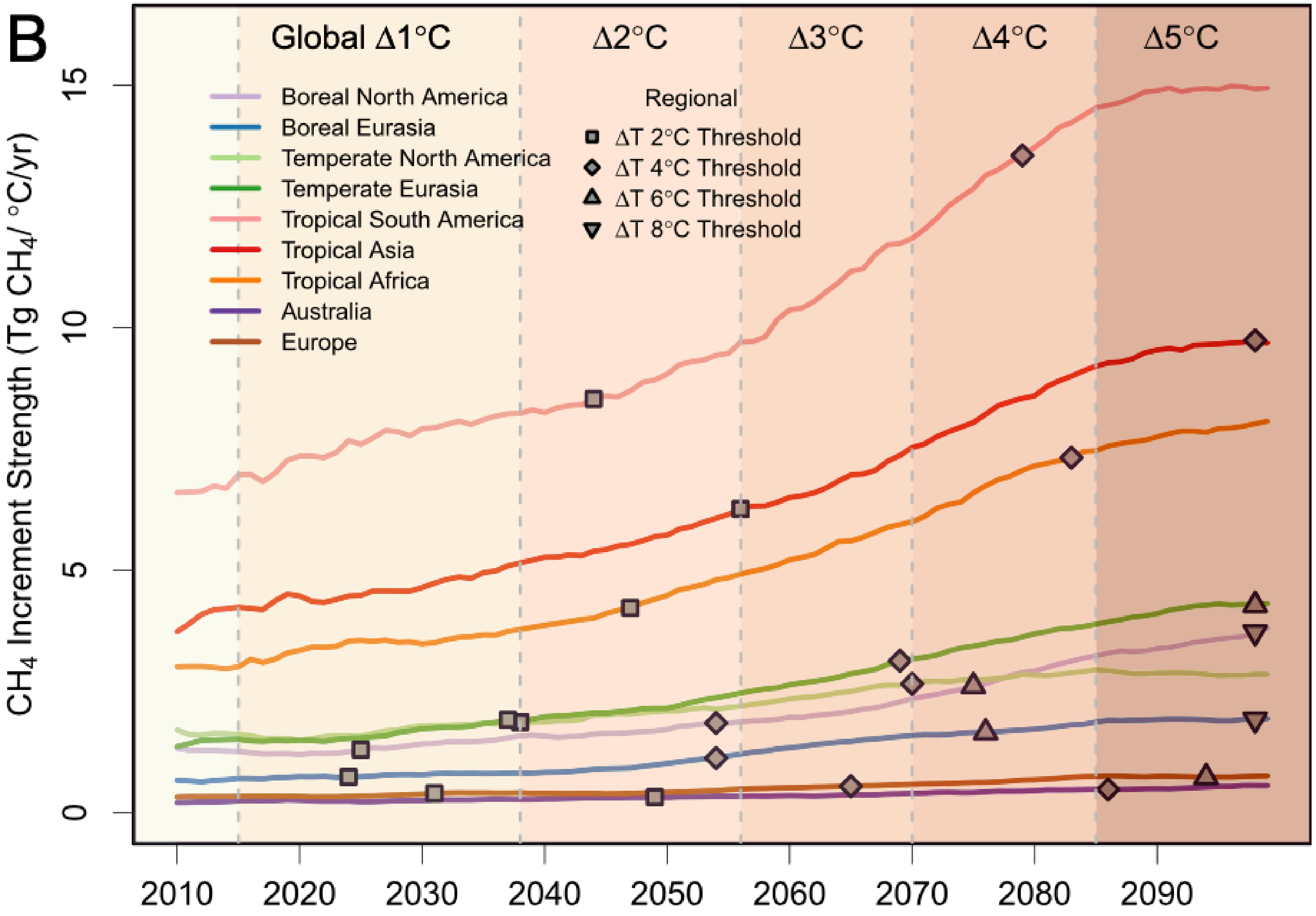
(Zhang et al., 2023)

Emergence of wetland CH_4 climate feedbacks

- Thawing permafrost and rising temperature would drive between an 18-42 $TgCH_4\ yr^{-1}$ for boreal and 48-87 $TgCH_4\ yr^{-1}$ increase in wetland methane emissions

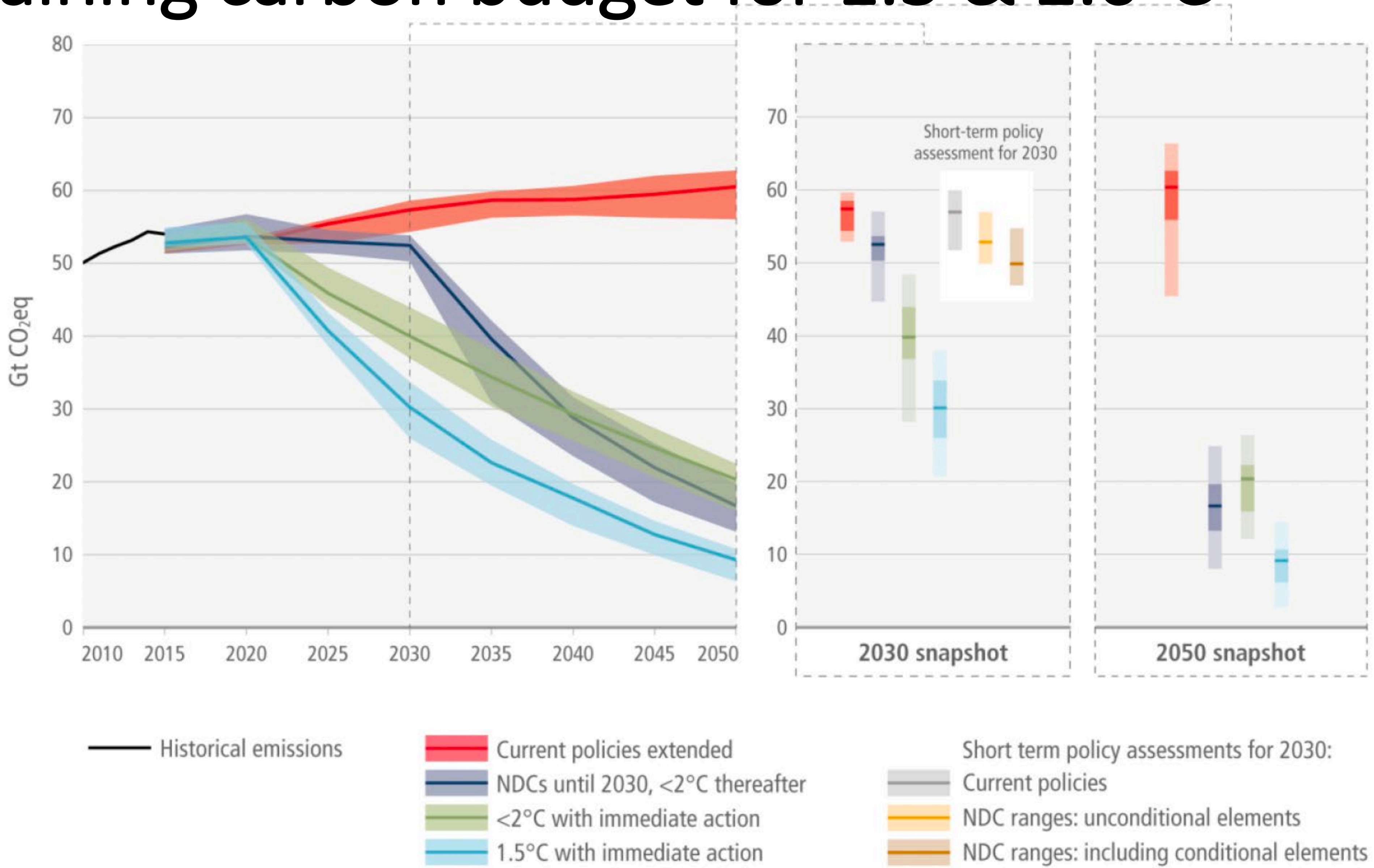
Wetland methane emissions (2000-2100)





(Zhang et al., 2017)

Non-CO_2 feedbacks poorly represented in remaining carbon budget for 1.5 & 2.0°C

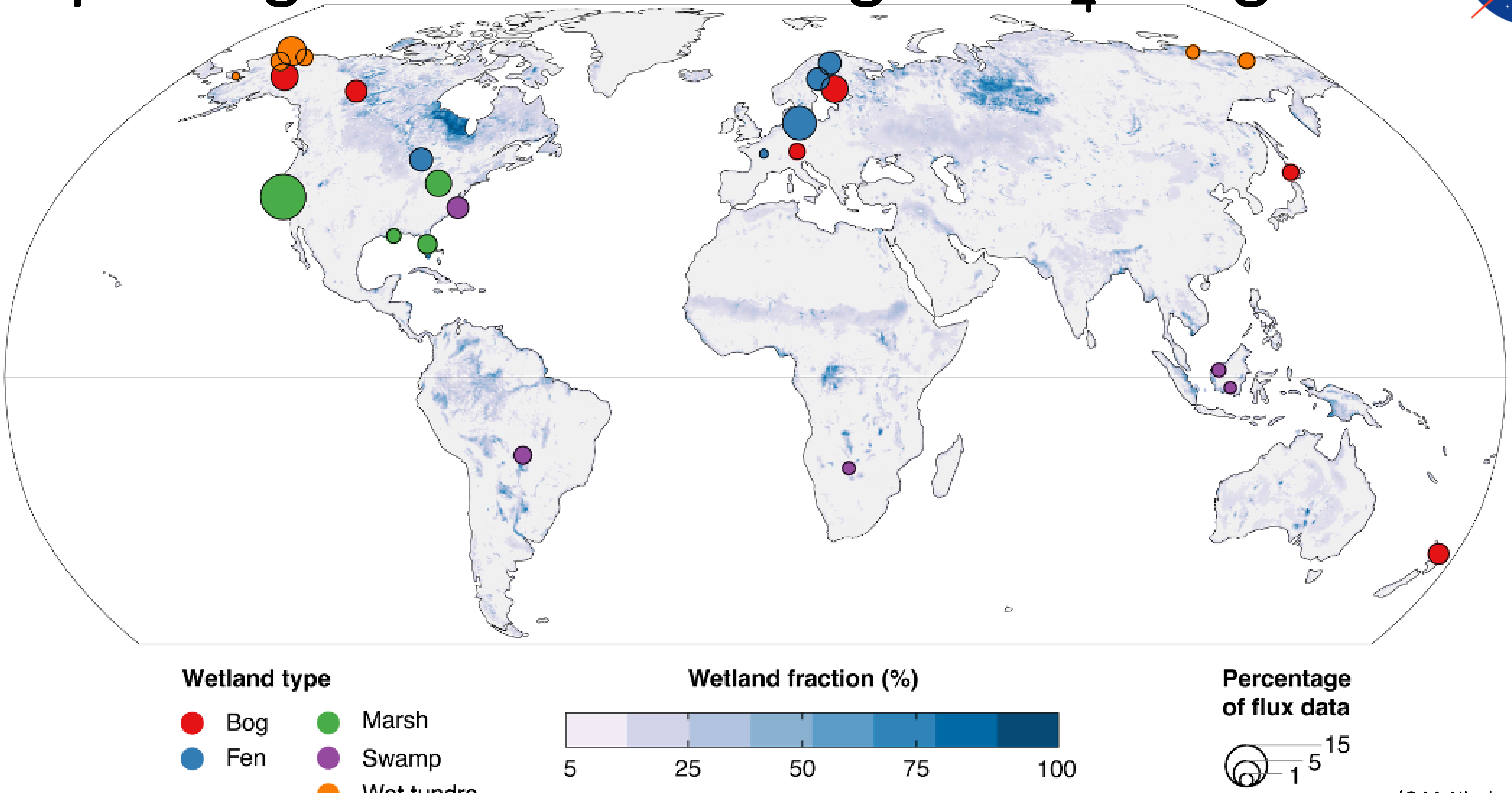


(IPCC AR6 WGIII)

Improving our understanding of CH_4 budget

Jacob et al., 2022

Improving our understanding of CH_4 budget



(G McNicol et al. in rev.)

Knowledge gaps, uncertainties & challenges

- Consensus emerging that wetlands are playing key role in accelerating growth of atmospheric methane
- Wetland-climate feedbacks remain poorly understood in terms of 1) mechanisms, 2) monitoring, and 3) management options with key knowledge gaps and risks to be addressed

Challenge	Knowledge Gaps and Uncertainties	Risks
Mechanisms controlling methane emissions and removals	• Methanogenesis (substrate, inundation) • Methanotrophy (soil, vegetation drivers) • Transport (soil, water, vegetation) • Oxidative sink • Sensitivity to temperature, precipitation, CO_2 • Magnitude of wetland CH_4 feedback	Under or over-estimate sensitivity of wetland methane to climate change
Monitoring trends and spatial patterns	• Tropical ecosystem gaps • Atmospheric chemistry and removal • Atmospheric transport and mixing	Biases in observing network geographically or at particular time of year
Management options and effectiveness	• Water management • Restoration of wetlands • Vegetation management	Management and restoration at odds, evaluation of co-benefits

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References

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