Key Drivers of Methane Lifetime from 1860-2100

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1. Introduction

- Methane (CH_4) is the 2nd most important anthropogenic greenhouse gas, and a precursor to tropospheric ozone (O_3) which adversely affects human health.
- Concentration of CH_4 has more than doubled since the preindustrial period.
- Global source and sink strengths are fairly well known, but uncertainties exist in their trends, and in the contribution from specific source sectors.

Objective

- Investigate the role of climate versus anthropogenic emissions in determining methane lifetime in a suite of historical and future simulations.

2. Model and Simulations

GFDL CM3: Fully coupled climate-chemistry model with interactive tropospheric and stratospheric chemistry [*Donner et al., 2011 ; Naik et al., 2013*].

Summary of forcings used in CM3/IPCC AR5 simulations.

	Solar	Volcanoes	WMGHG (radiation)	WMGHG (chemistry)	Aerosol emission	Ozone Precursors (emission/conc)	LandUse	Radiative and Land CO_2
CONTROL	1860	none	1860	1860	1860	1860	1860	1860
HIST (5-member ensemble)	Historical	Historical	Historical	Historical	Historical	Historical	Historical	Historical
AEROSOL[a] (3-member ensemble)	1860	none	1860	1860	Historical	1860	1860	1860
AEROSOL INDIRECT (3 member ensemble)	1860	none	1860	1860	1860 climatology	1860	1860	1860
ANTHRO (3-member ensemble)	1860	none	Historical	Historical	Historical	Historical	Historical	Historical
NATURAL[b] (3-member ensemble)	Historical	Historical	1860	1860	1860	1860	1860	1860
WMGGO3[c] (3 member ensemble)	1860	none	Historical	Historical	1860	Historical	1860	Historical
RCP2.6	RCP2.6	none	RCP2.6	RCP2.6	RCP2.6	RCP2.6	RCP2.6	RCP2.6
RCP4.5 (3-member ensemble)	RCP4.5	none	RCP4.5	RCP4.5	RCP4.5	RCP4.5	RCP4.5	RCP4.5
RCP4.5*[d] (3-member ensemble)	RCP4.5	none	RCP4.5	2005 for CH_4, N_2O, ODS	2005	2005	RCP4.5	RCP4.5
RCP6.0	RCP6.0	none	RCP6.0	RCP6.0	RCP6.0	RCP6.0	RCP6.0	RCP6.0
RCP8.5	RCP8.5	none	RCP8.5	RCP8.5	RCP8.5	RCP8.5	RCP8.5	RCP8.5

[a] AEROSOL: only aerosols, SO_2/BC/OC emissions are time-varying
[b] NATURAL: GHG for radiation and chemistry fixed at 1860 values. CFC s fixed at 1860 values.
[c] WMGGO3: SO_2 and aerosols held at 1860 values.
[d] RCP4.5*: CH_4, N_2O and ODS for chemistry are fixed at 2005 values. Aerosol and O_3 precursor emissions also fixed to 2005 values.

3. Methane Lifetime (τ_{CH_4})

- Determined mainly from oxidation by hydroxyl (OH) radicals
- 79-90% of CH_4 loss below 500hPa
- 75-78% in tropics

[*Spivakovsky et al., 2000; Lawrence et al., 2001; Fiore et al., 2008*]

$$\tau_{CH_4} = \frac{\int_{surface}^{TOA} [CH_4]}{\int_{surface}^{tropopause} k(T)[OH][CH_4]}$$

Total loss by tropospheric OH:
CM3 HIST ensemble (2000-2005 average): 562.30 ± 4.86 Tg CH_4
IPCC AR4 [*Denman et al., 2007*]: 581 ± 87 Tg CH_4

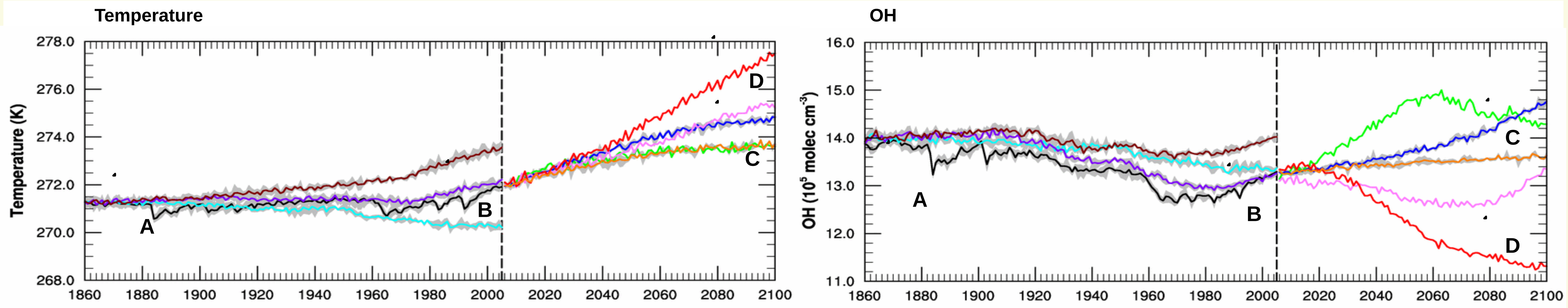
Drivers: Both climate and emissions control τ_{CH_4}

NO_x, H_2O, $J(O^1D)$ ↑

T ↑ > τ_{CH_4} ↓ < OH ↑

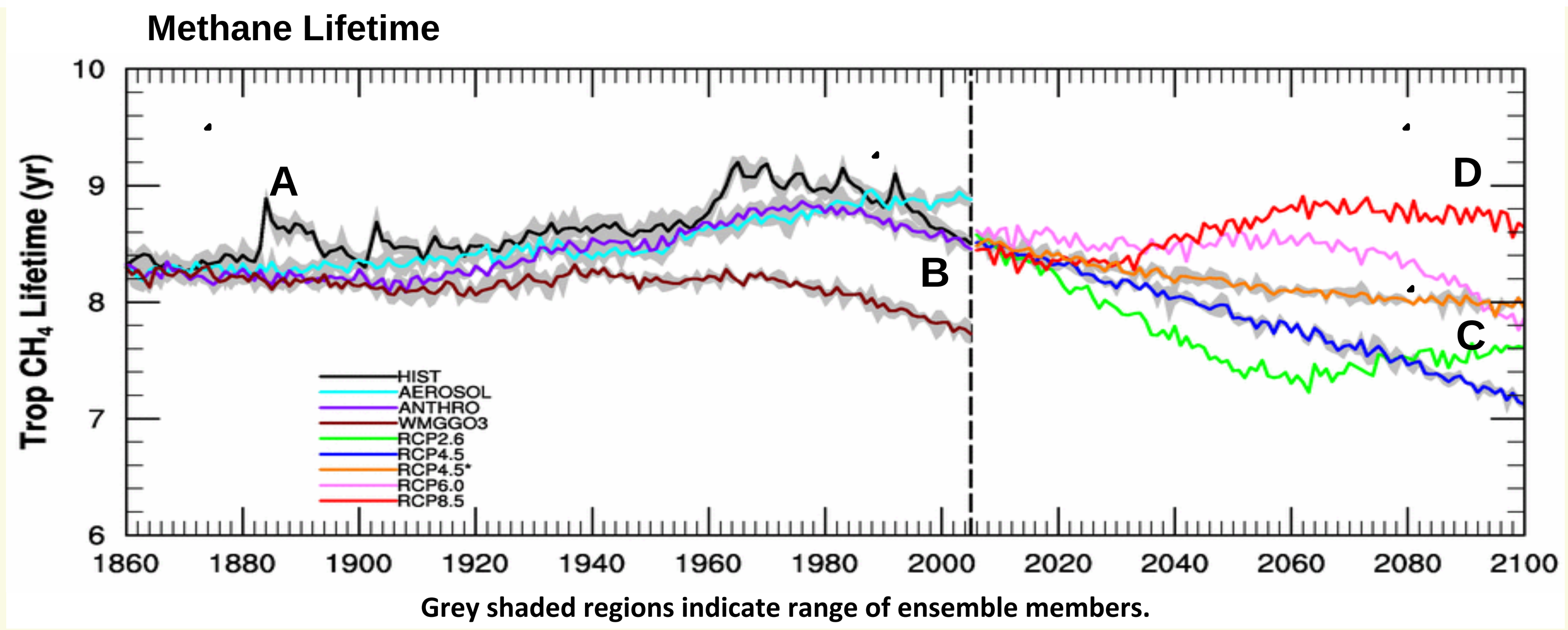
CH_4, CO, NMVOC ↓

4. Evolution of lower tropospheric (surface-500hPa) temperature and OH, and methane lifetime



A Volcanic aerosols:
T, H_2O ↓ OH ↓ τ_{CH_4} ↑

B Downward trend in methane lifetime over last 20 years suggesting a negative climate feedback [*Bekki and Law, 1997; Johnson et al., 2002, Fiore et al, 2006*]:
T, H_2O ↑ OH ↑ τ_{CH_4} ↓



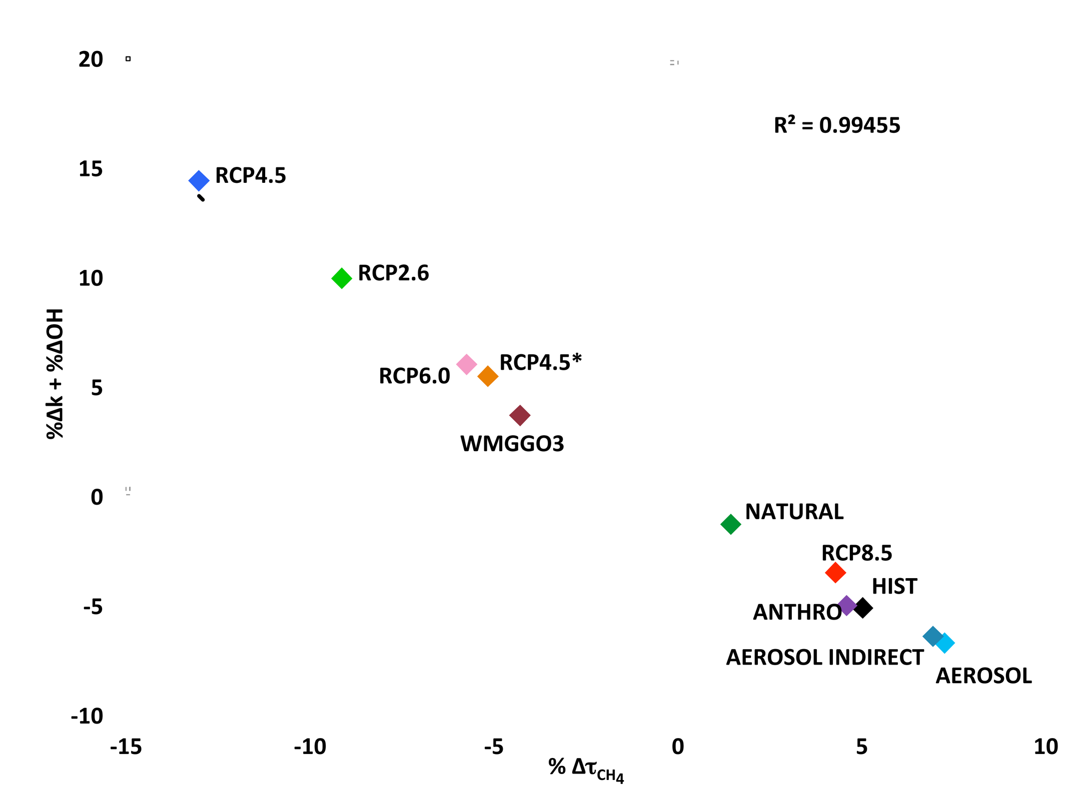
Grey shaded regions indicate range of ensemble members.

C RCP4.5 and RCP4.5*: Warming climate reduces methane lifetime.
T, H_2O ↑ OH ↑ τ_{CH_4} ↓

D RCP8.5: Methane abundance drives OH down and lifetime up, positive feedback to anthropogenic CH_4 increase despite increasing temperature [*Prather, 1994*].
CH_4 ↑ OH ↓ τ_{CH_4} ↑

5. Relationship between reaction rate constant (k), OH and methane lifetime

Globally we expect $\%\Delta\tau_{CH_4} = -(\%\Delta k + \%\Delta OH)$
This linear relationship is confirmed in figure below (r^2=0.99), by differencing 20-year averages at the start and end of model simulation periods.



Historical simulations: 1986-2005 minus 1860-1879
Future projections (RCPs): 2081-2100 minus 2006-2025

6. Drivers of methane lifetime in CM3 simulations

HIST and ANTHRO are primarily emission-driven.

Similar response of AEROSOL and AEROSOL INDIRECT implies aerosol-cloud interactions (indirect effect) play a major role in CM3 climate response.

Emission changes in RCP4.5 reinforce climate drivers to enhance OH and decrease methane lifetime.

Experiment	$\%\Delta\tau_{CH_4}$	%Δk	%ΔOH	$\%\Delta CH_4$	%ΔCOEMIS	%ΔNOEMIS	$\%\Delta LNO_X$	$\%\Delta H_2O$	$\%\Delta J(O^1D)$
HIST	5.0	0.8	-6.0	108.7	117.8	329.3	-2.5	2.0	0.74
AEROSOL	7.3	-2.2	-4.5	0	0	0	-6.9	-5.8	-1.2
AEROSOL INDIRECT	6.9	-2.0	-4.3	0	0	0	-4.7	-5.3	-1.2
ANTHRO	4.6	1.4	-6.6	108.7	117.8	329.3	-1.8	4.0	-1.9
NATURAL	1.4	-0.3	-1.1	0	0	0	-1.4	-0.8	-0.8
WMGGO3	-4.3	4.6	-1.2	108.9	117.8	329.3	4.6	12.9	-0.8
RCP2.6	-9.1	2.5	7.3	-27.1	-31.1	-46.5	4.4	6.8	0.4
RCP4.5	-13.0	5.4	8.7	-9.1	-42.6	-45.1	8.2	14.8	-0.4
RCP4.5*	-5.2	3.1	2.1	0.2	0	0	2.4	8.4	0.1
RCP6.0	-5.8	6.5	-0.8	2.3	-17.8	-46.4	11.5	18.2	-1.2
RCP8.5	4.3	10.8	-14.8	97.2	-26.2	-30.2	15.0	31.1	-6.4

Values below 500hPa are used for OH, water vapor and $J(O^1D)$.
Percent changes obtained by differencing 20-year averages.
Historical simulations: 1986-2005 minus 1860-1879
RCPs: 2081-2100 minus 2006-2025

factor increases methane lifetime
factor increases OH
factor decreases methane lifetime
factor decreases OH

7. Conclusions/Future Work

- **Preindustrial to present day increase in methane lifetime (5%) is mainly driven by anthropogenic emissions, although climate feedbacks are evident for certain periods.**
- **Trajectories of methane lifetime span a broad range in future scenarios (-13% to +4%).**
- **Ongoing multi-model studies (ACCMIP) provide opportunities to further explore and evaluate the processes driving the evolution of methane lifetime in historical and future (RCP) simulations and assess their robustness.**

8. References

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