Methane from the LGM to the present: The natural methane cycle

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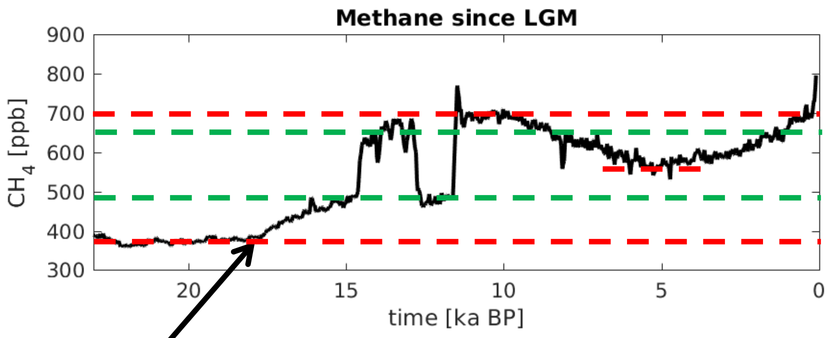
Introduction



Ice core CH_4 stack (Koehler et al., 2016)

2 exciting features:

1) Doubling of methane LGM -- 10ka BP,
   Mid Holocene decrease by ~100 ppb,
   PI as 10ka BP

2) ~150 ppb very rapid changes around
   Bølling/Allerød – Younger Dryas

To understand the exciting features of the ice core reconstructions of atmospheric CH_4 during the deglaciation, we perform a *transient* model experiment over the period 25ka BP to preindustrial (PI).

We use a methane-enabled version of the Max Planck Institute for Meteorology Earth System Model MPI-ESM in coarse resolution (T31, ~3.75°).
Methane emissions are determined by the land surface model JSBACH, and the emitted CH_4 is transported in the atmosphere model ECHAM6, with the sinks of methane represented in a sink parameterisation derived from the advanced atmospheric chemistry model EMAC.

Köhler, P., Nehrbass-Ahles, C., Schmitt, J., Stocker, T. F., and Fischer, H.: A 156 kyr smoothed history of the atmospheric greenhouse gases CO2, CH4, and N2O and their radiative forcing, Earth Syst. Sci. Data, 9, 363–387, https://doi.org/10.5194/essd-9-363-2017, 2017.

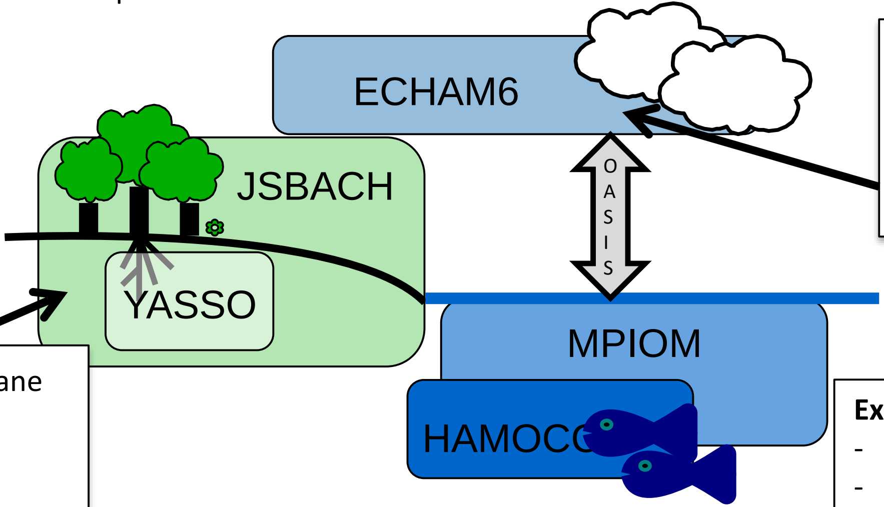
Model and experiment: MPI-ESM 1.2

Max **P**lanck **I**nstitute for Meteorology
Earth **S**ystem **M**odel MPI-ESM 1.2.01 (CMIP6):

Atmosphere model ECHAM 6.3.05p1
Land surface model JSBACH 3.20p1
Ocean model MPIOM 1.6.3p2

Model extensions (non-CMIP6)

- interactive land-sea mask, based on sea level change
- interactive river routing, based on ice sheet & bedrock adjustment
- **methane transport model in soil and atmosphere**



Module for methane transport and sink.
Sink parameterisation based on EMAC.

Modules for methane emissions from
1) wetlands
2) wildfires
3) termites

Experiments

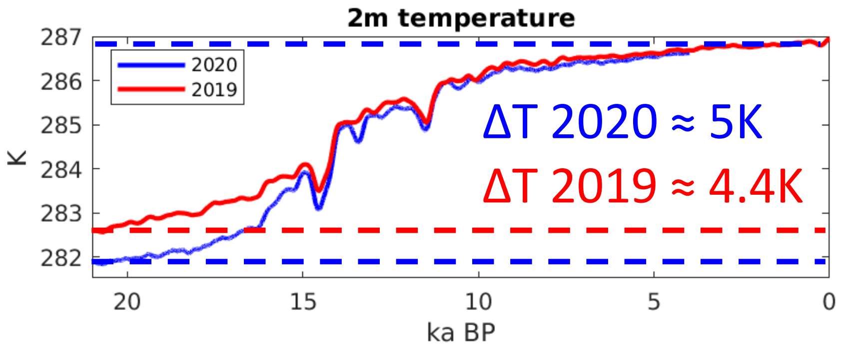
- Resolution T31GR30 (~3.75° at equator)
- transient experiments 25ka BP - PI
- Orbit (Berger), GHG (Koehler) prescribed
- ice sheets prescribed, GLAC1D (Tarasov)

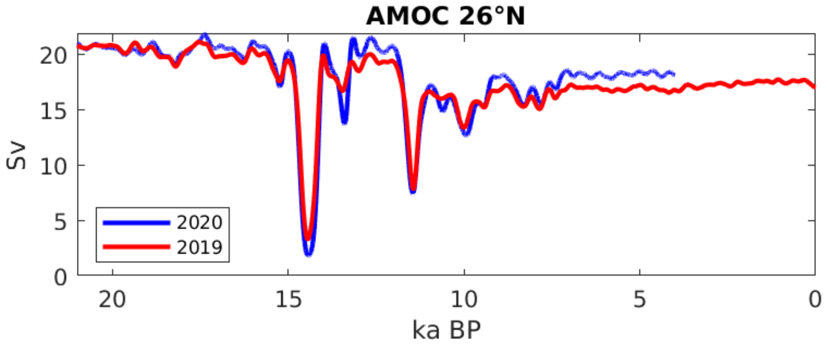
2 Experiments: 2019 and 2020

- We present results from two experiments, labelled 2019 and 2020
- 2019 was already presented at last year's EGU
- General model set up and forcing is identical
- Experiment 2020 is an update with a few changes:
  - Updated orography scripting, correcting an error that increased temperatures
  - Updated methane lifetime model
  - Updated methane emission model (Kleinen et al., 2020)
  - Improved vegetation model parameters, bringing preindustrial tree cover closer to observations
- Aim of the update was to address identified deficiencies of the 2019 model and experiment. However, experiment 2020 is not quite finished yet, will require another 2 weeks to reach the present.
- Some performance data: Turnover ~400 model years per day on 412 processing cores

Kleinen, T., Mikolajewicz, U., and Brovkin, V.: Terrestrial methane emissions from the Last Glacial Maximum to the preindustrial period, Clim. Past, 16, 575–595, https://doi.org/10.5194/cp-16-575-2020, 2020.

Climate of the deglaciation



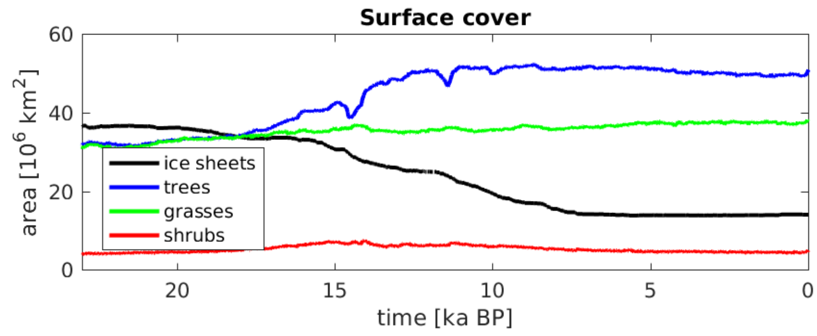


- Climate evolution differs from reconstructions: No pronounced transitions at Bølling-Allerød / Younger Dryas / Holocene
- Instead temperature drop at transition to B/A

- Glacial meltwater leads to AMOC shutdown early in Bølling-Allerød
- Likely due to incorrect meltwater treatment – ice sheet reconstruction gives amount of meltwater, but no information on timing of release to ocean

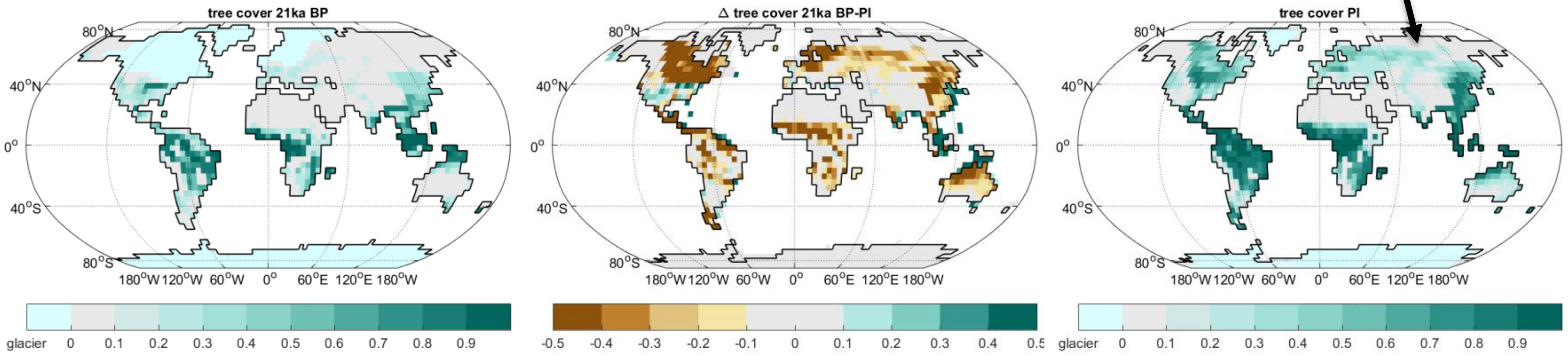
- We can achieve "correct" Bølling-Allerød / Younger Dryas transition, if we prescribe meltwater input timing

Land Surface cover (experiment 2019)

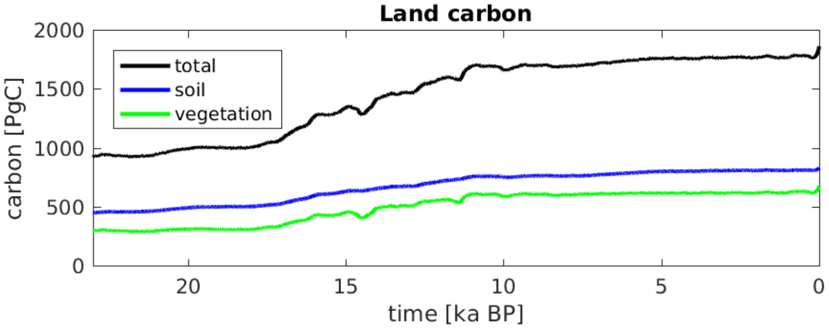


Total grass covered area stays nearly constant (though it shifts northwards), total tree area increases by same amount as ice sheet area decreases

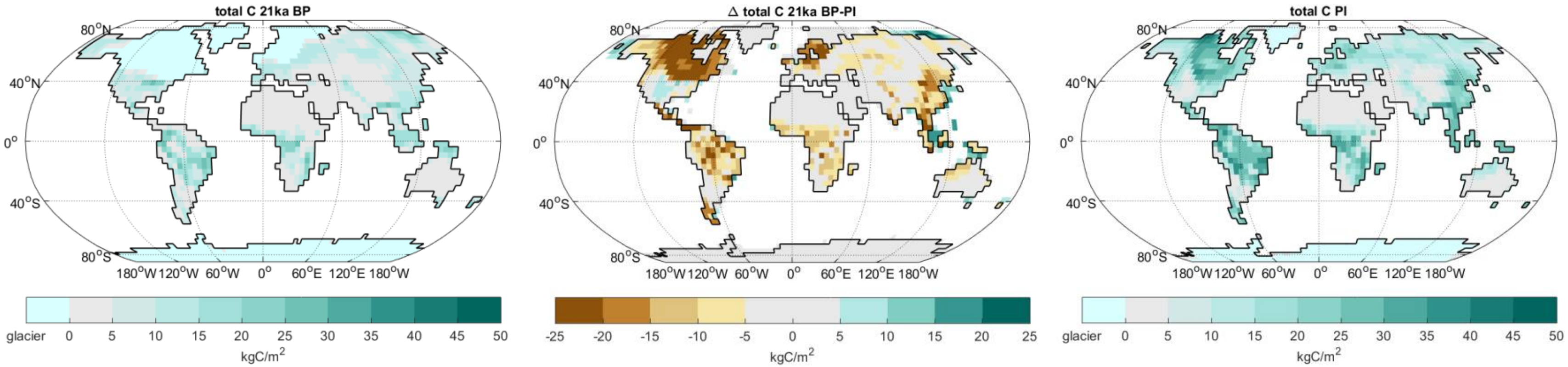
Here: 2019 experiment, 2020 experiment has higher tree cover (but hasn‘t reached PI yet)



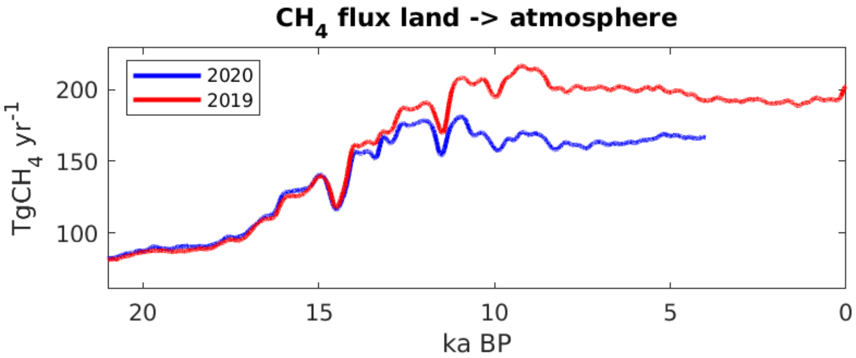
Land Carbon (experiment 2019)



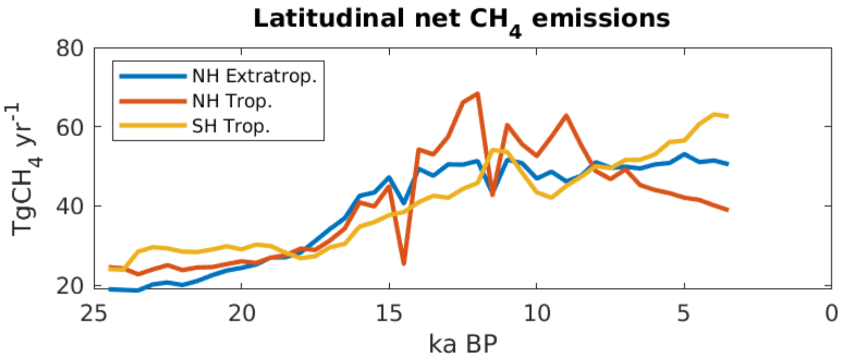
Land C increase LGM – PI similar in soil and vegetation, total increase higher than expected (850 PgC)



Methane emissions

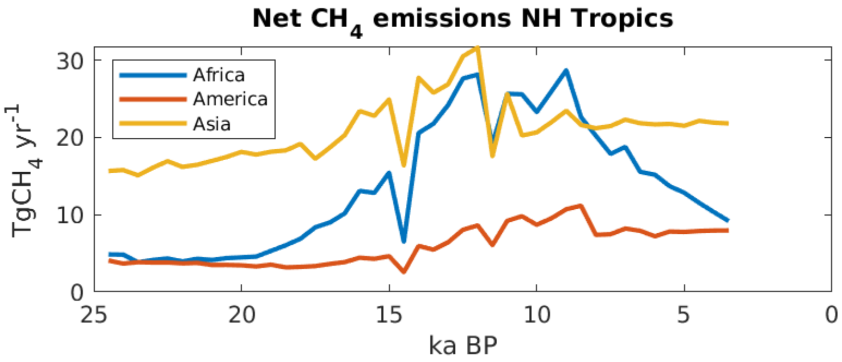


Net methane emissions roughly double from LGM to Holocene, increase was larger in 2019 experiment.

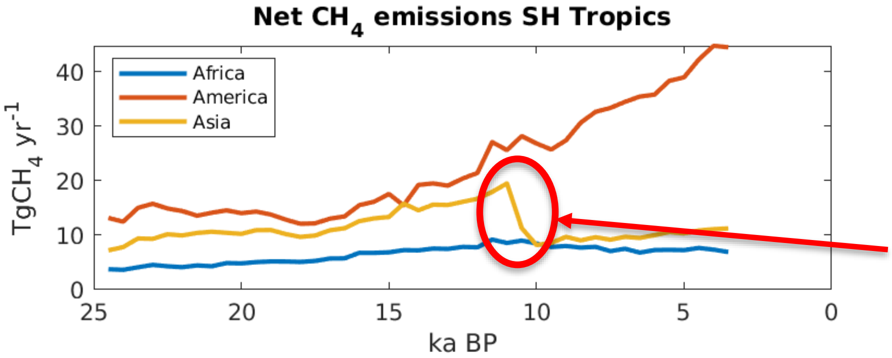


Contributions roughly equally distributed between NH extratropics, NH tropics, and SH tropics → 2/3 of emissions from tropics, 1/3 from NH extratropics.
NH tropics dominate before 8 ka BP, SH tropics afterwards

Tropical methane emissions



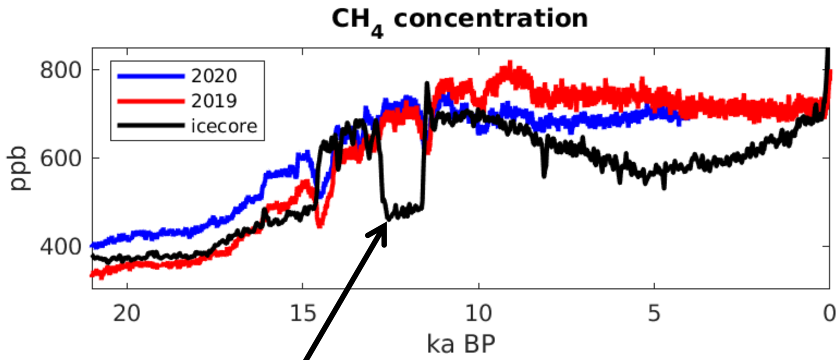
In NH tropics, Asia dominates emissions, especially before 12 ka BP, but Africa very important source during African Humid Period ("Green Sahara"), in our experiment 14 ka BP – 7 ka BP.



In SH tropics, America dominates emissions, especially after 10 ka BP, with emissions continually rising towards the late Holocene.

Drop in Asian emissions after 11 ka BP due to shelf flooding in Indonesia.

Atmospheric methane



Ice core CH_4 stack (Koehler et al., 2016)

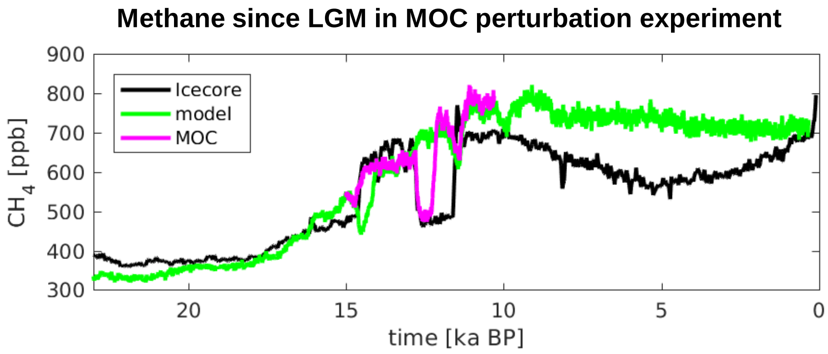
General change in CH_4 from LGM to PI is captured.

- 2019 experiment captures LGM concentration, but overestimates early Holocene
- 2020 experiment overestimates LGM, but captures early Holocene

HOWEVER:

- Model shows no pronounced CH_4 decrease at transition from Bølling-Allerød to Younger Dryas
- Holocene CH_4 slightly too high
- No decrease for mid-Holocene

CH_4: Bølling-Allerød -- Younger Dryas (2019 exp.)



We can capture magnitude and timing of CH_4 changes transitions into Bølling-Allerød and from Bølling-Allerød to Younger Dryas by modifying the meltwater flux, storing meltwater from the Laurentide ice sheet during the Bølling-Allerød and releasing it into the North Atlantic to induce the transition into the Younger Dryas.

Conclusions

- Methane changes LGM – Holocene well explained
  - Doubling of CH_4 concentration LGM – 10 ka BP
  - Methane changes Bølling-Allerød / Younger Dryas can be reproduced with MOC perturbation
- Holocene CH_4 less similar to ice core
  - No decrease at mid-Holocene
  - Likely due to timing and magnitude of emissions from NH tropical Africa: Earlier emission decrease or lower emissions during African Humid Period would lead to atmospheric CH_4 concentrations as observed in ice core