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

Thomas Kleinen\textsuperscript{1}, Sergey Gromov\textsuperscript{2}, Benedikt Steil\textsuperscript{2}, and Victor Brovkin\textsuperscript{1}

\textsuperscript{1}Max Planck Institute for Meteorology, Hamburg, Germany
\textsuperscript{2}Max Planck Institute for Chemistry, Mainz, Germany
thomas.kleine\textsubscript{n}@mpimet.mpg.de

EGU 2020, virtual session CL4.3
06/05/2020
Introduction

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
CH₄ 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 CH₄ 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.

Model and experiment: MPI-ESM 1.2

Max Planck Institute for Meteorology
Earth System Model 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

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

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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


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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

\[ \Delta T_{2020} \approx 5K \]
\[ \Delta T_{2019} \approx 4.4K \]
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.
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.
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
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