PalMod 2.2-2.3
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PalMod is a BMF funded project focused on understanding earth system dynamics and variability during the last glacial cycle. As part of PalMod, DKRZ project 947 “PalMod 2.2-2.3” in 2016 used computing time at DKRZ for model development and experiments related to the modelling of terrestrial carbon cycle dynamics and the methane cycle between the Last Glacial Maximum (LGM) and the preindustrial (PI).

Work was split into three parts: a) terrestrial carbon cycle (performed at MPI-M, Hamburg), b) terrestrial methane emissions (performed at MPI-M, Hamburg), and c) the atmospheric methane sink (performed at MPI-C, Mainz).

**Terrestrial carbon cycle**
Evaluation experiments were performed to determine the modelled distribution of vegetation for LGM and PI and compared to reconstructions.

![Vegetation distribution: JSBACH modelled (PI and LGM) and potential natural vegetation estimate from Ramankutty and Foley (1999)](image1)

Fig. 1 shows such a comparison of the modelled vegetation distribution. Overall, the modelled vegetation distribution is similar to expectations, though a few mismatches are visible, especially with too-large tundra areas in PI and a too-large polar desert at LGM. The terrestrial carbon storage for LGM conditions also is rather low in comparison to reconstructions. These issues will need to be addressed.

**Methane cycle, terrestrial processes**
We evaluated an existing model of terrestrial methane production and transport. It was found that the model performed rather poorly for modern conditions, and as a result a new terrestrial methane model was developed. Development of the model is nearly finished, though model calibration is not finalised yet.

![Modelled terrestrial CH₄ emissions (PI)](image2)
![Modelled terrestrial CH₄ emissions (LGM)](image3)

As an example, modelled terrestrial methane emissions are shown in Fig. 2 for the modern climate, and in Fig. 3 for LGM conditions. While the modern emissions are within the range of data-based estimates, LGM emissions are very low, indicating a need for further investigations.
Atmospheric methane

Within the project year 2016, we have conducted numerical experiments on particularities of atmospheric methane (CH₄) transport, chemical sinks and stable isotope fractionation escorting these processes. We pursued the following research questions:

- How different are the sinks/lifetime (τ₄CH₄) of CH₄ simulated in box-models and in an atmospheric chemistry general circulation model (AC-GCM)?
- How does the inhomogeneity in local τ₄CH₄ correspond to hemispheric/global CH₄ lifetimes?
- Does the local isotope enrichment of CH₄ scale with the local/global τ₄CH₄?
- Is there a distinct relationship between CH₄ lifetime, sink strengths and isotope enrichment?

We simulated multi-decadal CH₄ evolution using the 3D AC-GCM model EMAC, investigating long-term equilibration of CH₄ abundance and isotope ratios for several distributions of emission and OH fields.

Results

We obtained sensitivities of the sink terms distribution, lifetime (τ₄CH₄) and effective isotope enrichments in atmospheric methane (ε). The simulated hemispheric difference in ε correspond to previous estimates, however differences in local values may be substantially larger, scaling further up with hemispheric disequilibrium in source fluxes. This is important for gauging the correct strengths/isotope signatures of the sources derived from the CH₄ paleo-records.

We find that surface ε values can be approximated using local tropospheric CH₄ mixing ratios, however not lifetimes. Similarly, global/hemispheric τ₄CH₄ values only loosely correlate with the sink fluxes and sources in any domain, and strongly depend on the spatial inhomogeneity of the sources. Tropospheric effective enrichments generally do not correlate with global/local τ₄CH₄ values. Furthermore, as shown below in Figure 4, use of τ₄CH₄ in simplified models should take into account specifics of a given domain, that is: 1) Global/tropospheric averages of τ₄CH₄ are not a simple function of sink strength, 2) Tropospheric tropical τ₄CH₄ is least sensitive to the distributions used, and 3) Only the tropospheric extra-tropical lifetimes can be adequately approximated as being proportional to the local/global τ₄(source) strengths.

![Figure 4: Averages of simulated CH₄ lifetimes as a function of concomitant sink in the corresponding domain. Solid and dashed lines highlight presence of the relationship between methane lifetime and sink in tropics (IT) and higher latitudes (ETSH/ETNH), respectively.](image)

Another important result is that "nudging" (relaxation towards the observed/prescribed values) of CH₄ mixing/isotope ratios at the surface virtually removes the effective fractionation signal throughout the troposphere. In all other setups, zonal average values are not equally distributed and yield additional SH–NH gradients, with the difference being larger for surface air than for tropospheric averages.

Finally, we have estimated typical tropospheric source-sink-abundance equilibrium periods for CH₄ and its isotopologues experiencing a rapid change in sources. Generally, remote SH needs several years more to equilibrate mixing ratios of CH₄, with typical times being 42-46 years for the troposphere. Simplified models should use at least three zonal boxes (i.e. tropical and extra-tropical) to represent CH₄ lifetimes. On the other hand, CH₄ sinks may be simulated without representing the diurnal cycles of reaction partners.