Contribution ID: **112** Type: **Oral presentation**

Why is δ13CH4 so closely following atmospheric CO2 during glacial climate conditions?

Monday, 3 October 2022 14:00 (20 minutes)

Reconstructions of atmospheric methane mixing ratios have been available for decades. The large dynamic range, 350 to 800 ppb, and the abruptness of these CH4 changes suggest that CH4 is a powerful parameter to constrain past climate conditions, e.g. infer the extent of wetlands and their geographic location. The current view suggests low latitude wetlands as the dominant sources during cold and warm climate conditions. Stable isotopes of CH4 offer more insight into the underlying budget changes for past CH4 concentration changes. Especially δD of CH4 and 14CH4 successfully ruled out some scenarios (clathrate hydrates destabilization) and constrained the geologic and biomass burning sources. In contrast, the carbon isotopic signature of CH4 (δ13CH4) provided many surprises. It revealed that it is not just the mixing of isotopically distinct methane sources controlling the δ13CH4 record but that changes in the isotopic signatures of the sources themselves are essential. A remarkable feature of the δ13CH4 record of the last 450 kyr is its close resemblance to the CO2 record. For glacial periods the correlation between CO2 and δ13CH4 is very tight (r2 = 0.9), and there is no apparent phase lag between the two parameters. Both observations suggest a fast response of the d13C composition of the plant material ultimately used by methanogens for CH4 production on the CO2. However, other explanations are equally possible, e.g. both CO2 and d13CH4 could be modulated by a third factor, like the position of wind belts in the southern hemisphere that drives CO2 and d13CH4 via geographic shifts in rainfall. The regional differences in δ13CH4 within the low latitudes are presumably caused by their relative abundance of functional plant types (C3 vs C4 plants). However, the relative dominance of C4 vs C3 plants is not constant over time but can be modulated by climate and CO2. A recent paper by Yamamoto et al. 2022 exploits this CO2 –C4 vs C3 relation using δ13C of plant tissue (leaf wax) representative of the northeastern part of the monsoon-controlled Indian subcontinent to reconstruct atmospheric CO2 over the last 1.5 Mio years. The dynamic range in δ13C of the Yamamoto leaf wax record is ˜ 9‰, comparable to our δ13CH4 record, demonstrating that a δ13C change of the plant tissue is a potential player in the observed δ13CH4 dynamic. Here we will examine the shared similarities and differences between CO2 and the δ13C records of CH4 and the Yamamoto's leaf wax record to understand the driving factors behind it.

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Track Classification: Progress in proxy development and interpretation