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Path-dependent reduction in emission budgets caused by permafrost CO_2 and CH_4 release

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Emission budgets are defined as the cumulative amount of anthropogenic CO_2 emission compatible with a global temperature change target. The simplicity of the concept has made it attractive to policy-makers, yet it relies on a linear approximation of the global carbon-climate system's response to anthropogenic CO_2 emissions.

Here, we investigate how emission budgets are impacted by inclusion of CO_2 and CH_4 emissions caused by permafrost thaw, a non-linear process of the Earth system with some degree of irreversibility. We use the compact Earth system model OSCAR v2.2.1 and a new permafrost carbon emulator calibrated on four state-of-the-art land surface models that show a realistic representation of high-latitude processes: JSBACH, ORCHIDEE-MICT, and two versions of JULES.

We investigate the "exceedance" and "avoidance" approaches for estimating emission budgets, as defined and used for the fifth IPCC assessment report. The exceedance approach is the only approach that complex Earth system models can follow, and we find that it only partially accounts for the effect of permafrost carbon release. We therefore discard this approach, as it is not suited for estimating budgets when slow non-linear and irreversible processes are involved.

Following the avoidance approach, the emission budget for staying below 2°C (with a 50% chance) is reduced by 100 [20–270] $GtCO_2$ if net negative emissions prove feasible, by 150 [30–340] $GtCO_2$ if they do not, and by 190 [50–400] $GtCO_2$ if the target is overshot by 0.5°C. This corresponds to reductions in the remaining budget of 8% [1–25%], 13% [2–35%], and 16% [3–44%], respectively. The fact that this permafrost-induced reduction depends on the emission scenario proves that emission budgets are made path-dependent by the inclusion of permafrost carbon release.

Besides, our results also show that the effect of permafrost carbon release on emission budgets cannot be evaluated by naively subtracting cumulative permafrost emissions to existing budgets that do not include this process. Doing so disregards the complex dynamics of the coupled carbon-climate system.

The specific contribution of CH_4 emissions from permafrost is also investigated. We find it is path-dependent as well, since it amounts to 5% to 35% of the total permafrost effect, depending on the temperature target and the way this target is met. In overshooting scenarios, CH_4 plays a less important role, because the target is met later on, and CH_4 is a relatively short-lived greenhouse gas.

Finally, for the 1.5°C target, reductions in the remaining budget range from ~10% to more than 100%, indicating the budget may already have been exceeded. This would condemn humankind to removing more CO_2 from the atmosphere than it will emit in the future, if this target is ever to be reached.