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TELLUS

LETTER TO THE EDITOR

A comment on 'Vulnerability of permafrost carbon to global warming. Part I: model description and role of heat generated by organic matter decomposition' by D. V. Khvorostyanov et al. (2008)

By L. KUTZBACH*, *Institute for Botany and Landscape Ecology, Ernst Moritz Arndt University Greifswald, Grimmer Straße 88, D-17487 Greifswald, Germany*

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Permafrost is considered to be one of the most vulnerable carbon pools, which might lose massive amounts of carbon to the atmosphere in a warming climate, thus further accelerating climate warming (e.g. Davidson and Janssens, 2006; Zimov et al., 2006). Khvorostyanov et al. (2008a,b,c) recently presented simulations of the development of the permafrost carbon cycle in response to climate warming based on a deterministic numerical model, which accounts for heat and gas transport in the soil column as well as for the metabolic heat release during microbial organic matter decomposition. These simulations suggest rapid and deep permafrost thawing in response to a transient climate warming accelerated by a 'self-sustaining' positive feedback between thawing and heat release by microbial decomposition of the thawed organic matter. However, the simulation results and the corresponding conclusions appear questionable due to the application of an unjustifiable model boundary condition. The problematic boundary condition is given in eq. (3) in the paper of Khvorostyanov et al. (2008a) as

$$T(z = 0, t) = f_1\,(\mathrm{SHB}\,(t)), \qquad (1)$$

where $T(z = 0, t)$ is the soil surface temperature at time t and SHB(t) is the surface heat balance. SHB(t) is computed by the boundary layer scheme of the general circulation model LMDz3.3 of the French Laboratory of Dynamical Meteorology, using meteorological data of the Climate Research Unit of the University of East Anglia as forcing variables. Because, in the model, the SHB(t) is only a function of atmospheric forcing variables, with surface atmospheric temperature $T_{\mathrm{atm}}(t)$ having the greatest influence, the SHB(t) and, so, $T(z = 0, t)$ can be considered as an approximate function of $T_{\mathrm{atm}}(t)$ as illustrated in fig. 6 of Khvorostyanov et al. (2008a):

$$T\,(z = 0, t) = f_1\,(\mathrm{SHB}\,(t)) \approx f_1\,(f_2\,(T_{\mathrm{atm}}\,(t))) \approx f_3\,(T_{\mathrm{atm}}\,(t)). \qquad (2)$$

Such a boundary condition might be acceptable if heat sources within the soils can be assumed insignificant (e.g. Lawrence and Slater, 2005; Delisle, 2007); however, it is very problematic if significant heat generation due to microbial organic matter decomposition occurs as was assumed in the model of Khvorostyanov et al. (2008a). The questionable boundary condition neglects the fact that the SHB(t) and $T(z = 0, t)$ of permafrost soils are controlled not only by the atmospheric forcing variables but also by the soil heat budget. Hence, the control of $T(z = 0, t)$ should be given by

$$T\,(z = 0, t) = f_4\,(\mathrm{Meteorology}\,(t)\,, \mathrm{SoilHeatBudget}\,(t)), \qquad (3)$$

or as an approximate function of $T_{\mathrm{atm}}(t)$ and the soil temperature $T_{\mathrm{soil}}(t)$:

$$T\,(z = 0, t) \approx f_5\,(T_{\mathrm{atm}}\,(t)\,, T_{\mathrm{soil}}\,(t)). \qquad (4)$$

The last equation describes the trivial effect that $T(z = 0, t)$ increases when the soil heat content and the soil temperature $T_{\mathrm{soil}}(t)$ increase. This, in turn, leads to enhanced emission of long-wave radiation and increased fluxes of sensible and latent heat from the soil surface, which constitute major negative feedbacks on a warming soil. These negative feedbacks are

*Correspondence.
e-mail: lars.kutzbach@zmaw.de
Present affiliation: Institute of Soil Science, University of Hamburg, Allende-Platz 2, D-20146 Hamburg, Germany
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inherently inhibited by the boundary condition in the model of Khvorostyanov et al. (2008a), which causes the heat produced by the decomposition of thawed organic matter to accumulate within the soil column. Although the metabolic heat generation by the micro-organisms is small compared with the heat fluxes from and to the soil surface due to the diurnal and seasonal solar radiation variability, the accumulation of this heat, forced by the model, leads to the unrealistically strong soil warming and rapid and deep permafrost thawing as was projected by the simulations of Khvorostyanov et al. (2008a). A similar model bias problem was discussed by Delisle (2007), who criticised the projection of extensive near-surface permafrost degradation in the work of Lawrence and Slater (2005) because of a questionable model boundary condition that did not allow for heat fluxes between the thin top permafrost soil layer, to which the model was restricted, and the deeper body of permafrost (see also Alexeev et al., 2007).

In conclusion, it has to be stressed that the soil and the atmosphere must be modelled as a coupled system if the effects of climate change and increased metabolic heat release due to decomposition of thawed organic matter on the permafrost soil heat budget are to be investigated. Inappropriate model boundary conditions that inhibit a proper coupling of heat exchange processes can lead to serious bias in permafrost carbon cycle simulations and wrong conclusions about future stability of permafrost. The reasoning of this comment suggests that the prediction of a rapid permafrost thawing and a much accelerated carbon release as published by Khvorostyanov et al. (2008a,b,c) are probably exaggerated due to model shortcomings.

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