SIMULATION OF THE RESPONSE OF NORTHEAST SIBERIA PERMAFROST CARBON STOCK TO THE GLOBAL WARMING

D.V. Khvorostyanov[1,2], G. Krinner[2], P. Ciais[1], S. Zimov[3], and G. Guggenberger[4]

[1]*Laboratoire des Sciences du Climat et l'Environnement, Saclay, France; Philippe.Ciais@cea.fr*
[2]*Laboratoire de Glaciologie et Geophysique de l'Environnement, St Martin d'Heres, France; dimitri@lgge.obs.ujf-grenoble.fr*
[3]*Northeast Science Station, Cherskii, Russia*
[4]*Institute of Soil Science and Plant Nutrition, Martin-Luther-Universitaet, Halle-Wittenberg, Germany*

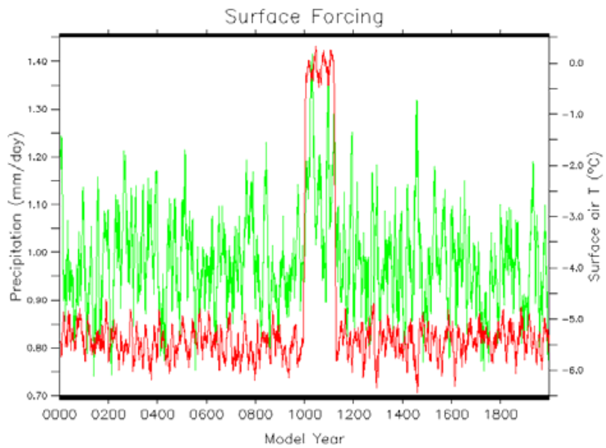
ABSTRACT
The Siberian permafrost carbon stock has been studied using a newly developed soil model, which takes into account soil freezing/thawing and organic matter decomposition in the form of soil respiration and methanogenesis. The results show that the soil response to a rapid external warming can be a self-sustaining process involving permafrost melting, deep-soil respiration with associated heat generation, and methanogenesis. Most of the soil carbon is thus consumed until there is not enough of it to feed intense respiration and/or methanogenesis. This behavior is manifested only at sufficiently warm climate established after the warming. Carbon consumption in the extremely carbon-rich Yedoma Ice Complex region appears to be moderate due to cold climatic conditions.

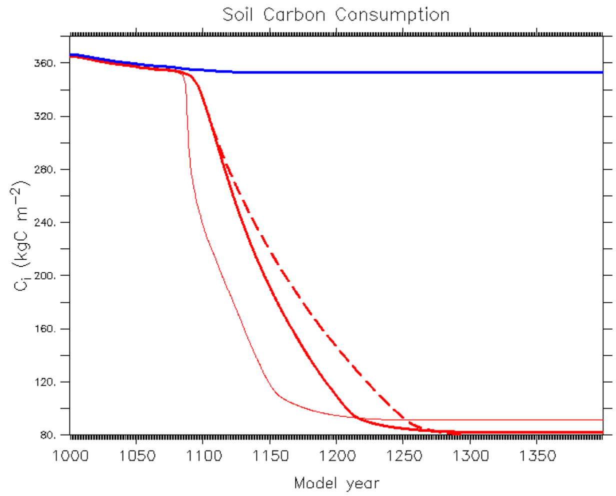
INTRODUCTION
Boreal ecosystems contain about 25% of the total world soil carbon pool, or 375 GtC, in the permafrost and the active layer. These estimates take into account only the carbon in the upper soil meters, but carbon is sometimes present in even larger quantities below that depth. According to Zimov et al [1997], an amount of 400 GtC is stored in the loess deposits of the *Yedoma Ice* in the northeast Siberia.

One of the main consequences of the anticipated climate change at high latitudes is a significant northward shift of the permafrost regions [*Anisimov and Nelson*, 1997]. Frozen soils in tundra regions, if thawed, could release CO_2 or CH_4 back to the atmosphere. Here we report on a model simulation of the fate of carbon contained in permafrost.

THE MODEL AND SIMULATION RESULTS
The newly developed model describes heat conduction with allowance for soil moisture freezing and thawing; hydrology of the upper meter of the soil, soil respiration and methanogenesis, both accompanied by heat release, diffusion of oxygen and methane in air- and water-filled soil pores, methanotrophy, methane ebullition, gas transfer and adjustment of gaz concentration to the vertical pressure gradient. The model results have been compared to measured methane fluxes in Cherskii. Simulated summer mean fluxes are in good agreement with the observations: 230 and 200 mg m^{-2} day^{-1} for the measurements and model results, respectively.

To study the soil response to a rapid warming, we applied a step-wise climate forcing at 101.5E, 59N., superimposed on interannual variability obtained from a weather generator, to the model (Fig. 1a). The dark curve shows the surface air temperature, and the gray one shows precipitation smoothed with a 10-year window. During the first 1000 years of the simulation present-day climate conditions were used. During the next 125 years, we applied the climate conditions corresponding to doubled CO_2 atmospheric concentration obtained from a GCM simulation. Afterwards, present-day climate conditions we restored. We consider three cases (Fig. 1b): 1) no oxygen limitation, i.e., soil respiration occurs regardless of oxygen availability (dashed line); 2) the oxygen limitation is included, but no processes involving methane occur (dash-dotted line); 3) methanogenesis and methanotrophy are taken into account, as well as the oxygen limitation (solid line). For each of these cases we compare scenarios with and without the additional heat release that accompanies soil respiration, methanogensis, and methanotrophy (thin and thick lines, respectively; the three thick lines coincide).





In all the three cases, there is an essential difference between the scenarios with and without the additional heat release. When the latter is taken into account, the carbon consumption continues after the forcing is terminated, until only 20% of initial carbon remain in the soil (Fig. 1b). With no additional heating the consumption stops shortly after the warming. The role of this heat release is essential only under specific local climate conditions, when the mean surface temperatures during the warmer climate are about 0^{o}C (Fig. 1a). Since oxygen limitation inhibits soil respiration, the carbon consumption occurs a little slower when it is present (Fig. 1b). At the same time methanogenesis accelerates the process.

Simulations for the Yedoma Ice region show that the climate remains relatively cold even during the "2xCO_2" climate. The carbon consumption occurs due to gradual active-layer deepening, and deep-soil respiration and methanogenesis do not start. About 4 GtC are released in the atmosphere as CO_2 from the one-million km^2 area during the first 200 years after the rapid 2xCO_2 warming.

REFERENCES

Anisimov, O.A., and F.E. Nelson, Permafrost zonation and climate change in the Northern Hemisphere: results from transient general circulation models, *Climatic Change*, **35**, 241-258, 1997.

Zimov, S., S. Davidov, G. Zimova, and others, Contribution of disturbance to increasing seasonal amplitude of atmospheric CO_2, *Science*, **284**, 800-802, 1997.