The Permafrost Dynamics from 1960 to 2300 Based on Simulations of the GIPL2 across Eurasia: Implications for Soil Carbon Vulnerability, Infrastructure and Socioeconomic Impact

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The impact of climate warming on permafrost and the potential of climate feedbacks resulting from permafrost thawing have recently received a great deal of attention. Most of the permafrost observatories in the Northern Eurasia show substantial warming of permafrost since the 1980s. The magnitude of warming has varied with location, but was typically from 0.5° to 3°C. The close proximity of the exceptionally ice-rich soil horizons to the ground surface, which is typical for the arctic tundra biome, makes tundra surfaces extremely sensitive to the natural and human-made changes that resulted in development of processes such as thermokarst, thermal erosion, and retrogressive thaw slumps that strongly affect the stability of ecosystems and infrastructure (*Figure 1*). The most significant impact on ecosystems, infrastructure, carbon cycle and hydrology will be observed in areas where permafrost contains a considerable amount of ground ice in the upper few meters.

Figure 1. *Ice and carbon rich permafrost degradation and their impact on landscapes, ecosystems and infrastructure.*

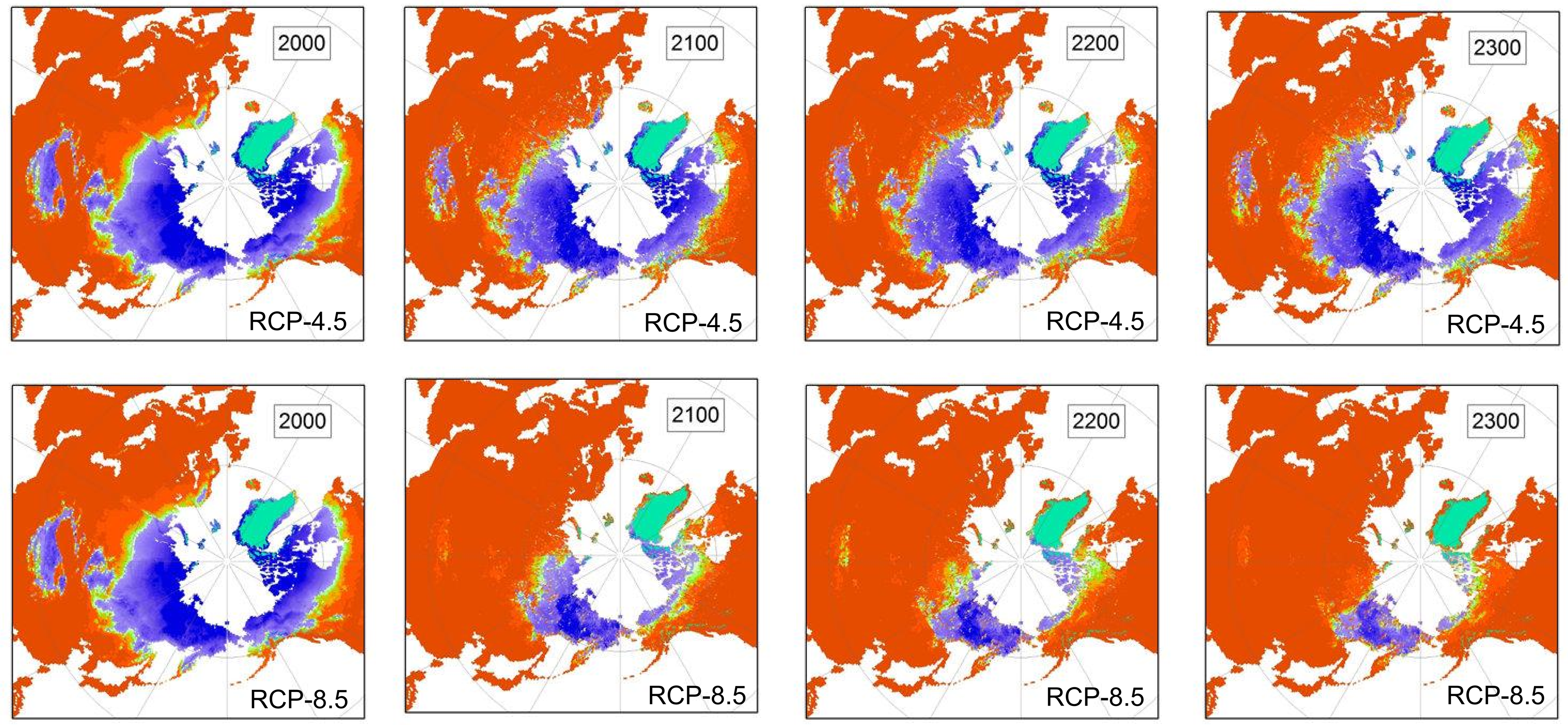

Figure 2. *Mean annual ground temperature at 3 m depth reconstructed for 2000 and predicted for 2100, 2200 and 2300 using CCSM4 RCN-4.5 (upper row) and RCN-8.5 (lower row) CO_2 concentration scenario as a climate forcing.*

The main aim of this study is to evaluate the vulnerability of permafrost under climate warming across the Permafrost Region of the Northern and High-altitude Eurasia in respect to ecosystems stability, infrastructure, socioeconomic impact, and to estimate the volume of newly thawed soils, which could be potential source or sink of additional amount of carbon in the Earth System. We applied the process-based permafrost dynamics model GIPL2 (Geophysical Institute Permafrost Lab), using a historical climate forcing CRU3.1 data set for retrospective (1960-2009) and CCSM4 RCP-4.5 and RCP-8.5 (2009-2300) for analysis of permafrost dynamics in the future.

Consistent with observations for the recent decades and with other model simulations of soil temperatures under future climate conditions, we find a widespread degradation of permafrost in Northern regions by the end of the century. The model results indicate 1.2K km^3 of seasonally unfrozen soils within the two upper meters across 10.8 Mio quadratic km of northern Eurasian permafrost domain during the last two decades of the 20th century. Our projections have shown that unfrozen volume of soil within two upper meters increases to 3.5K km^3 by 2050 and to 9.5K km^3 by the last decade of the 21st century due to active layer deepening. According to this specific climate scenario, the area of permafrost with active layer shallower than 3 m in depth could decrease from 10.8 Mio km^2 in 2000 to 9 Mio km^2 by 2050 and to 6 Mio km^2 by the end of current century. Our projections according to the CCSM4 RCP-4.5 and RCP-8.5 climate scenario indicate that the maximum unfrozen volume of soil within three upper meters across the northern Hemisphere permafrost doomain could change between 12.8K and 20.8K cubic km^3 during 2009-2300. If we assume a similar response (as modeled) of soil temperature and near-surface permafrost area shrinkage to warming in Eurasia, an additional 25% of the total volume of thawed soils could become biogeochemically active by the end of the current century and 60% by 2300.

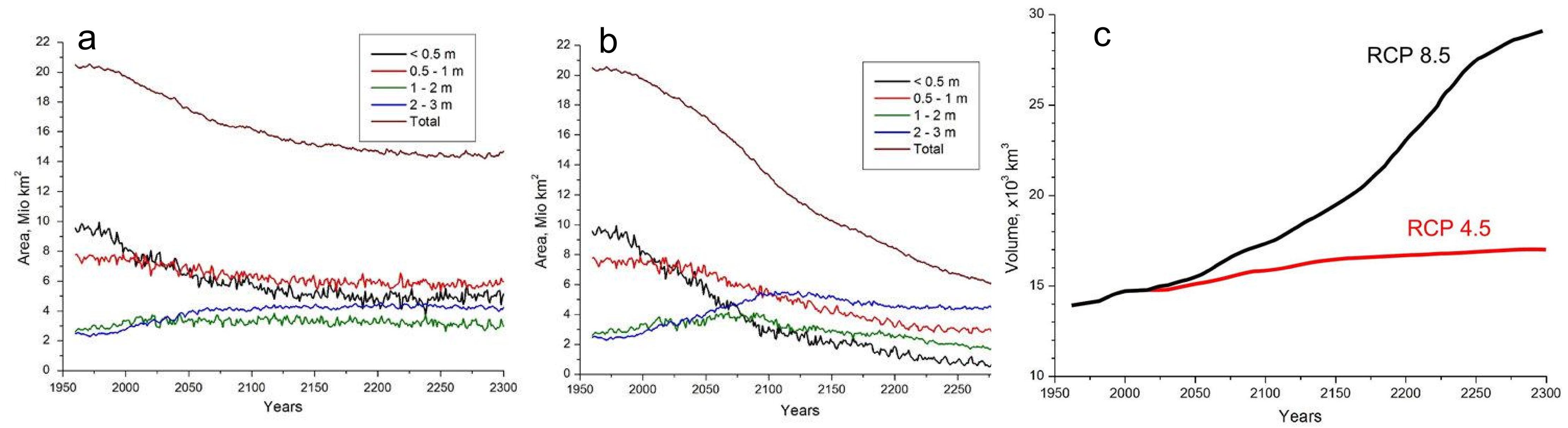

Figure 3. *Changes in area of permafrost for different depths of thaw penetration above 3 m across the RCN Domain according to RCP-4.5 (a) and RCP-8.5 (b) climate scenario and dynamics of the volume of thawed soil above 3 meters across the northern Hemisphere according to RCP-4.5 and RCP-8.5 climate scenarios (c)*