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Permafrost-snow-ecosystem in the late Quaternary climate: Distribution and interactions examined by global system modeling

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Change in the distribution and states of permafrost in time and space is an important non-local factor to understand the attribution and consequence of Quaternary climate change, and project and adapt to the future environment. The subsurface hydrothermal system interacts with overlying snow and the eco-system, offering physical foundation and conditions to the various terrestrial activities, from pure physical to hydrological to biogeochemical to societal aspects. Through various environmental pathways subsurface changes are significantly connected to the atmosphere and to the Oceans, as well. Large-scale numerical climate modeling with snow-permafrost-vegetation dynamics is a strong tool for investigation on the impacts and the attribution of changes in the regime. For more comprehensive understanding, however, theoretical approaches such as conceptual modeling, statistical analysis, and mathematical system analysis techniques should also be pursued. We illustrated the current capability and limitations of global climate models (GCMs), by statistically reconstructing the Northern Hemisphere frozen ground distribution for different late Quaternary eras with thermal indexes derived from GCM outputs, taken from the Paleoclimate Model Intercomparison Project 2 (PMIP2). Reconstruction of the current permafrost by the methodology showed reasonable distribution for large-scale analysis. Paleo-permafrost distribution was reconstructed for 0ka (pre-industrial), 6ka (mid-Holocene), and 21ka (the last glacial maximum; LGM). The Holocene simulations (0ka and 6ka) produced largely similar results. The LGM outputs showed substantial increase of the permafrost area by 49.6% relative to the pre-industrial conditions in median among the models, but also showed insufficient cooling during the cold season in some regions. PMIP2 outputs showed significant across-model variations. For more detailed regional reconstruction, we downscaled the map with high-resolution topography data for South America and east Asia so that they can better compare with the small-scale observations. Geographical, geomorphological, and paleobotanical evidences of the past and present periglacial processes that have been derived from observations and from literatures are being collected for comparison and validation of the reconstruction and further analysis, although data are often sparse or mutually contradictive. For analysis and investigation of the long-term behavior and interactions of the permafrost-snow-ecosystem, we will employ a hierarchy of numerical models, from detailed local permafrost-snow dynamics to regional models to GCMs with interactive permafrost-snow-ecosystem dynamics for further investigation, including analysis or PMIP3 outputs. Conceptual approaches with system analysis techniques will provide qualitative, yet essential understanding of the system.