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Permafrost as an additional driving factor for the extreme fire event in the boreal Baikal region in 2003

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Wildfires are a natural and important element in the functioning of boreal forests. However, in some years, fires with extreme spread and severity occur. Such severe fires degrade the forest, affect human values, emit huge amount of carbon and aerosols and alter the land surface albedo. Usually, wind, slope, and dry conditions have been recognized as factors determining fire spread. In the Baikal region, 127,000 km^2 burned in 2003, while the annual average burned area is approx. 8100 km^2. In average years, 16% of the burned area occurred in the continuous permafrost zone but in 2003, 33% of these burned areas coincide with the existence of permanently frozen grounds. Permafrost and the associated upper active layer, which thaws during summer and refreezes during winter, is an important supply for soil moisture in boreal ecosystems. This leads to the question if permafrost hydrology is a potential additional driving factor for extreme fire events in boreal forests.

Using temperature and precipitation data, we calculated the Nesterov index as indicator for fire weather conditions. Further, we used satellite observations of burned area and surface moisture, a digital elevation model, a land cover and a permafrost map to evaluate drivers for the temporal dynamic and spatial variability of surface moisture conditions and burned area in spring 2003. On the basis of time series decomposition, we separated the effect of drivers for fire activity on different time scales. We next computed cross-correlations to identify potential time lags between weather conditions, surface moisture and fire activity. Finally, we assessed the predictive capability of different combinations of driving variables for surface moisture conditions and burned area using multivariate spatial-temporal regression models.

The results from this study demonstrate that permafrost in larch-dominated ecosystems regulates the inter-annual variability of surface moisture and thus increases the inter-annual variability of burned area. The drought conditions in spring 2003 were accelerated by the presence of permafrost because less water was stored in the upper active layer from the dry previous summer 2002 and the permafrost table prevents vegetative water uptake from deeper layers. In contrast, weather conditions (precipitation anomaly, Nesterov index) are weaker predictors for the 2003 fire event.

Our analysis advances the understanding of complex interactions between the atmosphere, vegetation and soil on how feedback mechanisms can lead to extreme fire events. These findings emphasize the importance of a mechanistic coupling of soil thermodynamics, hydrology, and fire activity in earth system models for projecting climate change impacts over the next century.