**Permafrost, thermal conditions and vegetation patterns since the mid-20th century: a remote sensing approach applied to Jotunheimen, Norway**

Abstract

Northern high alpine regions are currently experiencing rapid warming, which often results in the degradation of sub-surface permafrost and the upslope advancement of vegetation. The present study combines remotely sensed MODIS Land Surface Temperatures (LSTs) and the Normalised Difference Vegetation Index (NDVI) with observed air temperatures to model the thermal and vegetational dynamics in NE Jotunheimen (Norway) for the period 1957-2019. An altitudinal transect on the north-facing slope of Galdhøpiggen was used for ground truthing. Results indicate a substantial warming trend since the late 1950s, accompanied by increased NDVI. The spatial and temporal patterns of observed change were not uniform. Winter surface temperatures increased most rapidly, by 2.4-2.8°C at mid- and low altitudes (600- 1500 m a.s.l.). The highest increases in NDVI (by ~0.1) were detected during the growing season (April-September) and over the mid-range altitudes (1050-1500 m a.s.l.), i.e. above the tree line on Galdhøpiggen. We attribute this to increased shrubification at these altitudes. Our results confirm that the surface temperatures near the previously estimated lower altitudinal limit of permafrost (~1450 m a.s.l.) have continued to increase during the past decade, likely facilitating further permafrost degradation. Finally, we demonstrate that mapping remotely sensed mean growing season LSTs below 0°C can be used to identify areas suitable for continuous sub-surface permafrost, and mean June-September LSTs above 7°C can detect areas suitable for tree (*Betula pubescens*) growth in NE Jotunheimen.