Influence of Slope Angle on the Convective Heat Transfer in Porous Permafrost Substrate

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Overview

In an Alpine permafrost setting, the coarse blocky terrain (talus slopes, rock glaciers etc.) is often very porous. The high permeability of such landforms allows air to circulate within the soil, which influences the ground temperature. This leads to local microclimates and is prominently visible at low elevation permafrost occurrences. Also at high elevation sites this internal air circulation has an influence on the ground thermal regime. This has been thoroughly studied in numerous fieldwork based studies. Recently, a numerical model approach showed that the internal air circulation takes place under free convection conditions as result of density differences between warm and cold air with no additional forcing (Wicky & Hauck, 2017). The resulting seasonally reversing (chimney-type-) circulation leads to a substantial cooling in the lower part of a talus slope. Different factors such as permeability, porosity, atmospheric forcing etc. influence the intensity of air circulation within the ground. The present study focuses on the slope angle and the permeability. As one can find permafrost in many different landforms with varying slope angle and permeability, this study is an indication to which extent slope angle and permeability influence the occurrence of an effective air circulation in the soil and thus a potentially cooler microclimate.

Slope Angle and Permeability

In our experiment, we use slope angles from 0° – 40° and permeabilities from 1x10⁻⁷ to 8.89x10⁻⁵ m². Fig. 2 shows the influence on the temperature in the lower part and the air velocity relative to different slope angles and permeabilities. Velocity increases with the increase of slope angle and permeability. Temperature shows a more complex behavior. The different behaviors are explained by different circulation patterns (Fig. 4).

Circulation pattern

Depending on the parameter setting three different circulation patterns may take place: Multicellular vertical convection, lateral advection cells and unidirectional downflow (Figs. 3 & 4). These circulation patterns have an influence on the ground temperature (GT):

- Seasonally reversing advection (chimney-type circulation) leads to a pronounced cooling in the lower part of the domain
- Multicellular convection leads to generally colder GT (compared to a setting without convection)
- Unidirectional downflow mainly leads to a very fast propagation of the surface boundary temperature into the ground.

What can we learn from such an experiment?

- Slope angle matters. The steeper, the higher the potential air velocity within the ground and thus the more effective the convection.
- Permeability matters. Is the soil permeability too low air circulation is weak (Fig. 2) and has no influence on the thermal regime. No convective heat transfer takes place. Is the permeability very high, the air circulation is directly coupled to the atmosphere and no reversing air circulation takes place.
- These results help to explain isolated permafrost occurrences and thermal anomalies within continuous permafrost. The improved process understanding may be integrated in permafrost mapping or long-term permafrost modelling projects.

Outlook

This parameter study gives promising insights on convective heat transfer processes within porous permafrost substrates. In future, the model will be further developed towards other landforms (e.g. rock glaciers) and calibrated for specific field sites to assess, compare and quantify the influence of convective heat transfer in air flow. Furthermore the modelling approach will be extended to overcome shortcomings like the lack of water or massive ice in the domain to represent the complex interaction of these different processes.

References