Modeling Convective Heat Transfer in the Porous Active Layer of an Alpine Rock Glacier

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Introduction: Permafrost is ground that stays frozen for at least two consecutive years. In the Swiss Alps it is a widespread phenomenon and it has an important impact on the landscape, especially regarding natural hazards. Rock glaciers (Fig. 1) are one of the most striking permafrost landform. Their ice rich body is often covered with coarse blocks which allow for air to circulate within the porous active layer (the uppermost 3-4m which thaw each summer) and act as a strong thermal filter between atmospheric and ground temperatures (Wicky & Hauck 2017).

Figure 1. Murtèl rock glacier (Engadin / CH)

Computational Methods: We couple the COMSOL Multiphysics® Modules Subsurface Flow – **Darcy's law** (w/ Boussinesq approx.) (eq. 1) and Heat Transfer – **Heat Transfer in Porous Media** (eq. 2).

$$(1)\ \boldsymbol{u} = -\frac{\kappa}{\mu}(\nabla p - \rho \boldsymbol{g}) \qquad (2)\ \boldsymbol{q} = -d_z k_{eff} \nabla T$$

The **geometry** consists of a simplified 2D rock glacier (Fig. 2) with 3 domains with different material properties (Tab. 1).

The upper thermal **boundary** (*Dirichlet*) is a temperature series from the uppermost thermistor data at borehole COR087 on Murtèl rock glacier (PERMOS 2016), lower thermal boundary is a constant geothermal heat flux (*Neumann*). Pressure is open to atmosphere ($\mathrm{p} = \rho g\, H_{p0}$).

	Porous AL (Granite / Air)	Rock glacier (Ice / Water)	Bedrock
Heat cap. [J kg^{-1} K^{-1}]	850 / temp. dep	2052 / 4179	850
Therm. cond. [W m^{-1} K^{-1}]	2.9 / temp. dep	2.31 / 0.613	2.9
Density [kg m^{-3}]	2600 / temp. dep	918 / 997	2600
Permeability [m^2]	1e-7	0	0
Porosity	0.5	0	0

Table 1. Material properties

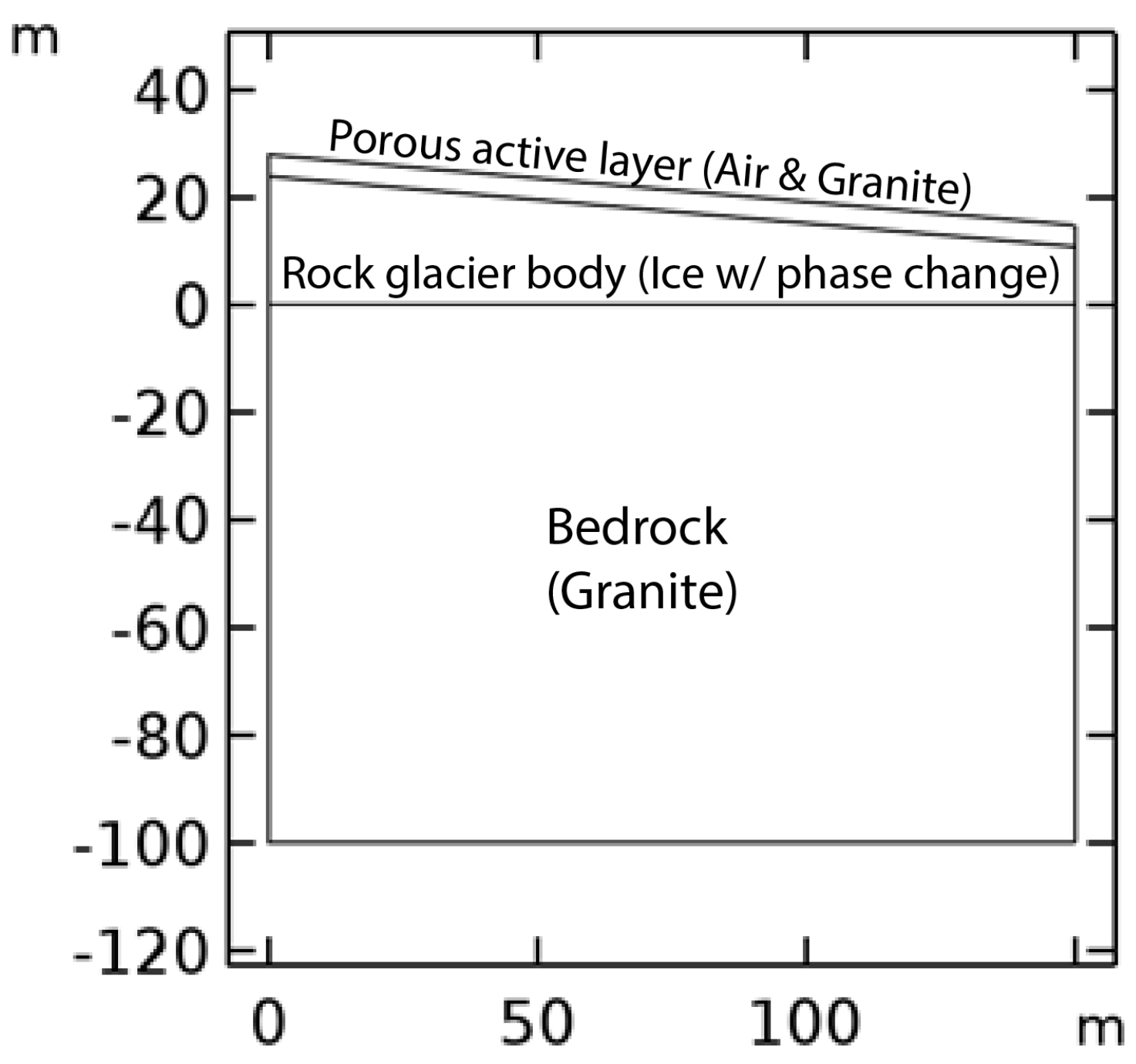

Figure 2. Geometry.

Results: Winter temperatures are highly influenced by convective heat transfer due to the unstable thermal stratification of the air which allows a pronounced convective cooling, whereas summer temperatures show almost no sensitivity to convective heat transfer (Fig. 3, 4).

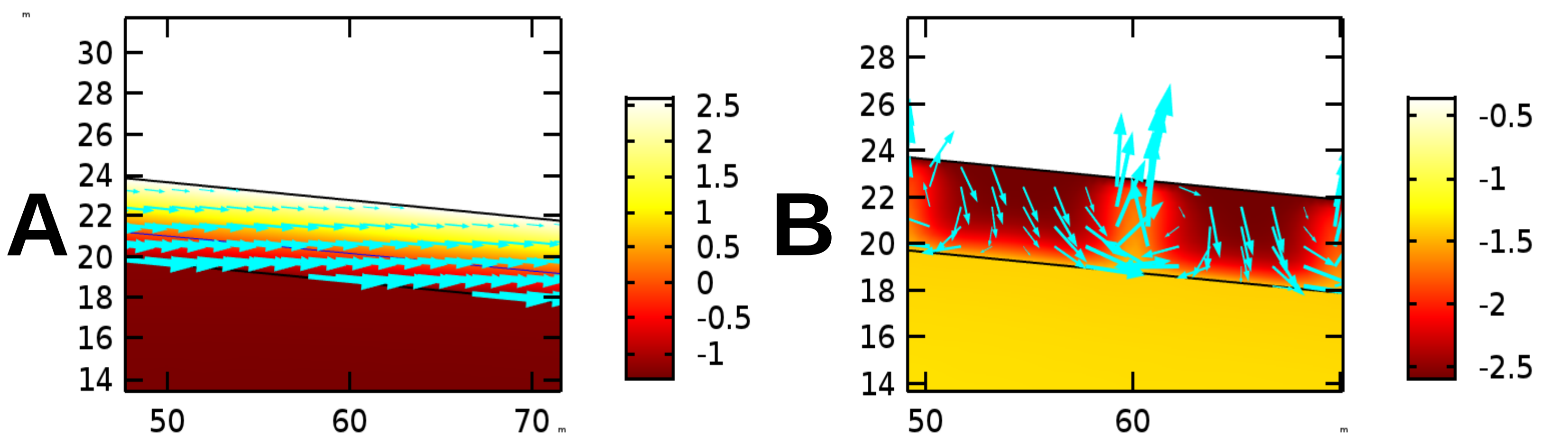

Figure 3. Active layer circulation snapshot. (A) Gentle down flow during summer. (B) Multicellular convection during winter (cooling). Scale in ° Celsius.

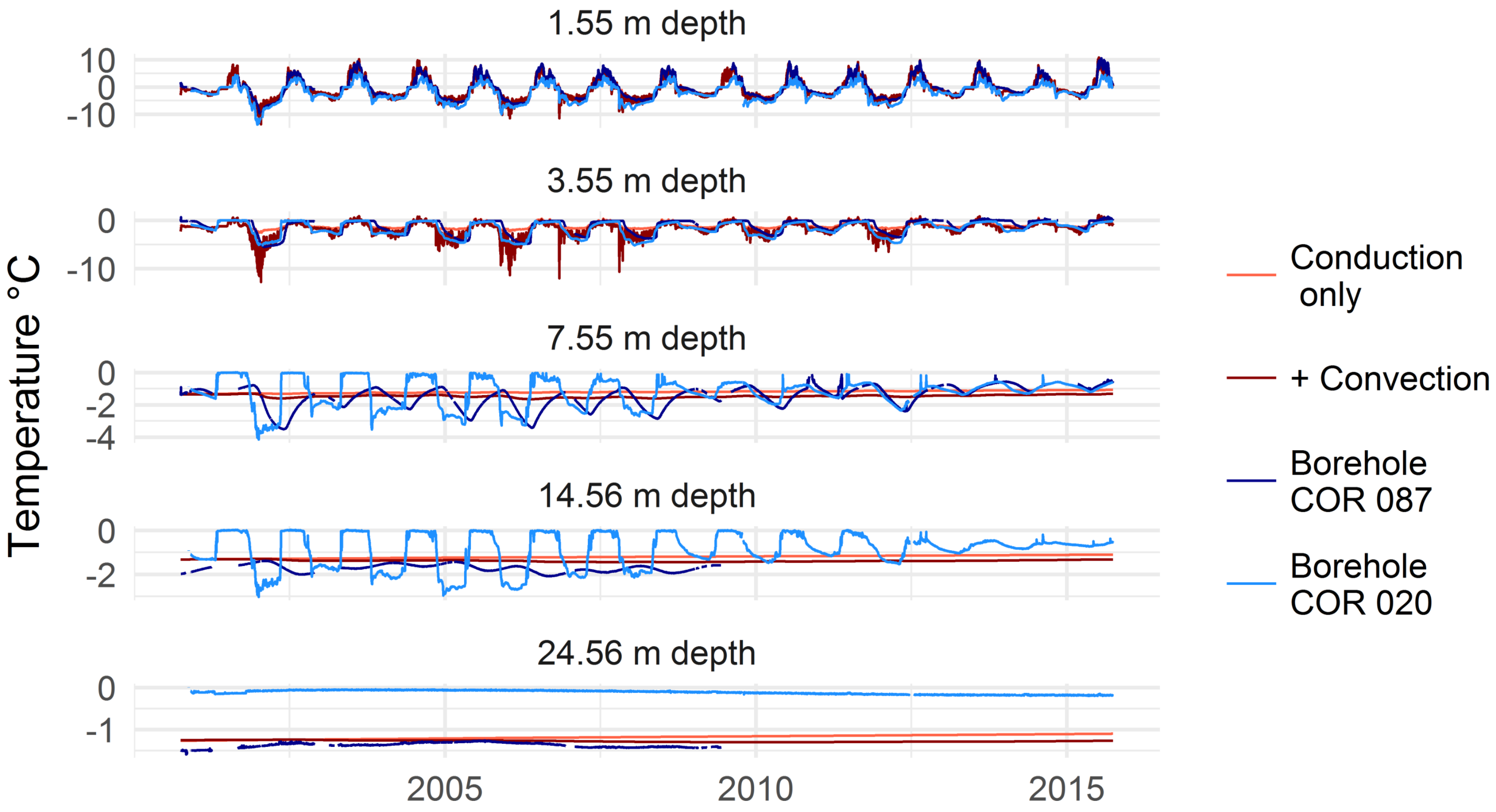

Figure 4. Temperature evolution over 15 simulated years at different depths.

Conclusions: The explicit modeling of 2D air convection within the soil is a novel approach in mountain permafrost research. The results clearly show that convection cannot be neglected and plays an important role in the thermal regime of a rock glacier. In future we aim to extend the model to further rock glaciers and to solve for Brinkman or Stokes flow as Darcy's law may not be valid anymore with high permeability.

References:

1. Wicky Jonas & Hauck Christian, Numerical modelling of convective heat transport by air flow in permafrost talus slopes, The Cryosphere, 11(3), 1311-1325 (2017)
2. PERMOS, PERMOS Database, Swiss Permafrost Monitoring Network, Fribourg, Switzerland (2016)

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