Alpine Permafrost Distribution at Massif Scale: Assessment of Mean Surface Temperatures During Winter Equilibrium Period Thanks to Topoclimatic and Geomorphological Data (Combeynot Massif, French Alps)

Xavier Bodin
University Paris Diderot-Paris 7 / Institute of Alpine Geography, Joseph Fourier University, Grenoble, France
Philippe Schoeneich
Institute of Alpine Geography, Joseph Fourier University, Grenoble, France
Monique Fort
UMR 8586 PRODIG, University Paris Diderot-Paris 7

Introduction
Statistical modeling using BTS (Bottom Temperature of the Snow cover; Haeberli 1985) have been attempted by authors (e.g., Hoelzle 1992, Gruber & Hoelzle 2001, Lewkowicz & Ednie 2004) to model mountain permafrost distribution. Field validations generally show good agreement with rock glaciers, which are the most common geomorphological evidences of the permafrost. The main limit of this approach is the necessity of well-distributed BTS data over the studied area.

In the Combeynot massif (Hautes Alpes, France – around 45.0°N, 6.4°E), numerous rock glaciers may be observed on various topoclimatic contexts, whereas BTS datasets are available on some limited areas (Bodin 2007). In order to get a spatialized overview of the surface temperature, and hence of the permafrost presence, a linear relationship between the main topoclimatic parameters (air temperature and solar radiation) and the WEqT is proposed.

A Spatial Model of the WEqT

Starting hypothesis
In order to quantify respective influences of the main parameters, the following hypotheses are made:

- The WEqT is equal to the mean annual air temperature (MAAT), to which is added, or subtracted, the influences of the solar radiation and the debris cover.
- The thermal influence of the solar radiation (a), positive, is linearly related to the potential solar incoming radiation (PSIR) during summer (June–July–August) and proportional to the PSIR/PSIRmax ratio.
- The thermal influence of the openwork debris mantles (β) is negative and, on yearly average, homogeneous independently of other factors.
- For similar topoclimatic conditions, WEqT is equal from one place to the other.

Parameterization of the linear model
Within the linear model of WEqT, the α and β parameters were parameterized by minimizing the sum of residuals in two steps:

1. First, for rock glaciers with topoclimatic conditions close to those of the root of the Laurichard rock glacier, where BTS in 2004 shows a mean WEqT of -3.44°C. Due to very low PSIR, α was minimal, and the adjustment led to β = -3.9°C.

Figure 1. Processing steps (1 = calibration of α and β by numerical adjustment; 2 = GIS processing) to model WEqT.
2. Second, for locations with high PSIR and using the previously defined $\beta$, the BTS values of the Pradieu Valley give $\alpha = 2.9^\circ$C.

The flow chart of the model describes the different datasets used and the main steps of the process (Fig. 1).

**Results at Different Spatial Scales**

*The Laurichard rock glacier case*

A first validation of the model is given by comparing the extrapolated WEqT to the measured BTS on the whole surface of the Laurichard rock glacier.

The model correctly reproduces the measured BTS on the rock glacier (Fig. 2), and suggests that the general trend of the WEqT is, at this scale, visibly driven by the solar radiation received during summer.

*The WEqT on the rock glaciers of the Combeynot Massif*

The mean modeled WEqT at the rooting zone of the rock glaciers of the Combeynot massif amounts to -3.4°C, whereas it reaches -2.9°C at the front of the landforms. Some fronts, nevertheless, are located on warmer conditions, mainly when glacier is or has been, historically, present on the rooting area.

**Conclusion**

A statistical model of the WEqT has been presented in which the influences of solar radiation and coarse debris presence have been adjusted thanks to BTS measurements. Though local processes (e.g., permafrost creeping) or influences of other parameters (e.g., snow) are not taken into account, the validation of the model on the Laurichard rock glacier encourages the use of this kind of topoclimatic approach for permafrost study at massif scale.

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**References**


