# Database- and GIS-based modeling of the regional permafrost distribution - Examples from the Mattertal, Swiss Alps


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As a lithospheric phenomenon dependent on temperature, mountain permafrost is directly affected by climatic change. Natural dangers due to slope instabilities are a consequence of the degradation of permafrost in mountainous regions. In order to be able to react to these natural dangers, knowledge of the distribution of permafrost is vital. However, permafrost can only be measured selectively. Thus, models based on parameters that influence the distribution of permafrost need to be applied to the area.

In widely examined areas empirical statistical models are a convenient method to simulate the distribution of permafrost. Multiple research projects in the Mattertal (Valais, Switzerland) during the last years provide sufficient data on permafrost. This has been facilitate above all the by PACE project. The permafrost model mod2 (GRUBER 2000) is based on this data. The DFG-funded project „Periglazial Mattertal" investigates mainly the influence of substrate and surface characteristics on the ground thermal regime and the distribution of mountain Permafrost (HERZ 2003). It revealed the cooling effect evoked by coarse block coverage. The empirical statistical permafrost models existing to date overestimate the occurrence of permafrost in the study area. In coarse block surface areas those models underestimate the distribution of permafrost. A new permafrost-model has been developed for two distinct areas of the Mattertal based on existing modeling approaches and long-term measurements. It takes into special account the surface influence.

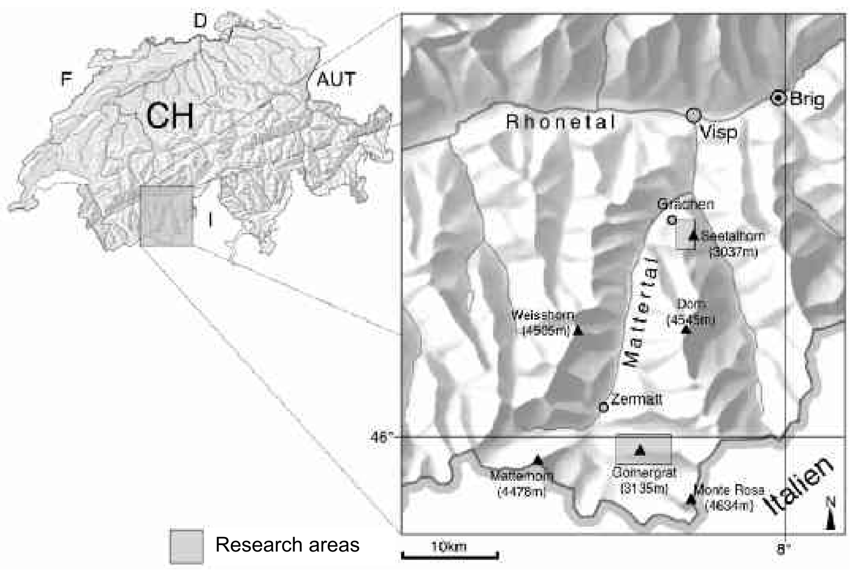



***Figure 1:*** **Overview map of the Mattervalley with the location of the two reserch areas.**

## 1 Research Area

The climate conditions in the Matter valley have a continental character with low precipitation and high radiation budgets. The glacial equilibrium-line altitude reaches up to 3300m. Therewith the valley is an excellent region for research projects in periglacial areas.

The new model was developed for two areas of the Mattertal. The first area with the size of 19,2km² is located in the southern part of the valley in the area of the from west to east ascending Gornergrat-Stockhorn crest. The altitude reaches from 2200m to 3500m at Stockhorn. On the Stockhorn-Plateau the most highly elevated PACE-Borehole is located (3410m).

The Grächen-Seetalhorn study area in the northern part of the valley reaches the altitude of 2200 to 3250m. It includes the entire upper Ritigraben catchment (Figure 1). On the altitude of 2615m there is a borehole with a ZAA of 14m and a MAGT of -0,37°C.

## 2 Model Design

Like other existing empirical-statistical models (e.g. HOELZLE + GRUBER) the presented model is based on two parameters, potential incoming short-wave solar radiation (PSWR) and air-temperature. These parameters simulate the complex energy exchange at the surface and in the active layer in a so called "gray box".

BTS values are a proxy for the MAGST and can be used for calibration of permafrost distribution models. As a new parameter the surface characteristic is implemented.

For the presented research a digital elevation model (DEM) of 10m Grid size was calculated under consideration of 150000 geodetic points. The interpolation was carried out with the IDW method through the open-source GIS GRASS (Geographic Resources Analysis Support System).

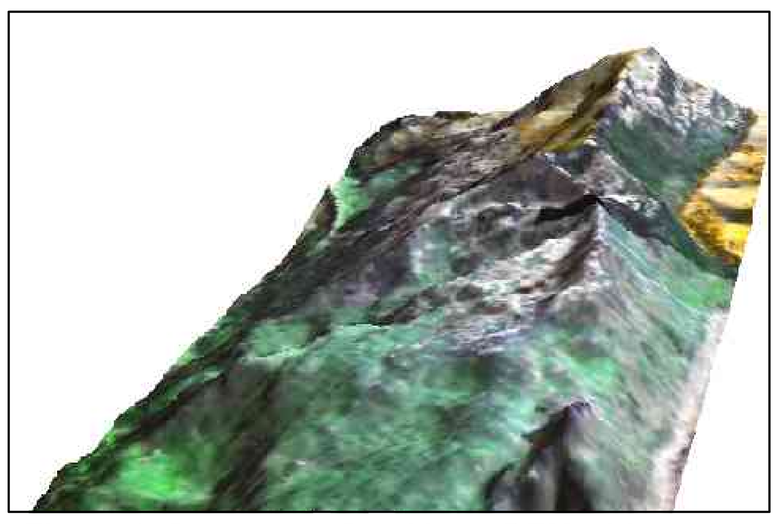


***Figure 1:*** **Gornergrat-Stockhorn DEM with overlaying Landsat Image**

The information on air temperature has been collected by eight SLF-climate-stations (Swiss Federal Institute for Snow and Avalanche Research). Some data have been collected for a period of 10 years. This database is constantly updated. For this model the three year MAAT (2000-2002) was used. The temperature gradient was estimated with polynom-regression analysis.

***Table 1:*** **Mountain climate-stations in the research area**

| Climate-station | Elevation | MAAT |
|---|---|---|
| Saas-Platthorn | 3246m | -3,9°C |
| Saas-Seetal | 2480m | 0,6°C |
| St. Niklaus Ob. Stelligletscher | 2910m | -1,7°C |
| Zermatt Platthorn | 3345m | -4,3°C |
| Zermatt Triftchumme | 2750m | -0,6°C |
| Zermatt Wisshorn | 2930m | -1,5°C |
| Gornergrat Windstation | 3130m | -2,5°C |
| Gornergrat Snowstation | 2950m | -1,8°C |

The PSWR has been calculated for the middles of the snow-free months (July to October) through the *r.sun module* of GRASS (HOFIERKA 2002). This program takes into special account the shading effect of surrounding topography, so that the results represent the distribution of irradiation exactly.

It has been computed for "clear sky" conditions. The implementation of Albedo and „Linke turbidity" could be neglected. The Albedo enters the model through the factor surface-characteristic. The differential inclusion of „Linke turbidity" had had a 6x higher calculation time without model improvement. An integrative value of 3,5 was chosen.

The Figure 2 shows the development of PSWR on W-E oriented Riffelhorn. The data clearly shows the up to the month October increasing shading effect on the north side of this mountain.

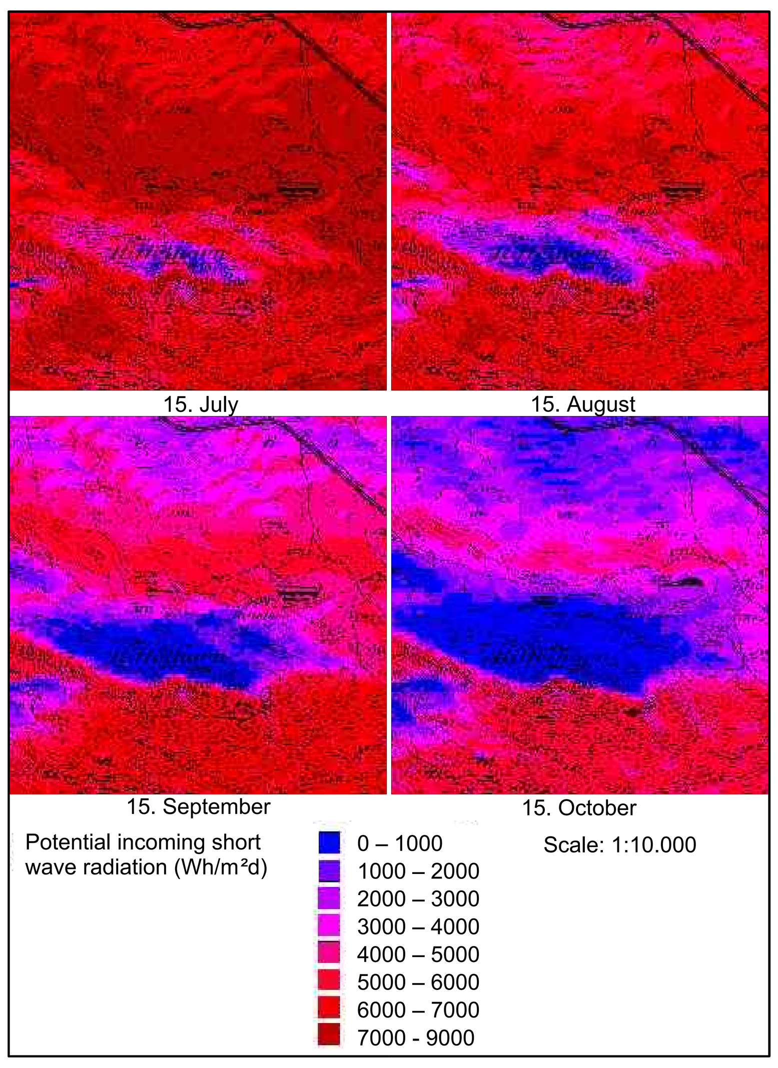



***Figure 2:*** **Calculated potential incoming short-wave radiation at Riffelhorn**

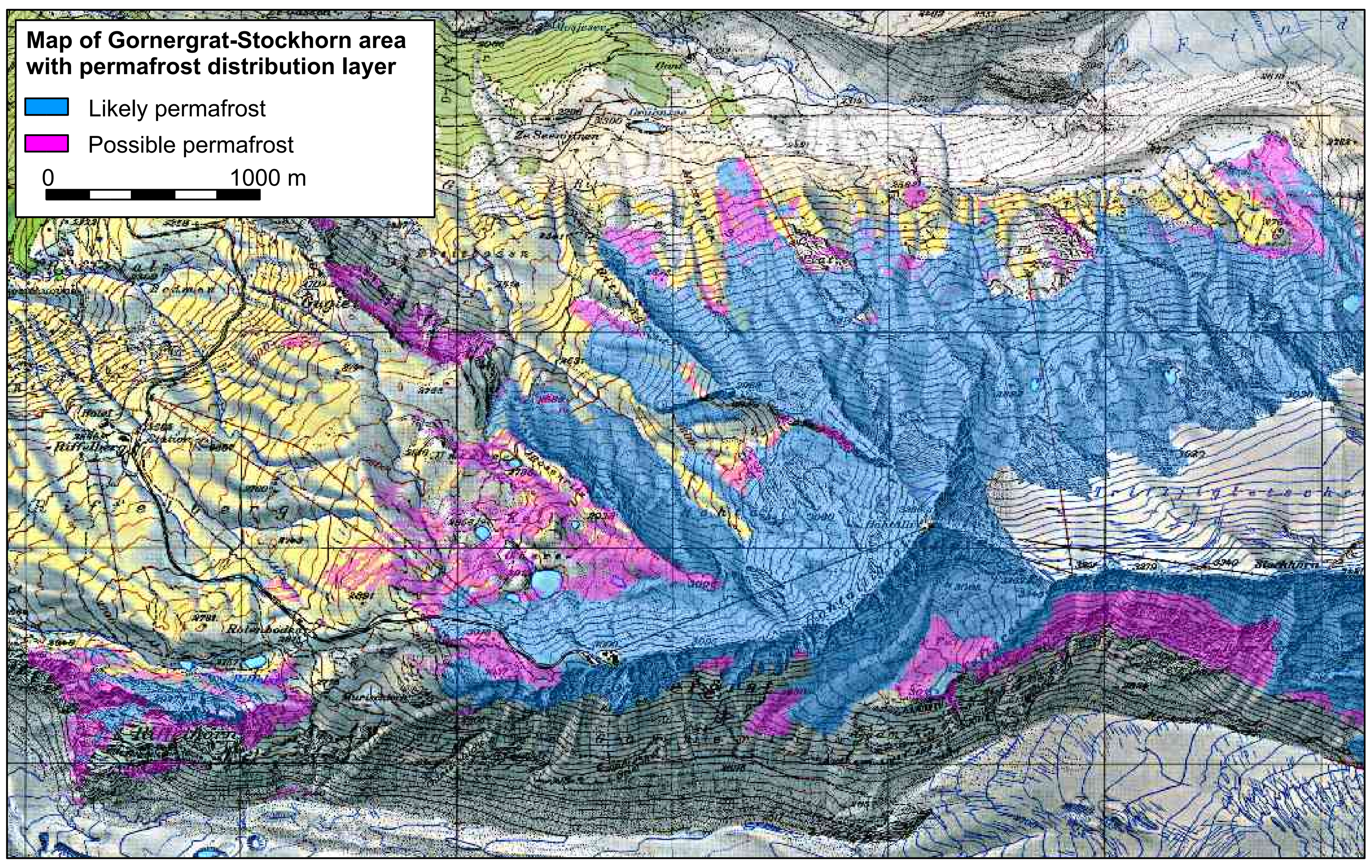
The data concerning the surface are taken from aerial photography and satellite imagery and were classified in three categories *fine grained material*, *bedrock/rock debris* and *coarse block coverage*. The Gornergrat-Stockhorn area is covered up to 57% with fine grained material. Coarse block coverage can only be found on 8% of the surface. On the contrary in the study area Grächen-Seetalhorn 71% are covered with coarse blocks.

***Figure 3:*** **Surface categories: fine grained material (left), bedrock/rock debris (middle) and coarse block coverage (right).**

For an extensive analysis as well as the calibration of the model 532 BTS values were used. With other spatial information this data is stored in a database so that queries can easily be done.

Air-temperature has the biggest influence on permafrost. It defines the minimum level of discontinuous permafrost belt. The effect of PSWR is secondary. It determines the existence of permafrost only within the given limits of the air-temperature.

It has been detected that BTS temperatures measured in rock debris areas were notably lower at the same temperature and irradiation conditions then data taken from areas with fine grained substrate.




BTS temperatures measured in areas with coarse block surface are even lower (Table 2).

The influence of PSWR on the BTS temperature could only be registred for areas with coarse block surface.

The average temperature of BTS-values at comparable temperature and irradiation conditions was -2,1°C for *fine grained substrate*, -3,6°C for *bedrock / rock debris* and -5,4°C for *coarse block coverage areas*. With this data the correction-factors (CF) of the different categories was derived.

***Table 2:*** **Mean BTS-temperatures at the same air-temperature and irradiation conditions**

| Air-temperature (°C) | Irradiation (Wh/m²d) | Fine grained substrate (mean BTS) | Bedrock/ rock debris (mean BTS) | Coarse block coverage (mean BTS) |
|---|---|---|---|---|
| >0 | 3000 – 4000 | -1,9°C | few data | -4,2°C |
| 0 - -1 | 5000 – 6000 | -2,1°C | few data | -4,9°C |
| 0 - -1 | 4000 – 5000 | -2°C | -3,9°C | -5°C |
| 0 - -1 | 3000 – 4000 | -2,8°C | -3,8°C | -5,5°C |
| 0 - -1 | 2000 – 3000 | -1,7°C | -2,5°C | -6,4°C |
| -1 - -2 | 5000 – 6000 | -1,5°C | -3,2°C | -5,3°C |
| -1 - -2 | 4000 – 5000 | -1,7°C | -3,5°C | -5,5°C |
| -1 - -2 | 3000 – 4000 | -1,5°C | -3,2°C | -6,1°C |
| -2 - -3 | 4000 – 5000 | -2,2°C | -3,7°C | -4,2°C |
| -2 - -3 | 3000 – 4000 | -3,2°C | -4,9°C | -5,2°C |

The multiple regression analysis showed that the model can only be based on the surface category *bedrock / rock debris*.

*Figure 4* shows the result of the analysis with 130 points. The remaining points were used for cross-validation. ($R^2 = 0,32$)

Under the application of correction factors the following regression equation results:

*BTS (mod) = -4,1713 + 0,6887 * air-temperature + 0,0003528 * PSWR + CF**

*CF for fine grained substrate = +1,48 / CF for coarse block coverage = -1,82

The single grids of this final layer were classified into the three categories *no permafrost* (BTS>-2°C), *possible permafrost* (BTS between -3° and -2°C) and *likely permafrost* (BTS<-3°C).

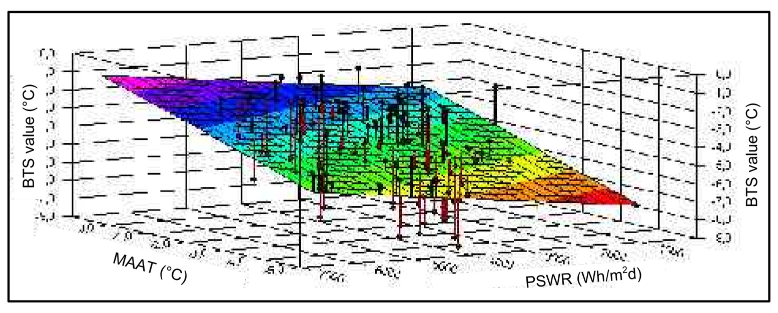



***Figure 4:*** **Result of the regression-analysis (surface-categorie *bedrock / rock debris*)**

## 3 Model result

The results of the cross-validation show that 63% of the points were correctly assigned to the three categories (Table 3). In 27 % of the cases the points were divided up into the neighbouring category. As in previous models this model overestimates the permafrost-distribution as well.

Figure 5 compares the new model with mod2 (GRUBER 2000) at Ritigraben catchment.

***Table 3:*** **Results of the cross-validation**

| BTS-category | BTS values | Permafrost model |
|---|---|---|
| no Permafrost | 38 | 30 |
| possible Permafrost | 8 | 20 |
| likely Permafrost | 54 | 50 |

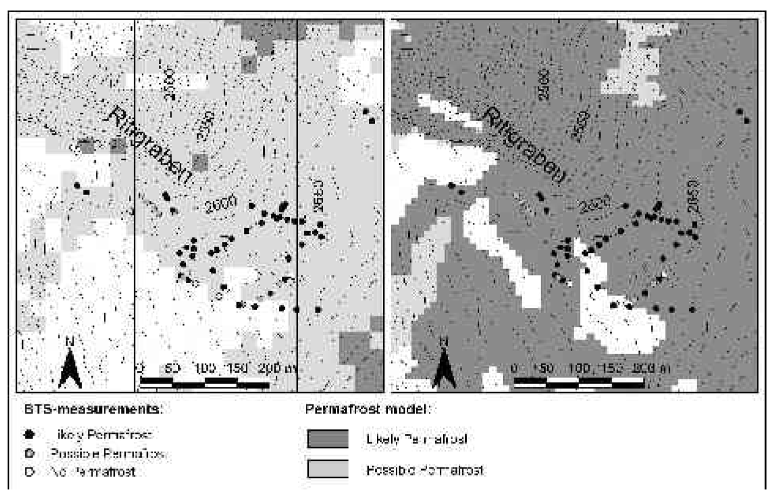



***Figure 5:*** **Comparison of mod2 (left) and the new permafrost model**

## 4 Conclusion

With the new permafrost model the description of the permafrost distribution distinctly improved in the study area since the cooling effect of coarse block coverage has been considered.

The results of the BTS analysis show that the surface characteristics should be taken into account, especially when calculating permafrost models on a regional scale.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