Influence of human activities and climatic change on permafrost at construction sites in Zermatt, Swiss Alps

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Zermatt is a touristic center in the Alps with alltogether 14,000 beds and more than one million official overnight stays per year. The necessary infrastructure consists of installations that often reach into permafrost areas, from the sporadic zone at about 2600 m a.s.l. up to the continuous permafrost zone above 3400 m a.s.l. The unglaciated permafrost area has a large vertical extension due to the surrounding high mountain ranges that reach above 4000 m a.s.l., resulting in a dry and sunny climate and a very high glacier equilibrium line.

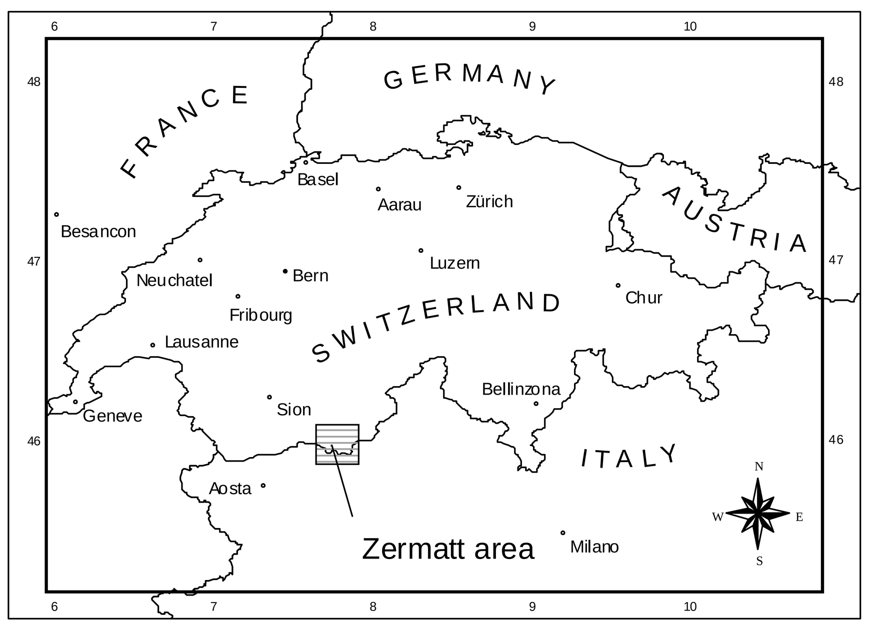
The infrastructure erected in the permafrost areas consists of:

(a) hotels, restaurants and mountain huts; (b) stations buildings of railways, funiculars and ski lifts;

(c) other related constructions as pylons, tunnels, elevators, shelters for vehicles, workshops etc., and

(d) subsurface water pipes (for drinking water, artificial snowing of ski-runs), sewage, communication and electricity lines.

Engineering geologists as well as the responsible persons for this infrastructure have become increasingly interested in the distribution and the characteristics of permafrost in the Zermatt area, as there have been problems due to permafrost degradation. The poster gives an inventory of existing constructions on probable and proven permafrost sites and describes problems encountered during the last 25 years.



1 Kulmhotel and Funicular Gornergrat

Gornergrat may be reached by a 9.3 km long rack railway line constructed between 1896 and 1898. The uppermost 500 meters have been added at its end in the year 1909 and the Kulmhotel Gornergrat was opened in 1910. The railway track and the hotel were mainly used in summer until the early fifties. Winter skiing became more and more attractive in the sixties when the hotel started to open also in winter. In the year 1985 two new astronomic observatories were added to the northern and southern towers and this caused a substantial additional load of the subsurface. Moreover, apartments for scientists were heated in the basement.

Soon after this, the northern tower that was erected on frozen debris started to settle due to permafrost degradation. The subsidence between tower and hotel was controlled with geodetic measurements and strain gauges and concrete was injected in the foundation in order to stop the differential settlement. Today, ground temperature measurements show, that the ground below the tower is probably not frozen for a depth of about 10 meters (cf. Figure 1), while the active layer at undisturbed sites is less than 2.5 meters. This difference must be attributed to heating of the basement for almost 20 years. During recent years, subsidence appears to have stopped.

Figure 1: View towards the Gornergrat Kulmhotel with the observatories in the northern (right) and southern tower (left). The prominent peak of Matterhorn (4478 m a.s.l.) is seen in the backgound

Figure 2 illustrates the warming effect to the underground near the tower in the period summer 1995 to summer 1998 measured with Pt100 sensors.

It is important to notice, that the annual average temperature measured close to the tower is about two degrees higher than the one at four meters distance.

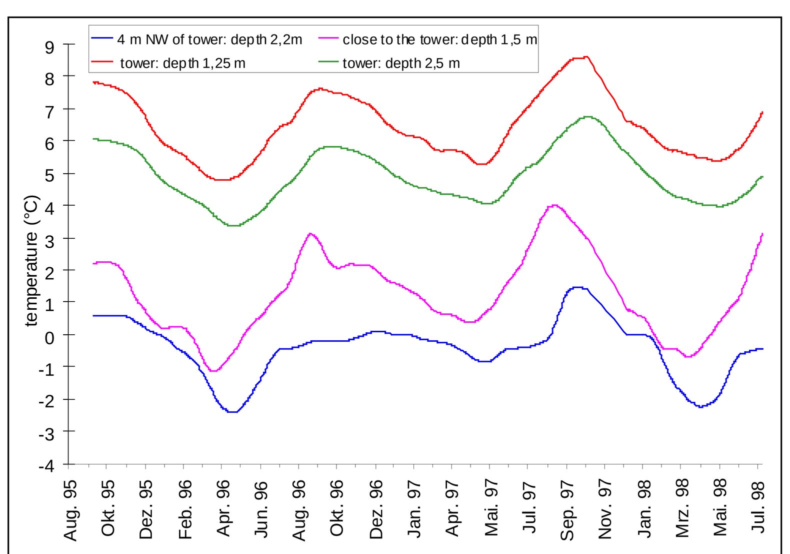


Figure 2: Floating mean monthly ground temperatures below the northern tower of Kulmhotel

2 Funicular Kleinmatterhorn

This funicular reaches up to 3820 m a.s.l. and has been constructed in 1981. It arrives at a tunnel cut in the northern wall of the mountain top. At its southern exit the ski run starts down to Zermatt. Bedrock temperatures as low as –12°C were reported during the construction (Keusen & Haeberli 1983). The same temperature was measured in the near surface rock material of the northern rockwall below the mountain top in a diploma study. The measured MAAT here was –8°C in the years 1998/99.

Bedrock temperatures have risen now to –3 to –2°C at several localities (cf. Figure 3 and 4). This is due to heating and to the heat brought into the tunnel by the more than 490,000 visitors per year. Additional heat is created by almost 70,000 elevator movements per year, transporting tourists to the mountain top. In summer 1997, meltwater created problems when re-freezing in the elevator shaft (King et al. 1998). In view of the considerable temperature rise in the bedrock, temperatures are monitored since 1998 at ten places in order to take countermeasures if necessary.

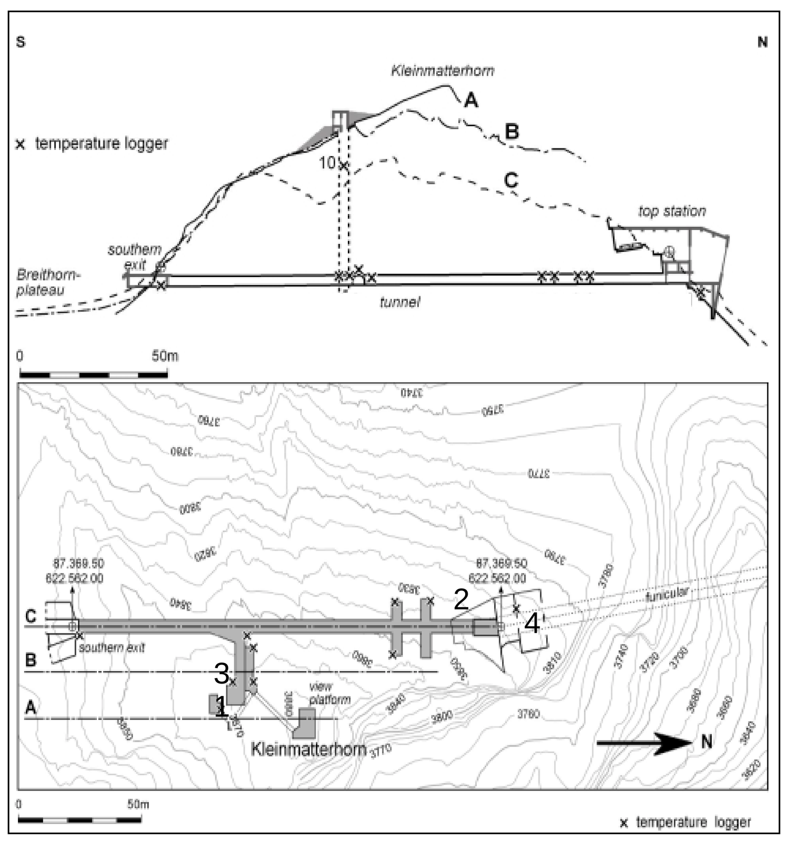


Figure 3: Cross sections (A,B,C) and map of mountain peak Kleinmatterhorn with touristic installations (10 meter contour lines)

Figure 4 represents the floating mean monthly temperatures at different places of the Kleinmatterhorn station measured with "UTL1-Miniloggers".

Whereas the linear temperature trend from 1998 to 2003 shows a nearly one degree decrease at the elevator shaft, the trend for the same period indicates a 0,5 - 1 degree increase in the storage room. This may be caused by the heat input from the highly frequented tunnel.

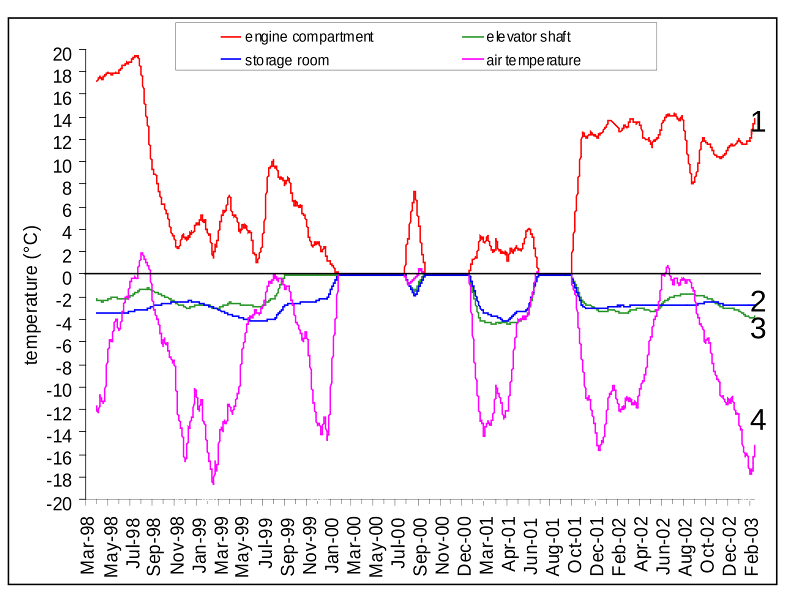
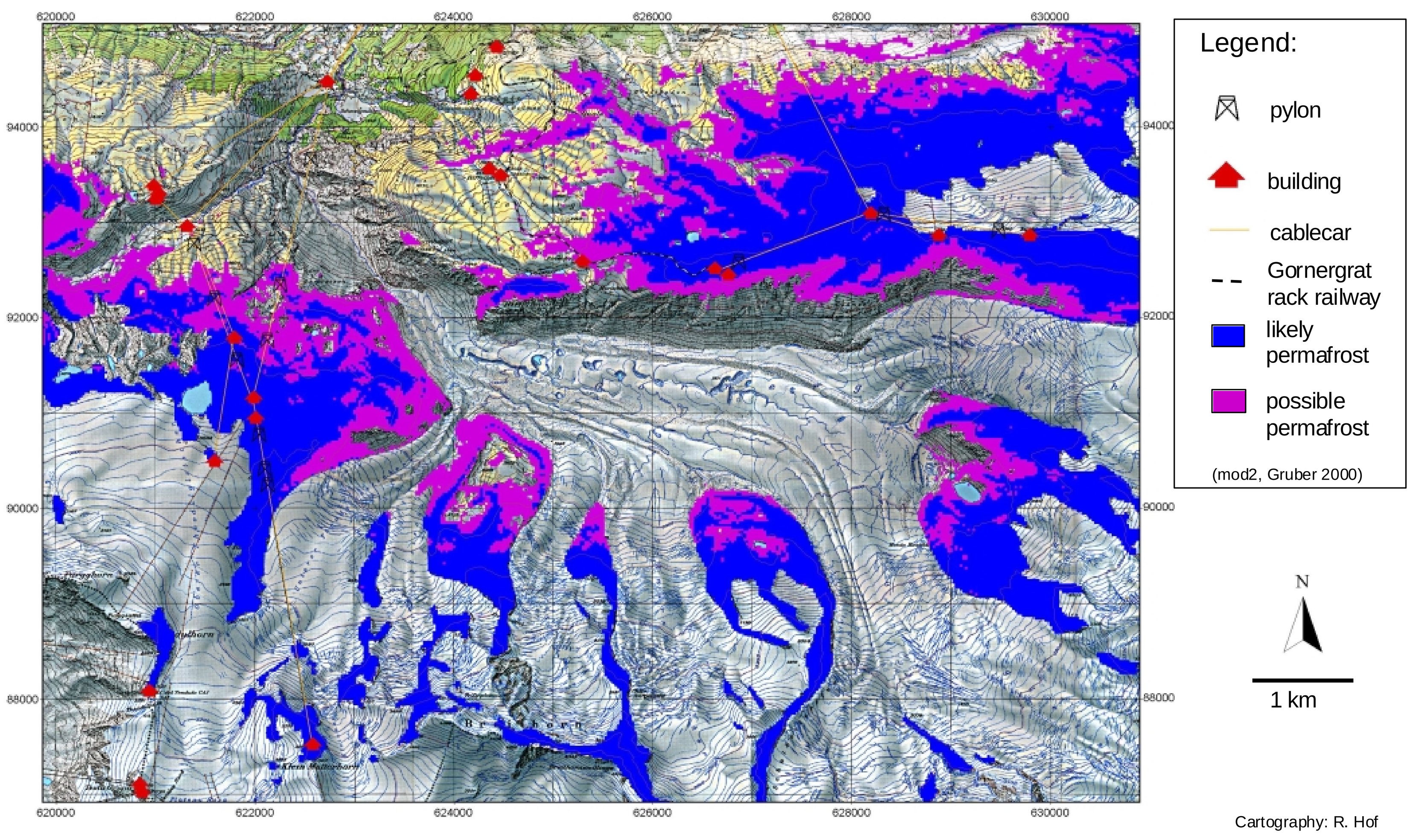


Figure 4: Floating mean monthly temperatures at different locations at the Kleinmatterhorn station (cp. Figure 3)

Permafrost distribution and touristic installations in the Zermatt area, Swiss Alps



3 Further construction sites on permafrost

In addition to the described locations there are a great number of further installations erected on permafrost. The most important of these buildings are mentioned in Table 1 and the map above. Human activities as well as a further climatic warming will influence active layer processes. These may affect the foundations of the installations. Particularly the pylons of the funiculars react most sensitive to the movement caused by permafrost creep or degradation.

Figure 5: View into the tunnel across the peak of Kleinmatterhorn (3820 m a.s.l.)

Table 1: Installations on permafrost in the Zermatt area with altitudes and expected MAAT

Name	Altitude (m a.s.l.)	MAAT (°C)
Kleinmatterhorn (station)	3820	-7,2
Kleinmatterhorn (summit elevator)	3883	-7,6
Testa Grigia (station)	3479	-5,3
Stockhorn (station)	3407	-4,9
Hohtälli (station)	3286	-4,2
Matterhorn Refuge	3260	-4,0
Rote Nase (station)	3250	4,0
Kulmhotel Gornergrat	3135	-3,3
Gornergrat rack railroad (top)	3090	-3,0
Trockener Steg (station)	2939	-2,2
Gandegg Refuge	3029	-2,7
Rothorn (station)	3103	-3,1

Figure 6: Kleinmatterhorn (3883 m a.s.l.) with funicular pylons (3012 m / 3025 m a.s.l.)

4 Conclusion

Degradation of permafrost due to climatic change and the influence of human activities are a serious challenge to touristic installations. Scientists working in permafrost areas therefore have the duty to give the necessary information to the managers of these installations and the authorities, so that facilities built on permafrost can be properly maintained.

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