Permafrost in Switzerland

2000/2001 and 2001/2002

Glaciological Report (Permafrost) No. 2/3

2004

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Permafrost Monitoring Switzerland

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Cover Page: Example of an acitve rock glacier: Suvretta rock glacier, Upper Engadine, Eastern Swiss Alps. Photo: R. Frauenfelder, July 1999.

Preface

The last two years of permafrost observation data at sites within the Permafrost Monitoring Switzerland (PERMOS) network are published in this issue No. 2/3 of the Glaciological Report (Permafrost) 2000–2002. The first report 1999/2000 aimed at bringing together the Swiss permafrost monitoring activities for the first time and ensuring that the available data are documented. The different contributors and sources of data were presented in a pragmatic and heterogeneous form. For the present report it was decided to base both, structure and layout, on the well known glaciological reports "The Swiss Glaciers". Since the PERMOS pilot phase started in 2000, the present report is the first official biennial Swiss permafrost report.

PERMOS consists of three elements: borehole temperatures, permafrost distribution areas and aerial photographs. During the pilot phase, it is crucial to evaluate the methodology of these elements with respect to their suitability for a long-term monitoring of mountain permafrost. This is done in close collaboration with the European permafrost colleagues, in particular within the ESF-funded PACE21-network, but also with the Global Terrestrial Network Permafrost (GTN-P) of the World Meteorological Organisation (WMO) and the International Permafrost Association (IPA). Compared to circumpolar permafrost, which often occurs on flat terrain, monitoring methods in mountain permafrost are more difficult and complex.

The permafrost community in Switzerland together with the Glaciological Commission, the Swiss Academy of Sciences and various Federal Offices made a strong joint effort to establish PERMOS in the ordinary Swiss monitoring structures after the pilot phase.

Dani Vonder Mühll
Permafrost Delegate, Swiss Glaciological Commission SAS

Published reports

The PERMOS-concept and annex were approved by the permafrost-coordination group on November 18, 1999 and by the Glaciological Commission on January 14, 2000 and were published in 2000.

Annual reports on "Permafrost in Switzerland" started in the year of 1999:

Years	Nr.	Source
1999/2000	1	www.permos.ch
2000/2001 and 20001/2002	2/3	www.permos.ch

Summary

The PERMOS-network 2000/2001 and 2001/2002 is composed of (a) 11 drill sites, most of them with several boreholes, (b) 10 areas where ground surface temperature (GST) and/or bottom temperatures of the snow cover (BTS) are systematically obtained and (c) aerial photographs taken by the Swiss Cadastral Survey. In summer 2002, two new drill sites (Flüela and Grächen), established for research projects of SLF Davos, were integrated into PERMOS.

The thermal regime of the ground and permafrost temperatures of the subsurface in particular, react sensitively to snow and its development during winter. The different characters of the two winters of the reporting period (Oct 2000–Sep 2002) could not have been larger: While in 2000/2001 snow came very early and in some places even reached maximum values, snow only came in February in many regions of the Swiss Alps in winter 2001/2002.

At most sites the active layer thickness remained close to the long-term average as it is mainly dependent on summer weather conditions. In contrast, permafrost temperatures were very warm in 2001, at some sites even the warmest since readings started, and cooled markedly due to the snow (little snow) conditions during winter 2001/2002 bringing permafrost temperatures back to a level that is only slightly warmer than the average since observation began in 1987. The extremely different snow conditions influenced both BTS and GST values: BTS and in particular GST were warm in 2001, and very cold in 2002. In contrast, the distribution pattern for both BTS and GST was similar for both years.

In general, near-surface Alpine permafrost reached very warm conditions in 2001. Due to little snow in winter 2001/2002, permafrost temperatures cooled down to about average values.

Zusammenfassung

Das Messnetz PERMOS besteht in den beiden Berichtsjahren 2000/20001 und 2001/2002 aus (a) 11 Bohrstellen, bei den meisten sind mehrere Bohrlöcher vorhanden, (b) 10 Gebieten, in welchen die Bodenoberflächentemperatur (Ground Surface Temperature, GST) und/oder die Basistemperatur der Schneedecke (BTS) systematisch gemessen werden und (c) Luftbildern, welche durch die Swisstopo erhoben werden. Im Sommer 2002 wurden zwei neue Bohrstellen (Flüela und Grächen) in PERMOS aufgenommen. Beide wurden im Rahmen von Forschungsprojekten des SLF Davos eingerichtet.

Die Temperaturverteilung im Boden und speziell die Permafrosttemperaturen werden stark durch die Schneedecke und deren Entwicklung während des Winters beeinflusst. Die Unterschiede der Schneeverhältnisse in den beiden Winter der Beobachtungsperiode (Okt. 2000–Sept. 2002) könnten nicht grösser sein: Während im Winter 2000/2001 bereits früh relativ viel Schnee fiel und an einigen Orten sogar Maximalschneehöhen erreicht wurde, blieb der darauf folgende Winter in vielen Regionen der Alpen bis im Februar 2002 fast schneefrei.

Die Mächtigkeit der Auftauschicht, welche hauptsächlich von den Wetterbedingungen im Sommer beeinflusst wird, lag in den Berichtsjahren an den meisten PERMOS-Messstellen im Bereich des langjährigen Durchschnitts. Hingegen waren die Permafrosttemperaturen im Jahr 2001 sehr hoch, an einigen Orten wurden sogar die wärmsten Werte seit Beginn der jeweiligen Messreihe registriert. Der schneearme Winter 2001/2002 brachte eine deutliche Abkühlung der Permafrosttemperaturen, welche damit beinahe wieder ähnliche Werte wie zu Beginn der Beobachtungen 1987 erreichte. Die unterschiedlichen Schneeverhältnisse der beiden Beobachtungsjahre beeinflussten auch die BTS- und GST-Werte: BTS- und vor allem GST-Werte waren 2001 warm und 2002 sehr kalt. Das Verbreitungsmuster der BTS- und GST-Werte war dagegen in beiden Jahren ähnlich.

Insgesamt erreichte der oberflächennahe Permafrost in den Schweizer Alpen im Jahr 2001 ungewohnt hohe Temperaturen. Aufgrund der geringen Schneemenge im Winter 2001/2002 kühlte er sich indes beinahe auf langjährige Durchschnittswerte ab.

Résumé

En 2000/2001 et 2001/2002, le réseau PERMOS s'est composé (a) de 11 sites de forage, la plupart comprenant d'ailleurs plusieurs forages, (b) de 10 sites où la température de la surface du sol (GST) et/ou la température à la base de la couche de neige (BTS) ont été relevées systématiquement et (c) de photographies aériennes prises par l'Office fédéral de topographie. Durant l'été 2002, deux nouveaux sites de forage (Flüela et Grächen), établis dans le cadre de projets de recherche de l'ENA Davos, ont été intégrés à PERMOS.

Le régime thermique du sol, en particulier la température du pergélisol dans les niveaux proches de la surface, réagissent étroitement aux conditions d'enneigement durant l'hiver. Les caractéristiques des deux hivers de la période reportée (oct. 2000 - sept. 2002) n'auraient pas pu être plus contrastées : alors qu'en 2000/2001, l'apparition de la neige fut très précoce et que des valeurs record furent même atteintes à certains endroits, la neige ne vint qu'en février dans bien des régions des Alpes Suisses durant l'hiver 2001/2002.

Dans la plupart des sites, l'épaisseur de la couche active - principalement dépendante des conditions météorologiques durant l'été - demeura proche de la moyenne à long terme. En revanche, la température du pergélisol fut très élevée en 2001. Sur plusieurs sites, elle fut même la plus chaude depuis le début des enregistrements. Par la suite, elle se refroidit de manière marquée en raison des conditions d'enneigement (peu de neige) de l'hiver 2001/2002. La température du pergélisol fut ainsi ramenée à un niveau plus bas, légèrement plus chaud que la moyenne observée depuis le début des mesures en 1987. Les conditions d'enneigement extrêmement différentes influencèrent les valeurs BTS et GST : BTS et en particulier GST furent chaudes en 2001, puis très froides en 2002. La structure de répartition spatiale des BTS et GST resta cependant similaire les deux années.

En général, proche de la surface, le pergélisol a connu des conditions très chaudes dans les Alpes en 2001. En raison du faible enneigement de l'hiver 2001/2002, la température du pergélisol s'est par la suite refroidie et a atteint des valeurs à peu près moyennes.

Contents

1 Introduction

1.1 From permafrost research to permafrost monitoring

Permafrost is defined as material of the lithosphere that remains at temperatures below 0 °C during at least one year. Thus, permafrost existence is exclusively defined by temperature and time and does not depend on the presence or absence of ice. Mountain permafrost is a consequence of climate conditions, in particular temperature but also precipitation. Climate change therefore has an impact on permafrost, that is an important indicator for environmental changes. Within the international framework of permafrost monitoring and research, the PERmafrost MOnitoring Switzerland (PERMOS) is one of the first components of the Global Terrestrial Network for Permafrost (GTN-P) that is currently being established within the worldwide climate-monitoring program (GCOS/GTOS) of the World Meteorological Organization (WMO) and others (FAO, UNEP, UNESCO, ICSI). In Switzerland, PERMOS complements the glacier monitoring network, which was already established towards the end of the 19th century (cf. 2-year reports on the Swiss glaciers by the Glaciological Commission of the Swiss Academy of Sciences).

In contrast to glaciers and snow, systematic scientific investigation of Alpine permafrost only was started in the early 1970s by a group of the University of Basel (Barsch, 1969; Haeberli, 1975). Later, permafrost research was focussed in particular on the Federal Institute of Technology (VAW-ETH; Haeberli, 1985; Hoelzle et al., 2002). Since the late 1980s (after the drilling through the Murtèl-Corvatsch rock glacier in 1987; Haeberli et al., 1988; Vonder Mühll and Haeberli, 1990), a number of Swiss institutes started performing research on low-latitude mountain permafrost (Haeberli et al., 1993). These activities formed the basis for establishing PERMOS that officially started in 2000 for a first pilot-phase 2000-2003. A valuable contribution was the EU-funded project PACE (Permafrost And Climate in Europe; Harris et al., 2001).

1.2 PERMOS elements

The main objective of PERMOS is a long-term and scientific documentation of the state of permafrost and its changes in the Swiss Alps. Based on the IPA-resolution released in August 1995 (Frozen Ground, 1995) the relevant elements to be obtained were chosen. During the pilot-phase 2000-2003, emphasis is on (a) continuation of the already established measurements series, (b) the consolidation of the organisation and (c) the methodology (PERMOS concept and annex, 1999).

PERMOS is based on three elements:

(1) Recording permafrost temperatures and thermal changes in boreholes and, depending on the situation at the borehole, horizontal and vertical borehole deformation.

(2) Bottom temperature of the snow cover (BTS), ground surface temperature (GST) and the development of the snow cover (duration and thickness) to determine the lateral distribution pattern near the lower limit of permafrost existence.

(3) Air photos (black and white, infrared) taken periodically from selected areas. Air photos enable the monitoring of surface changes in general. Additionally, both analogue and digital terrain information serve as a basis for photogrammetrical studies of rock glaciers as well as the documentation of geomorphological, hydrological and biological changes in permafrost environments.

In order to understand and interpret permafrost measurements, monitoring of the snow cover and weather conditions is essential. The meteorological basics as well as the three elements described above are each addressed in a separate chapter in this report.

The measurements undertaken within PERMOS are carried out by several institutes that are coordinated by the Glaciological Commission (GC) of the Swiss Academy for Sciences (SAS). The pilot phase of PERMOS is funded by SAS, SAEFL (Swiss Agency for the Environment, Forests and Landscape) and FOWG (Federal Office for Water and Geology). The permafrost delegate of the GC/SAS is responsible for the operation of the network. Measurements for the present report have been realised by the following institutes (in alphabetical order):

- ETH Zurich: Institute for Geotechnical Engineering (IGT-ETH)
- ETH Zurich: Laboratory of Hydraulics, Hydrology and Glaciology (VAW-ETH)
- Swiss Federal Institute for Snow and Avalanche Research Davos (SLF)
- University of Berne: Department of Geography (GIUB)
- University of Fribourg: Department of Geosciences, Geography Institute (IGUF)
- University of Lausanne: Faculty of Earth Science and Environment, Geography Institute (IGUL)
- University of Zurich: Department of Geography, Glaciology and Geomorphodynamics Group (GIUZ)

2 Weather and climate

2.1 Introduction

Two of the most crucial parameters governing the state of permafrost are the summer temperatures and – even more important – the snow conditions during winter. In the long run, they define the boundary conditions for the geothermal field in the subsurface. As snow has a strong insulating effect by decoupling the ground thermally from the atmosphere, the time of the first snowfall in autumn, the snow thickness as well as the time when the terrain is snow free in spring play decisive roles in permafrost monitoring.

If the first large snowfall in autumn takes place before the active layer freezes, the summer heat stored in the subsurface is preserved during wintertime causing warm permafrost temperatures and high BTS-values. Otherwise, if the snowfall takes place after the refreezing of the active layer, heat can easily be transferred out of the ground, leading to cold permafrost temperatures and low BTS-values. In addition, the mean winter temperature of the ground is influenced by the thickness of the snow cover. For example, a long lasting and thin snow cover during the months November to February facilitates a lowering of the mean surface temperature favouring the conservation or even formation of permafrost.

The time in spring when the terrain becomes snow free is another important factor for ground temperatures, as a long lasting snow cover can delay the warming of the near-surface subsoil. Together with late snowfall and an intense cooling of the ground during early wintertime, this may lead to permafrost preservation or even regeneration.

2.2 Weather and climate in 2000/2001

Both the weather and the climate data are taken from reports by the "MeteoSwiss" [MeteoSwiss, 2000-2001a,b], the snow data originate from SLF.

Weather and climate conditions in the hydrological year 2000/2001
Throughout the world, the year 2001 was one of the warmest since the 1860s, when instrumental measurements were introduced. For the 23rd consecutive time, the global mean of temperatures near the earth's surface surpassed the long-term mean value for 1960 to 1990, this time by a full 0.4 °C. Nine out of the ten warmest years have been recorded since 1990. And once again, the number of climatic extreme events such as tornadoes, floods, and droughts was above average (WMO, 2001).

Table 2.1: Key climatic features from the "Monthly weather reports of MeteoSwiss" [Meteo Swiss, 2000-2001a].

2000	
October	Storm disasters in Valais, highest water levels in Lago Maggiore since 1868
November	Unsettled in the north, mild with foehn winds, extremely wet in the south
December	On the north side of the Alps and in Valais: extremely mild and very little precipitation
Year overall	Unusually warm, extreme autumn rain in the south and in Valais
2001	
January	Mild with foehn winds. Lack of snow on the north-alpine slopes, little sun in the south
February	Very mild in the first half of the month; not much fog in the lowlands
March	Rainy and mild; record amounts of precipitation north of the Alps
April	Changeable in the south, cold and wet in the north; return of delayed winter
May	Sunny, dry and extremely warm
June	First wet and cool, then sunny and warm in the last third of the month
July	Cool and rainy at mid-month, midsummer conditions in the last third of the month
August	Very warm, abundant sunshine on the north side of the Alps, generally too dry
September	Very cool; unusually dull on the north side of the Alps
Year overall	Warm and quite sunny in the lowlands, wet on the north side of the Alps.

In Switzerland, the 2000/2001 hydrological year was warmer than average too, and precipitation was abundant. A wet, rather cool October and November were followed by an unusually mild December that, except in Ticino and Grisons, was extremely dry. The mild temperatures continued until April, when winter returned, to be followed then by a spring marked by heavy precipitation and little sunshine. The summer was changeable and warmer than average until the extremely early onset of winter at the beginning of September. The middle of October 2000 witnessed disastrous storm activity in Valais, while in many places the warmest May since measurements began, and the coolest September since 1972, especially in mountain regions, were recorded.

Snow

Whereas the southern flank of the Alps and the Upper Engadine had large amounts of snow during the entire winter, there was very little snow in the North for a long time. Intense snowfall only started in April down to low altitudes.

Winter 2000-2001 was characterised by much precipitation coming in from the South. This brought significant amounts of snow in October at high altitudes and at lower altitudes in November. At the beginning of December there was already 1.5 m of snow at 2000 m a.s.l. in the Tessin and 1 m between the Vispertälern and the Upper Engadine. In other areas on the main Alpine ridge and in central Grisons there was only half a metre of snow at the same time and even less on the Northern flank of the Alps. The maximum snow depths were twice to four times as much as the long-term average in the South and about half in the North.

This distribution remained the same until mid-April. On March 13th the snow depth on Corvatsch at 2690 m a.s.l. in the Upper Engadine was 261 cm, the deepest measured in eight years. On the same day, a new maximum value of 178 cm was measured in St. Moritz, after 49 years of measurements. At the end of February and in March the air temperatures were so warm that a spring-like situation reigned. The long-awaited snowfalls from the Northwest finally arrived in April and led to wintery conditions. The snow depths consequently rose above the long-term average North of the Alps, too. They attained 220 cm in Elm on April 22nd at 1690 m a.s.l. Wintery conditions also prevailed on the Swiss plateau, with around 20 cm of snow in the East of Switzerland.

Summer temperatures May – September 2001
The summer started with an extremely warm May, in some places the warmest since measurements began in the 1860s. In June, temperatures were lower than usual until the 20th, whereas the last third of the month was very warm. In July again the temperatures recorded were above average all over the country. In the western and southern parts the excess heat was less than in the rest of Switzerland. In August the temperatures recorded were around 2 °C higher than average changing to rather cool and below average temperatures in September.

2.3 Weather and climate in 2001/2002

Both the weather and the climate data are taken from reports by the "MeteoSwiss" [MeteoSwiss, 2001-2002a,b]. The snow data originate from SLF.

Weather and climate conditions in the hydrological year 2001/2002
The global mean surface temperature in 2002 was 0.48 °C above the 1961–1990 annual average. Therewith 2002 is the second warmest year in the temperature record since the 1860s. The five warmest years in this period of record now include, in decreasing order, 1998, 2002, 2001, 1995 and 1997 WMO (2002).

Generally warmer than normal conditions for the year as a whole occurred across much of Europe and Asia. A period of severe drought was experienced in central European Russia from April to August, when the five-month precipitation total was only one-third of the 1961-1990 average. Dry conditions in the second half of 2002 led to water shortage problems for hydropower generation in Norway, Sweden and Finland. In contrast, extraordinary rainfall events caused exceptional flooding of the Elbe and Danube rivers in Germany and Czech Republic. In some places even all previously recorded flood levels were exceeded.

In Switzerland the relatively cold December and beginning of January led to the freezing of several lakes in the lowlands. February to April was generally very mild and dry. June was extremely warm

Table 2.2: Key climatic features from the "Monthly weather reports of MeteoSwiss" [MeteoSwiss, 2001-2002a].

2001	
October	Record temperatures and abundant sunshine on the north side of the Alps, dry in Valais
November	Dryness in the south, early winter on the north side of the Alps
December	Massive cold snap, extremely dry on the south side of the Alps
Year overall	Warm and quite sunny in the lowlands, wet on the north side of the Alps
2002	
January	Freezing of lakes at the beginning, then very warm, extremely dry in the south
February	Extremely mild, changeable and windy, sunny in the south
March	Very mild with abundant sunshine, dryness in the south
April	Mild and sunny in the north, very dry in the west and in the south
May	Changeable and wet, extreme amounts of precipitation in the south and in Urnerland
June	Sunny and extremely warm, record heat period
July	Rather changeable, in some areas heavy rainfalls in the middle of the month
August	Changeable, above average amounts of precipitation, local heavy thunderstorms
September	Cool, dull, abundant rainfall in the north, extreme cold snap
Year overall	Very warm and wet, extreme precipitation in the south and in Grisons

and produced a record heat wave. In September there was abundant rainfall and it was relatively cool.

Snow

Winter 2001-2002 was characterized by snow depths which were lower than average, particularly below 2000 m a.s.l. After first snowfalls at high altitudes in September and October 2001, snow fell down to below 1000 m a.s.l. on November 9th, accompanied by stormy north-westerly winds. On the Northern flank of the Alps and in Northern Grisons 20-50 cm of snow fell, whereas the other areas received less. At the end of November another 50-100 cm fell in the same areas. The 0 °C isotherm then rose to around 3000 m a.s.l., causing rain to fall at high altitudes. In the first half of December 2001 low air temperatures led to the freezing of the soaked snow cover. Towards the end of the year it snowed around 1 m above 2000 m a.s.l. with strong westerly winds.

At the end of January, the snow depths were lower than the long-term average in all regions. In the North the snow depth was only about half the normal value for that time of year and in the South and in the Upper Engadine snow depths were lower than ever registered in 50 years. Areas below 2000 m a.s.l. were particularly affected. The snowfalls started in February and were accompanied by intense avalanche activity. At the beginning of March 50-80 cm of snow fell in the Western Swiss Alps and in the Upper Engadine, and more came around March 20th. In April it snowed several times. Towards the end of the month the snow cover was soaked through up to an altitude of about 2500 m a.s.l. Snowmelt occurred about a month earlier than usual at lower altitudes.

As if to make up for the poor winter, large amounts of snow fell from May 1st to 5th in the South and in the Engadine. The main precipitation area was located between the Vispertäler and the Valle de Maggia, with over 2 m of snow. The lower snowfall limit was initially around 2500 m a.s.l. and gradually sank lower. Intense avalanche activity with large, wet snow avalanches resulted.

Summer temperatures May – September 2002
In May temperatures were higher than average. Exceptions are the western part of Switzerland, the Valais and the valleys on the southern side of the Alps. In these regions temperatures were average. Due to a 10 day period of high temperatures, June was the warmest June recorded in many places since measurements began. In July the weather was changeable with almost average temperatures. August did not considerably deviate from the 1961-1990 temperature mean either, and the western and southern parts of the Alps were again cooler than the East. Due to an intense cold snap together with snowfall down to 600 m a.s.l. September temperatures were slightly below average in most regions and particularly in the Alps.

2.4 Climate deviation from the mean value 1961-1990

The regional differences in the important climatic elements for the permafrost conditions are illustrated in the Figures 2.1 and 2.2. Mean values 1961-90 for both summer air temperature and annual precipitation are based on the standard values that have been determined within the projects KLIMA90 (Aschwanden et al., 1996) and NORM90 (Begert et al., 2003). In case the standard values of the two projects disagree, the values of NORM90 are considered. Temperature values from 2001-2002 are taken from the automatic measurement stations (ANETZ), precipitation values 2000-2002 from the observational network NIME.

Photo 1: Ridge-and-furrow topography of a rock glacier at Albula. Photo. C. Rothenbühler, August 2002.

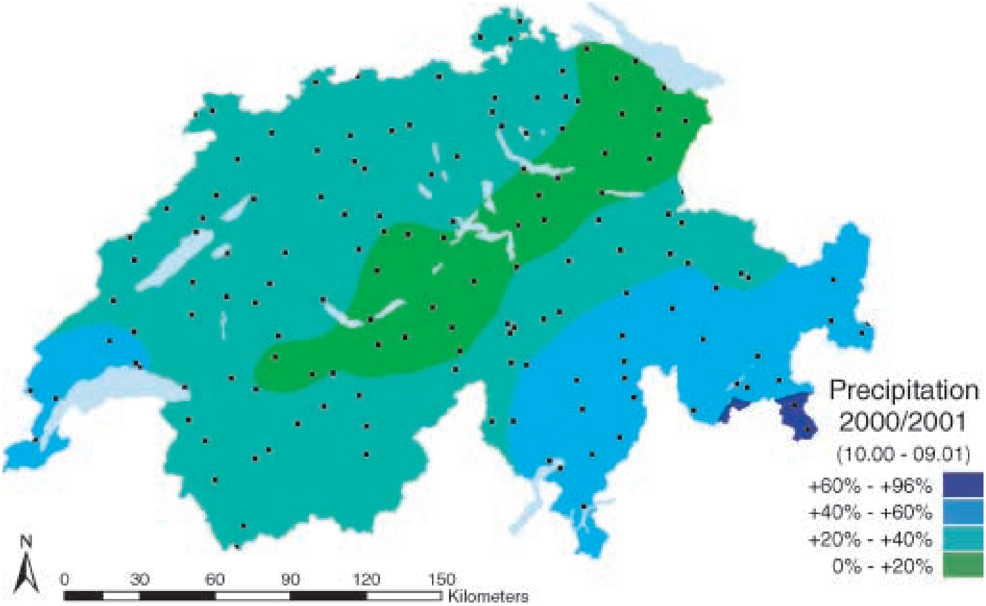


Figure 2.1a: Annual precipitation 2000/2001 – Deviation from the mean value 1961-1990. Deviation in percentage.

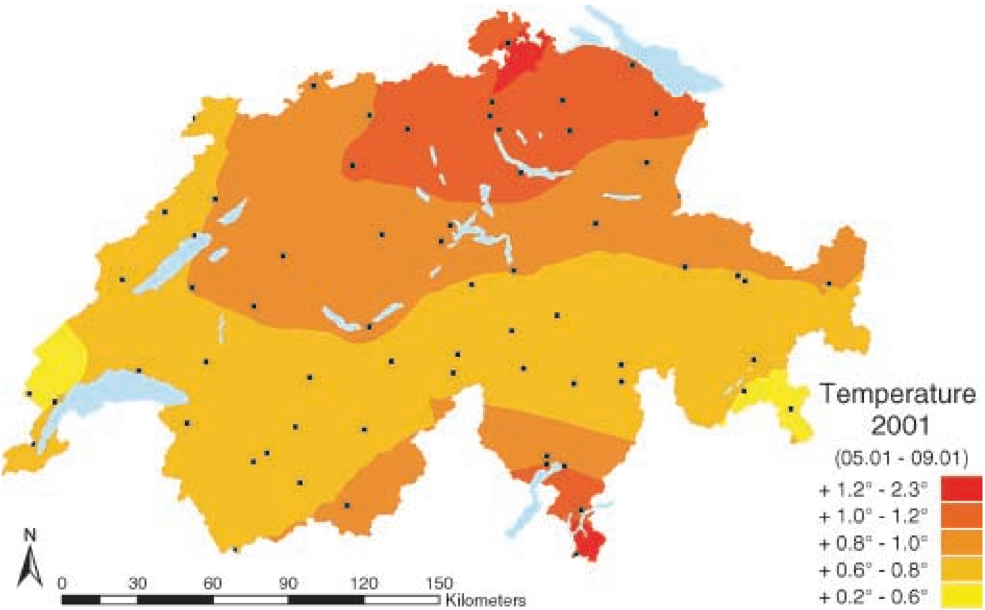


Figure 2.1b: Mean summer air temperatures 2001 – Deviation from the mean value 1961-1990. Deviation in degree Celcius.

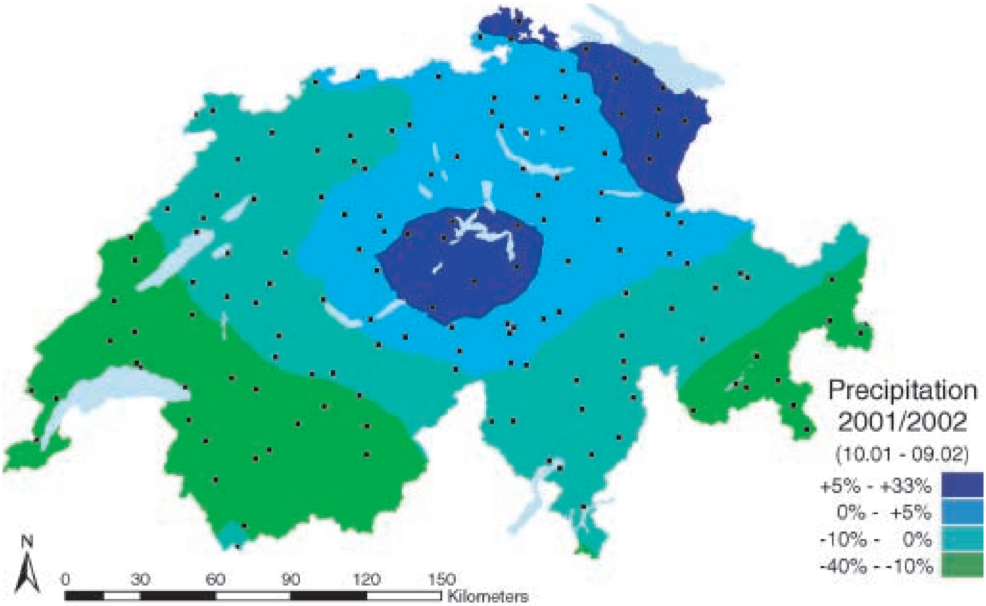


Figure 2.2a: *Annual precipitation 2001/2002 – Deviation from the mean value 1961-1990. Deviation in percentage.*

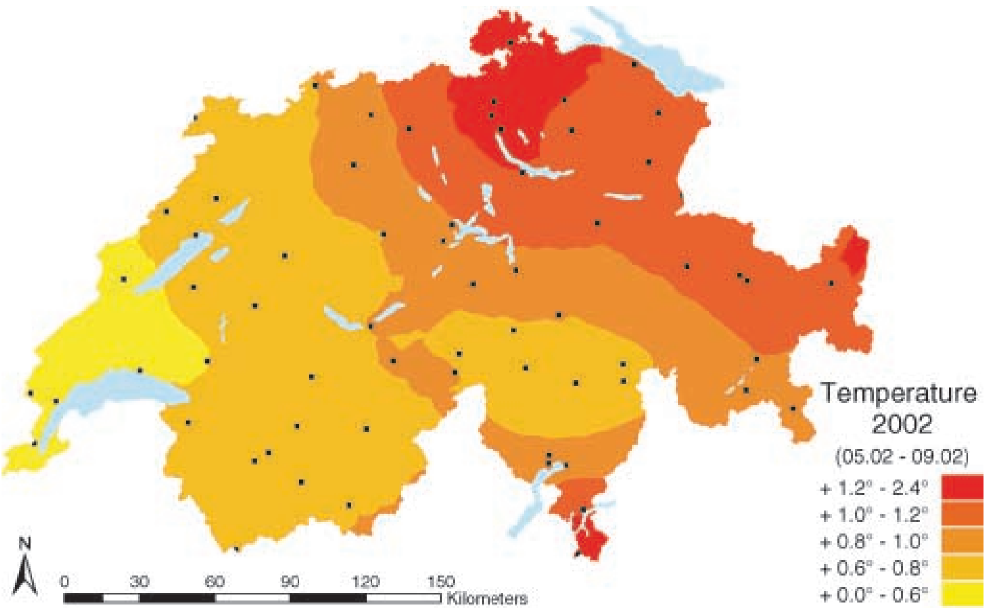


Figure 2.2b: *Mean summer air temperatures 2002 – Deviation from the mean value 1961-1990. Deviation in degree Celcius.*

2.5 Duration of the snow cover

Ground surface temperature (GST) continuous recording (cf. chapter 4.1) permits us to determine the date when the snow disappears (the first day with temperature above 0 °C). Figure 2.3 shows the results for all PERMOS-sites where GST observations are available.

The Furggentälti/Gemmi series (1994/1995-2001/2002) shows that after the snowy year 1995 (snow melted completly on August 5th), the snow has tended to melt earlier (Figure 2.3). In 2002, the snow completly melted out on July 3rd, 10 days earlier than 2001 and 33 days earlier than 1995. However, the snow already disappeared on June 29th in 1998 and 2000, 5 days earlier than in 2002.

On the other sites in the western Valais Alps, the series are shorter, but tend to fit with the data from Gemmi. The data from Murtèl in Upper Engadine indicate an advance of the snow melt date in 2002 in comparison with 2001 (about 20 days).

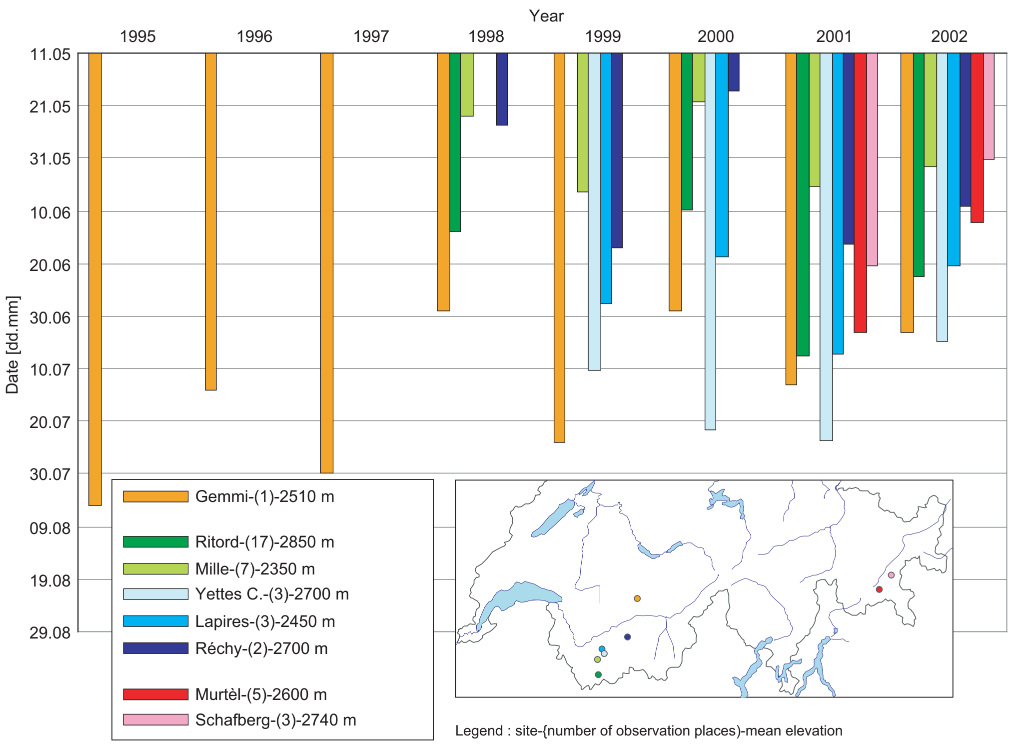


Figure 2.3: Date of snow melt (1995-2002) on PERMOS GST-sites (for sites location, see Figure 4.5). Mean value per site (when several series available).

3 Borehole measurements

3.1 Introduction

Drilling in mountain permafrost requires particular techniques and is logistically challenging as the sites are usually not easy to access. The permafrost thickness is mainly influenced by the temperature at the base of the active layer and the thermal characteristics of the frozen material. In the Swiss Alps permafrost thickness varies from several metres up to hundreds of metres. At the locations of the PERMOS boreholes it ranges between 20 and more than 100 m (Table 3.1, Figure 3.1). Another difficulty that occurs in rugged terrain, such as rock glaciers, is the determination of the simple term "surface" which represents the depth 0.0 m. Usually, it is defined at the uppermost end of the tube, which allows the thermistor string to be removed and recalibrated. However, this might be some centimetres or even decimetres above the actual "surface". On a bouldery surface voids cause a contact to the atmosphere even further down the tube.

Within PERMOS, temperatures are measured with various setups. Most of the boreholes are equipped according to the "Manual of instructions for temperature monitoring in mountain permafrost"

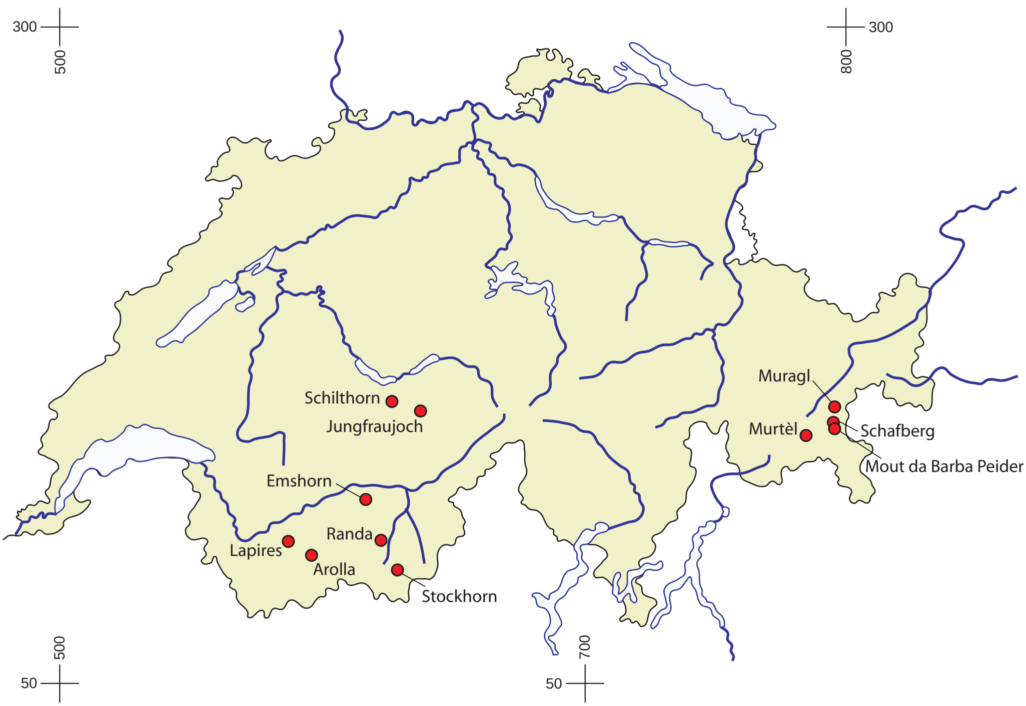


Figure 3.1: Locations of the PERMOS boreholes.

Table 3.1: Borehole study sites. Data in PERMOS: L: Logger-measurements, M: Manual measurements; L. sensor: lowest sensor.

Borehole	Abbrev.	Data	Region	Depth [m]	L.sensor [m]	Since [year]
Jungfraujoch	N/95	L	Berner Oberland, BE	11.0	11.0	1995
Jungfraujoch	S/95	L	Berner Oberland, BE	10.0	10.0	1995
Schilthorn	51/98	L	Berner Oberland, BE	14.0	13.7	1998
Schilthorn	50/00	L	Berner Oberland, BE	101.0	100.0	2000
Schilthorn	52/00	L	Berner Oberland, BE	100.0	92.0	2000
Flüela	1/02	L	Flüelapass, GR	23.0	20.0	2002
Muot da Barba Peider	B1/96	L	Upper Engadine, GR	18.0	17.5	1996
Muot da Barba Peider	B2/96	L	Upper Engadine, GR	18.0	17.5	1996
Muragl	1/99	L	Upper Engadine, GR	70.2	69.7	1999
Muragl	2/99	L	Upper Engadine, GR	64.0	59.7	1999
Muragl	3/99	L	Upper Engadine, GR	72.0	69.6	1999
Muragl	4/99	L	Upper Engadine, GR	71.0	69.6	1999
Murtèl-Corvatsch	1/87	M	Upper Engadine, GR	39.0	21.0	1987
Murtèl-Corvatsch	2/87	L	Upper Engadine, GR	62.0	58.0	1987
Murtèl-Corvatsch	1/00	–	Upper Engadine, GR	51.9	–	2000
Murtèl-Corvatsch	2/00	L	Upper Engadine, GR	63.2	62.0	2000
Schafberg-Pontresina	1/90	–	Upper Engadine, GR	67.0	–	1990
Schafberg-Pontresina	2/90	L	Upper Engadine, GR	37.0	25.2	1990
Arolla, Mt. Dolin	B1/96	L	Val d'Herens, VS	10.0	5.5	1996
Arolla, Mt. Dolin	B2/96	L	Val d'Herens, VS	10.0	5.5	1996
Emshorn	4/96	M	Central Valais, VS	8.0	6.4	1996
Emshorn	5/96	M	Central Valais, VS	8.0	6.4	1996
Emshorn	6/96	M	Central Valais, VS	8.0	6.4	1996
Grächen	1/02	L	Matter Valley, VS	25.0	24.0	2002
Grächen	2/02	L	Matter Valley, VS	25.0	24.0	2002
Lapires	1/98	L	Val de Nendaz, VS	19.6	19.6	1998
Randa Wisse-Schijen	1/98	L	Matter Valley, VS	4.0	2.8	1998
Randa Wisse-Schijen	2/98	L	Matter Valley, VS	4.0	2.8	1998
Randa Wisse Schijen	3/98	L	Matter Valley, VS	4.0	2.8	1998
Stockhorn	60/00	L	Matter Valley, VS	100.0	98.3	2000
Stockhorn	61/00	L	Matter Valley, VS	31.0	20.0	2000

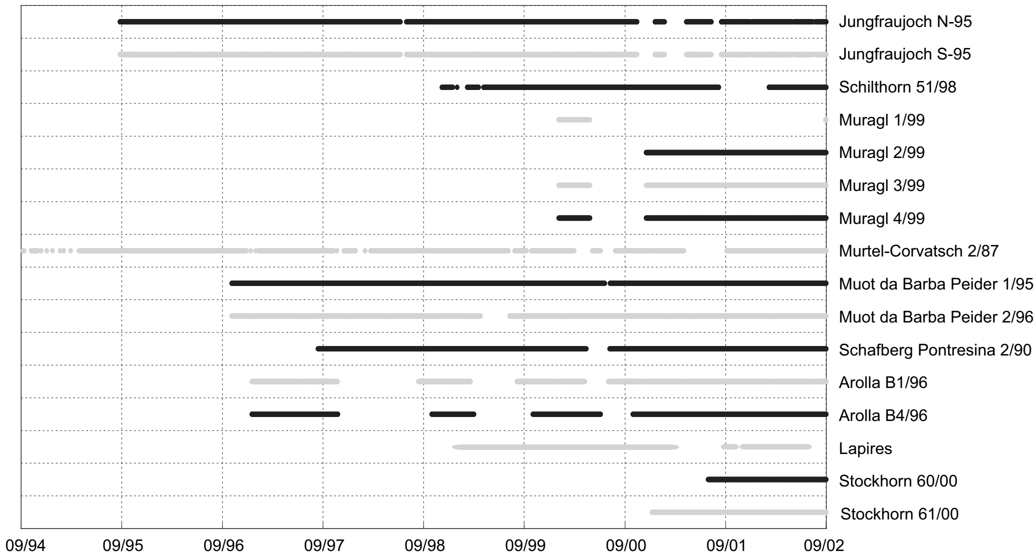


Figure 3.2: Available data for the PERMOS boreholes. Details for each borehole can be found in the appendix.

that was developed during PACE (cf. appendix B). In other boreholes, single-channel-dataloggers are lowered or the measurements are taken "by hand" using a multimeter to read out the thermistors resistance. Most important is a regular recalibration of the sensors to allow corrections for a drift. This has to be done at least every five to ten years.

Figure 3.2 gives an overview of the data available for the PERMOS boreholes. Data gaps are due to various reasons: technical problems with the data logger, low battery, no thermistor chain etc. Details for each borehole can be found in appendix A.

3.2 Active-layer thickness

The thickness of the active layer depends on local (elevation, aspect, soil characteristics, water supply etc.) as well as climatic factors (duration and thickness of the snow cover, summer temperatures, time of first snowfall). Temperature and thickness of the active layer are hardly influenced by the conditions of the previous year, and thus represent the conditions of the observed year. In this sense, they are comparable to the glacier mass balance.

The active-layer thickness does not consider subsidence of the surface. When supersaturated permafrost warms up, e.g. in a rock glacier, ice at the permafrost table starts to melt. In fact, the surface subsides, but the active layer cannot thicken due to a lack of debris material. Subsidence survey of the topography using photogrammetrical measurements complement active-layer measurements, e.g. at Murtèl-Corvatsch (Kääb et al., 1998). Within PERMOS, the depth of the active layer is defined thermally (Table 3.2, Figures 3.3 and 3.4), i.e. by interpolating linearly between the adjacent thermistors. Therefore continuous temperature data of the late summer and early autumn are required. Data on active-layer thickness have to be interpreted with care due to the above mentioned difficulty in determining the depth 0.0 m.

Table 3.2 and Figures 3.3-3.5 give a detailed overview of the active-layer thickness at the PERMOS borehole sites in the reported years. In Figure 3.3. the time series of data is assembled for each site. Due to the method (linear temperature interpolation), the depths are given to the nearest 0.1 m. In general variations from one year to the next amount to a few decimetres. However, they vary strongly from one site to the next. At Murtèl-Corvatsch (Figure 3.4), a rock glacier site with the longest time series, active-layer thickness ranged from 3.0 to 3.5 m within the 15-year observation period. As for the date of maximum active-layer thickness (Table 3.2 and Figure 3.5), again, the variation of both, between sites and years, is considerable. However, the active layer is generally thickest between August and November depending on specific site characteristics and the meteorological conditions of the year. There is no systematic behaviour of the three climatic regions (Grisons, Bernese Oberland, Valais) to be observed whatsoever.

Table 3.2: Maximum thickness of the active layer and corresponding date.

Borehole	2000 zmax [m]	date	2001 zmax[m]	date
Jungfraujoch S/95	3.64	18.12.2000	1.78	20.-23.11.2001
Jungfraujoch N/95	–	no a.l. recorded	–	no a.l. recorded
Schilthorn 51/98	4.88	05.10.2000	–	no data
Muot da Barba Peider 1/96	0.74	18.09.2000	0.84	30.08.2001
Muot da Barba Peider 2/96	1.90	01.09.2000	1.92	30.08.2001
Muragl 1/96	–	no data	–	no permafrost
Muragl 2/99	4.86	07.10.2000	5.05	12.10.2001
Muragl 3/99	–	no data	4.37	27.08.2001
Muragl 4/99	–	no data	3.48	03.09.2001
Murtèl-Corvatsch 2/87	3.44	23.08.2000	3.47	05.-06.09.2001
Schafberg-Pontresina 2/90	4.97	03.09.2000	5.06	10.09.2001
Arolla B1/96	2.46	01.09.2000	2.48	01.-04.09.2001
Arolla B2/96	–	no permafrost	–	no permafrost
Lapires 1/98	3.7	25.09-5.10.2000	3.8	10.09.2001
Stockhorn 60/00	–	no data	3.22	03.-09.09.2001
Stockhorn 61/00	–	no data	3.49	26.-30.09.2002

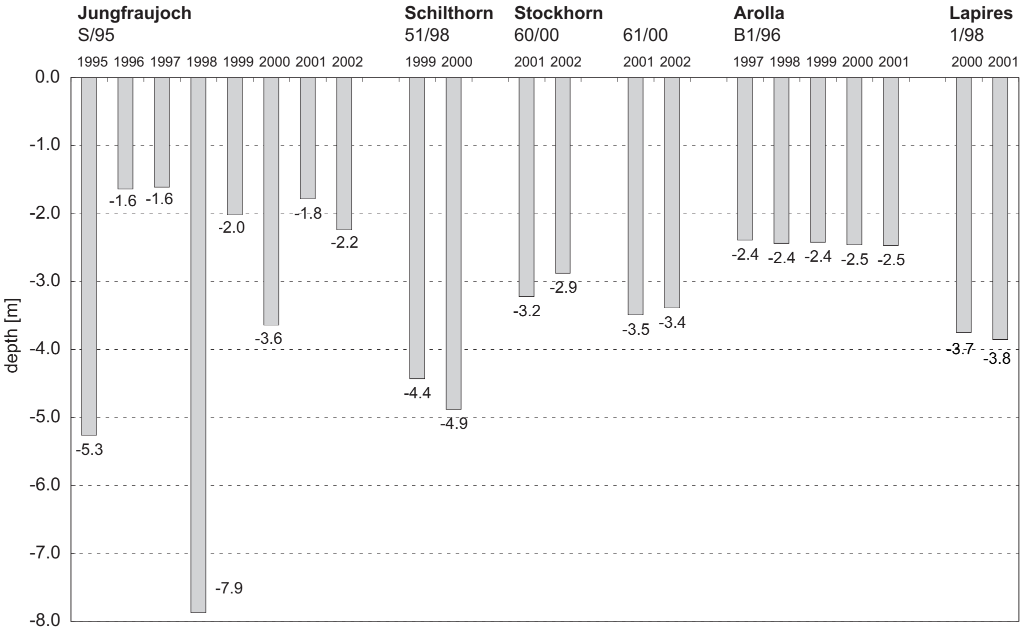


Figure 3.3a: Maximum active-layer thickness for the boreholes in Valais and the Bernese Alps, until 2002.

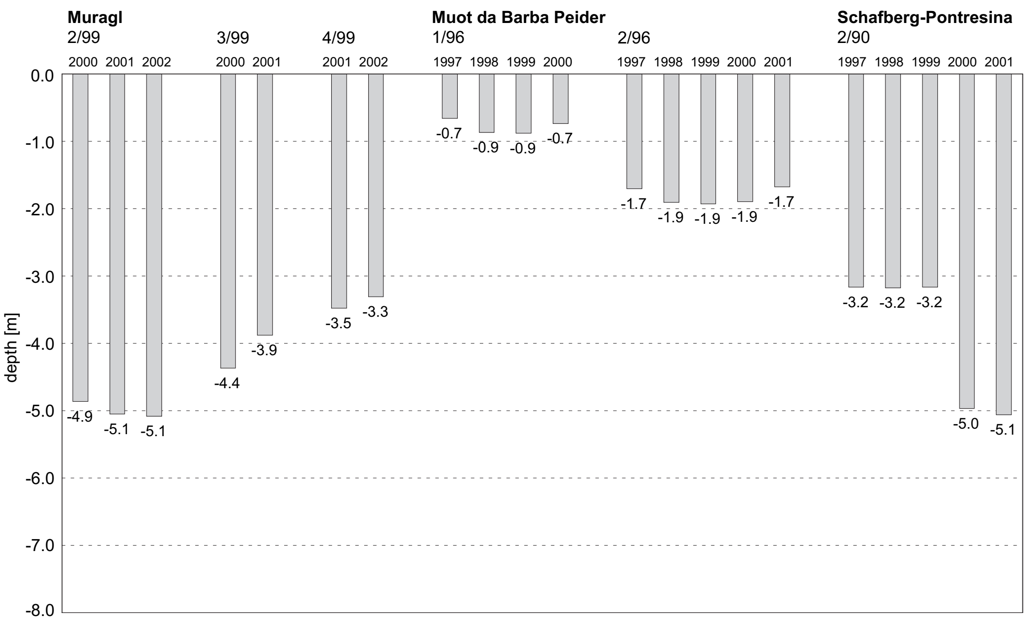


Figure 3.3b: Maximum active-layer thickness in the boreholes in Grisons, until 2002.

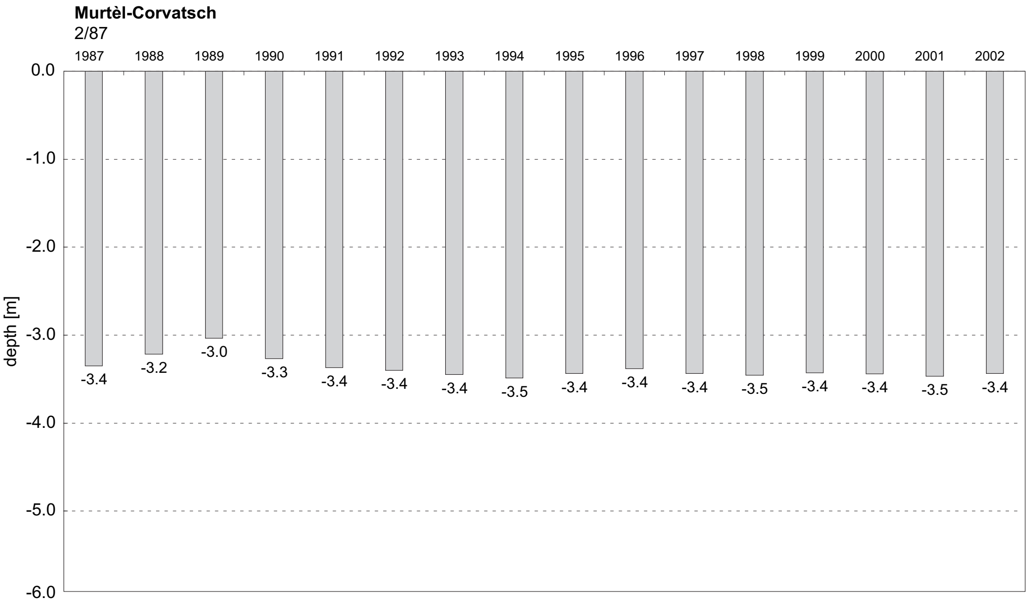


Figure 3.4: Maximum active layer thickness of the Murtèl-Corvatsch borehole 2/87, until 2002.

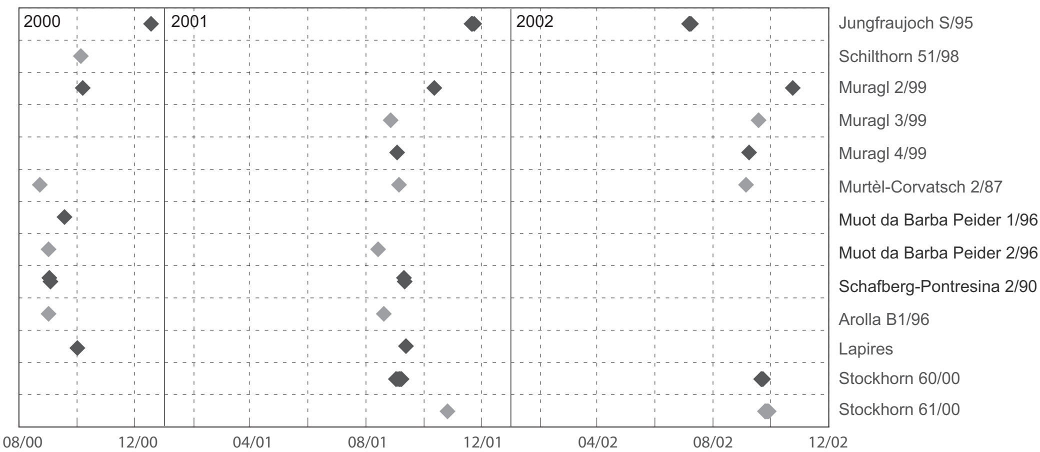


Figure 3.5: Date of maximum active-layer thickness, 2000-2002.

3.3 Permafrost temperatures

In regions close to the lower limit of permafrost occurrence, ground temperatures are only slightly below the freezing point. Permafrost temperatures generally range between –3 and 0 °C resulting in a permafrost thickness between 20 and more than 100 m (see Figure 3.6). In order to allow for comparisons between all PERMOS sites, focus is on temperature series at about 10 metres depth, because at this depth short-term (high-frequency) fluctuations of the atmosphere are filtered out. It takes summer heat around half a year to penetrate to this depth by heat conduction.

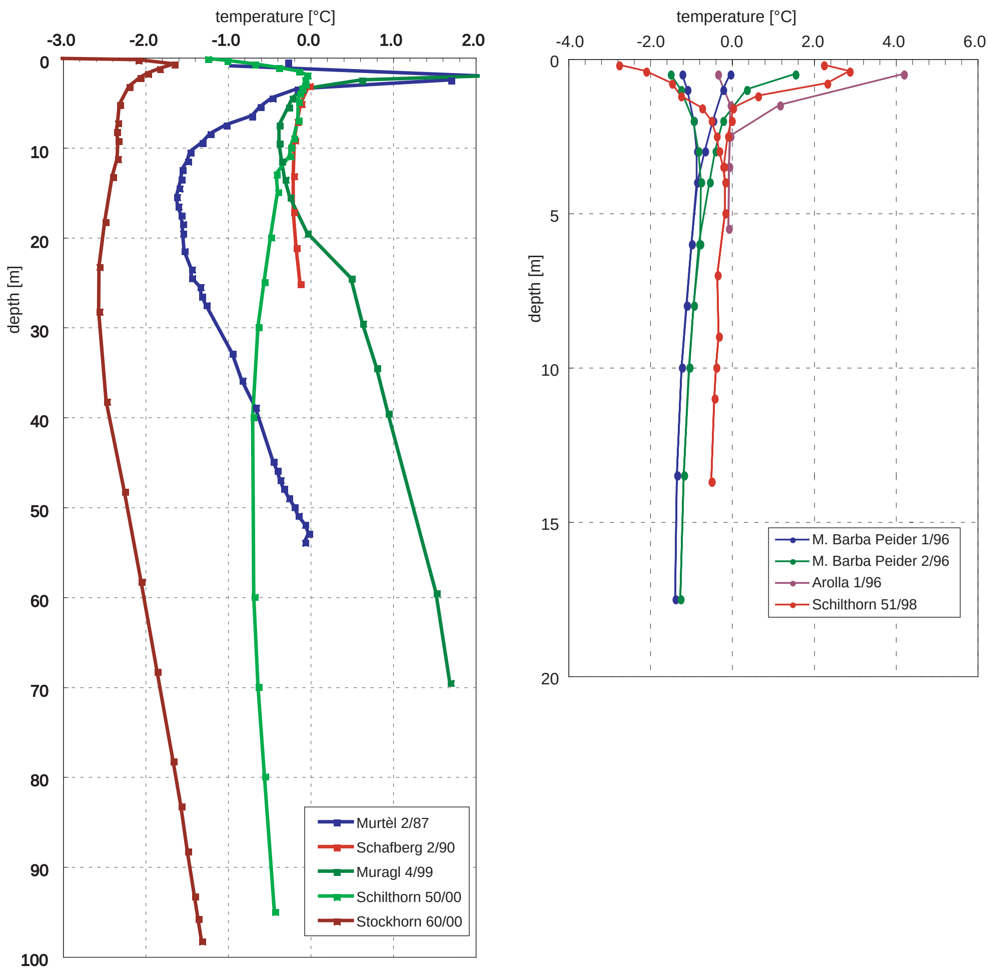


Figure 3.6: Permafrost-temperature distribution with depth at PERMOS drill sites. The permafrost thickness ranges from 20 to more than 100 metres (left). The average thickness of the active layer during summer is 3 to 5 metres (right).

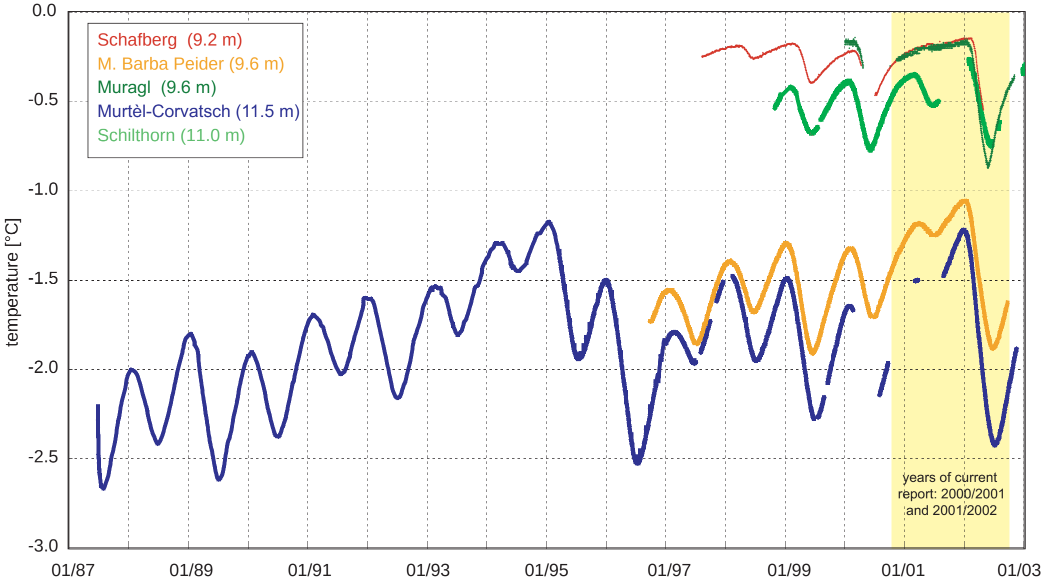


Figure 3.7: The longest time series at Murtèl-Corvatsch allows us to relate the reporting period to the last 15 years. Temperatures between 2000 and 2002 are only slightly above average of the whole period because of the cold winter 2001/2002.

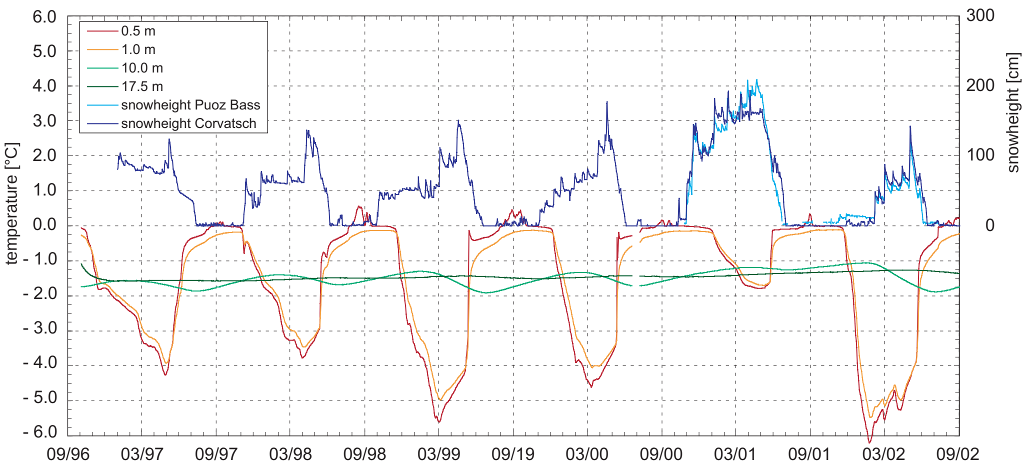


Figure 3.8: Temperature-time-plot of the borehole Muot da Barba Peider 2/96 for the thermistors at 1.0, 2.0, 10.0, and 17.5 m depth. Additionally, the snow height at Puoz Bass as well as on Corvatsch is displayed.

The closer ice-bearing permafrost temperatures are to the melting point, the larger is the unfrozen water content. Energy changes lead to a change in temperature but also in phase changes by melting ice or freezing water. Therefore the observed temperature fluctuations close to 0 °C are smaller than those at cold temperatures.

In winter 2000/2001, the temperature minimum at 10 m depth, which only occurred in summer 2001 due to the phase lag, was shifted towards warmer values at all sites. In the boreholes located in the Upper Engadine, the temperature minimum was even warmer than the summer maximum in 1999. The differences of the extreme values of summer 2001 and winter 2001/2002 were pronounced at all sites located in the Upper Engadine due to a thin snow cover during wintertime. This cold winter interrupted the warming trend that had been observed since 1997. However, borehole temperatures measured at Murtèl-Corvatsch from 2000 to 2002 still showed warmer values than average compared to the last 15 years (Figure 3.7).

In appendix A, temperature data are plotted in one graph for each borehole. Snow depth of the closest snow measurement field and temperature data at following four depths are plotted: (1) in the active layer, (2) the first sensor below the permafrost table, (3) at about 10 m depth and (4) the lowest sensor in permafrost. In Figure 3.8 the plot of borehole Muot da Barba Peider 2/96 is shown as an example. During the 6-year period of observation, the active-layer temperature at

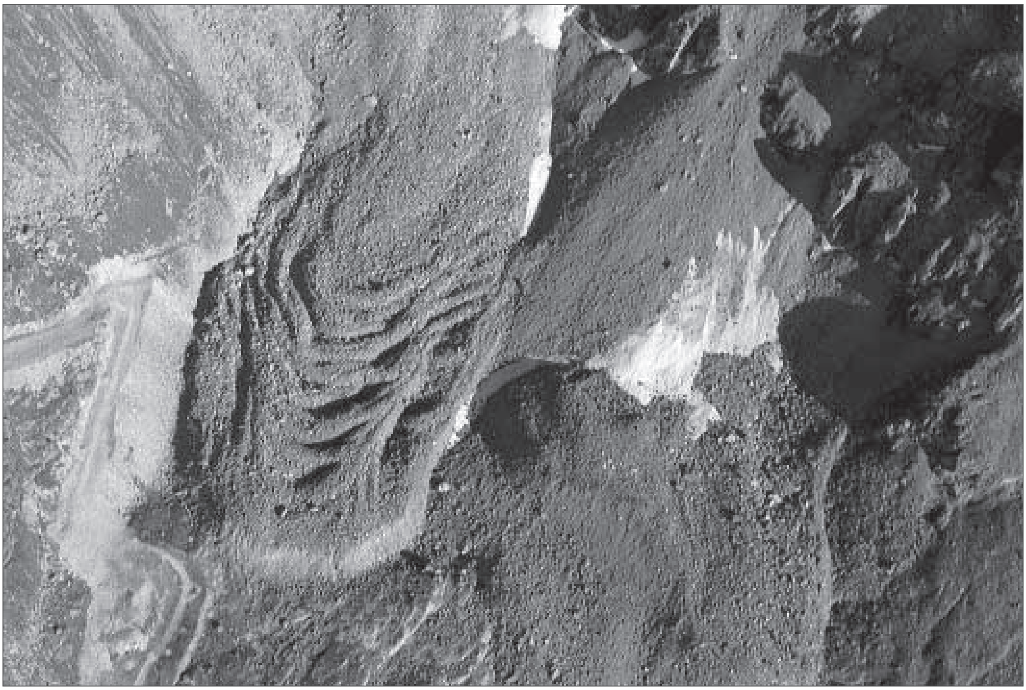
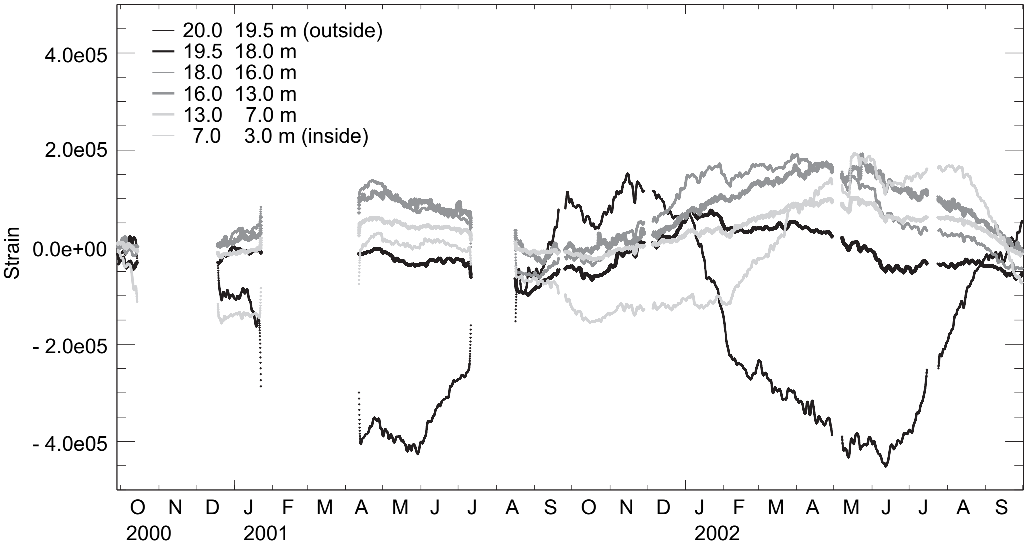


Photo 2: Rock Glacier Murtèl at Corvatsch, Upper Engadine. Photo: C. Rothenbühler, August 2002.



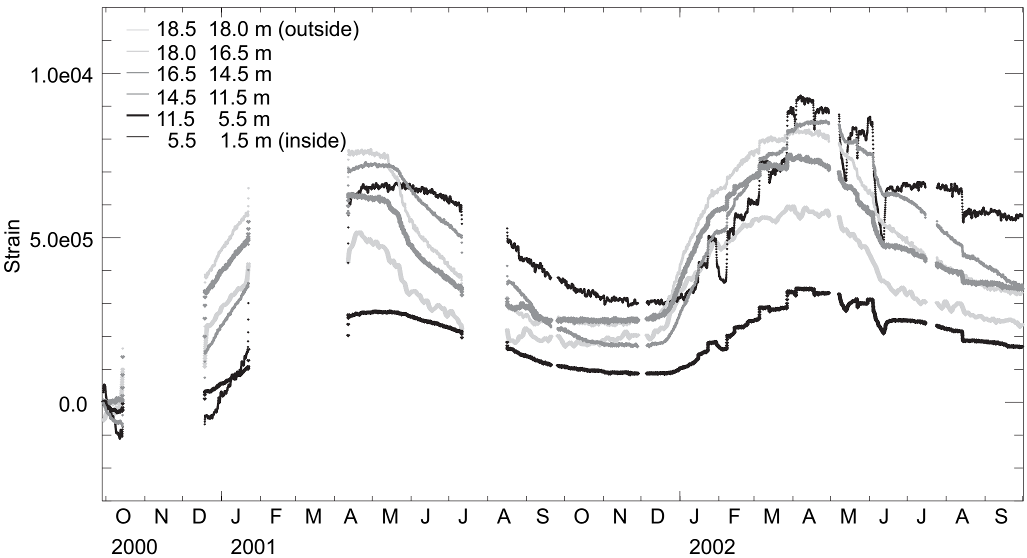


Figure 3.9: Axial strains within the boreholes Jungfraujoch N (top) and Jungfraujoch S (bottom) during the reporting years.

1 m depth reached some +1 to +2 °C in summer, while winter temperatures are typically about –3 °C. There are two consecutive winters with an early, thick snow cover (2000/2001) and late, thin snow cover (2001/2002), respectively. As a consequence, permafrost temperatures are higher and lower afterwards.

3.4 Borehole deformation

The most accurate information concerning deformations within a permafrost area can be obtained by deformation monitoring within boreholes. However, such installations are expensive and the lifetime of the instrumentation is only temporary. In general, temperatures can be recorded much longer. Within PERMOS, only the boreholes at Jungfraujoch North and South are still recording data. Unfortunately, battery problems during the last observation period resulted in severe loss of data (Figure 3.9, top). Within the recently drilled boreholes at the rock glacier Murtèl-Corvatsch, a new deformation monitoring system, time domain reflectometry (TDR) was installed in 2000. The deformations within the rock glacier, however, are currently not large enough to provide data about its deformation behaviour.

A comparison between deformation profiles of the rock glaciers Murtèl-Corvatsch, Schafberg-Pontresina and Muragl revealed that the temperatures and the internal structure are the main factors that influence the deformation behaviour of those rock glaciers (Arenson et al., 2002). The deformation behaviour is very similar to earlier observations. However, the strains in the North wall of the Junfraujoch were more pronounced than during previous years, which might be caused by slightly higher temperature changes during that period (Figure 3.9, bottom).

Photo 3: Rock glacier Muragl, Upper Engadine. Photo: R. Frauenfelder, September 1999.

3.5 Conclusions

The two winters 2000/2001 and 2001/2002 were completely different in terms of snow cover conditions: While in fall 2000 a considerable snow cover had already developed, this only occurred in February 2002 the following year. Consequently, differences in the thermal regime of the subsurface are observed.

The active-layer thickness generally reached average values at all sites. It was slightly thinner in 2001 than in 2002 at all sites where data can be compared. The date of maximum active-layer thickness is similar for each site, but varies from one site to another. Obviously, the thickness of the active layer mainly depends on the time of snow disappearing and summer temperatures.

Permafrost temperatures at about 10 m depth are highest in 2001 for all observed sites. The annual amplitude was very small in 2000/2001 (Muot da Barba Peider: 0.05 °C), but very large in 2001/2002 (Muot da Barba Peider: 0.80 °C). According to the Murtèl-Corvatsch data series, the shallow snow of winter 2001/2002 caused a cooling after 5 years of general warming. A similar effect occurred in 1995 and 1996 after two consecutive winters with very little snow.

4 Surface temperatures

4.1 Introduction

Measurements of the Bottom Temperature of the Snow cover (BTS) in wintertime and the year-round and continuous recording of Ground Surface Temperature (GST) are indirect methods for detecting permafrost occurrences in the Alps. They both deal with the temperature at (or down to a few centimetres beneath) the ground surface, which is a key parameter governing the thermal regime of permafrost. Within PERMOS 10 BTS-GST-areas are monitored (Figure 4.1).

BTS is measured at the ground surface at a time of year when this temperature is most influenced by the thermal state of the subjacent underground (Haeberli, 1973; Lewkowicz and Endnie, 2004), i.e. in February, March or April. Generally, permafrost occurrence can be assumed for BTS-values below –2 to –3 °C. Despite the fact that BTS depends on ground surface characteristics and is susceptible to significant changes depending on interannual variability in snow conditions, it is still the best technique for obtaining high resolution maps of permafrost. The interpretation of the

Figure 4.1: Locations of the BTS- and GST-sites

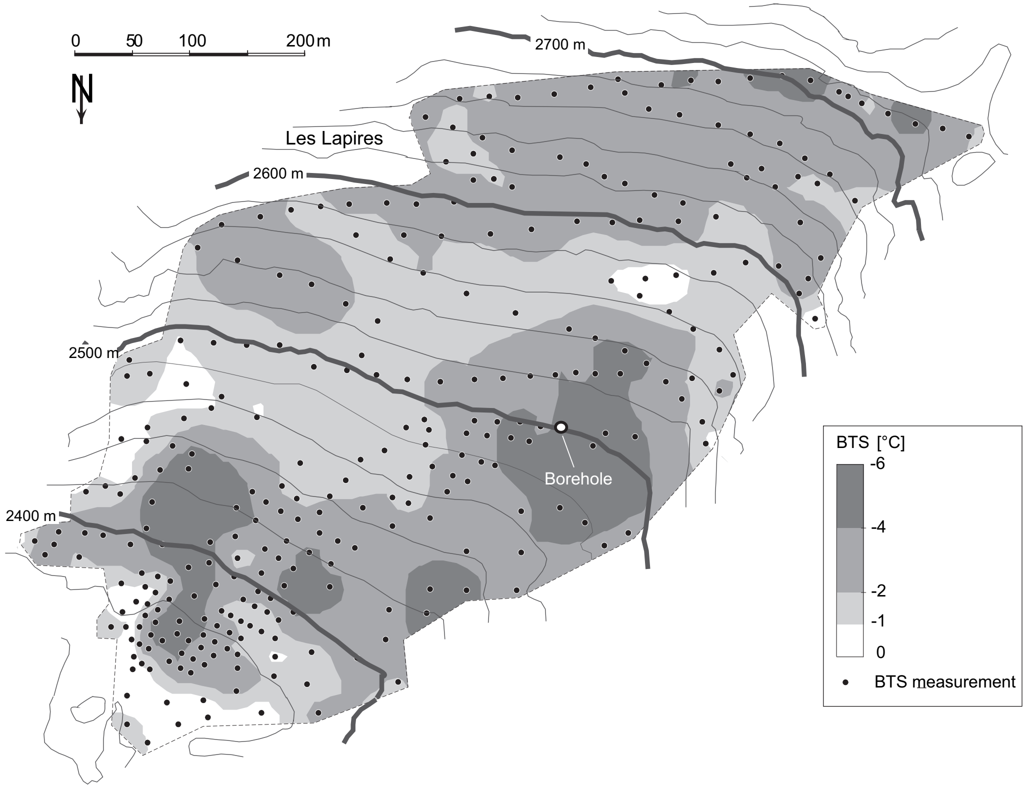


Figure. 4.2: PERMOS BTS/GST-site at Lapires (Valais), modified after Turatti, 2002.

results can be improved when measurements are repeated at exactly the same points and averaged for several (ideally 3-4) years. The BTS map of the large talus slope at Lapires (Figure 4.2) shows that the thermal state of the ground is spatially very heterogeneous and not related to elevation in a simple way.

GST is continuously recorded with single-channel temperature loggers of type UTL-1 (Universal Temperature Logger; www.utl.ch; Krummenacher et al., 1998; Hoelzle et al., 1999) that are placed just below the ground surface and serviced once a year. GST provides valuable data on the temporal evolution of the thermal state of the ground surface (Hoelzle et al., 2003) and particularly also for calculating mean annual ground surface temperatures (MAGST; Delaloye and Monbaron, 2003). Unlike BTS-values, MAGST contains information on the snow-free period and therefore the warming of the (sub)soil during summer months. One of the most important parameters determined by GST-measurements is the Ground Freezing Index (GFI), that is the sum of all daily negative ground temperatures measured during the winter expressed in °C·d. GFI indicates how cold a winter is at the ground surface. Another parameter that can be obtained is the date of snow disappearing (cf. chapter 2.5).

4.2 Surface-temperature measurements in 2000/2001 and in 2001/2002

4.2.1 Bottom Temperature of the Snow cover (BTS)

BTS campaigns were carried out at 5 sites for the two winters 2000/2001 and 2001/2002. On 3 other sites BTS campaigns were only carried out in 2000/2001 (Table 4.1, Figure 4.1) because either the snow cover conditions were problematic (insufficient snow, avalanche danger) or no measurement team was available in 2001/2002.

Compared to other years, BTS values were relatively warm in 2001 due to an early and well-developed snow cover already in October/November 2000 (Figure 4.4 for sites in the Valais Alps), particularly in the Engadine. In 2002, they were colder after a shallow snow cover during first part of the winter 2001/02. In fact, the two consecutive winters exhibit two different extremes in terms of snow conditions.

The longest BTS-series at Alpage de Mille (1996-2002)
At Alpage de Mille, the same 41 BTS-stations have been measured during 7 consecutive winters since 1996. The mean value of BTS of all 41 points was slightly warmer in 2001 than the 1996-2002 mean, and reached exactly this value (-3.1 °C) in 2002 (see Figure 4.4).

The pattern of the BTS-values does not vary very much from one year to another. However, absolute values, and hence averages, fluctuate markedly. Nevertheless, minor pattern changes occur, i.e. the coldest zones are not always located precisely at the same place (Figure 4.3). At Alpage de Mille, two different patterns can be distinguished: the first occurred in 1997 and 1998 when the coldest places were observed above 2400 m a.s.l., the second was characteristic in 2001 when the coldest

*Table 4.1: BTS sites and available data, *=different annual datasets, BH=Borehole linkage.*

Site	Region	Available BTS	BTS 2001	2002	BH
Furggentäli/Gemmi	Gemmipass, BE	2000 – 2001*	02.04	no BTS	no
Schilthorn	Berner Oberland, BE	2000 – 2002*	no BTS	03.04	yes
Muragl	Upper Engadine, GR	2000 – 2001*	no BTS	no BTS	yes
Murtèl-Corvatsch	Upper Engadine, GR	2000 – 2001*	02.04	15.04	yes
Alpage de Mille	Val de Bagnes, VS	1996 - …	10.03	08.03	no
Lapires	Val de Nendaz, VS	2001 - …	21-23.02	07-09.03	yes
Réchy	Val de Réchy, VS	2000 - …	26-27.02	19.02	no
Yettes Condja	Val de Nendaz, VS	2001 - …	21.02	27-28.02	no

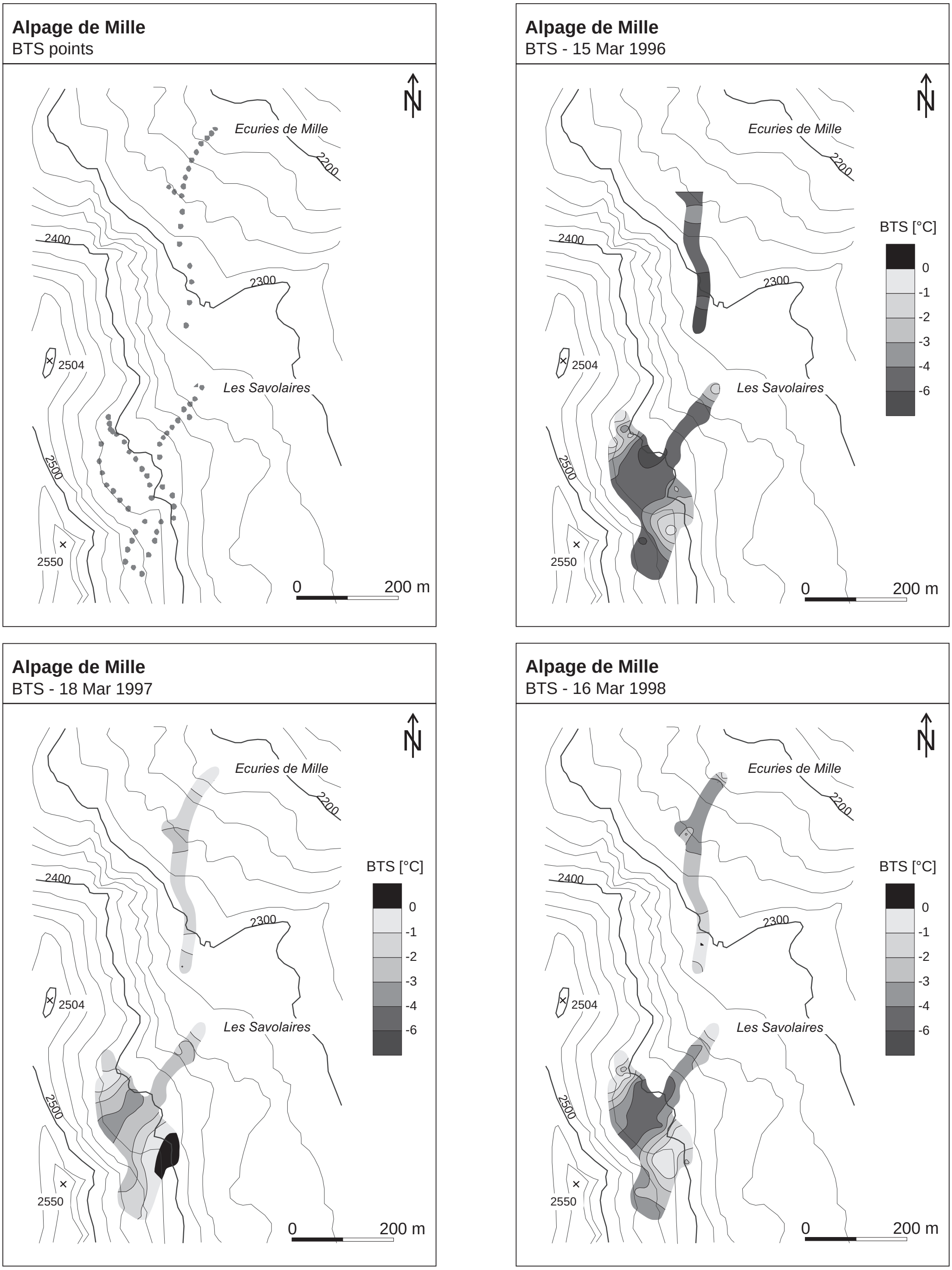
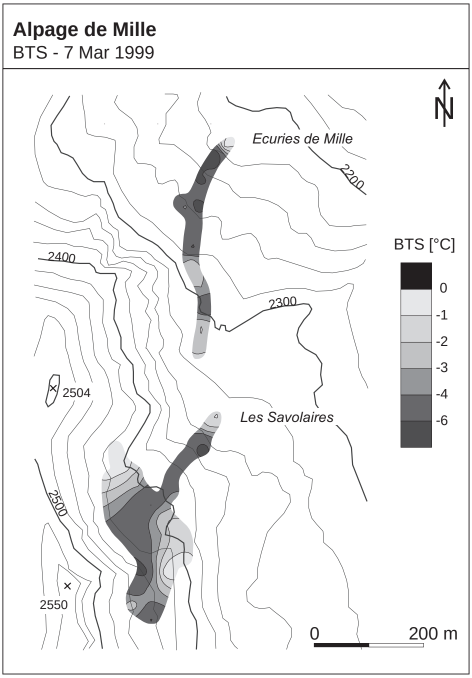
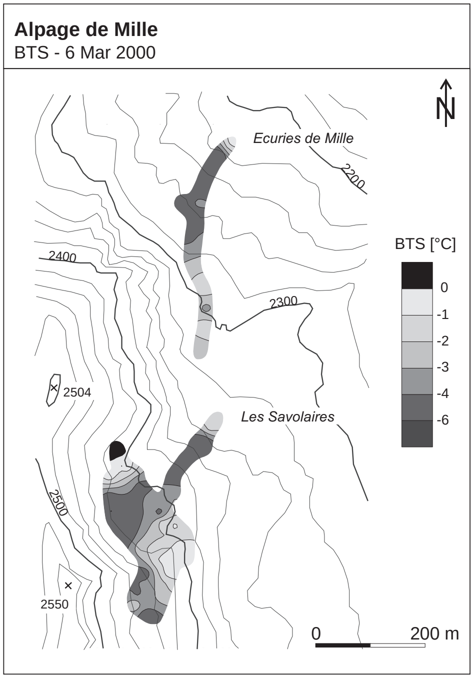
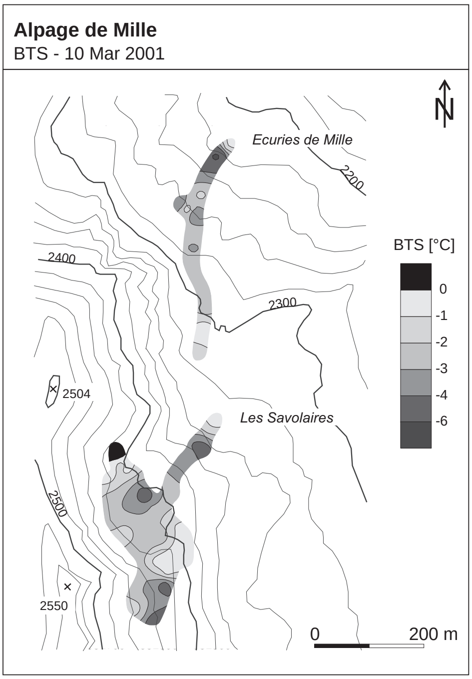
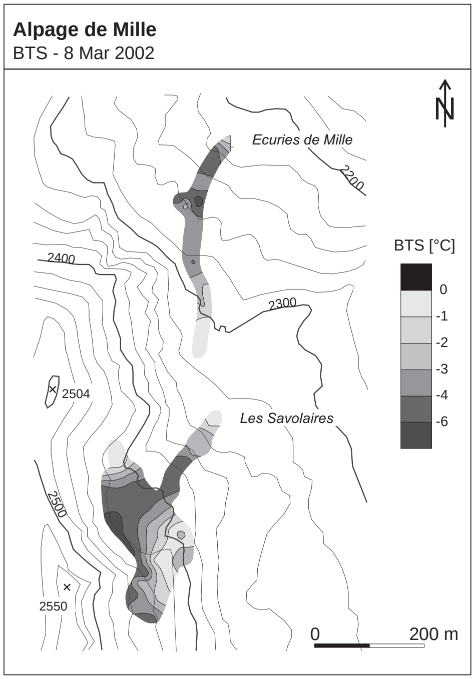


Figure 4.3: Yearly repeated BTS measurements at Alpage de Mille between 1996-2002.


Alpage de Mille
BTS - 7 Mar 1999
N
Ecuries de Mille
2200
2400
2300
2504
Les Savolaires
2500
2550
BTS [°C]
0
-1
-2
-3
-4
-6
0
200 m


Alpage de Mille
BTS - 6 Mar 2000
N
Ecuries de Mille
2200
2400
2300
2504
Les Savolaires
2500
2550
BTS [°C]
0
-1
-2
-3
-4
-6
0
200 m


Alpage de Mille
BTS - 10 Mar 2001
N
Ecuries de Mille
2200
2400
2300
2504
Les Savolaires
2500
2550
BTS [°C]
0
-1
-2
-3
-4
-6
0
200 m


Alpage de Mille
BTS - 8 Mar 2002
N
Ecuries de Mille
2200
2400
2300
2504
Les Savolaires
2500
2550
BTS [°C]
0
-1
-2
-3
-4
-6
0
200 m

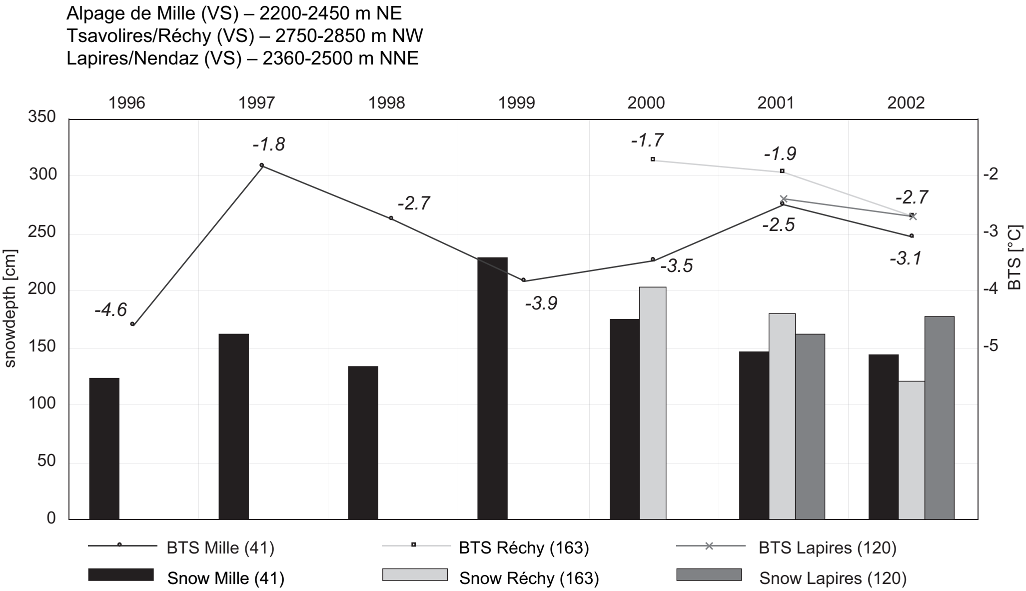


Figure 4.4: Mean BTS and snow depth values since 1996 on three sites in the Valais Alps. In brackets, the annual number of BTS measurements.

places were measured much lower in the frontal part of two inactive and relict rock glaciers. Air circulation through the rock glaciers, controlled by the thermal evolution of the weather during the whole winter, seems to be the reason for these differences in the BTS patterns (Delaloye, 2004).

At the other sites, the PERMOS-standard BTS-series (same annual datasets) are not yet long enough to be analysed in the current report.

4.2.2 Ground Surface Temperature (GST)

At each BTS site, 5 to 38 UTL sensors have been dispatched. At Schafberg-Pontresina and Ritord-Challand only GST-data are recorded (Table 4.2, Figure 4.5). Battery problems occurred frequently in 2000/2001 and several UTL sensors stopped functioning before being replaced. In 2001/2002, most of the UTL sensors worked perfectly. In Figures 4.6-4.7, only series with no gaps are presented.

Figure 4.5 shows the evolution of mean annual ground surface temperature (MAGST) for all the PERMOS-sites that have been observed for several years. After early snow melt in spring/summer 2000 and a warm GFI during winter 2000/2001, MAGST at all sites reached its highest level towards the end of winter 2000/2001 (March 2001) since at least 1998. In 2002, MAGSTs dropped to the coldest values since at least 1998 and probably 1996 due to long lasting snow cover in summer 2001 and (very) low GFI during the winter 2001/2002. A slight warming is observed in summer 2002 caused by early snowmelt.

The snow cover development contrasted markedly in the two winters 2000/2001 and 2001/2002 everywhere in the Alps, especially in the Engadine (Figure 4.6). Therefore, the GFI varies significantly between the two years.

In the Furggentälti, where GFI has been determined since 1995, it was second highest in 2000/2001, but second lowest in 2001/2002. The latter was about double the amount of the precedent year (-622 °C·d versus -302 °C·d). Dividing this difference by 365 days, the colder winter 2001/2002 contributed to a MAGST decrease of 0.9 °C.

The longest GST-series at Furggentälti-Gemmi (1994-2002)
The longest time series of the GST within PERMOS originates from one UTL sensor at Furggentälti/Gemmi. The data set goes back as far as October 1994 (Krummenacher et al., 1998). A number of trends can be identified, although they might not be representative for a larger area. However, they allow to assess the role of different climate-related parameters.

In 1995, the snow cover persisted until very late in spring/summer, protecting the ground from summer heating. During the next winter the build-up of a thick snow cover only occurred in January 1996, causing an intense cooling of the ground and, hence, a strong MAGST decrease in spring 1996 (Figure 4.5; see also Vonder Mühll et al., 1998). Since the beginning of the snow monitoring at Furggentälti/Gemmi in 1993, a similar evolution of the snow cover is only known for 1995/1996.

Table 4.2: GST-sites and available data. GST-measurements: c/n + (i), n = total number of measurements places ; c = complete series ; i = incomplete series. BH = Borehole linkage.

Site	Region	Available data	GST 2001	GST 2002	BTS	BH
Gemmi	Berner Oberland, BE	1994 - …	35/38	31/38	yes	no
Schilthorn	Berner Oberland, BE	1999 - ...	7/10	0/10	yes	yes
Ritord – Challand	Central Valais, VS	1997 - …	15/22 + (5)	22/22	no	no
Alpage de Mille	Val de Bagne, VS	1997 - …	17/18	18/18	yes	no
Muragl	Upper Engadine, GR	1998 - ...	0/12	0/12	yes	yes
Murtèl-Corvatsch	Upper Engadine, GR	2001 - …	5/9	5/9	yes	yes
Schafberg-Pontresina	Upper Engadine, GR	2001 - ...	7/9 + (1)	2/9 + (3)	no	yes
Lapires	Val de Nendaz, VS	1998 - …	13/15 + (2)	15/16	yes	yes
Réchy	Val de Réchy, VS	1997 - …	4/8 + (4)	10/10	yes	no
Yettes Condja	Val de Nendaz, VS	1998 - …	14/19 + (4)	14/19 + (1)	yes	no

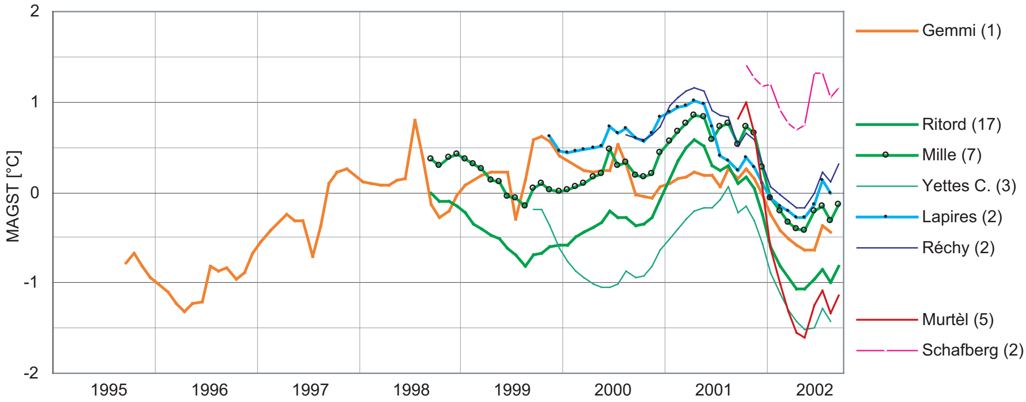


Figure 4.5: *Evolution of the mean annual ground surface temperature (MAGST) on PERMOS GST-sites. MAGST is the arithmetic average of the 12 preceding monthly mean values. Dates correspond to the end of the annual period used for the calculation. Legend: site– (total number of UTL-1).*

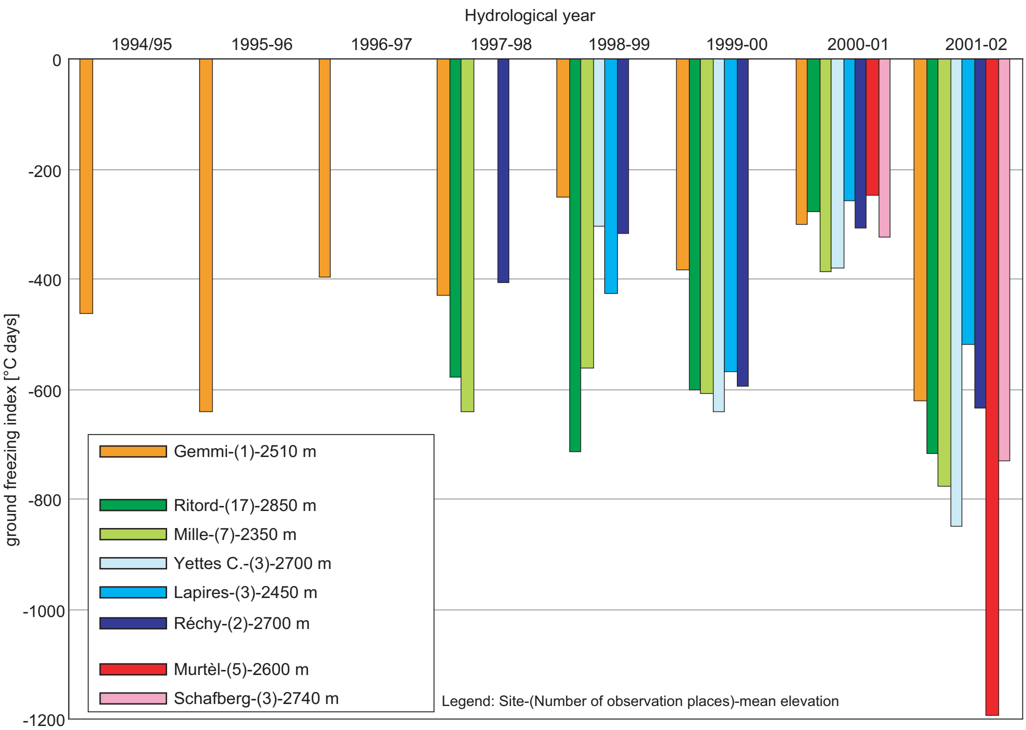


Figure 4.6: *Ground freezing index (GFI) at PERMOS GST-sites.*

Similar conditions were encountered in the Engadine and on the southern side of the Alps in 2001 inducing the effective cooling of the MAGST that occurred in 2002.

At Furggentälti/Gemmi the snow tended to disappear earlier in summer (-3.6 days per year) between 1995 and 2002 (cf. chapter 2.5, Figure 2.3). The mean ground surface temperature is about +7 °C in July (when there is no snow). Consequently, the trend towards an earlier snow melt could have induced an increase in MAGST of about 0.5 °C over the whole period 1995-2002.

Since the beginning of the measurements at Furggentälti/Gemmi, the GFI slightly increased by 9.4 °C·d per year (Figure 4.6), which results in a MAGST increase of about 0.2 °C over the period 1995-2002. However, there are large inter-annual variations of snow cover development, which can easily break or reverse that trend, as seen in 1995 and 1999.

The MAGST has tended towards an increase of 0.9 °C over the period 1995-2002 (Figure 4.5). This increase appears to be mainly explained by an earlier date of the snow melt (contribution estimated at +0.5 °C) and slightly warmer values of GFI (contribution: +0.2 °C).

4.3 Surface-temperature measurements in the forthcoming years

4.3.1 BTS

The comparison of several annual sets of BTS measurements and notably those of the two contrasting years 2000/2001 and 2001/2002 shows that the relative spatial variation of BTS does not significantly change from one year to another. Therefore, BTS measurements should only be carried out annually for a reduced number of “control” sites. The number of BTS sites will be reduced after the first pilot phase of PERMOS.

For each site, the obtained values will be averaged and used to produce a plot of a “BTS mean 2000”. A similar plot shall be repeated in a decade or more in order to detect possible changes in the relative spatial pattern of the winter ground surface temperatures (BTS).

4.3.2 GST

GST recordings will continue at all sites. These measurements will be complemented by UTL sensors installed in rock faces at one site in Upper Engadine, at Jungfraujoch/Schilthorn in the Bernese Alps and at Lapires/Mont-Gelé in the Valais.

Photo 4: *Les Savolaires rock glacier (2340-2450 m a.s.l.) at Alpage de Mille. Photo: R. Delaloye, October 2002.*

Photo 5: *Performing BTS measurements at Alpage de Mille; GPS survey permits to locate BTS points every year at the same places (precision :+/- 5 m). Photo: R. Delaloye, March 2004.*

4.4 Conclusions

Three main conclusions on surface temperature measurements (BTS and GST) can be drawn:

- Due to significant differences in snow cover conditions, contrasting thermal regimes were observed at the ground surface during the hydrological years 2000/2001 and 2001/2002. The contrast was more strongly accentuated in the more southerly regions. Mild temperatures for both BTS and GST were recorded during winter 2000/2001 and the MAGST reached its highest level since at least 1998. Much lower temperatures were measured during the following winter. Consequently, the MAGST fell to its lowest level since at least 1996, being 1–2 °C lower than the year before.
- Annual repetition of BTS measurements showed that the spatial distribution of relatively cold and temperate (or warm) areas did not significantly change even though absolute BTS values strongly differed from one year to the next. Moreover, in some cases the BTS maps show the extreme complexity of the permafrost distribution.
- The methodology applied to measure ground surface temperatures is still not entirely satisfactory. To date, there is hardly any information available on surface temperatures in steep (snow free) rock faces. This gap needs to be filled in the future. Due to the influence of permafrost degradation on the stability of steep rock faces and the expected increase in permafrost-related rock falls, it is important to gather information on the spatial and temporal distribution of rock temperatures. Corresponding measurements strategies have been developed (Gruber et al., 2003) and such data will be presented in the following reports.

5 Air photos

Aerial photographs are collected for documentation purposes and photogrammetric analyses. Several areas have been flown over regularly since the 1980s (Table 5.1, Figure 5.1). The aerial photographs are archived in order to be analysed later in the scope of a project (e.g. PhD thesis, masters thesis etc.). At least one flight per year is planned.

For photogrammetrical interpretation and analysis aerial photos have to be taken in a regular cycle. Information about surface phenomena at a certain time is abundant on aerial photos which allows to qualitatively determine different parameters using photogrammetry (e.g. permafrost creep velocity over several decades, changes in vegetation or geomorphological activities; Figures 5.2 and 5.3; see Kääb et al., 1997; Kääb and Vollmer, 2000).

Based on the aerial photographs, the horizontal surface velocity field and changes in thickness of the rock glaciers Gross Gufer and Réchy are presently being measured. Initial analyses for the Réchy

Figure 5.1: Areas where air photos are taken regularly. In red the sites that have been flown over in 2000/2001 and in 2001/2002.

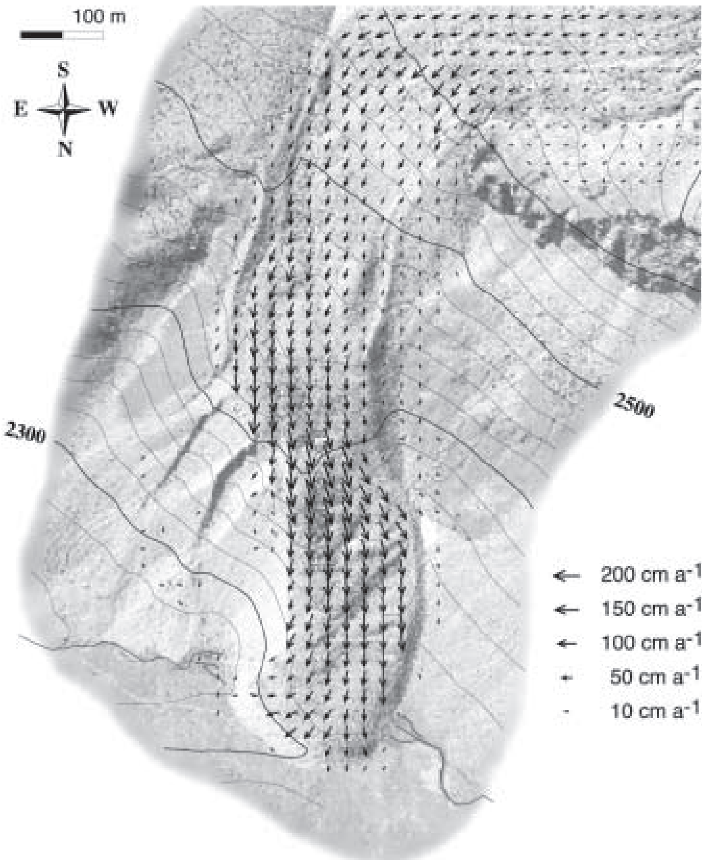


Figure 5.2: *Average horizontal surface velocities on the lower part of Suvretta rockglacier, Grisons, measured from aerial photography of 1992 and 1997. Aerial photography by Swisstopo flightservice. From Kääb (2004).*

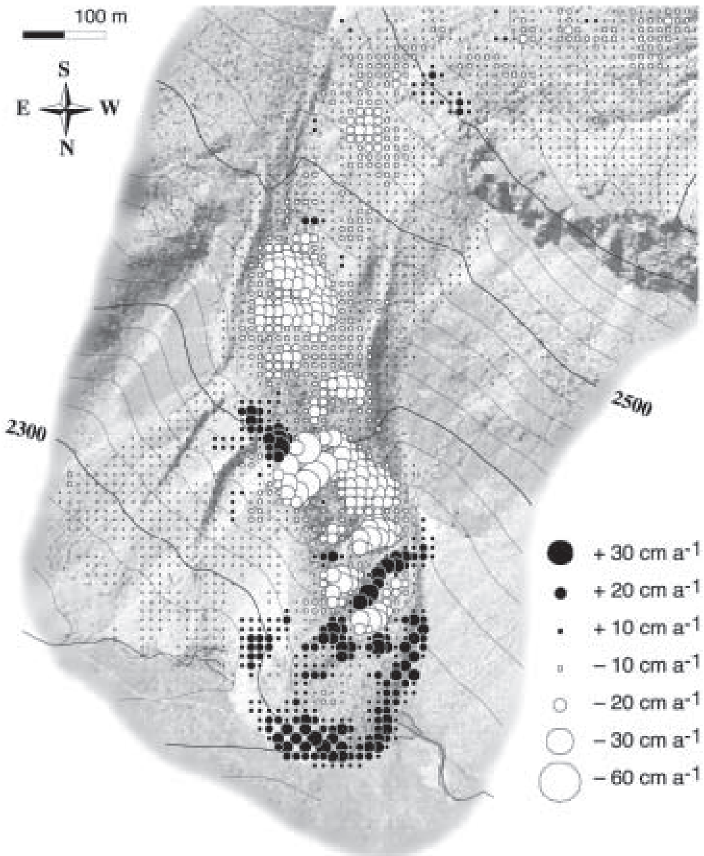


Figure 5.3: *Average thickness changes on the lower part of Suvretta rockglacier, Grisons, measured from aerial photography of 1992 and 1997. Aerial photography by Swisstopo flightservice. From Kääb (2000).*

rock glacier 1987-2000 showed, for the most part, constant permafrost thickness and horizontal speeds of up to 2.5 m per year.

Due to poor weather conditions, no aerial photos were taken in 2001. In 2002 photos were taken in the Upper Engadine region (Corvatsch-Murtèl, Val Muragl and Suvretta; Table 5.1).

Table 5.1: Rock glacier areas that are flown over regularly in the context of systematic permafrost monitoring since 1980 (low flying height (low f. h.), black and white (b-w)).

Region	Type	Max. speed	Available years
Murtèl	low f. h., b-w	15 cm/a	1987, 1988, 1991, 1995, 1996, 2002
Muragl	low f. h., b-w	50 cm/a	1981, 1985, 1990, 1994, 1998, 1999, 2000, 2002
Schafberg	low f. h., b-w	10 cm/a	1991, 1994, 1998, 1999, 2000
Réchy	low f. h., b-w		1986, 1991, 1995, 1999
Gruben	low f. h., b-w	100 cm/a	1967, 1975, 1983, 1985, 1988, 1989, 1990, 1991, 1992, 1994, 1995, 1996, 1997, 1999, 2000
Suvretta	low f. h., b-w	200 cm/a	1992, 1997, 2002
Gross Gufer	low f. h., b-w	250 cm/a	1987, 1994, 2000
Furggentälti	low f. h., b-w	70 cm/a	1990, 1995, 1999, 2000

Table 5.2: Available infrared air photos.

Region	IR-air photos
Morteratsch	1981
Goms North	1983
Goms South	1983
Goms-Gerental	1983
Goms-Münsterbach	1983
Upper Engadine – Julier	1988
Upper Engadine – Val Roseg	1988
Piz Quattervals	1984
Piz Vadret – Piz Fora	1984
Vals da Camp	1984
Val Maroz – Julier – Piz Ot	1984
Roseggletscher	1985
Val Réchy – Moiry	1986
Simplon	1987
Turtmann – Zinal	1987
Mattertal	1991
Saastal	1991
Simplon – Almagell	1991
Flüelapass	1997

6 Conclusions

PERMOS officially started after the concept had been approved by the SAS Glaciological Commission in January 2000. The present report documents measurements of the three elements observed within PERMOS: (1) Borehole temperatures including active-layer thickness where data are obtained by a data logger, (2) Areas at the lower boundary of permafrost distribution, where the permafrost pattern is observed by measurements of both bottom temperature of the snow cover (BTS) and ground surface temperatures (GST) all year around, (3) Aerial photographs that will allow photogrammetrical analysis of surface characteristics later on in the scope of different research projects.

The official first two years of PERMOS were characterised by warm summer temperatures and large amounts of snow that came early in winter 2000/2001, and by contrasting conditions in winter 2001/2002 when only little snow was measured and heat could easily be extracted from the ground.

The thickness of the active layer is mainly influenced by summer temperatures. In both summers of the observed period, the active layer reached thicknesses comparable to previous years at most PERMOS sites. Values vary between less than 1 m at Muot da Barbar Peider 1/96 and almost 5 m at Schilthorn 51/98. Due to the very different snow conditions of the winters 2000/2001 and 2001/2002 respectively, permafrost temperatures below the active layer were very high in 2001, but cooled down substantially in 2002. As far as methodology is concerned, it is clear that borehole temperatures must be a part of a mountain permafrost monitoring network. The principles of the PACE-manual (cf. appendix B) have been found to be adequate.

In winter 2000/2001 the early snowfalls and large amounts of snow caused warm BTS- and GST-values. As the snowcover was very shallow until late winter 2002, BTS-measurements were difficult to perform in some places. Moreover, BTS and GST values dropped and GST values reached temperatures that represent about the average since measurements began.

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Appendix

A – Boreholes

Jungfraujoch N/95 and S/95

Site	
Description	North/South face of Jungfrau Ostgrat
Coordinates	N: 641000/155120, S: 640990/155050
Elevation	N: 3590, S: 3580
Slope angle [°]	N: ca. 55°, S: ca. 50°
Slope aspect	N: ca. 5° E, S: ca. 135° E
Morphology	Rock wall
Lithology	Gneiss
MAAT	-7.9 °C
Vegetation	No vegetation
Borehole	
Drilling date	1995
Depth [m]	N: 21, S: 20
Chain length [m]	N: 21, S: 20
Thermistor depth [m]	(a) distance from tunnel (see Figure A.2) N: 2.7, 6.7, 9.7, 11.7, 15.7, 19.2, 20.2 S: 1.2, 5.2, 8.2, 11.2, 14.2, 16.2, 17.7, 18.7 (b) depth below surface (see Figure A.2) N: 10.5, 11.0, 8.9, 7.3, 6.3, 6.0, 5.9 S: 10.0, 8.0, 6.6, 5.4, 3.8, 2.6, 1.7, 1.4
Thermistor type	NTC Thermistor, Model 111-103-EAJ-H01 (Fenwal Electronics)
Last calibration	1995
Responsible	VAW ETH, T. Sueyosi
Other measurements	Deformation measurement (1995-2003)
Comments	Boreholes are not vertical; they are drilled outwards from the inner-tunnel. Installation of new thermistor chain is planned in 2004.
Available data	Temperature (time series)

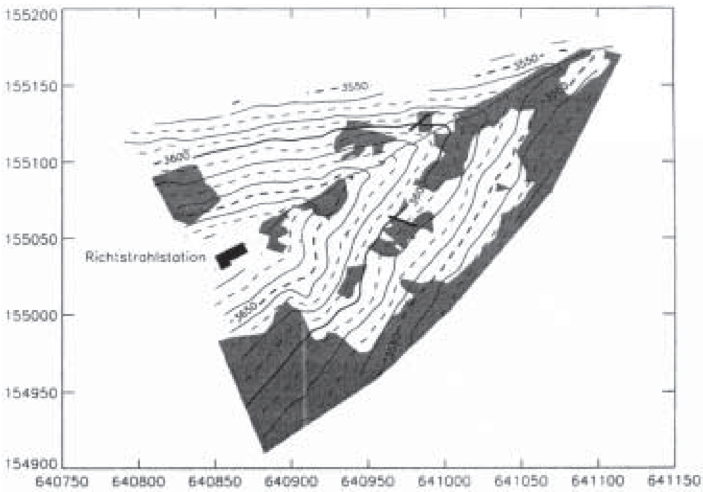

Fig. A.1: *Situation at the Jungfrau East ridge. Snowpatches and glacier boundaries are drawn in grey, the ridge, the Richtstrahlstation and the two boreholes are also displayed. From Wegman (1998).*

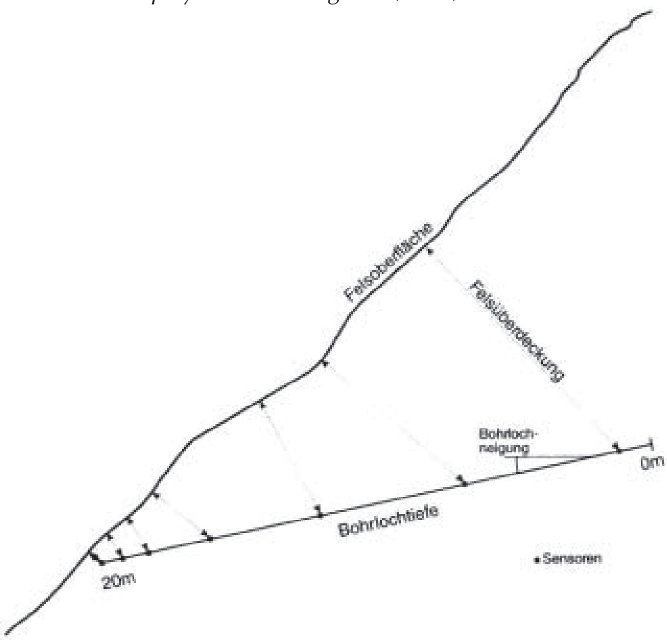

Fig. A.2: *The borehole depth is measured from the inside of the Jungfrau East ridge. The rock depth is the shortest distance of a sensor to the rock surface. From Wegmann (1998) .*

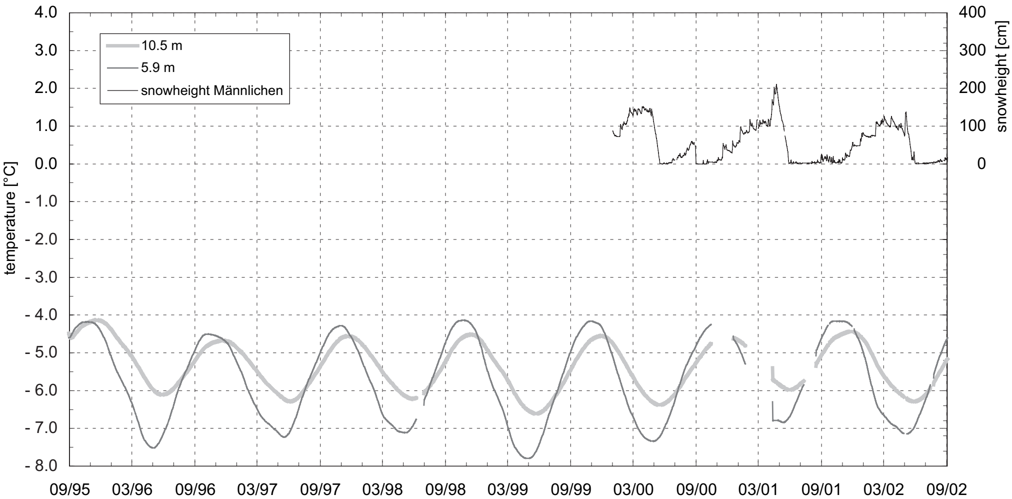

Fig. A.3: *Temperature-time plot of the borehole Jungfraujoch N/95 for the thermistors at 5.9 m and 10.5 m depth. Additionally, the snow height on Männlichen is displayed.*

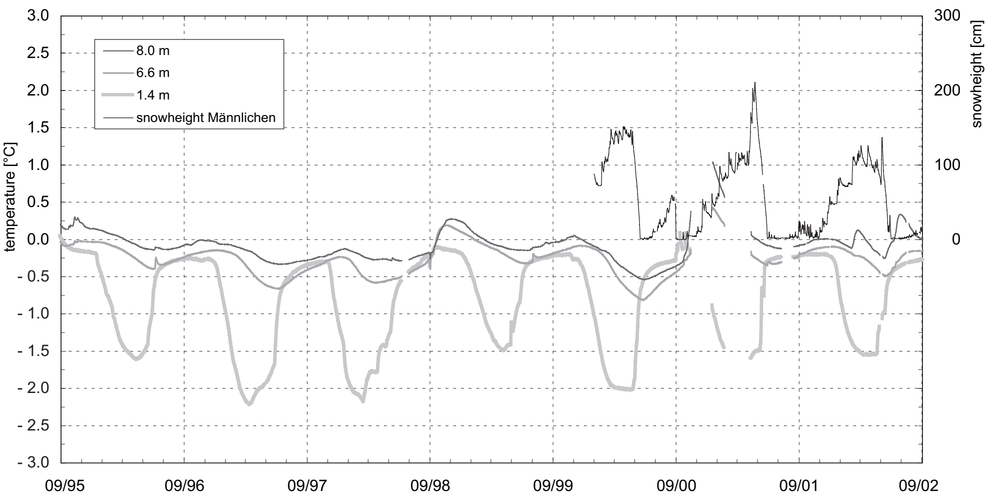

Fig. A.4: *Temperature-time plot of the borehole Jungfraujoch S/95 for the thermistors at 1.4 m, 6.6 m and 8.0 m depth. Additionally, the snow height on Männlichen is displayed.*

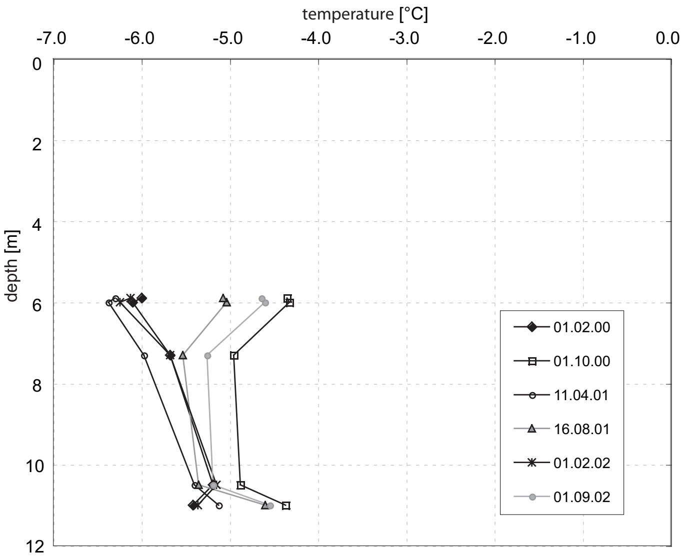

Fig. A.5:
Temperature profile Jungfraujoch N/95. This borehole was drilled from the tunnel (11 m depth) without reaching the surface (0 m). Two sensors (at 6.3 m and 8.7 m depth) showed a large drift of about 2 °C between 1996 and 1998 and are therefore omitted in this plot. The annual temperature amplitude increasing below 8 m depth again indicates the influence of the tunnel temperature.

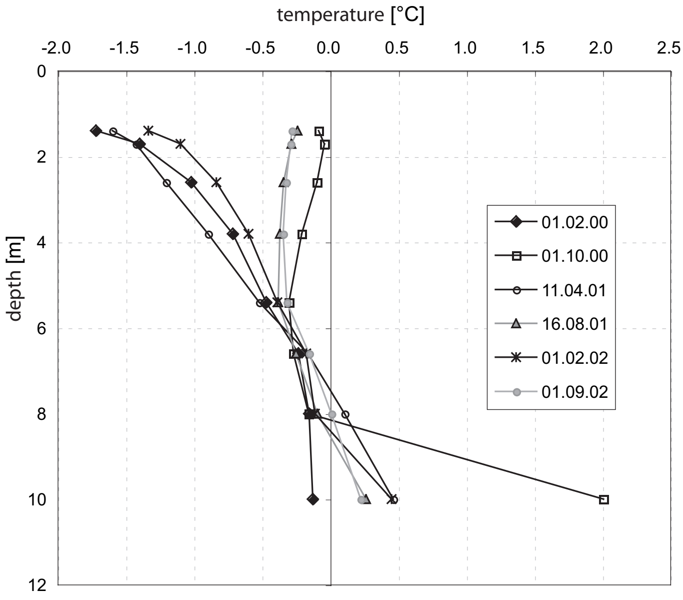

Fig. A.6:
Temperature profile Jungfraujoch S/95. This borehole was drilled from the tunnel (10 m depth) reaching the surface (0 m). Similarly to borehole N/95, anual temperature amplitude increases below 7 m depth, indicating the influence of the tunnel temperature.

Schilthorn 51/98, 50/00 and 52/00

Site	
Description	North-east face of Schilthorn, Lauterbrunnental, BE
Coordinates	51/98: 630365/156410, 50/00: 630350/156410, 52/00:630350/156410
Elevation [m a.s.l.]	51/98: 2909, 50/00: 2910, 52/00: 2910
Slope angle [°]	30
Slope aspect	NE
Morphology	Slope beneath summit
Lithology	Limestone schists
MAAT/Precipitation	-4.3 °C / 2700 mm
Vegetation	No vegetation
Borehole	
Drilling date	51/98: 14.10.1998, 50/00 and 52/00: 8.2000
Depth [m]	51/98: 14 m , 50/00: 101.0 m, 52/00: 100.0 m
Chain length [m]	51/98: 13.7 m, 50/00: 100.0 m, 52/00: 100.0 (installed down to 92.0)
Thermistor depth [m]	51/98: 0.2, 0.4, 0.8, 1.2, 1.6, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0, 7.0, 9.0, 10.0, 11.0, 13.0, 13.7 50/00: 0.2, 0.4, 0.8, 1.2, 1.6, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0, 7.0, 9.0, 10.0, 11.0, 13.0, 15.0, 20.0, 25.0, 30.0, 40.0, 50.0, 60.0, 70.0, 80.0, 85.0, 90.0, 95.0, 97.5, 100.0 52/00: 0.0, 1.0, 2.0, 3.0, 5.0, 7.0, 12.0, 17.0, 22.0, 32.0, 42.0, 52.0, 62.0, 72.0, 77.0, 82.0, 87.0, 89.5, 92.0
Thermistor type	NTC-YSI 440006
Last calibration	51/98: 1998, 50/00: 1999, 52/00: 1999
Meteostation	
Installation date	10.1998
Sensors	air temperature, relative humidity, net radiation, snow-depth, wind speed/ direction
Responsible	GIUZ/Univ. Basel, D. Vonder Mühll
Other measurements	BTS/GST, energy balance
Comments	Temperate (warm) permafrost
Available data	Since 1998 (with some gaps)

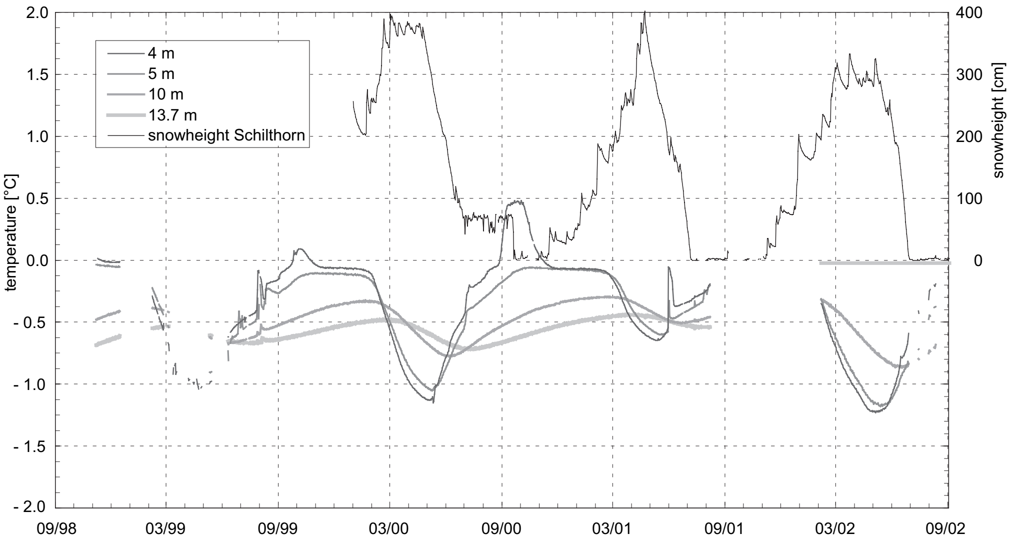

Fig. A.7: Temperature-time plot of the borehole Schilthorn 51/98 for the thermistors at 4.0, 5.0, 10.0 and 13.7 m depth. Additionally, the snow height on Schilthorn is displayed.

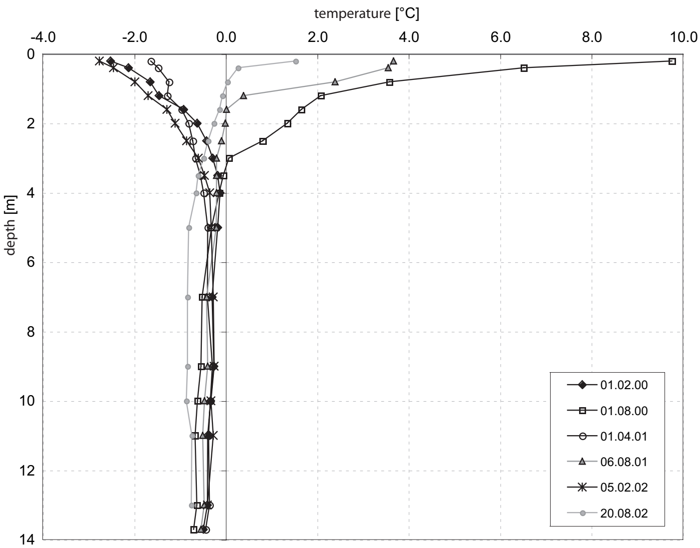

Fig. A.8: Temperature profile Schilthorn 50/00.

Muot da Barba Peider B1/96 and B2/96

Site	
Description	Schafberg-Pontresina (Muot da Barba Peider), Upper Engadine, GR
Coordinates	B1/96: 791300/152500; B2/96: 791300/152500
Elevation [m a.s.l.]	B1/96: 2946; B2/96: 2941
Slope angle [°]	38
Slope aspect	NW
Morphology	Scree slope
Lithology	Gneiss
MAAT/Precipitation	-4.5 °C / 2000 mm
Vegetation	No vegetation
Borehole	
Drilling date	1996
Depth [m]	18
Chain length [m]	17.5
Thermistor depths [m]	0.5, 1.0, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, 13.5, 17.5
Thermistor type	YSI 46008 + Campbell CR10X 1996
Last calibration	1996
Meteostation	
Installation date	1996
Sensors	air temperature (UTL), radiation, snow-surface, wind speed/direction
Responsible	SLF, M. Phillips
Other measurements	BTS/GST
Comments	Snow nets at B1/96, no snow nets at B2/96
Available data	Since 1996

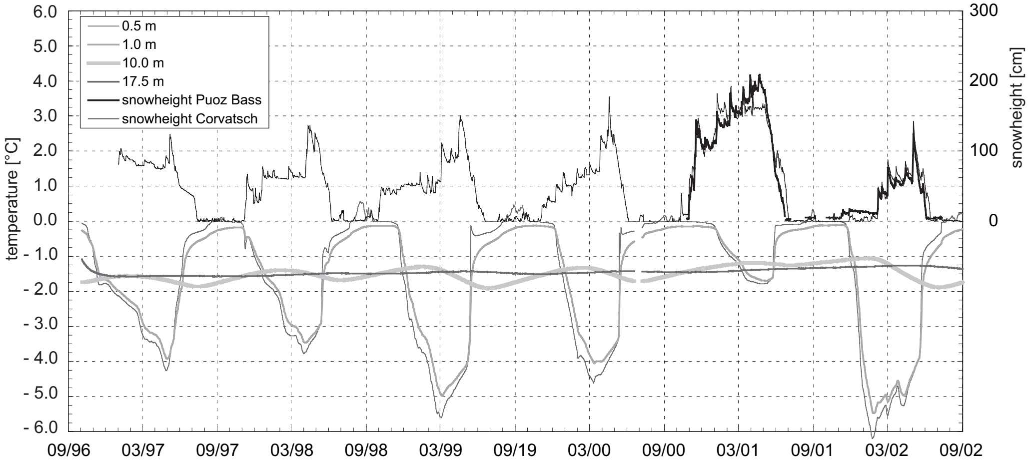

Fig. A.9: *Temperature-time plot of the borehole Mout da Barba Peider B1/96 for the thermistors at 4.0, 5.0, 10.0 and 13.7 m depth. Additionally, the snow height at Puoz Bass and Corvatsch is displayed.*

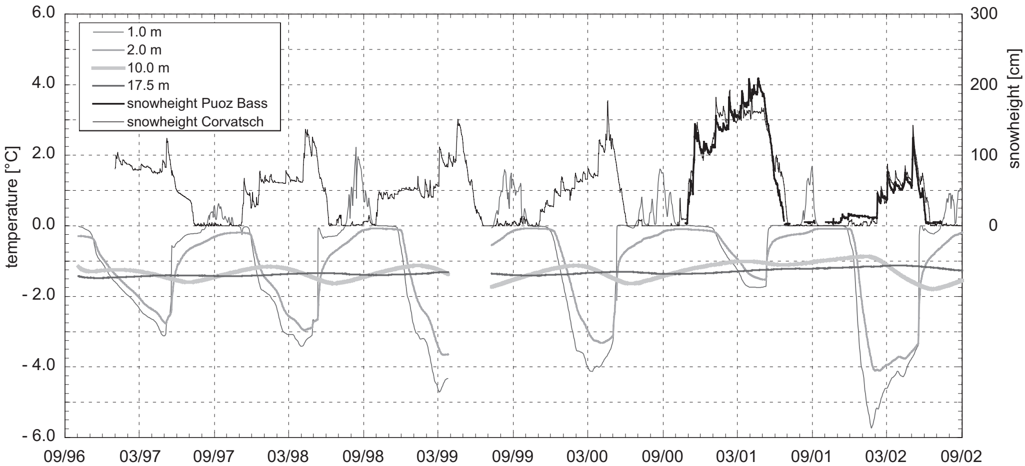

Fig. A.10: *Temperature-time plot of the borehole Mout da Barba Peider B2/96 for the thermistors at 4.0, 5.0, 10.0 and 13.7 m depth. Additionally, the snow height at Puoz Bass and Corvatsch is displayed.*

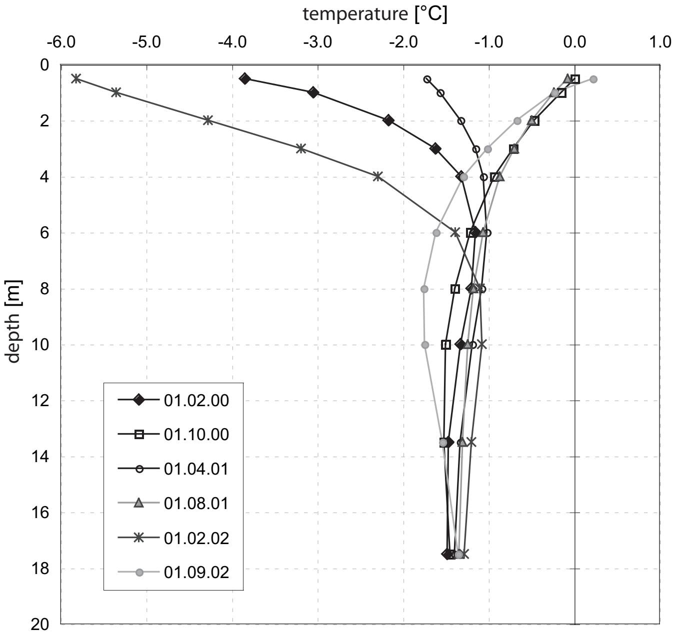

Fig. A.11: Temperature profile Muot da Barba Peider B1/96.

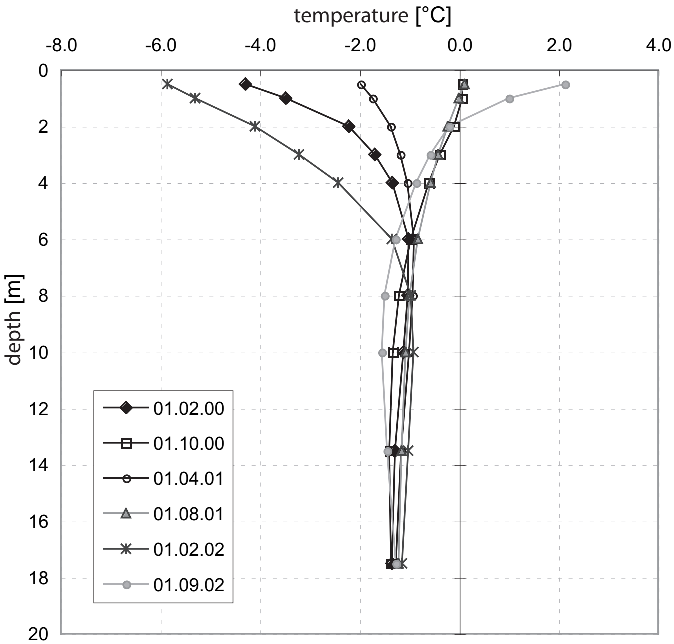

Fig. A.12: Temperature profile Muot da Barba Peider B2/96.

Muragl 1/99, 2/99, 3/99 and 4/99

Site	
Description	Active rock glacier in the Muragl Valley with a pronounced curvature in the flow. Approx 45 min from Muottas Muragl.
Coordinates	1/99: 791025/153726, 2/99: 790989/153687 3/99: 791038/153679, 4/99: 791017/153688
Elevation [m a.s.l.]	1/99: 2536.1, 2/99: 2538.5 3/99: 2558.2, 4/99: 2549.2
Slope angle [°]	1/99: 15°, 2/99: 5°, 3/99: 15°, 4/99: 15°
Slope aspect	1/99: W, 3/99: SW, 4/99: SW
Morphology	Active rock glacier
Lithology	Albit-Muskowit schists
MAAT/Precipitation	-2.2 °C / 2000 mm
Vegetation	No vegetation
Borehole	
Drilling date	May, June 1999
Depth [m]	1/99: 70.2, 2/99: 64.0 3/99: 72.0, 4/99: 71.0
Chain length [m]	1/99: 69.7, 2/99: 59.7 3/99: 69.6, 4/99: 69.6
Thermistor depths [m]	1/99: 0.0, 0.2, 0.8, 1.4, 2.0, 3.0, 4.0, 5.0, 7.0, 9.0, 11.0, 14.0, 19.0, 24.0, 29.0, 39.0, 54.0, 69.0 2/99: 0.0, 0.1, 0.5, 0.9, 1.3, 1.7, 2.2, 2.7, 3.7, 4.7, 5.7, 7.7, 9.7, 11.7, 13.7, 15.7, 19.7, 24.7, 29.7, 34.7, 39.7, 59.7, 59.7 3/99: 0.0, 0.4, 0.8, 1.2, 1.6, 2.1, 2.6, 3.6, 4.6, 5.6, 7.6, 9.6, 11.6, 13.6, 15.6, 17.6, 19.6, 24.6, 29.6, 34.6, 39.6, 49.6, 59.6, 69.6 4/99: 0.0, 0.4, 0.8, 1.2, 1.6, 2.1, 2.6, 3.6, 4.6, 5.6, 7.6, 9.6, 11.6, 13.6, 15.6, 19.6, 24.6, 29.6, 34.6, 39.6, 59.6, 69.6
Thermistor type	YSI 44006
Last calibration	05.999
Responsible	IGT, Lukas Arenson, Sarah M. Springman
Other measurements	BTS/GST
Comments	–
Available data	1/99: 10.99–04.00, 09.02–, 2/99: 11.00– 3/99: 10.99–04.00, 09.02–, 4/99: 10.99–04.00, 09.02–

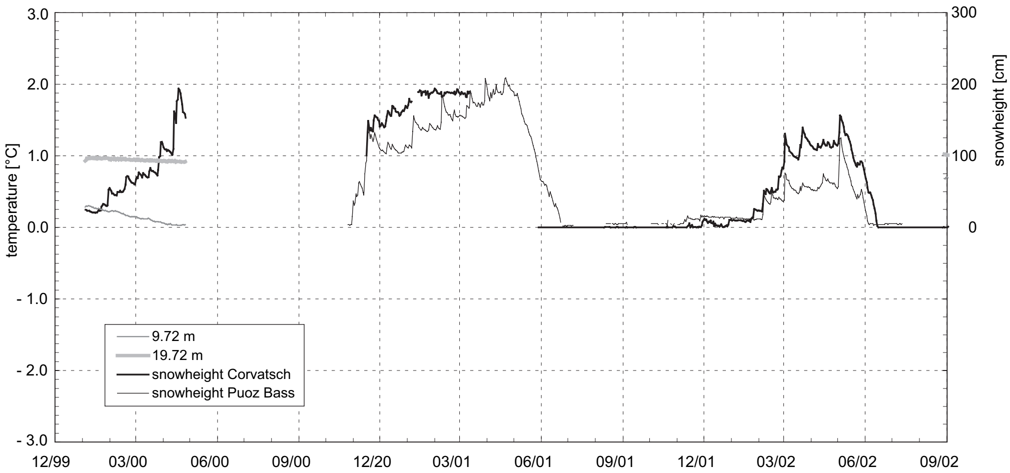

Fig. A.13: *Temperature-time-plot of the borehole Muragl 1/99 for the thermistors at 9.72 and 19.72 m depth. Additionally, the snow height at Puoz Bass and Corvatsch is displayed.*

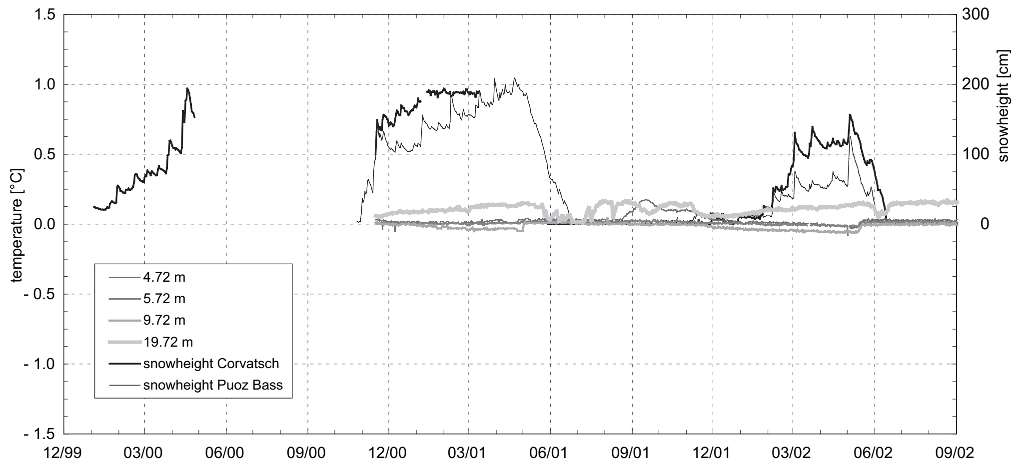

Fig. A.14: *Temperature-time-plot of the borehole Muragl 2/99 for the thermistors at 4.72, 5.72, 9.72 and 19.72 m depth. Additionally, the snow height at Puoz Bass and Corvatsch is displayed.*

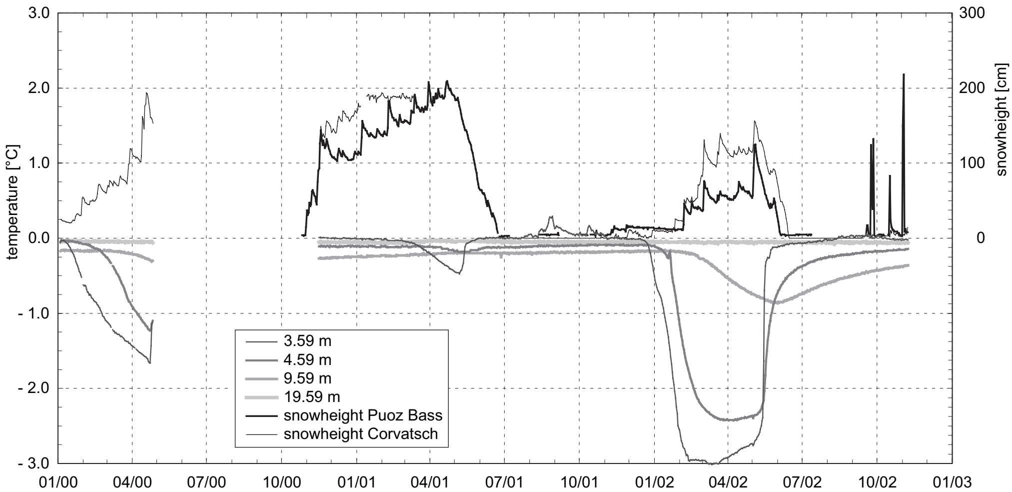

Fig. A.15: *Temperature-time plot of the borehole Muragl 3/99 for the thermistors at 3.59, 4.59, 9.59 and 19.59 m depth. Additionally, the snow height at Puoz Bass and Corvatsch is displayed.*

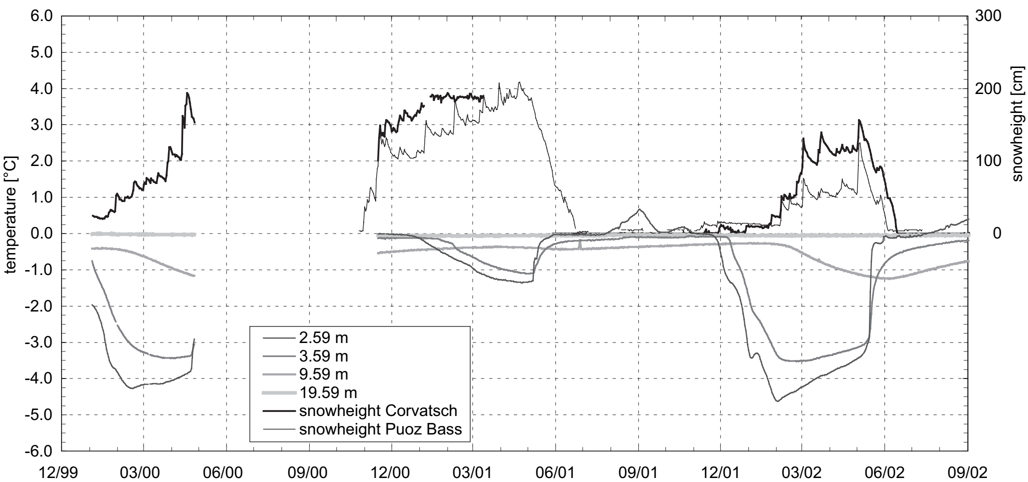

Fig. A.16: *Temperature-time plot of the borehole Muragl 4/99 for the thermistors at 2.59, 3.59, 9.59 and 19.59 m depth. Additionally, the snow height at Puoz Bass and Corvatsch is displayed.*

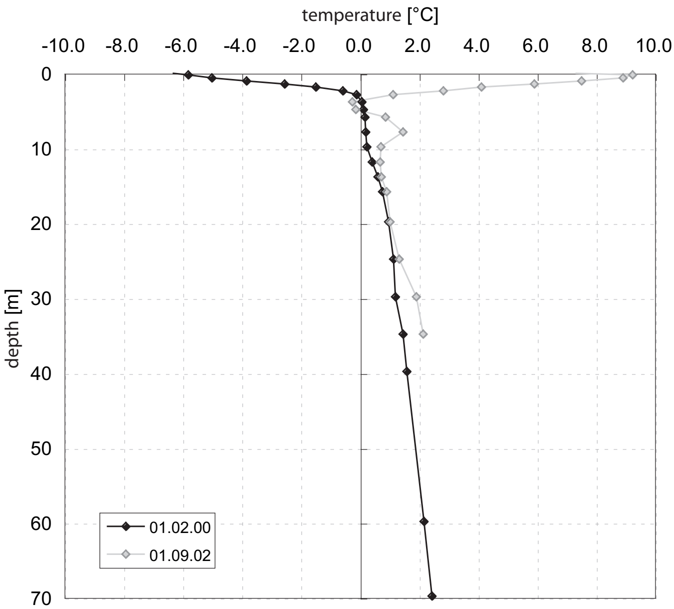

Fig. A.17: *Temperature profile Muragl 1/99.*

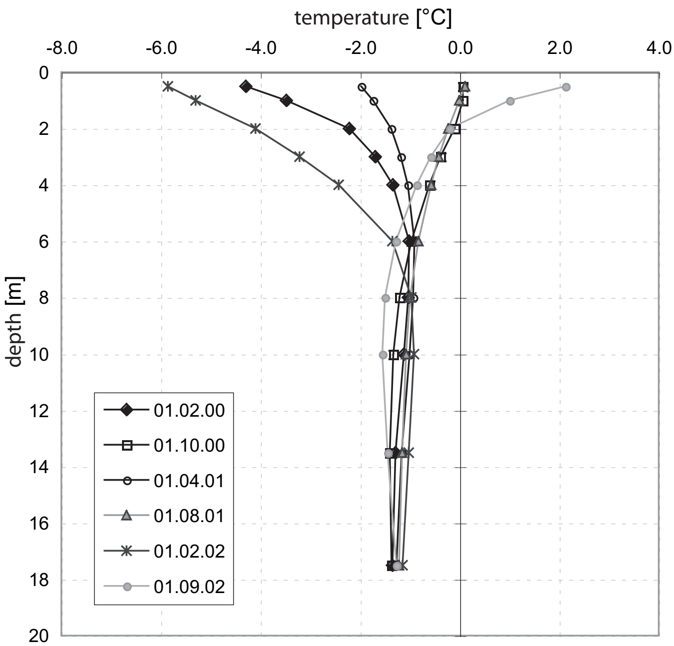

Fig. A.18: *Temperature profile Muragl 2/99.*

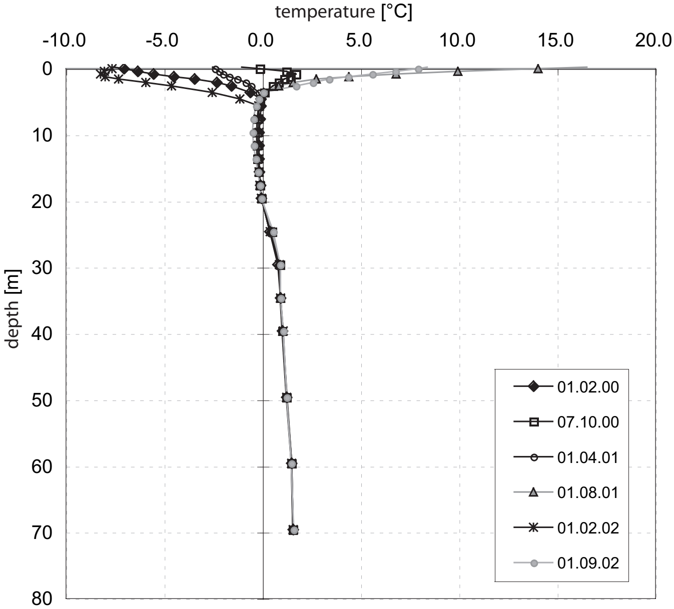

Fig. A.19: Temperature profile Muragl 3/99.

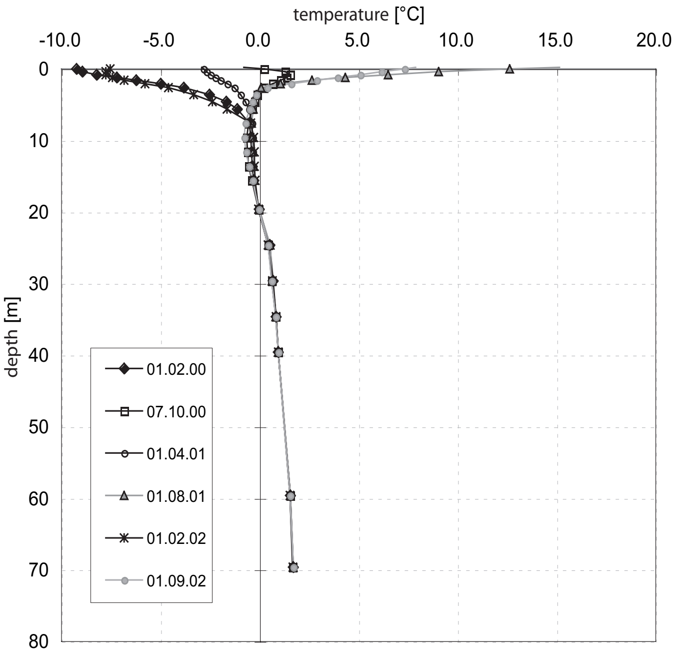

Fig. A.20: Temperature profile Muragl 4/99.

Murtèl-Corvatsch 1/87, 2/87, 1/00 and 2/00

Site	
Description	Active rock glacier south-west of the cable car station Murtèl
Coordinates	1/87: 783158/144720, 2/87: 783160/144720 1/00: 783168/144703, 2/00: 783175/144692
Elevation [m a.s.l.]	1/87: 2670, 2/87: 2670, 1/00: 2673, 2/00: 2672
Slope angle [°]	10°
Slope aspect	NNW
Morphology	Rock glacier
Lithology	Crystalline rock of the Corvatsch nappe: granodiorit, schists
MAAT/Precipitation	-3 °C / 2000 mm
Vegetation	No vegetation
Borehole	
Drilling date	1/87: 05.1987, 2/87: 06.87, 1/00: 05.2000, 2/00: 06.2000
Depth [m]	1/87: 32.0, 2/87: 62.0, 1/00: 51.9, 2/00: 63.2
Chain length [m]	1/87: 21.0, 2/87: 58.0, 1/00: no temperature sensors installed, 2/00: 62.0
Thermistor depths [m]	1/87: 0.8, 1.8, 2.8, 3.8, 4.8, 5.8, 6.8, 7.8, 8.8, 9.8, 10.8, 11.8, 12.8, 13.8, 14.8, 15.8, 16.8, 17.8, 18.8, 19.8, 20.8 2/87: 0.6, 1.6, 2.6, 3.6, 4.6, 5.6, 6.6, 7.6, 8.6, 9.6, 10.6, 11.6, 12.6, 13.6, 14.6, 15.6, 16.6, 17.6, 18.6, 19.6, 20.6, 21.6, 23.6, 24.6, 25.6, 26.6, 27.6, 30.0, 33.0, 36.0, 39.0, 42.0, 45.0, 46.0, 47.0, 48.0, 49.0, 50.0, 51.0, 52.0, 53.0, 53.9, 54.9, 55.9, 56.9, 58.0 2/00: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0, 7.5, 10.0, 15.0, 20.0, 25.0, 30.0, 40.0, 42.0, 44.0, 46.0, 48.0, 50.0, 52.0, 54.0, 56.0, 57.0, 58.0, 60.0, 61.0, 62.0
Thermistor type	1/87 and 2/87: YSI 44006, Fernwall UUA 41J1, 2/00: YSI 44006 (Stump String #21)
Last calibration	1/87: and 2/87: 1987 (fix installed), 2/00: July 2000
Meteostation	
Installation date	1.1997
Sensors	air and surface temperature, relative humidity, net radiation, snow-depth, wind speed/direction,
Responsible	1/87: GIUZ, M. Hoelzle, 2/87: GIUZ, Univ. Basel, D. Vonder Mühll 1/00 and 2/00: IGT, L. Arenson, Sarah M. Springman
Other measurements	BTS/GST
Comments	Air circulation through talus slope
Available data	2/87: since 1987 (with some gaps); 2/00: since 2000.

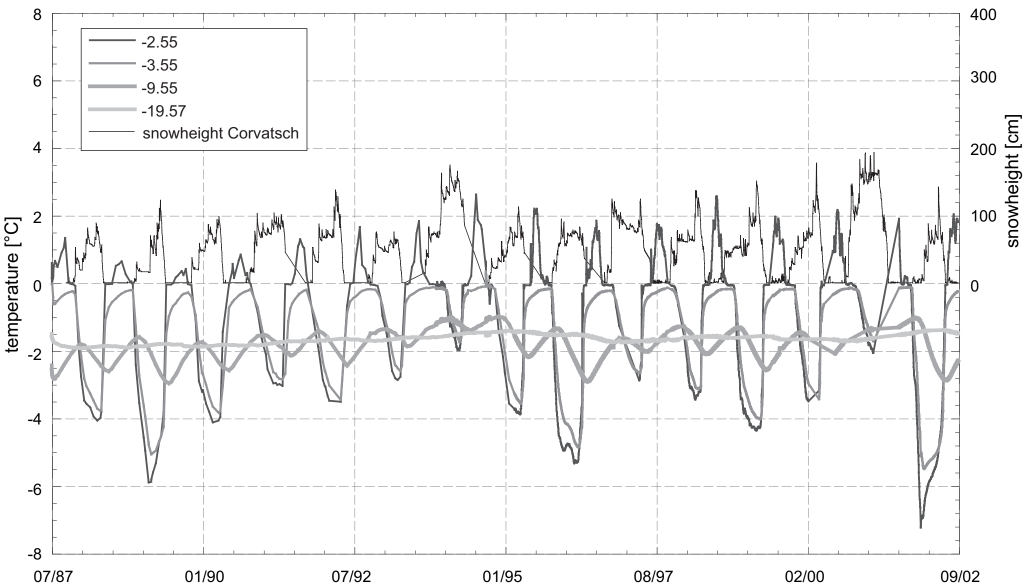

Fig. A.21: *Temperature-time plot of the borehole Corvatsch 2/87 for the thermistors at 2.55, 3.55, 9.55, 19.57 and 32.56 m depth. Additionally, the snow height at Corvatsch is displayed.*

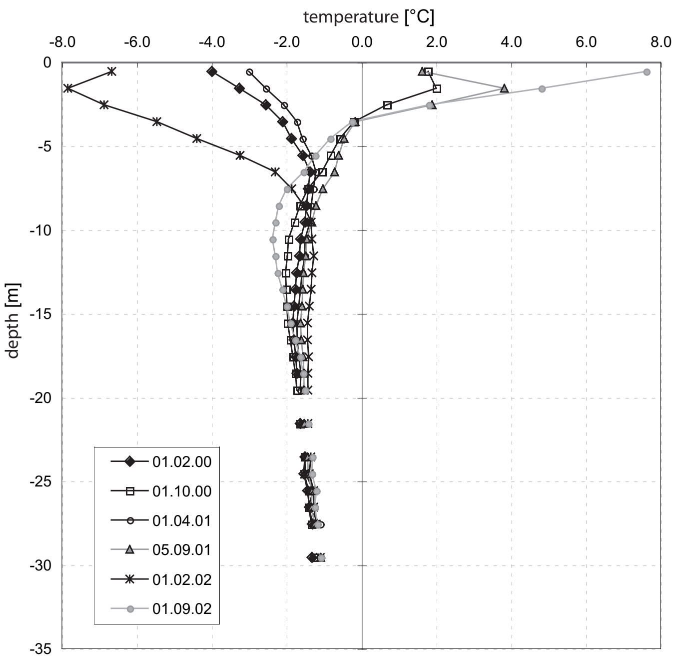

Fig. A.22: *Temperature profile Corvatsch 2/87.*

Schafberg-Pontresina 1/90 und 2/90

Site	
Description	Schafberg-Pontresina (Muot da Barba Peider), Upper Engadine, GR
Coordinates	1/90: 791000/152500, 2/90: 790750/152775
Elevation [m a.s.l.]	1/90: 2755, 2/90: 2735
Slope angle [°]	flat
Slope aspect	flat
Morphology	Rock glacier
Lithology	Gneiss
MAAT/Precipitation	-3.5 °C / 2000 mm
Vegetation	No vegetation
Borehole	
Drilling date	1990
Depth [m]	1/90: 67.0, 2/90: 37.0
Chain length [m]	1/90: 18.0, 2/90: 25.2
Thermistor depths [m]	2/90: 0.0, 1.2, 3.2, 5.2, 7.2, 9.2, 13.2, 17.2, 21.2, 25.2
Thermistor type	2/90: YSI 46006 + Campbell CR10X
Last calibration	2/90: 1997
Meteostation	
Installation date	Planned for summer 2004
Sensors	Air temperature, relative humidity, net radiation, snow depth/surface/temperature, wind speed/direction
Responsible	1/90: VAW, 2/90: SLF, M. Phillips
Other measurements	BTS/GST
Comments	Borehole 2/90 sheared off in 2000 at 28 m
Available data	2/90: Since 1997

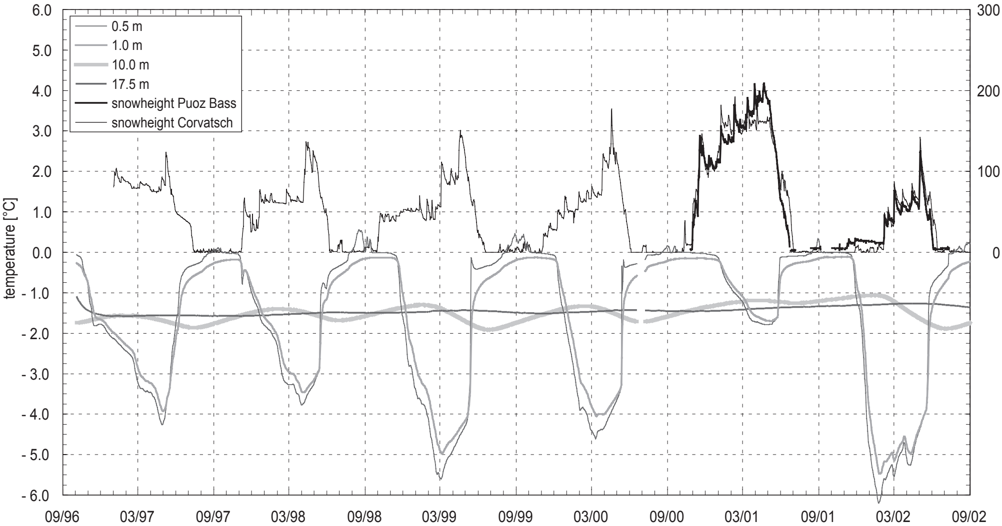

Fig. A.23: *Temperature-time plot of the borehole Schafberg-Pontresina 2/90 for the thermistors at 0.5, 1.0, 10.0 and 17.5 m depth. Additionally, the snow height at Puoz Bass and on Corvatsch is displayed.*

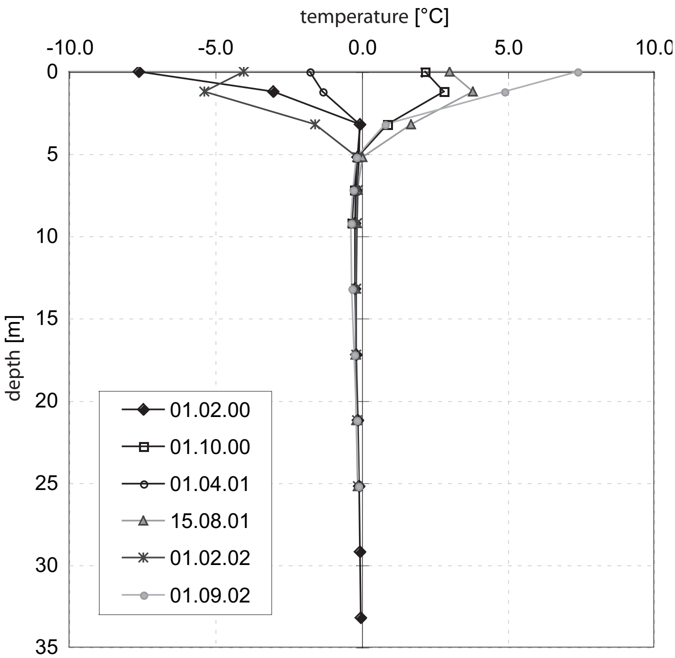

Fig. A.24: *Temperature profile Schafberg-Pontresina 2/90.*

Arolla, Mt. Dolin B1/96 and B2/96

Site	
Description	Arolla, Mt. Dolin, VS
Coordinates	B1/96: 601246/97232, B2/96: 601257/97248
Elevation [m a.s.l.]	B1/96: 2840, B2/96 2820
Slope angle [°]	38-40
Slope aspect	NE
Morphology	Scree slope
Lithology	Dolomite
MAAT/Precipitation	– / –
Vegetation	No vegetation
Borehole	
Drilling date	1996
Depth [m]	10
Chain length [m]	5.5
Thermistor depths [m]	0.5, 1.5, 2.5, 3.5, 5.5
Thermistor type	YSI 46008 + Campbell CR10X
Last calibration	1996
Responsible	SLF, M. Phillips
Other measurements	BTS/GST
Comments	Snow nets
Available data	Since 1996

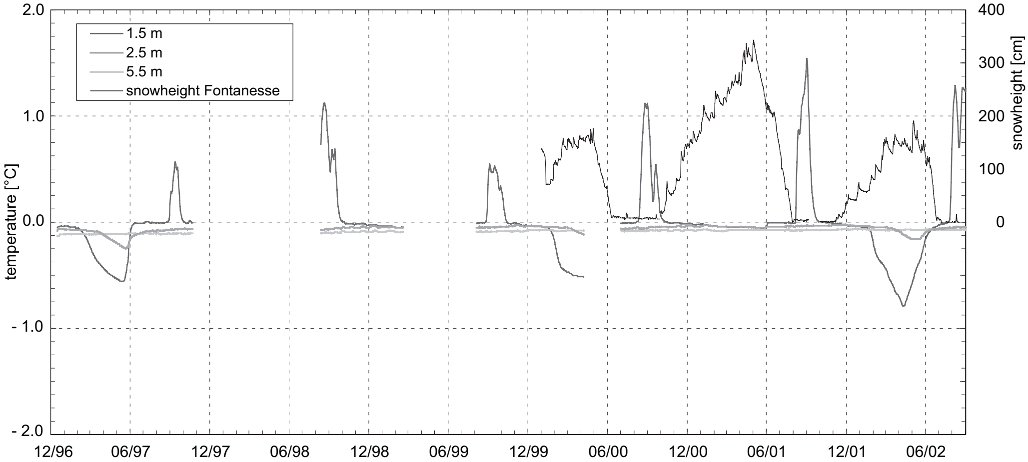

Fig. A.25: *Temperature-time plot of the borehole Arolla B1/96 for the thermistors at 1.5, 2.5 and 5.5 m depth. Additionally, the snow height at Fontanesse is displayed.*

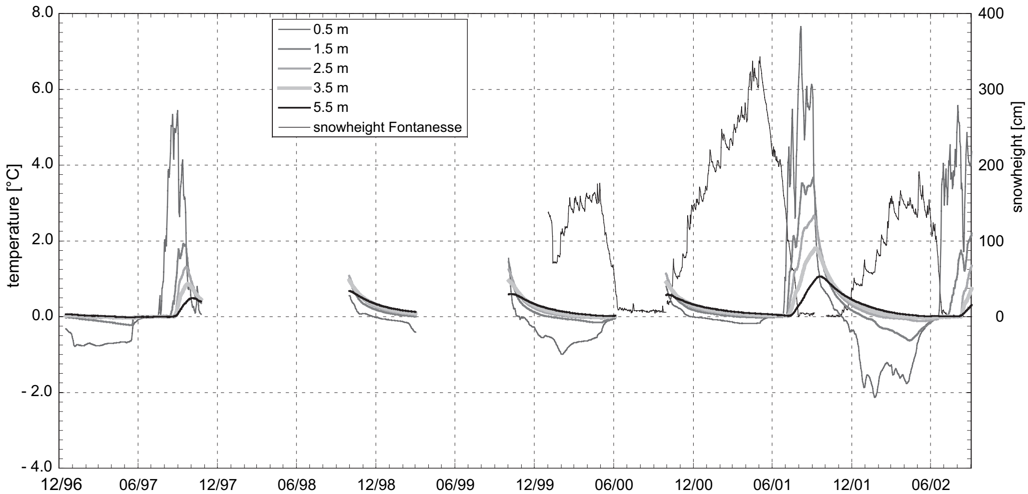

Fig. A.26: *Temperature-time plot of the borehole Arolla B2/96 for the thermistors at 0.5, 1.5, 2.5, 3.5 and 5.5 m depth. Additionally, the snow height at Fontanesse is displayed.*

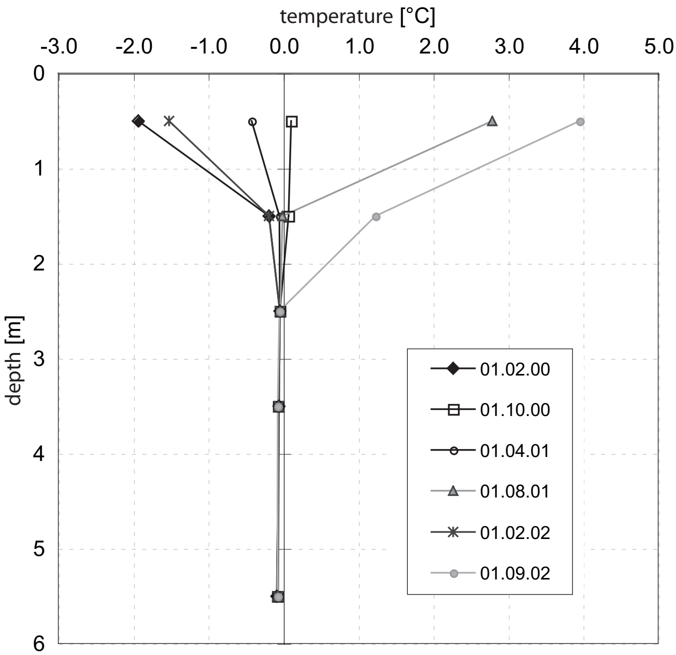

Fig. A.27: *Temperature profile Arolla B1/96.*

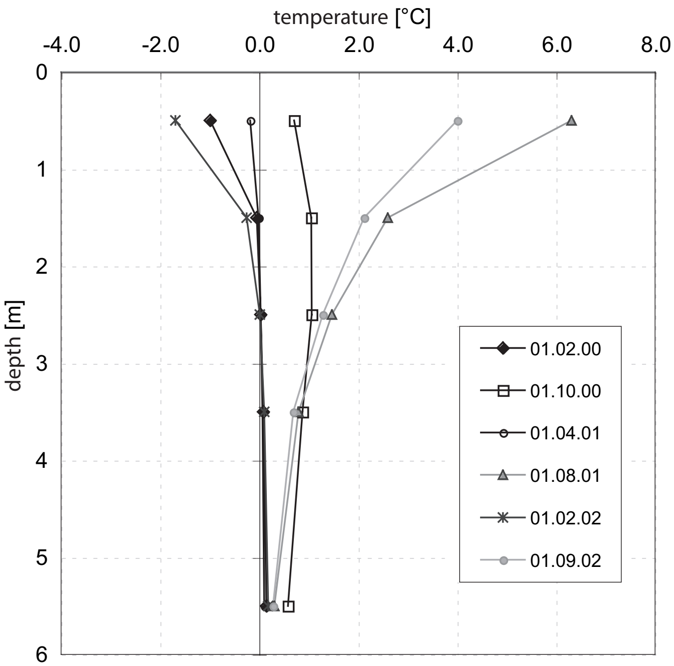

Fig. A.28: *Temperature profile Arolla B2/96.*

Emshorn 4/96, 5/96 and 6/96

Site	
Description	Emshorn, Central Valais, VS
Coordinates	618500/124100
Elevation [m a.s.l.]	2470-2500
Slope angle [°]	35
Slope aspect	NE
Morphology	Steep grassy ridge
Lithology	Shale (?)
Vegetation	Alpine grass
Borehole	
Drilling date	1996
Depth [m]	6-8
Chain length [m]	–
Thermistor depths [m]	–
Thermistor type	–
Last calibration	– .
Responsible	SLF, M. Phillips, GIUZ/Univ. Basel, D. Vonder Mühll
Other measurements	–
Comments	Manual measurements
Available data	Since

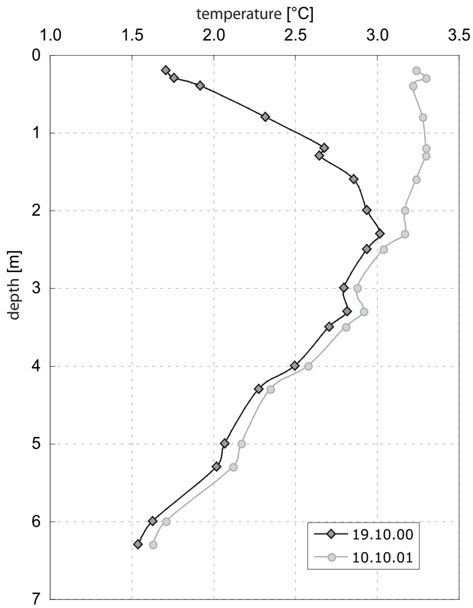

Fig. A.29:
Temperature profile Emshorn 4/96.

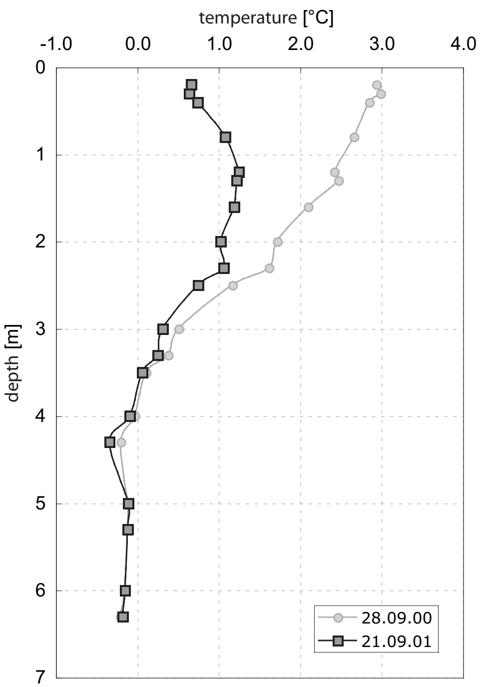

Fig. A.30: Temperature profile Emshorn 5/96.

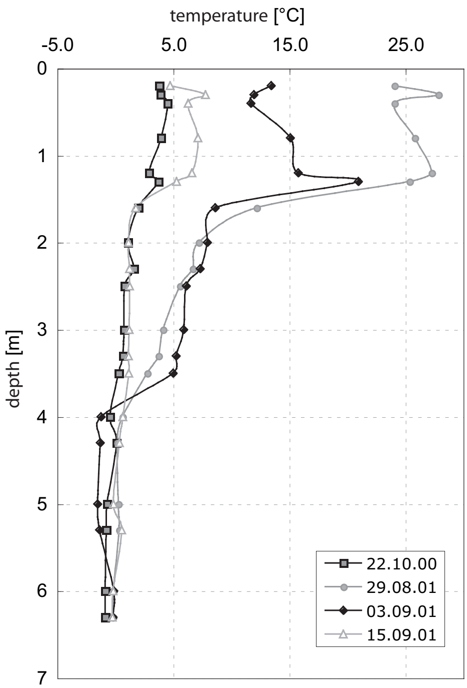

Fig. A.31: Temperature profile Emshorn 6/96.

Lapires 1/98

Site	
Description	Val de Nendaz, VS
Coordinates	588070/106080
Elevation [m a.s.l.]	2500
Slope angle [°]	25
Slope aspect	NE
Morphology	Talus slope
Lithology	Gneiss (mainly)
MAAT	0.5 °C
Vegetation	No vegetation
Borehole	
Drilling date	10.1998
Depth [m]	19.6
Chain length [m]	19.6
Thermistor depths [m]	0.7, 1.7, 2.45, 2.8, 3.15, 3.61, 4.03, 4.51, 5.01, 6.7, 11.1, 19.6
Thermistor type	Pt 100
Last calibration	11.1998
Meteostation	
Installation date	11.1998
Sensors	air temperature, shortwave radiation, reflected shotwave radiation
Responsible	IGUF, R. Delaloye
Other measurements	BTS/GST
Comments	Temperate (warm) permafrost; air circulation through the talus slope.
Available data	Since 1998 (with some gaps)

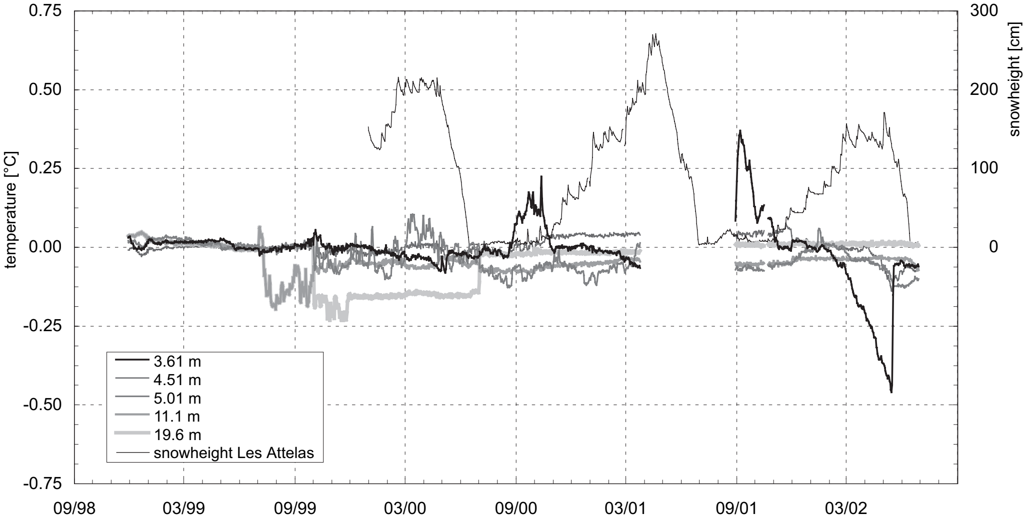

Fig. A.32: *Temperature-time plot of the borehole Lapires 1/98 for the thermistors at 3.61, 4.51, 5.01, 11.10 and 19.60 m depth. Additionally, the snow height at Les Attelas is displayed.*

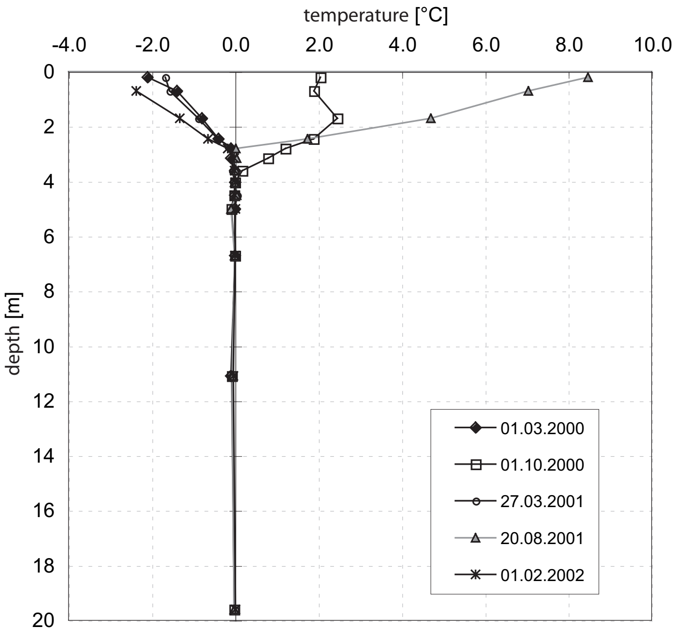

Fig. A.33: *Temperature profile Lapires 1/98.*

Randa Wisse-Schijen 1/00, 2/00 and 3/00

Site	
Description	Matter Vallex, VS
Coordinates	1/00: 624032/105064, 2/00: 624050/105080, 3/00: 624140/105100
Elevation [m a.s.l.]	1/00: 3070, 2/00: 3045, 3/00: 2950
Slope angle [°]	40
Slope aspect	ENE
Morphology	Scree slope
Lithology	Gneiss, quarzite, marble
MAAT/Precipitation	–
Vegetation	No vegetation
Borehole	
Drilling date	2000
Depth [m]	4
Chain length [m]	2.8
Thermistor depths [m]	0.3, 0.8, 1.8, 2.8
Thermistor type	UTL
Last calibration	1997
Responsible	SLF, M. Phillips
Other measurements	BTS/GST
Comments	Snow nets, boreholes deeper, but filles with salt
Available data	Since 2001

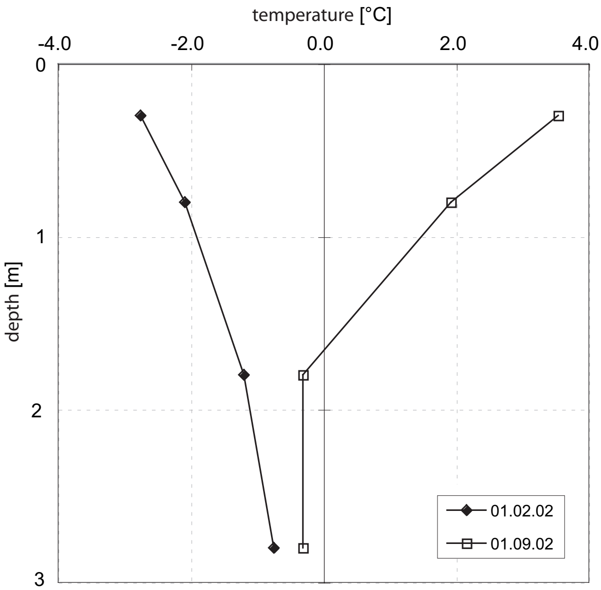

Fig. A.34: *Temperature profile Randa Wisse-Schijen 1/00.*

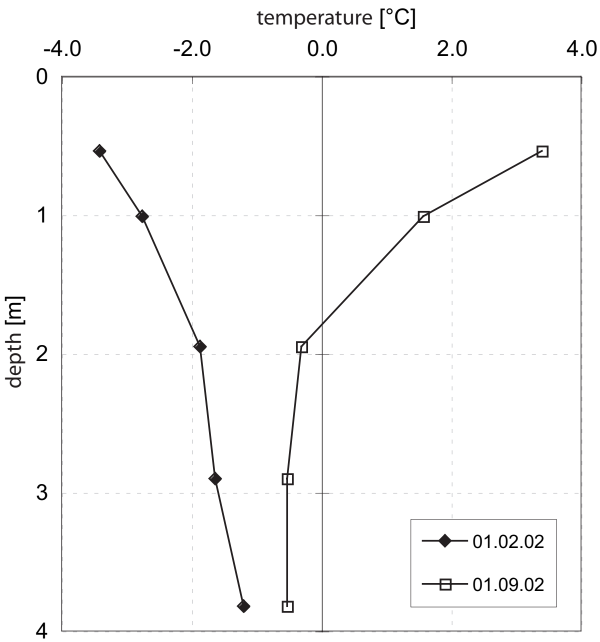

Fig. A.35: *Temperature profile Randa Wisse-Schijen 2/00.*

Stockhorn 60/00 and 61/00

Site	
Description	Stockhorn Plateau, Gornergrat, Matter Valley, VS
Coordinates	60/00: 629878/92876; 61/00: 629867/92850
Elevation [m a.s.l.]	3410
Slope angle [°]	8
Slope aspect	S
Morphology	Plateau on crest
Lithology	Albit-Muskowit schists
MAAT/Precipitation	-5.5 °C / 1500 m
Vegetation	Virtually none
Borehole	
Drilling date	August 2000
Depth [m]	60/00: 100; 61/00: 31
Chain length [m]	60/00: 100; 61/00: 17
Thermistor depths [m]	PACE standard
Thermistor type	NTC-YSI 440006
Last calibration	August 2000
Meteostation	
Installation date	6.2002
Sensors	air temperature, relative humidity, net radiation, snow-depth, wind speed/ direction
Responsible	GIUZ, M. Hoelze and S. Gruber, Univ. Giessen, L. King
Other measurements	BTS/GST
Comments	–
Available data	Since 2000

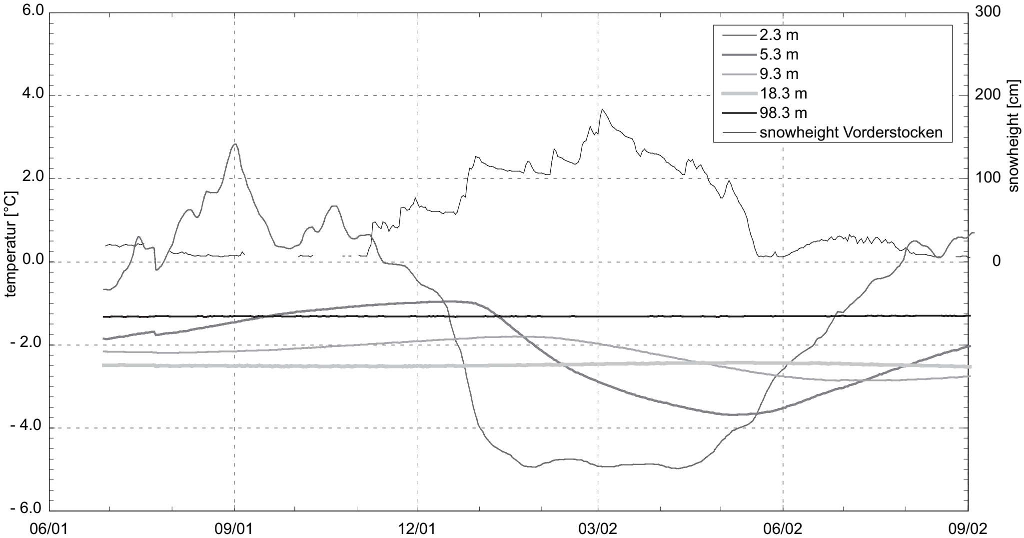

Fig. A.36: *Temperature-time plot of the borehole Stockhorn 60/00 for the thermistors at 2.3, 5.3, 9.3, 18.3 and 98.3 m depth. Additionally, the snow height at Vorderstocken is displayed.*

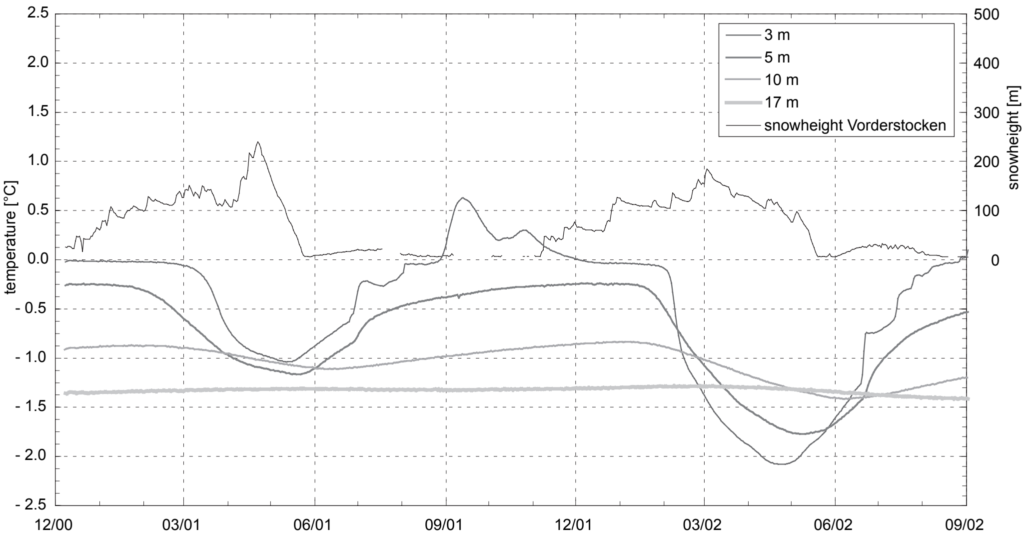

Fig. A.37: *Temperature-time plot of the borehole Stockhorn 61/00 for the thermistors at 3.0, 5.0, 10.0 and 17.0 m depth. Additionally, the snow height at Vorderstocken is displayed.*

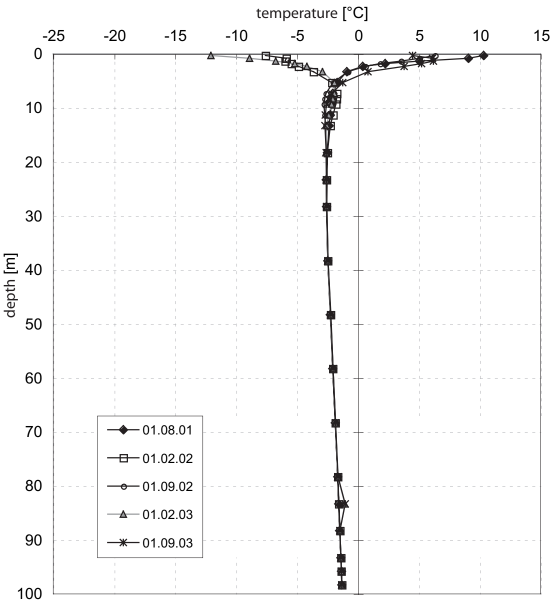

Fig. A.38: Temperature profile Stockhorn 60/00.

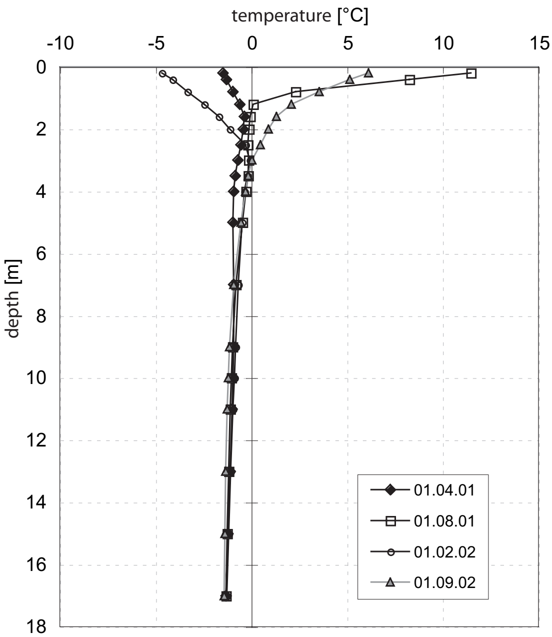

Fig. A.39: Temperature profile Stockhorn 61/00.

Flüela 1/02

Site	
Description	Flüelapass Schottensee, GR
Coordinates	791375/180575
Elevation [m a.s.l.]	2394
Slope angle [°]	26
Slope aspect	NE
Morphology	Scree slope, slope base
Lithology	Amphibolit, paragneiss
MAAT/Precipitation	–
Vegetation	No vegetation
Borehole	
Drilling date	19.8.2002
Depth [m]	23
Chain length [m]	20
Thermistor depths [m]	0.25, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, 15.0, 20.0
Thermistor type	YSI 46006 + Campbell CR10X
Last calibration	1.10.2002
Responsible	SLF, M. Phillips
Other measurements	–
Comments	–
Available data	Since 2002

Grächen 1/02 and 2/02

Site	
Description	Midway station Seetalhorn chairlift
Coordinates	6235490/112120
Elevation [m a.s.l.]	2450
Slope angle [°]	flat
Slope aspect	NW
Morphology	Moraine, artificially modified
Lithology	Moraine
Vegetation	No vegetation
Borehole	
Drilling date	09.2002
Depth [m]	25
Chain length [m]	24
Thermistor depths [m]	0.25, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 6.0, 8.0, 10.0, 15.0, 24.0
Thermistor type	YSI 46006 + Campbell CR10X
Last calibration	2002
Responsible	SLF, M. Phillips
Other measurements	None
Comments	One borehole has a 20 m thick talik (0-20), the other an active layer of ca. 6 m
Available data	Since 2002

B – Instructions for temperature monitoring in mountain permafrost (PACE-manual)

By Daniel Vonder Mühll, University of Basel

Note: This manual was written in 2000. Mentioned prices may have to be adapted accordingly.

Objectives of temperature measurements

Permafrost is defined by material (lithosphere), time (more than one year) and temperature (below 0 °C). The temperature in the soil is the crucial parameter for permafrost areas. The goals of the temperature measurements are different depending on the depth.

a) Surface and active layer

The bottom temperature of the winter snow cover (BTS) is an indicator for the distribution of permafrost. It can only be applied when the snow cover thickness is greater than 80 cm. BTS depends on the evolution of the snow cover in winter (e.g. a large snowfall in early winter causes warm values, whereas when only little snow falls, the BTS may be very cold).

To measure temperature at the surface a BTS probe can be used (commercially available from markasub ag, CH-Basel; approx. € 1’000). To record the temperature continuously, so called UTL1 (universal temperature loggers; B. Blank, University Bern; approx. € 150) can be installed at the surface or in the uppermost centimeters of the active layer.

The temperature measurements at the surface and/or in the active layer may be ambiguous with respect to permafrost. Even calculating a running mean with a time window of one year may result in positive temperatures, as has been shown in the permafrost borehole Murtèl-Corvatsch (Vonder Mühll et al., 1998).

Measurements above the permafrost table aim to observe the input signal which governs the thermal regime. In combination with energy balance measurements they can help to understand the various heat fluxes involved. The active layer reacts instantaneously to changes in climate conditions. Therefore a high spatial resolution of temperature readings is crucial.

b) Below the permafrost table

These measurements can prove the presence of active permafrost. The readings remain negative all year around. Seasonal variations are observed down to the ZAA (depth of zero annual amplitude) with amplitude diminution and phase lag effects. Thermal characteristics can be calculated and climate variations integrated over a few years can be observed in this depth range. The major part of the heat transport takes place as thermal conduction.

c) Near the permafrost base
An important parameter of drillings in permafrost is the thickness of the permanently frozen body. Near the permafrost base, temperatures are close to 0 °C. Similar to zero curtain effects in the active layer, temperature may be close to 0 °C within a particular depth range (e.g. at borehole Pontresina-Schafberg 2/90). In the Murtèl-Corvatsch drilling, even an intrapermafrost talik has been encountered. Theoretically, the modification of the permafrost base takes place very slowly.

Thermistors

Various type of temperature sensors are available. Negative temperature coefficient electrical resistivities (thermistors) are easy to install and have shown good results so far. The conversion from the resistivity R [Ohm] into temperature T [°C] is defined by the Steinhart-Hart equation:

$$\frac{1}{T} = A + B \ln R + C (\ln R)^3$$

The coefficients A, B and C are determined by calibration.

Precision

Thermistors with different accuracies can be obtained. The more accurate they are, the more expensive. There is a drift with time. In general, the sensors are recalibrated periodically. Well calibrated thermistors determine temperature with an absolute precision of ±0.1 °C and a relative one of ±0.05 °C.
In the Murtèl borehole the following types were used with good results:
– Yellow Spring Instruments (YSI) 44006 (25 °C = 10 kOhm; 0 °C = 29.5 kOhm)
– Fernwall UUA 41J1 (25 °C = 15 kOhm; 0 °C = 34 kOhm)

The thermistor chain

The thermistors are attached to a cable at appropriate distances, which can be chosen. The cable should not be elastic to ensure the thermistors' position remains constant. It is important that the final position of the thermistors is measured when the cable hangs freely. A weight is placed at the lower end of the chain, to feel when the chain reaches the bottom of the hole.

Spacing of the thermistors

In principle the spacing of the thermistors is logarithmic. However, where depth ranges are of special interest, a cluster of thermistors must be installed.

Such zones are:

- the active layer
- around the permafrost table
- around probable shear horizons
- around probable intrapermafrost taliks (e.g. borehole Murtèl-Corvatsch 2/87)
- around the permafrost base
- in the bedrock (to determine the lower input of heat flow)

In the active layer down to approx. 1 m below the permafrost table a spacing of less than 0.5 m is recommended. Then, a 1 m spacing is appropriate down to 15 m, then 5 m spacing to 30 m depth, etc.

Example of spacings for 30 thermistors in a 100 metre deep borehole:

0.0, 0.4, 0.8, 1.2, 1.6, 2.0, 2.5, 3.0, 4.0, 5.0, 7.0, 9.0, 11, 13, 15, 20, 25, 30, 40, 50, 60, 70, 80, 85, 90, 92, 94, 96, 98, 100 m.

Preparation of the borehole

It is very important that the temperature sensors can be extracted. The thermistor chain is lowered in a tube which may be used for borehole deformation measurements (diameter ca. 72 mm) or a tube which has to be installed specifically for this purpose. The diameter of the tube depends on the amount of borehole deformation: the larger the deformation the bigger the diameter to prevent an early cut off of the tube by shearing.

Installation

The chain is lowered down in the tube until the weight reaches the bottom of the hole. Then the chain is pulled some cm upwards and fixed. There are several possibilities to fix the chain. When the temperature sensors are lowered in the slope-indicator tube, the tube must be treated carefully. The tube must be sealed to prevent the penetration of water.

Temperature readings

Temperature readings should always follow the same procedure. If the access to the borehole is time consuming, readings should be taken either with a data logger and/or at least once every year at more or less the same date (allowing comparison from one year to the other).

a) Manual readings using a digital multimeter
Each thermistor's resistivity is measured by a digital multimeter. The values are written onto the form and temperatures calculated in the office.

b) Storing data with a logger
A data logger allows a high temporal resolution of the readings. In principle, the sampling rate should be different at different depths. To avoid aliasing every sine cycle should consist of at least 4 readings. Near surface thermistors down to approximately 5 m should be read every 6 hours, further down, once every day.

The problem of energy supply must be considered carefully. Solar panels may be a good solution. The logger readings should be compared to readings taken by a multimeter to ensure the accuracy. Calibrations should be done with the original field system (including data logger etc).

Data management

The data are stored in the PACE data base (see there).

Purchase or fabrication of thermistor chains

Stump Bohr AG (Mr. U. Sambeth, CH-Nänikon) produce such thermistor chains for VAW-ETH Zürich.

Approx. costs (true for the year 2000):

15 thermistors, 30 m long chain	SFr. 2'500 (≈ € 1'600)
30 thermistors, 90 m long chain	SFr. 5'200 (≈ € 3'300)
45 thermistors, 90 m long chain	SFr. 7'800 (≈ € 5'000)