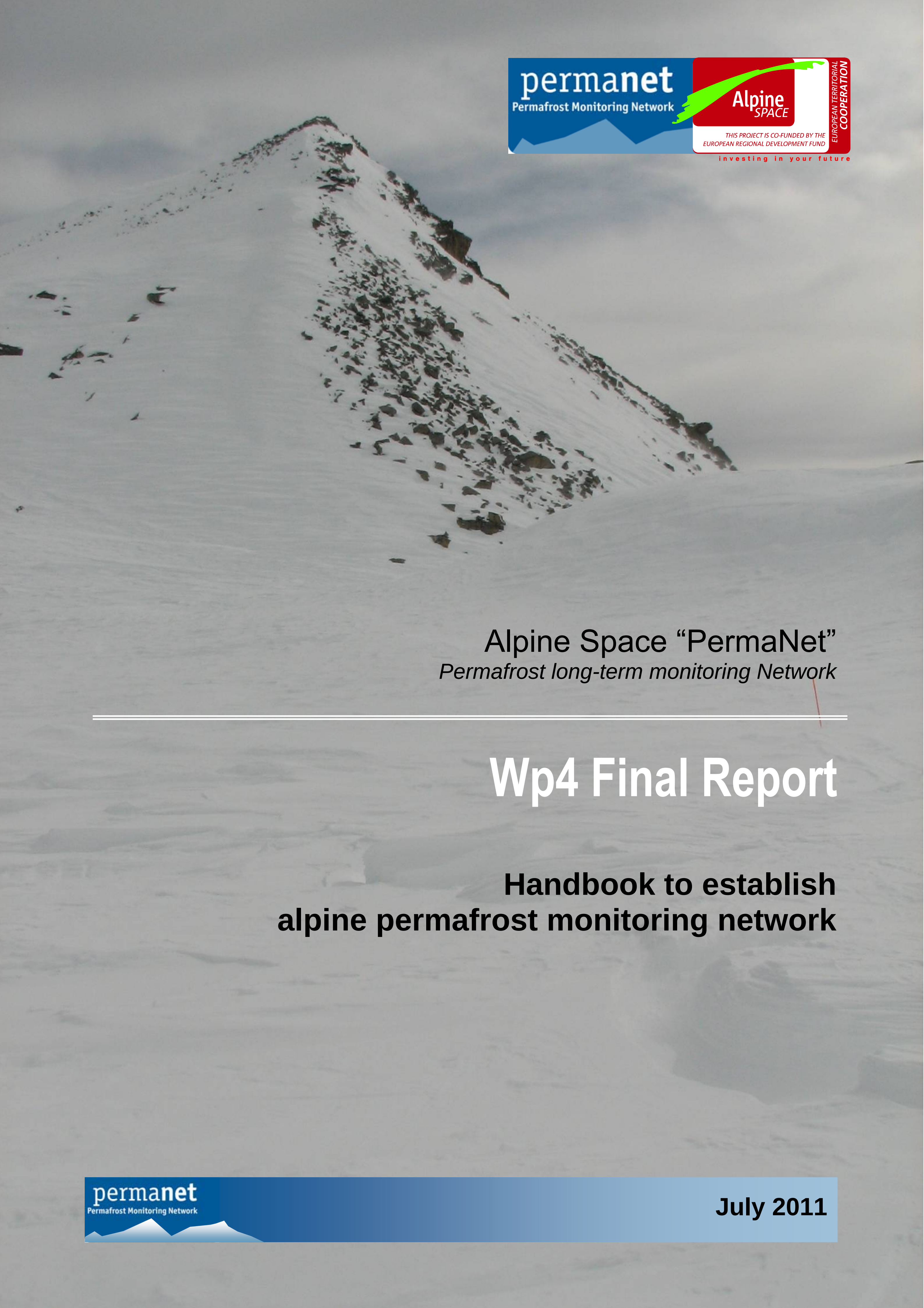

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Alpine Space “PermaNet”

Permafrost long-term monitoring Network

Wp4 Final Report

Handbook to establish alpine permafrost monitoring network

July 2011

WP4 – Permafrost monitoring network (WP coordinator: Arpa Piemonte, Italy)
FINAL REPORT
Handbook to establish alpine permafrost monitoring network

Output 4.2: Recommendations for building up national monitoring networks
Output 4.4: handbook for the installation and maintenance of an Alpine-wide permafrost monitoring network

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Cover photo: Mt. Moro Pass, Italy (by Arpa Piemonte)

Summary

Alpine Space "PermaNet" Project
Work Package 4 "Permafrost monitoring network"

Preface

The knowledge linked to glacial and periglacial processes in alpine areas is heterogeneous and incomplete. Particularly, most aspects related to climate change and its effects on the Alps are unknown or quantitatively not studied.

Recently, in the actual frame of climate change, the awareness of the scientific community and regional administration for the "hidden part" of cryosphere, the permafrost, is getting higher. Alpine permafrost distribution is still generally unknown, although several authors in the past analyzed its the distribution and the main characteristics of some permafrost indicators such as the rock glaciers.

In most mountain regions, the climate change reduces the extent and the volume of glaciers, the amount of permafrost and the seasonal snow cover. Along with changes of the precipitation regime and quantity, soil stability and water resources are affected and a large range of socioeconomic activities (e.g., agriculture, tourism, hydropower, and logging) are compromised.

The increasing tourist activities in high mountain areas and the economic development linked to natural resources exploitation, are under discussion in the frame of the future scenarios.

Glaciers retreat, permafrost degradation, perturbations of the water regime and slope instability in mountains, will produce major consequences for mountainous inhabitants and for people living downstream, outside of the mountains, who heavily depend on hydrological resources.

Regional administration, responsible authority for natural risks and water resources management, is facing new events, not considered before the 1990s: debris flows and landslides triggered in permafrost areas, river discharge reducing especially in the summer period, drought, extreme runoff and flood events, etc.

The challenge of regional authority is to experiment pilot projects with the application and implementation of new management approaches on permafrost areas. Strategic instruments and methods for a sustainable use of the mountainous areas must be developed. The transnational cooperation, through the exchange of knowledge and ideas, offers the possibility to harmonize the different approaches.

The Permafrost Monitoring Network

The core of "PermaNet" project is the creation of measuring stations for the monitoring of the main climatological parameters of the near surface atmosphere and the permafrost thermal regime. Location of the monitoring sites will be established on the basis of the geologic, climatologic and logistic features.

Thermal regime will be monitored through the installation of thermistors or thermocouples settled within boreholes (few cm to a hundred m deep) drilled in bedrock and in deposits.

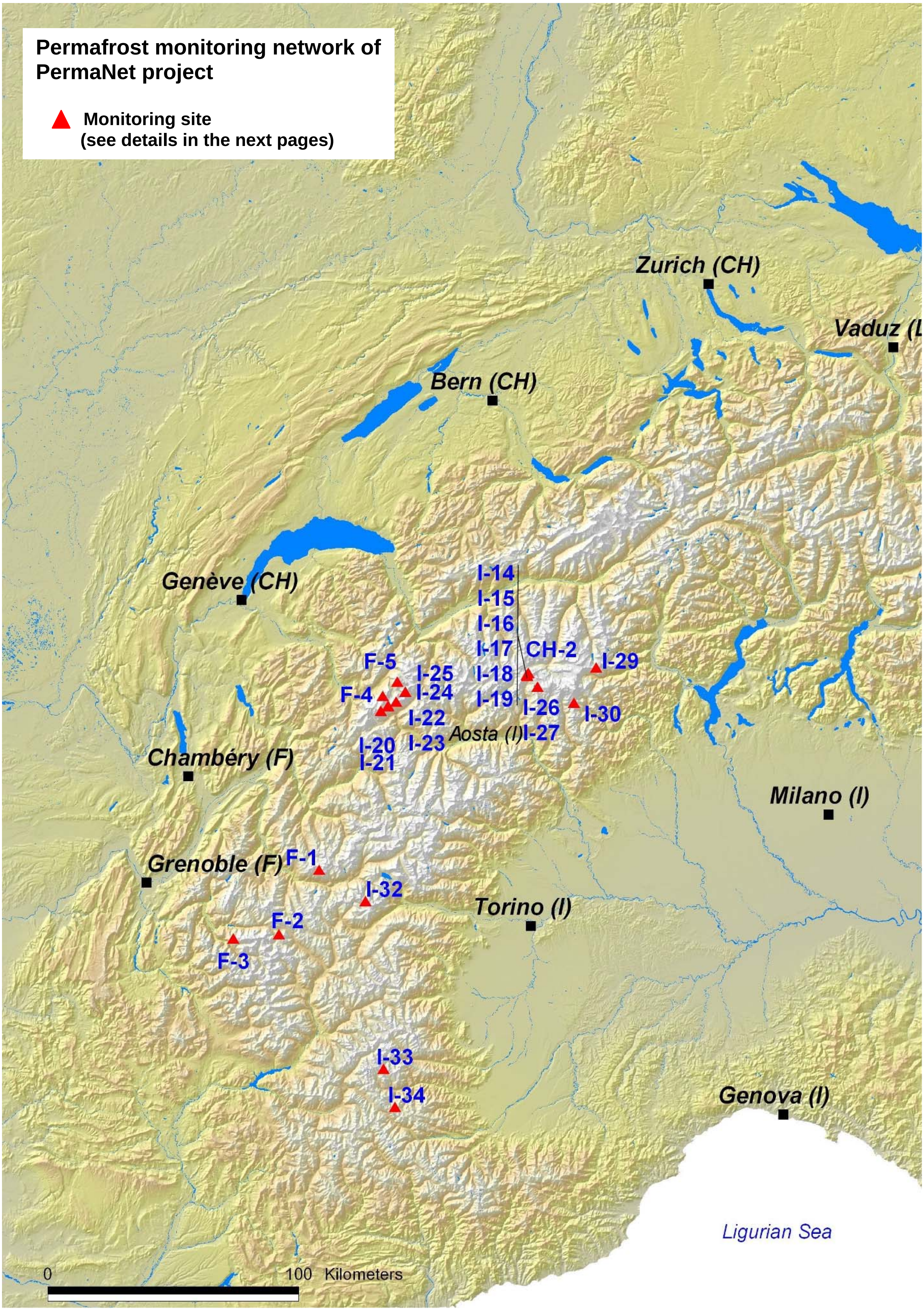
The common task is that the long-term monitoring activity will continue beyond the end of the PermaNet project, allowing the evaluation of the development of alpine permafrost degradation or aggradation.

It is absolutely fundamental, that PermaNet project builds up a network that is well planned, remains useful and operational in the long run, and leads to policy-relevant knowledge that can support future decisions. Key tasks for this are: I) the selection of the monitoring parameters, II) the key sites, and III) the standardization of the setting up of both, national and trans-national structures for the monitoring system to ensure long-term continuation and data quality. And not least, the release of a handbook, as also planned in WP4, should reflect both, existing knowledge of monitoring mountain permafrost and new experiences gained within this project.

Governance

The main goals of this monitoring network towards a governance aspects, are:

- application and dissemination of strategic approaches to land use planning and managing, through new governance processes;
- development of a communication network to support participation processes;
- development of cooperation instruments to promote natural heritage as a basis for a sustainable living in Alpine Space;
- to promote the creation of an expert team in Alpine Space to face problems linked to future scenarios of the climate changes in mountainous areas.


Permafrost monitoring network of PermaNet project
Monitoring site
(see details in the next pages)
Zurich (CH)
Vaduz (L
Bern (CH)
Genève (CH)
Chambéry (F)
Grenoble (F)
Milano (I)
Torino (I)
Genova (I)
Aosta (I)
Ligurian Sea
I-14
I-15
I-16
I-17
I-18
I-19
CH-2
I-29
I-26
I-30
I-27
F-5
F-4
I-25
I-24
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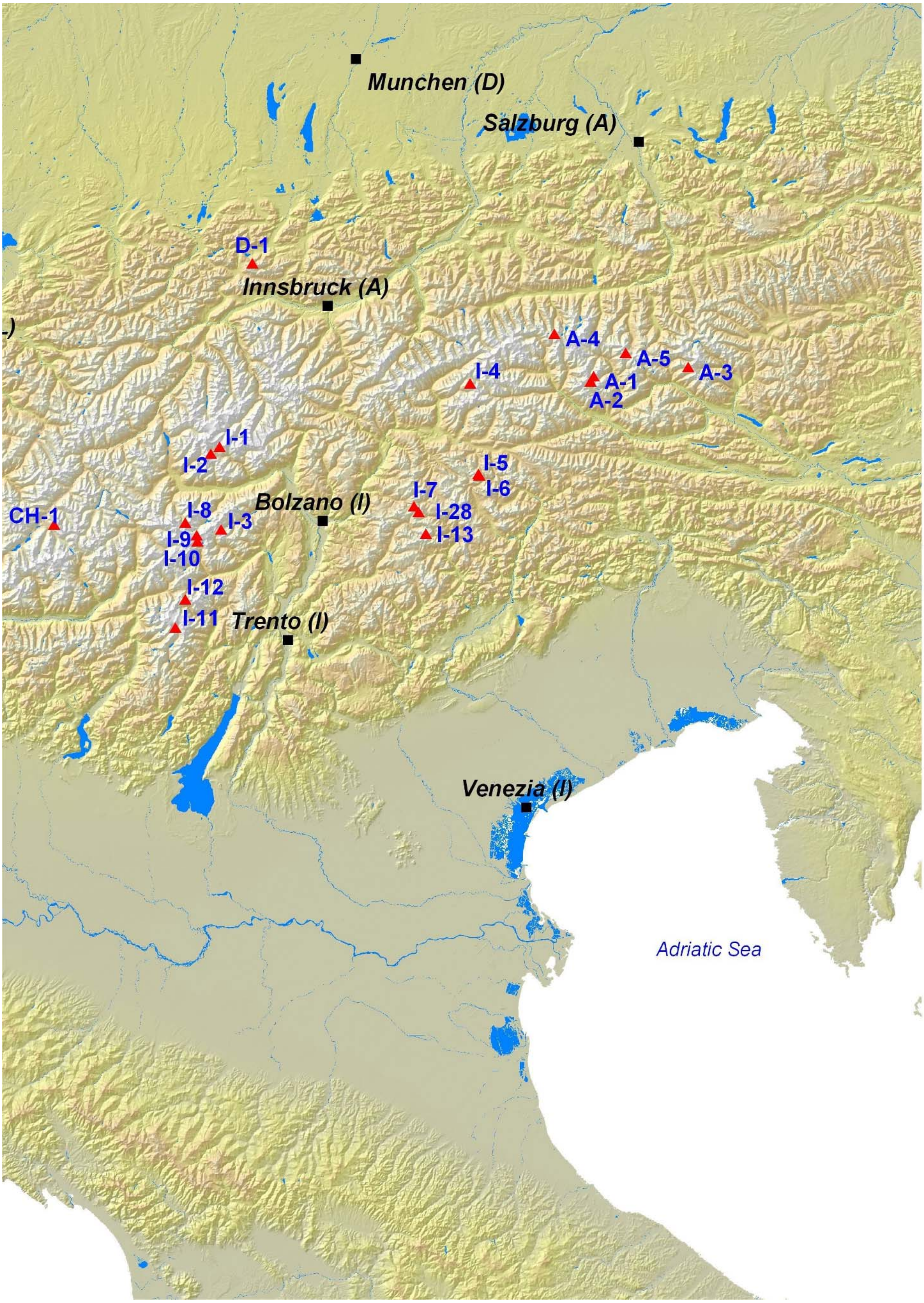
Munchen (D)
Salzburg (A)
D-1
Innsbruck (A)
A-4
A-5
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I-2
I-5
I-6
I-7
CH-1
I-8
I-3
Bolzano (I)
I-28
I-9
I-13
I-10
I-12
I-11
Trento (I)
Venezia (I)
Adriatic Sea

Permafrost monitoring network of PermaNet project

PermaNET collects the metadata of the most important permafrost monitoring sites and compiles it into a standardized permafrost monitoring network (only in the area included in the project). On key monitoring sites, new monitoring stations have been installed and instrumented.

The PermaNet Alpine-wide monitoring network now consists of about 50 monitoring sites which are measuring different parameters and characteristics of permafrost in rock and debris covered soils. The installation of new monitoring stations was partly financed by the PermaNet project. The maintenance over long periods is guaranteed by the institute or authority that installed the monitoring station.

General information

In order to supplement the monitoring network and to guarantee the compatibility of the measured data, a set of guidelines for the installation and maintenance of the monitoring stations have been formulated.

Permafrost temperatures define the thermal state of permafrost and are obtained by lowering a calibrated thermistor into a borehole, or recording temperature from multi-sensor cables permanently or temporarily installed in the borehole. Measurements may be recorded manually with a portable temperature logging system or by data loggers. Less frequent site visits are required if data loggers are used. The accuracy and resolution of the thermistors and measurement varies but it is desirable for accuracy to be ±0.1°C or better.

The depth of boreholes varies from less than 10 m to greater than 100 m. At shallower depths, generally less than 15 m, ground temperatures experience an annual temperature cycle and it is desirable to have several measurements throughout the year, at a minimum spring and fall but ideally monthly. Data loggers may be utilized for daily measurement of shallow temperatures to reduce the number of site visits and provide a continuous record of ground temperatures (GST).

The surficial part of the ground (sediment or bedrock), in the permafrost context, that experienced seasonal frost-thawing cycles is named “active layer”. At most active layer monitoring sites, the maximum thickness of the active layer is determined. However seasonal progression of the active layer, may also be monitored at sites of intensive investigations for process understanding.

Typical morphological elements in the periglacial environment are rock glaciers. These debris bodies are located in the upper part of cirques or of slopes; if they are dynamically active, they flow downward and indicate the probable presence of permafrost.

PermaNet network includes different types of permafrost monitoring, briefly described below (refers to the following tables).

Permafrost bedrock = Boreholes drilled a) on flat bedrock outcrops (vertically; depth > 20 m) or b) on steep or very steep rock faces (inclined or horizonthally) instrumented to measure the permafrost and active layer thermal profile.

Permafrost rock glacier = Boreholes drilled within rock glacier and a) instrumented to measure the thermal profile of permafrost and overlying active layer; b) to measure the horizonthal displacement along the depth profile; c) to measure a and b; d) not instrumented but drilled only to collect samples of the ice or frozen sediments.

Active Layer Rock face = Very shallow boreholes (< 1m) on vertical or vey steep rock faces instrumented with more than 2 thermistors in order to measure the thermal regime of the active layer or its upper part.

Active layer sediments = Shallow boreholes (< 10 m) drilled in sediments (i.e scree slopes; rock glacier) and instrumented with more than 2 thermistors in order to measure only the active layer thermal regime or part of it.

GST = Sites instrumented to measure ground surface temperature (GST, usually first 2 cm from the surface) in order to understand the spatial variability of the surface temperature and therefore possible permafrost conditions.

Following the example of the Swiss permafrost monitoring network PERMOS, national permafrost monitoring networks have been founded. In France, the PermaFRANCE network has been established. In Italy and Austria, national monitoring networks are in preparation. The national monitoring networks are coordinating the monitoring activities on national scale. An overview about the results of permafrost monitoring in the European Alps can be compiled periodically on the basis of data from the key monitoring stations.

PermaNet monitoring network: site details (for each Country)

AUSTRIA

ID	Location	Elevation	Permafrost		Active layer		GST	Other and Notes
			Bedrock	Rock Glacier	Rock Face	Sediment		
Istitution: University of Innsbruck, Institute of Geography								
A-1	Hinteres Langtal Hohe Tauern	2500-2770	X	X	X	X	X	
A-2	Weissen Cirque, Hohe Tauern	2670	X	X	X	X	X	
A-3	Dösen Valley, Hohe Tauern	2500-2630	X	X	X	X	X	
Istitution: Central Inst. For Meteorology and Geodynamics (Salzburg)								
A-4	Hoher Sonnblick	3105	X (a)					www. sonnblick.net
A-5	Goldbergspitze	2400-2800					X	

FRANCE

Istitution: PERMAFrance (J. Fourier University, CNRS and Grenoble Institute of Technology)

ID	Location	Elevation	Permafrost		Active layer		GST	Other and Notes
			Bedrock	Rock Glacier	Rock Face	Sediment		
F-1	Orelle	2780 - 3050					X	
F-2	Laurichard	2450 - 2630		X			X	
F-3	Deux Alpes	3178	X (a)				X	
F-4	Aiguille de Midì	3820			X			in collaboration with Arpa Valle d'Aosta
F-5	Les Drus	3280			X			in collaboration with Arpa Valle d'Aosta

GERMANY

Istitution: Bavarian Environment Agency, Geological Survey

ID	Location	Elevation	Permafrost		Active layer		GST	Other and Notes
			Bedrock	Rock Glacier	Rock Face	Sediment		
D-1	Zugspitze	2940	X (b)					

SWITZERLAND

Istitution: BAFU and Zurich University

ID	Location	Elevatio n	Permafrost		Active layer		GST	Other and Notes
			Bedrock	Rock Glacier	Rock Face	Sediment		
CH-1	Muot da Barba Peider, Pontresina	2980		X		X		
CH-2	Hörnligrat, Matterhorn	3260			X			

ITALY

ID	Location	Elevation	Permafrost		Active layer		GST	Other and Notes
			Bedrock	Rock Glacier	Rock Face	Sediment		
Istitution: Autonomous Province of Bolzano, Office for Geology and Building Materials Testing								
I-1	Senales - Grawand (BZ)	3140	X (b)					
I-2	Senales - Lazaun (BZ)	2570		X (c)			X	Georadar, GPS, discharge
I-3	Ultimo - Rossbänk (BZ)	2550		X (c)			X	Georadar, GPS, discharge
I-4	Riva di Tures - Napfen (BZ)	2600						BTS, GPS, discharge
I-5	Braies - Croda Rossa "Cadin del Ghiacciaio" (BZ)	2350					X	Georadar, GPS, spring temperature, temperature profile (0-150cm) on the rockglacier
I-6	Braies - Croda Rossa "Cadin di Croda Rossa" (BZ)	2460					X	Georadar, spring temperature, temperature profile (0-150cm) on the rockglacier
I-7	Passo Gardena - Lech del Dragon (BZ)	2670					X	Georadar, spring temperature, temperature profile (0-150cm) on the rockglacier
I-8	Solda - Madritsch (BZ)	2900					X	BTS since 1992
Istitution: Autonomous Province of Trento, Civil and Territory Protection department, Geological Survey								
I-9	Cavaion (TN)	2890	X					
I-10	Cavaion (TN)	2865					X	
I-11	Lobbie (TN)	3050	X					
I-12	Presena (TN)	2650					X	
I-13	Cima Uomo (TN)	2460					X	
Istitution: Aosta Valley Region and Arpa Valle d'Aosta, www. arpa.vda.it								
I-14	Matterhorn Carrel South (AO)	3820			X			
I-15	Matterhorn CarreL North (AO)	3815			X			
I-16	Matterhorn Cheminee - new (AO)	3750			X			
I-17	Matterhorn Cheminee - old (AO)	3750			X			
I-18	Matterhorn Oriondè - fractured (AO)	2995			X			
I-19	Matterhorn Oriondè - not fractured (AO)	2992			X			
I-20	Col d'Entreves South (AO)	3510			X			
I-21	Col d'Entreves North (AO)	3535			X			
I-22	Grandes Jorasses South - right (AO)	4100			X			
I-23	Grandes Jorasses South - left (AO)	4100			X			
I-24	Col Peuterey North (AO)	3965			X			
I-25	Aiguille Marbree (AO)	3250			X			
I-26	Cime Bianche Pass - shallow (AO)	3100				X		
I-27	Cime Bianche Pass - deep (AO)	3100	X					
Istitution: Region of Veneto, Geological Survey and Arpa Veneto								
I-28	Piz Boè (BL)	2908	X (a)					
Istitution: Arpa Piemonte, Regional Center for Geological Researches, www. arpa.piemonte.it								
I-29	Mt. Moro Pass (VB)	2870	X (a)				X	
I-30	Salati Pass - Mosso Inst. (VC)	2950			X		X	
I-31	Salati Pass - Corno dei Camosci (VC)	3020	X (a)					
I-32	Sommeiller Pass (TO)	2985	X (a)		X		X	
I-33	La Colletta Pass (CN)	2850	X (a)				X	
I-34	Gardetta Pass (CN)	2490	X (a)				X	

Guidelines for monitoring

1. International networks and recommendation for a national permafrost monitoring network

Output 4.2: Recommendations for building up national monitoring networks

1.1 International networks

Among the international network related or interested on permafrost GCOS (Global Climate Observing System) is surely the most important. This network is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). Its goal is to provide comprehensive information on the total climate system and all the atmospheric, oceanic, hydrological, cryospheric and terrestrial processes. In detail, the FAO-UNEP-UNESCO-ICSU Global Terrestrial Observing System (GTOS) is the observing system in which permafrost is one of the key monitored elements. GCOS is intended to meet the full range of national and international requirements for climate and climate-related observations. Within GTOS the Global Terrestrial Network for Permafrost (GTN-P) is the primary international programme concerned with monitoring permafrost parameters. GTN-P was developed in the 1990s with the long-term goal of obtaining a comprehensive view of the spatial structure, trends, and variability of changes in the active layer and permafrost temperature (Brown *et al.*, 2000). More recently the International Polar year (2007-2009) provided the motivation to expand the GTN-P and to obtain a global snapshot of permafrost temperatures and active layer measurements. The IPy-Project called Thermal State of Permafrost (TSP) collect approximately 500 candidate sites, many of which are instrumented with data loggers. The coverage can be considered representative in North America and in some parts of the Nordic region in Europe, in Russian Federation and Central Asia while in other parts of the world like South America, Antarctica, Hymalayan or North American mountains areas large gaps still exist.

Borehole metadata (provided on a standardized form) for the TSP component and summary data, for some sites, are available on the GTN-P web site (www.gtnp.org) hosted by the Geological Survey of Canada's permafrost web site. More detailed data sets are also transferred or linked periodically to a permanent archive at the National Snow and Ice data Center (NSIdC) in Boulder, Colorado. Data may also be archived and available through various national government organizations with metadata accessible through NSIdC and other data portals.

Within the Europe, after the experience of the European funded project PACE (Permafrost and Climate in Europe) that developed between 1997 and 2001 a network of boreholes 100 m deep along a latitudinal transect between Svalbard Island and South Spain through the Alps (Harris et al., 2001; Harris et al., 2003; Guglielmin, 2004) the networks have been developed only at national scale like in the case of Switzerland for PERMOS (Vonder Muehll et al., 2008). Concerning only the active layer the CALM network (www.udel.edu/Geography/calm/ coordinated through the University of Delaware) is surely the network more developed and ancient (developed during the within the ITEX initiative). Metadata and ancillary information are available for CALM site, including climate, site photographs, and descriptions of terrain, soil type, and vegetation. This site description information is provided by investigators on a standardized form that is available on the web sites. Data are transferred or linked periodically to a permanent archive at the NSIdC.

1.2 Recommendation for a national permafrost monitoring network

The main goal of national or transnational permafrost monitoring programme should be to document the state of permafrost on a long-term basis, and hence, temporal permafrost variations. Among the observed parameters different strategies can be adopted but in a pragmatic way these network has to start from the existent infrastructure (equipped drillings, ground surface temperature sites, rock wall temperature sites, calm grid) that was established within research projects. New and explicit sites will be placed only after available and existing stations are updated to a common standard.

New stations should be located in regions where gaps occur and above all, ideally each climate region of the Alps should be covered.

The knowledge on the climate assessment and permafrost distribution are therefore the base for developing new structures.

The two main principle are in fact territorial (try to describe all the alpine territory where permafrost occur) and climatic (try to have monitoring sites on all the different types of climatic conditions at the regional scale at least).

Permafrost monitoring is important both for its contribution to understanding issues related to environment, climate change, and natural hazards and therefore also towards society and politics.

The choice of new sites should also decided considering its accessibility, installation and maintaining costs.

Where monitoring structures are already present, the first step toward the creation of a permafrost monitoring network should be the standardization of these structures, especially in terms of timing of sampling and recording of data, data transmission and data archiving.

One of the crucial point is the creation of a national or a transnational data archive.

The best way to achieve this goal is to build an agreement among all the local public administrations, the academy and all the other public and private subjects that can be interested to be involved in the creation, management and in the use of the realized data.

Only with a multi-participate structure the long-term conduction of the network can be assured.

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Guidelines for monitoring

2. Handbook to establish alpine permafrost monitoring network

Output 4.4: handbook for the installation and maintenance of an Alpine-wide permafrost monitoring network

2.1 General information

This handbook mainly collects the PermaNet experience in establishing an Alpine-wide permafrost monitoring network. Moreover, it takes into account several other experiences, developed before the PermaNet project, in the Alps and around the World, but intensively applied in this Alpine Space application.

In the PermaNet project many methodologies for permafrost monitoring have been applied. It is important to underline that only the thermal conditions of the ground and underground (permafrost and active layer) have been considered in this handbook.

Specifically, we refer to:

- GST (Ground Surface Temperature)
- Ground near surface temperature in steep rockwall
- BTS (Bottom Temperature of Snow cover)
- Thermal monitoring of active layer
- Thermal monitoring of permafrost

Other techniques, like geophysics, GPS or other monitoring system in order to analyse presence, distribution and movement related to permafrost and frost creep, are not considered in this handbook. Presence, distribution and evolution of permafrost are topics of Wp5 “Permafrost and climate change”, while frost creep is a specific topic of Wp6 “Related natural hazard”; also the thermal analysis of the water and springs linked to permafrost ice degradation is not considered in this handbook, since it is a focus of Wp7 “Water resources”. Results and outputs of these Wps are available on the PermaNet website.

In this handbook, information about each kind of thermal monitoring are reported as guidelines and database. Guidelines have been structured in: definition, measurement techniques, data analysis or measurement strategies; in some case, a particularly significant PermaNet experience is presented. The database describes how to organize the data collection, with specific field definition (metadatabase).

GST
Ground Surface Temperature

GST monitoring through datalogger (photo by: Provincia Autonoma di Trento)

Guidelines for monitoring

Definition

Ground Surface Temperature (GST) is defined as the surface or near-surface temperature of the ground (bedrock or surficial deposit), measured in the uppermost centimetres of the ground.

GST depends from the energy balance of the surface and from its characteristics (vegetation cover, roughness, colour and moisture; Klene et al., 2001).

GST is an important parameter to understand the thermal evolution of the active layer and the underlying permafrost.

GST monitoring has to be continuously all year round in order to understand the energy balance of the surface.

GST monitoring is also useful as a part of the active layer monitoring (see chapter n.) and for understanding the relationships between the climate and the active layer and its underlying permafrost.

Some authors (Haeberli 1973) enhance the importance Winter Equilibrium Temperature (WEqT), defined as the GST at the moment in which ground surface is insulated from the the atmosphere (generally reached when the snow cover is thicker than 80-100 cm and for a sufficient time period). On the other hand this parameter is quite ambiguous because depends from the onset of the snow cover and from the snow cover thickness, therefore lacking the snow monitoring is better not consider it.

Measurement techniques

GST should be monitored through a temperature probe connected to a mono or multichannel logger. The depth of the probe should be 2 cm according several authors (Osterkamp, 2003; Guglielmin, 2006; CALM protocol).

The probes should be inserted parallel to the surface avoiding any ruptures or fracture on the surface where fine soil or vegetation mat occur. On bare screes the probes should be taped on the bottom face of a tabular stone and adjusted in the middle of the other debris.

In any case is necessary to avoid the direct radiation.

The probes should have an accuracy of 0.1-0.2°C and a minimum resolution of 0.1°C

The sampling interval should be hourly although 10 minutes is recommendable.

Minimum, maximum and daily mean should be recorded although hourly data are better if the capacity of the chosen datalogger allow it.

The datalogger should be waterproof and with a memory and a battery that have to assure at least 1 year of life with the sampling and recording chosen set up .

If temperature probes are external to the datalogger, is really important to buried accurately all the cables in order to prevent any damages.

Considering the extreme high variability of the GST according the surface characteristics a set of 3 to 4 measurements points is a minimum for a monitoring site and has proved to be a good compromise between cost and representativity.

For each measurement point the elevation (m a.s.l.), the slope and aspect of the surface (considering the mean value of a square of 2 m centred at the point), the nature of the surface (bare or vegetated), the mean grain size of the surface material. For the vegetated surfaces the main type and % of vegetation cover should be noted.

Monitoring sites can be very different: rock glacier; scree slope, glacial foreland etc and for example for rock glacier monitoring we suggest at least three points on the rock glacier surface, placed respectively on the root zone, the centre and the frontal lobe and a couple outside (one below the front and another laterally, better at the same altitude of the central).

Data Analyses

The GST data can be analysed in a different ways according the main proposes of the research. If air temperature data on the monitoring site are lacking we suggest to calculate five derived parameters:

- Annual GST mean : mean of the 365/6 daily GST mean; values below 0°C indicate permafrost presence.
- Summer GST mean: conventionally has been calculated (on the northern hemisphere) as the mean of the daily mean values of the period from 1 June and 31 August. It is important parameter that leads the active layer thickness.
- Annual Thawing Degree Days (TDD_y): Sum of all the daily mean values higher or equal to 0°C. It is a parameter that describe the energy balance of the year (together with the annual Freezing Degree Days) with negative balance (permafrost conditions) when
- -Annual Freezing Degree Days (FDD_y): Sum of all the daily mean values lower to 0°C.
- Summer Thawing Degree Days (TDD_s): Sum of all the daily mean values higher or equal to 0°C for the period between 1 June and 31 August.

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Monitoring metadatabase

Specific field definition

GST_ID	unique identification code. Can be the code used by the contributor if he uses one.
GST_mean	annual mean of GST (°C) at the GST location
GST_mean Summer	Summer(June-August) mean GST (°C)(*)
TDDy	Annual Thawing Degree Days *(*)*
TDDs	Summer Thawing Degree Days (*)
FDDy	Freezing Degree Days (*)
GST_period	(MM.YYYY-MM.YYYY)
GST_measurement_depth	burial depth of probe (m)
GST_probe	type of probe used
RFGT _sam	time interval set for the sampling of temperature
*RFGT_rec***	time interval set for the recording of the values
GST_accuracy	accuracy of measurement (± °C)
GST_ Slope	Slope of the 2 m square centered at GST point
GST_Aspect	Aspect of the 2 m square centered at GST point
GST_Gs	Main grain size of the 2 m square centered at GST point (in mm)
GST_Surf	Nature of the surface of the 2m square centered at GST point (b= bare; v=vegetated)
GST_Veg	Main type and % of vegetation coverage (m= moss; l = lichens; gr= grass and other alpine plants; sh= shrubs; ot=other)

Coordinates and altitude should follow the format proposed for PED
The proposed sheet structure is suitable for single GST loggers or for every temperature probe.

(*) these fields are not mandatory.
** number of minutes and letter for type of record (e.g. hourly average = 60A; hourly minimum = 60Mi; hourly maximum = 60Mx

Ground near-surface temperature on steep rockwall

GnST monitoring site on the Mt. Blanc (Photo by: Arpa Valle d'Aosta)

Guidelines for monitoring

Definition

On steep bedrock slopes (rockwalls) near ground surface temperature (GST) are important to detect the permafrost presence and monitor the possible variation of the active layer within the rock surface. According some authors (??) the ground surface temperature (GST) on the rock steep faces is measured at 10 centimetres of depth.

As well as the GST on the other material the Mean Annual Ground Surface Temperature (MAGST) can be reasonably used as an indicator of permafrost presence. MAGST values lower or equal to 0°C indicate permafrost presence.

Measurement techniques

Instruments

The temperature should be measured with thermistor or thermocouple with an accuracy of 0.25°C and a resolution better than 0.1°C.

The choice of the measurement point is crucial on the rock wall. The facet chosen for measurement should resemble the general character of the large face as closely as possible.

Measurements should only be attempted on surfaces that are homogeneous and free of visible fractures or discontinuities within a radius of around the square of the maximum depth (i.e. 1 m of radius for measures performed 10 cm below the surface or 2.5 m for 50 cm depths).

Near-vertical situations are preferable in case the effect of snow cover wants be reduced to a minimum. On the other hand, lower slope angles likely promote formation of thin snow cover which can strongly affect the rock thermal regime; measures in such conditions are of particular interests because scarce. In both cases, a vertical distance of several meters should be kept to the flat terrain below in order to avoid coverage by snow piles.

The thermistors should be placed according this installation procedure:

- A - Test the positioning of the mini-logger without boreholes and brackets to see if access to the battery is possible after installation, i.e. the backside of the logger is not obstructed.
- B - Drill the sensor hole with a 5 mm Ø drill bit, 10 cm deep. Pay maximum attention to the depth measure of the borehole.
- C - Remove as much dust as you can by sliding the turning drill in and out of the borehole or using compressed air (not ecological

solution) or using an air pump by hand.

- D - Insert the sensor cable fully and determine the best placement for the Logger and brackets, then remove the sensor.
- E - Use the driller to mark the location of the anchoring holes.
- F - Drill the anchoring holes with a drill bit of the proper diameter in function of the hydraulic hose brackets purchased (Fig. 5).
- G - Insert the sensor cable about 50 mm and then cover the hole and the rest of the cable with the silicon. Insert the cable fully while rubbing the silicone around the hole. In this way, sealing of the borehole surface is ensured.
- H - Fix the logger firmly with the brackets.
- I - Double-check the proper sealing of the cable.
- J - Connect to the logger and: (1) synchronize logger clock, (2) display an instant measure, (3) check sampling parameters, (4) clear logger memory.

The 1st uses a single-thermistor string specifically designed for permafrost monitoring on rockwall (Fig. 1). The rock temperature is measured at 10cm of depth and logged by the M-Log5W mini-logger. Sensor type: PT1000, accuracy +/- 0.1°C, resolution 0.01°C.

The 2nd and 3rd solutions use a multi-thermistor string cabled to an M-Log5W mini-logger (Fig. 2 and 4A) and to an iLog-3V-GPRS datalogger (Fig. 3 and 4B) respectively. The length of the string, the number and the positions of the thermistor must be defined in advance with the manufacturer. Sensor type: Dallas DS1820, accuracy +/- 0.25°C, resolution 0.065°C.

Fig. 1 – Mini-logger M-Log5W-ROCK by Geoprecision

Fig. 2 – Mini-logger M-Log5W with temperature string by Geoprecision

Fig. 3 – iLog-3V-GPRS with temperature string by Geoprecision

The main advantages of the solutions adopting the M-Log5W (1st and 2nd) are the fast placement and the "lightness" of the resulting installation. The communication from PC to the mini-logger is ensured by an USB wireless device (Fig. 4A) with an operating range nominally up to 100 m. This range is real with a direct view of the instrument.

The main advantage of the 3rd solution is the automatic transmission of the data by GPRS that allows to know every day if the instrument is working or not. On the other hand the installation procedure is more time expensive and cumbersome. Moreover the instrument must be prepared before the field installation, for protects the slack cables of the thermistor and antenna (Fig. 4B).

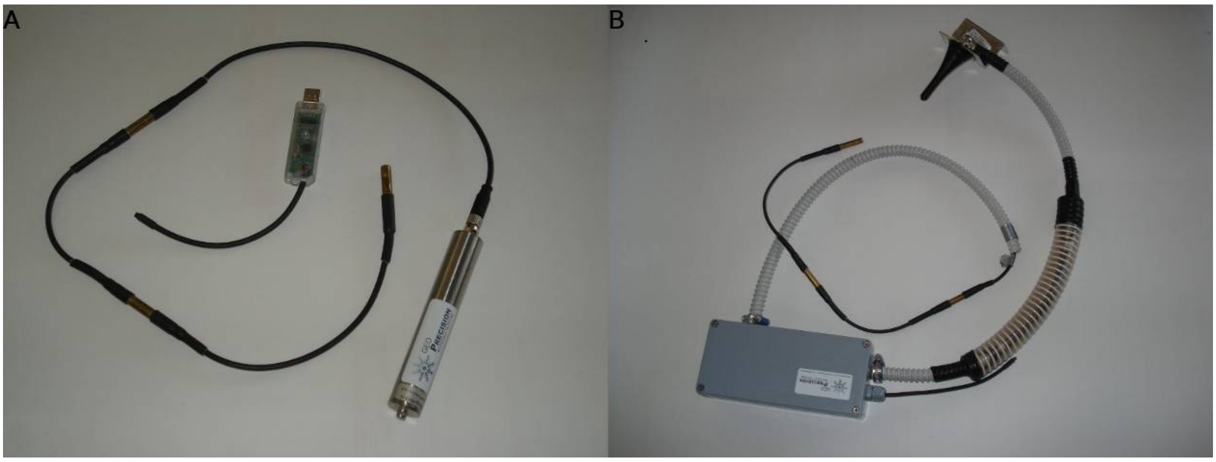

Fig. 4 – A: an M-Log5W with a temperature string with 3 nodes for a 55cm deep borehole and the USB device for the wireless comunication. B: an iLog-3V-GPRS with the protections for the slack cables and the support for the antenna. The protections are realized with flexible plastic hose and thermo-shrink wrap

The technical specifications of both the suggested dataloggers are summarized in tables 1 and 2.

Housing dimensions	120 x 20 mm (cilinder)
Housing specifics	Waterproof stainless steel
Memory capacity	Up to 500.000 measure value / 2048Kb
Data integrity	Non volatile flash memory
Scan cycle	2 sec. to 12 hours
Energy consumption	Up to 10 years with one battery
Battery specifics	2.400 mAh / -55°C to 85°C / Li-COCl2
Communication	Wireless (range up to 100 m)
Operating temperature	-40°C / + 60°C

Tab. 1 – Technical specifications of the M-Log5W mini-logger.

Housing dimensions	175 x 80 x 55 mm
Housing specifics	Waterproof rugged aluminium
Memory capacity	Up to 500.000 measure value / 2048Kb
Data integrity	Non volatile flash memory
Scan cycle	2 sec. to 12 hours
Energy consumption	Up to 3 years (with daily GPRS transm.)
Battery specifics	2.400 mAh / -55°C to 85°C / Li-COCl2
Communication	GPRS and Wireless (range up to 100 m)
Operating temperature	-40°C / + 60°C

Tab. 2 - Technical specifications of the iLog-3V-GPRS datalogger.

Installation procedure

The access to the installation site is usually done by abseil and the technicians must work on the rope. In such conditions the tools needed for the instruments placement must be reduced to the essential and the sequence of operations must be well planned and tested before start to work on the rope.

The installation procedures described below are for the following sensor configurations:

1. M-Log5W-ROCK, 1 node, measure depth: 10 cm
2. M-Log5W with string, 3 nodes, measure depths: 10, 30, 55 cm
3. iLog-3V-GPRS with string, 3 nodes, measure depths: 10, 30, 55 cm

List of tools (Fig. 5).

- Cordless Driller (Suggested: Hilti TE6-A36) (1)
- Diamond drill bits of various diameters and lengths (2)
- Compressed air or hole blow out pump by hand (3)
- Silicon (dispenser size as toothpaste) (4)
- Hydraulic hose brackets for diameters of 20mm (¾ inches) (5)

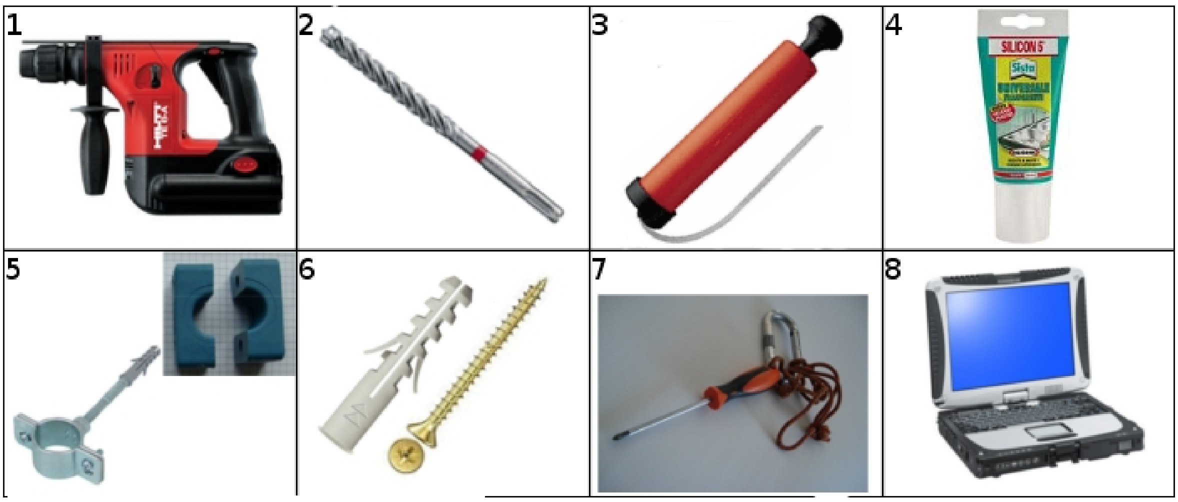

Fig. 5 - Tools overview

- Wall plugs and screws (6)
- Screwdriver with lanyard (7)
- Rugged field PC (Suggested: Panasonic Toughbook-19) (8)

Step by step installation procedures.

1. M-Log5W-ROCK, 1 node, measure depth: 10 cm

2. M-Log5W with string, 3 nodes, measure depths: 10, 30, 55 cm

Follow the steps of the first procedure with the following differences.

A - Drill the sensor hole with a 10 mm Ø drill bit, 56.5 cm deep. Pay maximum attention to the depth measure of the borehole.

B - Remove as much dust as possible by sliding the turning drill in and out of the borehole and using compressed air (not ecological solution) or an air pump by hand. Pay maximum attention to this cleaning operation for these small diameter boreholes deeper than 10 cm.

C - Insert the sensor cable about 50 cm and then cover the hole and the rest of the cable with the silicon. Insert the cable fully while rubbing the silicone around the hole. In this way, sealing of the borehole surface is ensured.

3. iLog-3V-GPRS with string, 3 nodes, measure depths: 10, 30, 55 cm

Follow the steps of the first procedure with the following differences.

A - Test the positioning of the logger and antenna without boreholes, choosing a surface as regular as possible in order to ensure a good contact of the housing base with the rock surface. Chose the position of the sensor hole as far as possible from the logger in order to avoid disturbance due to the logger presence.

B - Drill the sensor hole with a 10 mm Ø drill bit, 56.5 cm deep. Pay maximum attention to the depth measure of the borehole.

C - Remove as much dust as possible by sliding the turning drill in and out of the borehole and using compressed air (not ecological solution) or an air pump by hand. Pay maximum attention to this cleaning operation for these small diameter boreholes deeper than 10 cm.

D - Insert the sensor cable fully and double-check the best placement for the Logger and antenna.

E – Remove the housing cover of the logger (put it in the back bag) and mark the location of the 2 anchoring holes by a 4 mm Ø drill bit.

F - Drill the 2 anchoring holes with a 5 mm Ø drill bit.

G - Insert the sensor cable about 50 cm and then cover the hole and the rest of the cable with the silicon. Insert the cable fully while rubbing the silicone around the hole. In this way, sealing of the borehole surface is ensured.

H - Fix the logger firmly with the 2 screw and close the logger cover.

I - Double-check the proper sealing of the cable.

J - Connect to the logger and: (1) synchronize logger clock, (2) display an instant measure, (3) check sampling parameters, (4) clear logger memory.

K - Drill the anchorage hole for the antenna in function of the chosen support. Firmly fix the antenna at the rock surface.
L - Fix the free cables of antenna and temperature string placing two additional hydraulic hose brackets of proper diameter in the middle of the cable. In this way cables shaking during the storms are avoided.

Measurement strategies

The monitoring of Ground Surface Temperature (GST) on near vertical rockwalls is performed by the application of mini-datalogger powered by batteries and having one or more thermistors channels. The objective of this measures is record the temperature fluctuations of a rock surface for as much time as possible. In high-mountain rockwalls the environmental conditions can become very hard for the instruments mainly because the very low temperatures, strong winds and ice formation. For these reasons the choice of the exact location where to put the instruments and the quality of the installation are fundamental. This guidelines aims to give very practical suggestions for successfully place dataloggers on steep slopes and get reliable dataseries of rock temperatures.

At regional scale the selection of the rockwalls where put the instruments is done according to their elevation, exposition and expected temperature, in function of our research purposes.

Once identified some potential sites, the accessibility must be considered in function of:

1. the budget (e.g. on foot, by cable car, helicopter and so on)
2. the safety of the technicians (e.g. access/escapes routes, rock/ice falls, mobile/radio coverage, etc.)
3. the expected number of visits per year (i.e. easy access for frequent visits)

Monitoring metadatabase

Specific field definition

The following information are the essential metadata that should be collected for each monitoring site. The aim of these metadata is provide, to a potential unknown user, all the necessary information for fully understand in which conditions were acquired the data that is watching. These metadata should be compiled within an ASCII file or a document or an excel sheet, this is not important.

1) SITE
Site Name = (e.g. Aiguille Marbrée North)

* Site Code = (e.g. AM)
Geographic Area = (e.g. Mont Blanc)
Responsible = (e.g. username@gmail.com)
Latitude (WGS84-dd) = (e.g. 47.5426771)
Longitude (WGS84-dd) = (e.g. 7.8213672)
* X-coordinate [system] = (e.g. 5689492 [UTM ED50 zone32N])
* Y-coordinate [system] = (e.g. 321654 [UTM ED50 zone32N])
Elevation (m) = (e.g. 3500)
Slope (°) = (e.g. 87)
Aspect (°) = (e.g. 315)
Vegetation [None, Sparse, Partly-Cov, Full-Cov] = (e.g. None)
Surface Type [Coarse Debris, Fine Debris, Bedrock] = (e.g. Bedrock)
Morphology [Slope, Ridge, Peak, Slope Base, Plateau, Depression] = (e.g. Slope)

2) INSTRUMENTS
*Logger = (e.g. M-Log6 Geoprecision)
Thermistor = (e.g. PT1000)
Accuracy [°C] = (e.g. +/- 0.1°C)
Depth [m] = (e.g. 0.03,0.3,055)
Sampling frequency [s] = (e.g. 600)
Date Begin [dd.mm.yyyy] = (e.g. 21.12.2006)

(*) optional

BTS
Bottom temperature of snow cover

BTS measurement at the Salati Pass (photo by: Arpa Piemonte)

Guidelines for monitoring

Definition

The Bottom Temperature of Snow cover (BTS) is defined as the temperature measured at the snow/ground interface (Haeberli 1973).

BTS measurement give an estimation of the energy balance of the surface in a period in which snow cover insulates the ground from any exchanges with the atmosphere.

This conditions of insulation can be not reached every year at the same site and in the same period depending from the evolution of the snow pack.

Classically, the following typical threshold values of BTS were used as indicators:

- BTS > - 2 °C : permafrost unlikely.
- -2 < BTS < -3 °C : permafrost possible.
- BTS < - 3 °C : permafrost probable.

Measurement techniques

BTS has to be carried out at the end of the winter (generally February-March but also in early April) but in any case before the beggining of the snow melt.

The measurement point has to have at least 80-100 cm of snow cover in a ray of 10 m around. Indeed, the occurrence of big boulders very close or emerging from the snow surface can influence deeply the temperature.

Generally the snow heigth at the measurement point should be noted as well as the temperature of the interface from snow and ground.

BTS is measured through the snow cover with special probes. The special probe can be homemade with a ligth standard carbon fiber avalanche to a length probe of 3 m equipped with a thermocouple, with direct reading of temperature with an accuracy of 0.1-0.2°C and a resolution better than 0.1°C.

Commercial device are also available.

Several problems may occur during measurement due to the internal structure of the snow cover :

- The probe must reach the ground. On rocky material, the sound usually allows a confident control, but on soft ground it may be difficult to be sure that the probe really touches the ground.
- The presence of icy freezing levels in the snow pack may hinder the penetration of the probe.
- Even without ice layers, the penetration can be difficult, especially when "depth hoar" occur at the basal layer and tends to fill the hole and/or compact by the probe.

- The limited length of the probes doesn't allow measurements on deep snow accumulation areas.

In order to prevent many of these problems is suggested to use another metallic probe (sligth larger than the BTS probe) to do a hole in which insert the BTS probe.

A spacing of 15-30 m is recommended, depending on the heterogeneity of the micro-topography and the extent of the area to map.

On rugged surface as, for example, rock glacier, the density can be increased. The most efficient way is to use a rope of fixed length for the interval and to measure parallel lines. In some cases can be more usefull to chose the measurements points considering the different morphological conditions (ridges, furrows, saddle etc) and surface characteristics (big open work structure; gravel and pebble; soil; vegetated) that can influence strongly both the snow pack eveolution and the ground temperature and therefore BTS result.

For each measure a different stabilization time is needed depending the type of chosen thermometer probe (2-20 minutes).

The location of the single points can be carried out through DGPS or through anchoring on fixed land-marks (e.g. rising blocks, poles, …). The use of a regular grid spacing facilitates the positionning on a limited number of anchor points (precision of ± 2-3 m is sufficient).

The method provides a temperature map on a given date. The best strategy is an association of GST loggers with BTS mapping.

BTS mapping can be used once on a site, in order to assess the permafrost limits (provided that the winter is suitable for a good contrast), or repeated during successive winters for assessment of temperature distribution pattern changes.

PermaNet experiences

The French team tested a system self-made adapted (Fig. 6) using a carbon probe (thermal insulator and lightweight) with an aluminium tip (conductor) linked to a thermocouple K with precision ± 0.5 °C. Through a data reader connected to the thermocouple is possible to read and to record data. In order to measure BTS is sufficiently to knock in the snow the probe reaching the ground with the aluminium tip. After few minutes of thermometer stabilization the measure is caught.

In this configuration it is important to take into account that the electrical connections have to be limited in numbers and that the electronic components used have to resist to cold temperature.

Arpa Piemonte (Italy) tested a system a little bit different using an aluminium rod (3 meter long, divided in three pieces of 1 m long each one, and Ø 3 cm; about 4 kg weight) in order to drill the snow. In this hole, the thermal sensor is introduced reaching the ground and measuring directly the BTS (Fig. 7).

The system adopted by Arpa Piemonte than that used by the French team allows to drill very resistant surfaces (e.g. ice crusts) and to place the sensor directly in contact with the ground. The main problems encountered using this technique are related to the speed of execution of the measures and the difficulty of keeping open the hole before inserting the temperature sensor. Best results have been obtained operating in team of two people in site with no more of 2÷2.5 m of snow cover. One person select the site of snow drilling with the rod and one person is dedicated to BTS measure. While BTS is measuring, the next measure point is selected. With this procedure is possible to collect 5 to 10 points per hour.

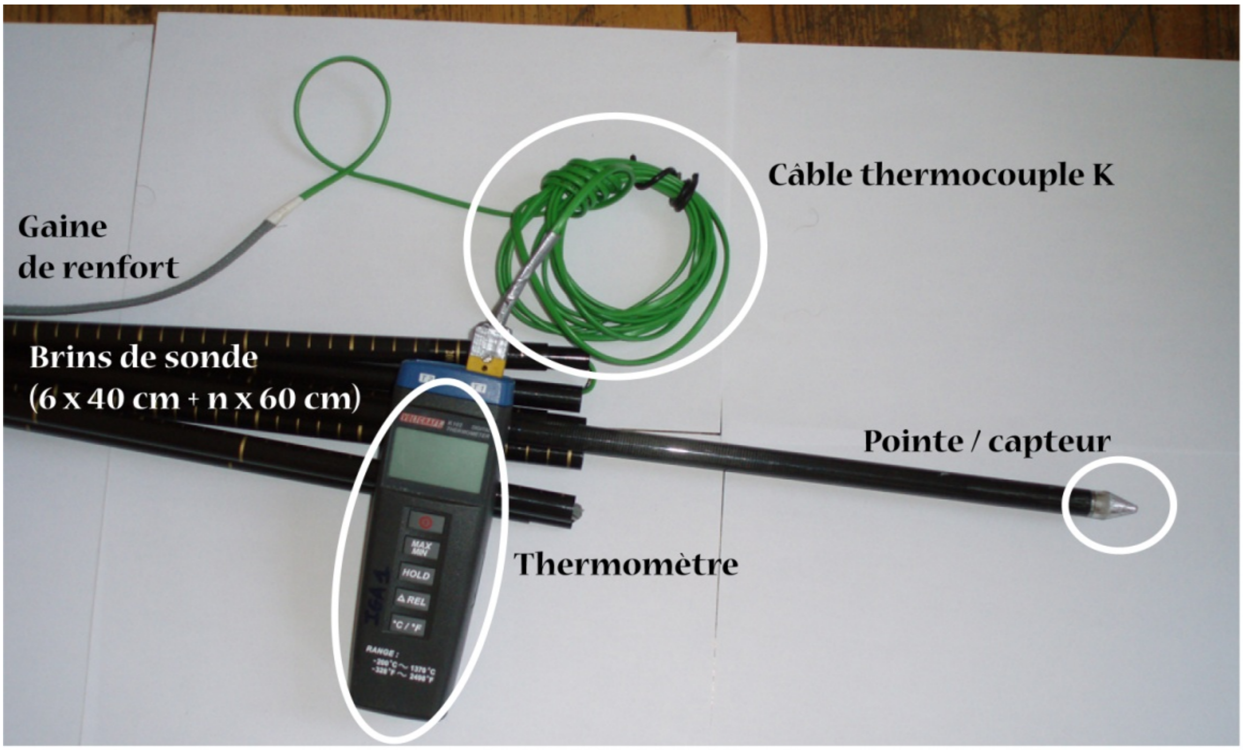

Fig. 6 – BTS measurement system used by the PermaNet French team (photo by: PermaFRANCE)

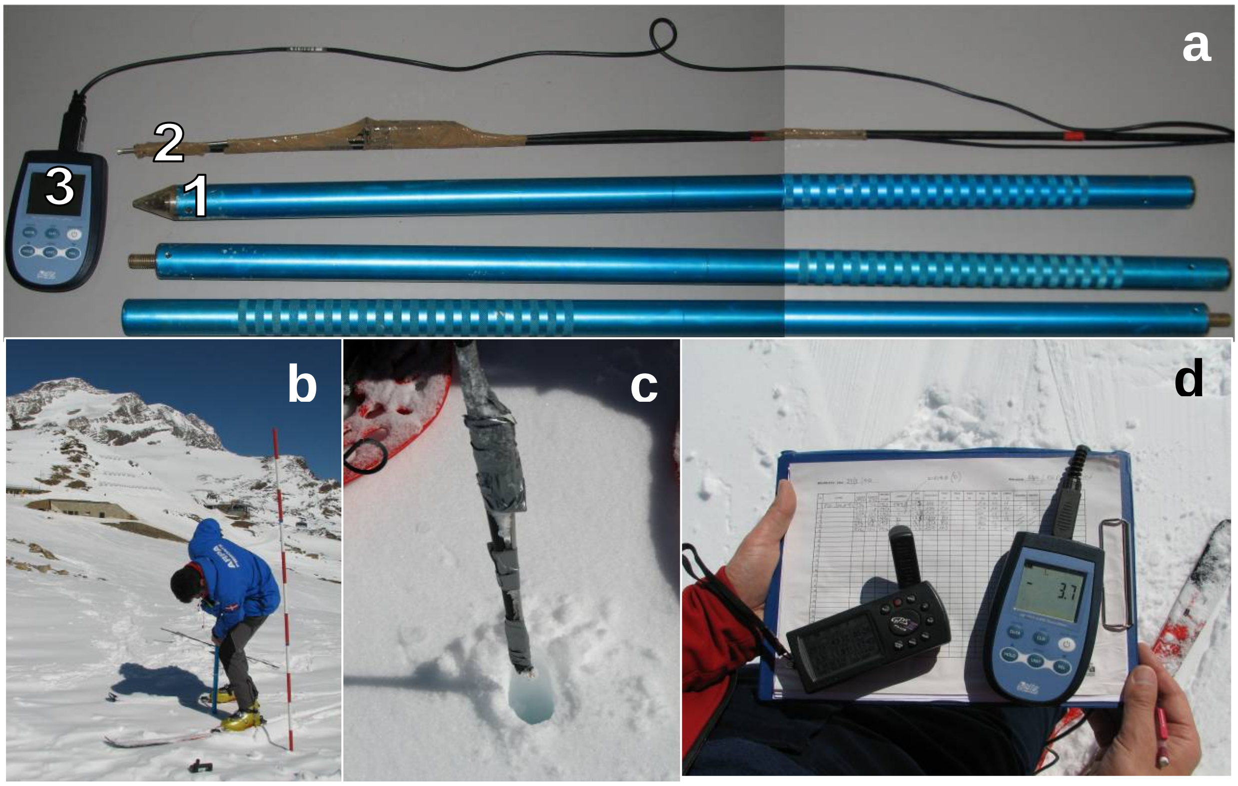

Fig. 7 – BTS measurement system tested by Arpa Piemonte. a) Aluminium rod (1), thermal sensor fixed to a rigid support (2) and datalogger (3); b) snow drilling with the rod; c) insertion of the thermal sensor in the hole; d) data reading and filling-in database (photos by: Arpa Piemonte).

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Monitoring database

Specific field definition

BTS_ID	Unique identification code. Can be the code used by the contributor if he uses one.
BTS_date	date (DD.MM.YYYY) of BTS survey
BTS_area	area in ha covered by the BTS survey
BTS_points	text field indicating sampling strategy used : number of points, gridding, spacing, …
BTS_probe	type of BTS probe used (with hole before the measurement or direct measurement; accuracy of the thermometer)
Snow Heigth	Mean and Standard Deviation of the Snow cover of the surveyed area(cm)
BTS_comment	comment on the results

- coordinates and altitude : enter the central point of the surveyed area

The proposed sheet structure is suitable for an area of BTS surveys.

Thermal monitoring of the Active Layer

CALM grid area at Cime Bianche site (photo by: Arpa Valle d'Aosta)

Guidelines for monitoring

Definition

The active layer can be defined as "the top layer of ground subject to annual thawing and freezing in areas underlain by permafrost" according to ACGR, (1988) or as ‘depth of the

maximum seasonal penetration of the 0 C° isotherm according to the classical defintion of Muller, (1947). Within the Alps, generally the second definition is applied because the salinity of the ground is limited and the freezing point of the ground is reasonably equal to 0 C°.

Moreover within the Alps and in general in mountain environment the grain size of the terrain is generally heterogenous and often coarse or very coarse and for this reason the classical probing method (inserting a metal rod of less than 1 cm of diameter in the ground until that the frozen material is reached) of active layer monitoring is not applicable.

In addition, active layer is generall thicker than 1 m in our mountain even at very high altitude and also for this the probing method is not suitable.

The spatial variability of the active layer is generally very high and depends mainly from the Ground surface tempeperature (GST) but also by the geological characteristics of the active layer (water content; ground texture; Guglielmin, 2006; Nelson et al., 1998).

For this reason active layer monitoring in the mountain environment has been traditionally and improperly limited to the monitoring of the depth of the 0°C isotherm within singular boreholes.

Measurement techniques

In order to understand the spatial variability of te active layer the monitoring of the active layer in alpine environment should be carried out chosing an area reasonably representative of the examined site. Generally, to chose the right location of the monitoring site, is suggested to monitor the GST of several points (at least 4-5, but better 9-10) located on points representative of the different snow accumulation, vegetation (if present) and surficial lithology type (fine grained soil; gravelly-sand soil; gravel and pebbles; open work blocks) at least for a couple of years before to install the permanent monitoring grid.

The monitoring grid can be also smaller than the classical 100X100 m with a spacing of the nodes every 10 m (5 m in case of grid smaller of 50X50). Each node should be marked on the ground with wooden stakes or better with snow poles and its coordinates should be recorded through DGPS (accuracy better than 1 m). The numbering of the nodes could be carried out starting with the NW corner (1) eastward and then with the following lines always starting from west to east.

Some of the nodes (at least 5 selected on the basis of the consideration above) should be equipped with at least three thermisthors (or termocouple) placed at 0.02; 0.3; 0.6 (in the case of three sensor) or four at 0.02; 0.3; 0.6; 1 m.

Where logistical constraints allow the realization of deeper boreholes we recommend to add at least two additional sensor placed at ± 0.5 m respect the permafrost table at the moment of the drilling.

Normally, 1 m deep boreholes of small diameter (smaller than 3 cm) are possible to drill with different types of handble drill or also manually with manual auger.

The sensors at 0.02 should be installed parallel to the surface according the GST guidelines. The other sensors should be inserted at the different depth within a HDPE (or other plastic) pipe of 1 inch of diameter ceiled at the bottom and closed carefully at the top allowing only the passage of the cables. The top of these pipes should emerge from the surface at least 20 cm.

To help the installation of the thermistors at right depth can be useful to tape the sensors at small plastic or wood stake already at the right depths.

Thermistors should have an accuracy better than 0.2°C and a resolution better than 0.1°C.

Waterproof multichannel datalogger, programmable, with battery and memory able to assure a life of 1 year with the chosen sampling and recording intervals, are recommended. The sampling interval should be hourly altough 10 minutes is recommendable. Minimum, maximum and daily mean should be recorded every hour or at least every day.

It is highly recommendable to bury completely all the cables in order to prevent damages by animals. The dataloggers should be also buried but always over the original topographic surface (creating a small relief of stone).

In addition, at the other nodes of the grid at the end of the summer (late august) or in any case during the maximum thawing ground temperature at the depths of 0.02, 0.2 and 0.3 m could be measured once time (in the same day) with needle portable thermometer (with similar accuracy of the permanent datalogger) in order to have a better idea of the spatial variability.

Data analyses

The annual maximum temperature recorded at the different depths in the different monitored points should be used to interpolate the ground temperatures envelope obtained determining the maximum depth of the 0°C isotherm. In case of only three available thermistors in each point we recommend to interpolate only the two deepest sensors.

References

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Monitoring metadatabase

Specific field definition

AL_ID	unique identification code for each grid.
AL_GrId	number of the node of the grid in which is located the monitoring system
AL_Grt	number of temperature sensors and their depth
Al_size	Size in m of the grid and number of the nodes
AL_Taccu	accuracy of the temperature sensor (± °C)
AL_Tint	Interval of sampling and recording of the sensors
AL_interp	Range of depths used for the ground temperature interpolation
*AL_Thick**	mean maximum depth of 0°C isotherm
*AL_thSD**	Standard deviation of the maximum depth of 0°C isotherm

Following informations are in the general part of the PED :
- coordinates and altitude

Comments and open questions

Better description of the monitoring grid with all the characteristics considered for GST in each node of the grid could be included

* mean and standrd deviation are referred to the whole number of points monitored.

Thermal monitoring of the Permafrost

Permafrost monitoring site at the Sommeiller Pass (photo by: Arpa Piemonte)

Guidelines for monitoring

Definitions

Permafrost is defined as ground (soil or rock) that remains at or below 0°C for at least two consecutive years (Muller, 1947). Consequently permafrost is a physical state of the material depending from the surface energy balance and from the thermal characteristics of the material itself.

Permafrost can be dry (without any ice or water within) or contain water both as liquid water or ice depending from the temperature of freezing point. The temperature propagation from the surface to the interior depends upon the thermal properties of the ground that filter and smooth the temperature signal. The permafrost thermal regime reacts to climate variations at different time scales: (1) seasonally above the depth of zero annual amplitude (ZAA), (2) annually at the ZAA and (3) from years to millennia at progressively greater depths.

Zero Annual Amplitude depth is defined as " the depth at which the amplitude of the annual wave is virtually equal to zero" but conventionally is defined as "the depth where the annual temperature variation is ± 0.1°C" (Lachenbruch and Marshall, 1986).

Permafrost table and permafrost base are defined as, respectively the upper and lower surfaces of the permafrost (French, 2007).

Measurement techniques

The sites chosen for monitoring the thermal regime of permafrost should follow some criteria in order to have a less disturbed signal both for extremely local climatic events but above all by important geological controls that can change significantly laterally and vertically the thermal characteristics of the rock. In details we recommend to follow these criteria:

- On a flat or a very gently sloping area without particular relief disturbance in the surrounding;
- No cliffs or very steep slope within a distance equal to the depth of the borehole (to avoid three-dimensional problems in modelling);
- Shadow effects by obstacles should be minimised (high mountains obstructing the horizon);
- Exposed bedrock (or very thin sediments cover);
- No geothermal flow anomalies
- No tectonic disturbance within the depth of the borehole (thrust or fault);
- The borehole should be in the same rock type for its whole depth (to avoid differences in rock thermal properties);

- No lakes or large water body in the surroundings;
- No Glaciers or glacierets in the surroundings;
- Age of deglaciation older than 200-300 years (or better, never glaciated during the Holocene);

The drilling should be vertical but also inclined boreholes (if perpendicular to the surface) are well accepted.

The depth of the borehole at least, should exceed of some meters the ZAA (30 m is a depth recommended) but possibly could reach the permafrost base.

Some 100 m deep boreholes are welcome because could be compared with the boreholes of the result of the previous European project PACE (with boreholes in Norway, Sweden, Switzerland, Italy and Spain; Guglielmin, 2004; Harris et al., 2001;2003).

The drilling should be carried out without water, antifreeze liquids, and only with compressed air. The diameter of the hole can range between 70 and 100 mm. The drilling can be carried out without coring but at least one sample for each significant lithology change is required. The hole must be cased (continuous pipe) and ceiled on the bottom and closed on the top to prevent collapse and water infiltration. The pipe must be not in metal to avoid any thermal perturbation therefore HDPE or other plastic material are recommended. The cap on the top should be made in order to minimize the disturb on the pattern of snow accumulation and the albedo of the surface.

Temperature monitoring

The accuracy of the sensors should be of 0.1°C or better and the resolution better than 0.1°C.

Thermistors or thermocouple should be placed in the borehole each one with a single cable or within a multipole thermistors string. In the case of the use of thermistors calibration should be done by the ice-bath method twice per year least once before installation.

The timing of the sampling (s) and of the recording (r) intervals depends from the depth with the more surficial sensors from 0.3 to 1 m with (s) = 10 minutes and (r) = 1 hour and the deeper with (s)= 1 hour and (r)= 1 day.

Maximum, minimum and mean values should be recorded in each programmed time intervals.

Regarding the depths two different ways can be adopted:

1) fixed depths
2) variable depths.

The first strategy is surely easiest and give immediate data, but it can be not so accurate in determining both ZAA depth, its temperature and active layer thickness because these are variable in each site depending from energy balance and thermal properties of the rocks and above all, for the active layer suffer great inter-annual fluctuations.

The second strategy is more accurate but needs at least one year of monitoring to estimate the ZAA depth and the active layer depth and successively needs a re-adjustment of the monitoring depths.

In the first case we suggest the following sequence:

0.3; 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 14, 15, 16, 17, 18, 19, 20, 22 and a sensor at the maximum depth. Additional sensors at least at 5 m of interval below 22 m are recommendable.

In the second case some depths are in any case at fixed depths and are: 0.5, 1, 1.5, 5, 8, 10, 12, and a sensor at the maximum depth. In addition Active Layer sensors should be 4 sensors located between 1.5 and 5 m of depth at 25 cm each other in the meter cantered on the depth of permafrost table while ZAA sensors should be 4 sensors located at

0.5 m each other around the supposed ZAA depth (2 above and 2 below it).

Moreover at least 2 sensors for GST should be located according the protocol for GST in a radius of 20 m of the borehole.

Main climatic data as air temperature and snow cover should be recorded on the borehole site.

Dataloggers should be programmable and placed within waterproof case (possibly anchored on a pole at more than 1 m of height respect the surface) and powered with solar panels and eventually other power system (hydrogen cells or wind generator) and with batteries (at least 100Ah, lead gel). GPRS data transmission is also recommended.

PermaNet experiences

In the PermaNet project different kind of permafrost monitoring have been applied, sometimes already existing before the project (Germany, Austria, Switzerland, and Trentino and Valle d'Aosta in Italy), and sometimes totally new (France and most of Italian Alps: Piemonte, Veneto, Trentino - Alto Adige).

In the following list, all PermaNet monitoring sites of permafrost in the involved Countries (see also map and table in the Preface of this handbook):

● Austrian Alps: three vertical boreholes, each 20 m deep;
● French Alps: two vertical boreholes (13 and 14 m deep) drilled in a rock glacier, and one 100 m deep borehole drilled in bedrock; one horizontal 10 m deep borehole drilled in bedrock;
● German Alps: one borehole (inclined of 35° from horizontal) drilled for 50 m in bedrock;
● Italian Alps:
- Piemonte: eight vertical boreholes in bedrock (two of 5 m, one of 10 m, four of 30 m, one of 100 m deep);
- Valle d'Aosta: one vertical borehole in bedrock (43 m deep);
- Veneto: vertical borehole (30 m deep) in bedrock;
- Trento (Province of): three vertical boreholes in bedrock (two of 20 m deep and one of 50 m deep);
- Bolzano (Province of): two boreholes in bedrock (one horizontal and 122 m long, another one inclined of 8° from the horizontal and 160 m long) and three vertical boreholes in two rock glaciers (30, 32 and 40 m deep);
● Switzerland: two vertical boreholes in bedrock (17.5 and 65 m deep) of the PERMOS network.

In Germany the northernmost site of the European Alps, in Italy the southernmost and in France a borehole at the 45°N has been drilled. Switzerland collects the longest hystorical data serie of permafrost monitoring in the Alps.

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Monitoring metadatabase

Specific field definition

PM_ID	unique identification code for each borehole.
PM_Lit	Main lithology from the stratigraphy*
PM_Ice	*Mean % of ice along the borehole*
PM_dst	Specify type of heat sources or source of thermal disturbance and their distance (e.g. lake, building; vertical roch wall)
Pm_age	Estimated age of deglaciation of the site**
Pm_depth	Depth of the borehole measured from the surface.
Pm_dri	Type of drilling method and date of drilling
PM_Bh_id	unique identification code for each sensor.
PM_Bh_sen	Number of sensors and their depths
PM_Bh_acc	Type and accuracy of the sensors
PM_Bh_time	Timing of sampling (s) and recording (r)
PM_P_thick	Estimated permafrost thickness (m)
PM_P_ZAA	Depth of ZAA
PM_P_ZAA_t	Mean annual Temperature at ZAA depth

PM_P_AL	Active layer thickness (m)
PM_P_PT	Mean annual temperature at permafrost table***
PM_P_GST	Mean annual temperature at the surface ****

Following informations are in the general part of the PED :

- coordinates and altitude

Comments and open questions

Better description of the stratigraphy and of the site would be useful.
Parameters PM_Bh should be described for each sensor in another excell sheet where on the rows are the different PM_Bh_id and the other colums are PM_Bh_sen;acc;time.

*Consider as main lithology the rock type that is present in more than 40% of the depth. If 2 lithology types exceed the limit, please indicate both.
** Minimum Estimated Age of deglaciation
*** Mean annual temperature at the depth closest to the determined permafrost table depth.
**** Mean annual ground surface temperature of the 2 or more superificial sensors.

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