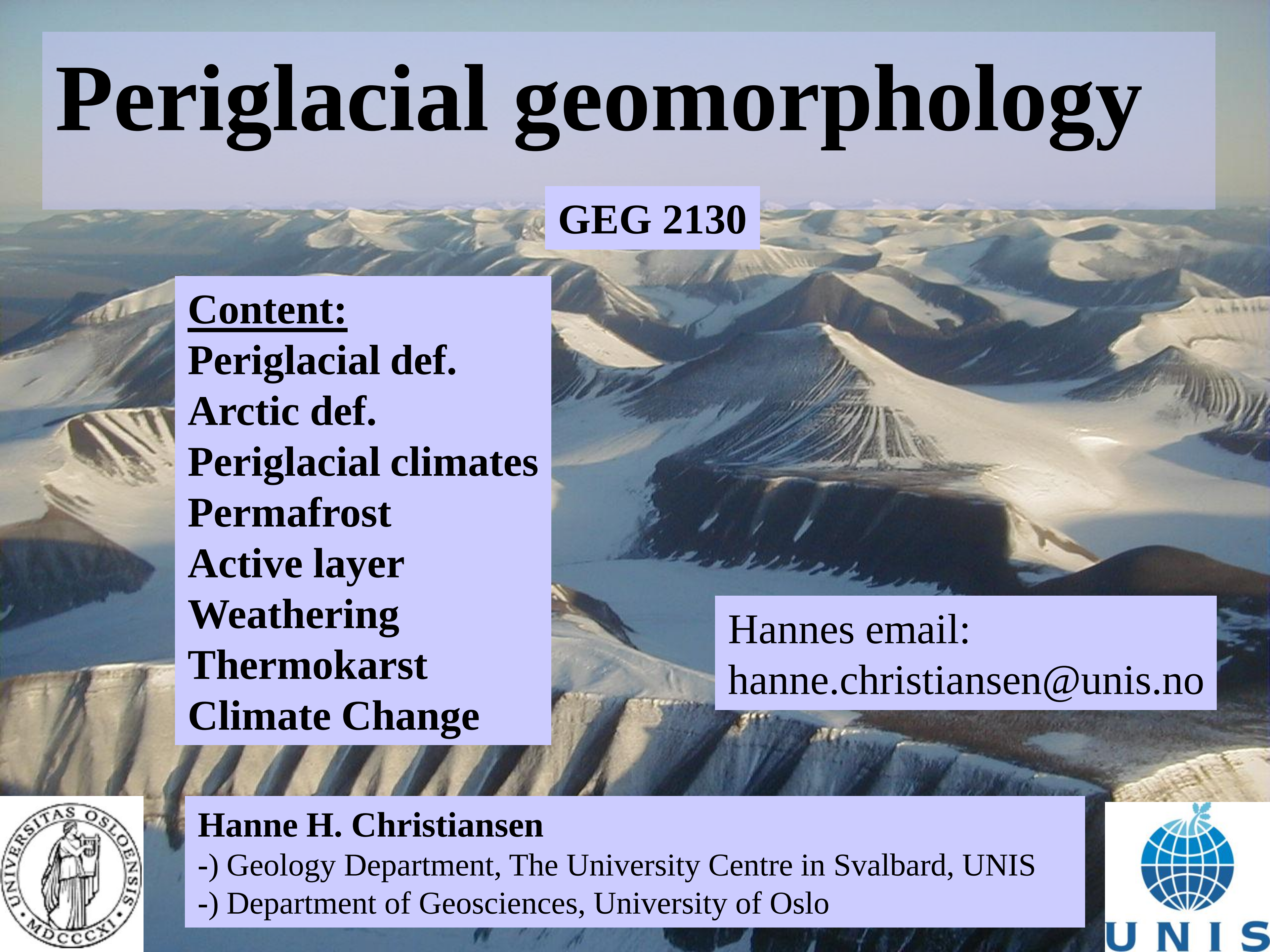
Periglacial geomorphology

GEG 2130



Content:

Periglacial def.
Arctic def.
Periglacial climates
Permafrost
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Weathering
Thermokarst
Climate Change

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Periglacial

Definition:

Periglacial environments are characterised by frost action and the recurrent presence of a snow cover. If the ground surface consists of sediments, sorted ground phenomena are widespread.

Please note:

Periglacial environments may have permafrost but many periglacial regions have not.

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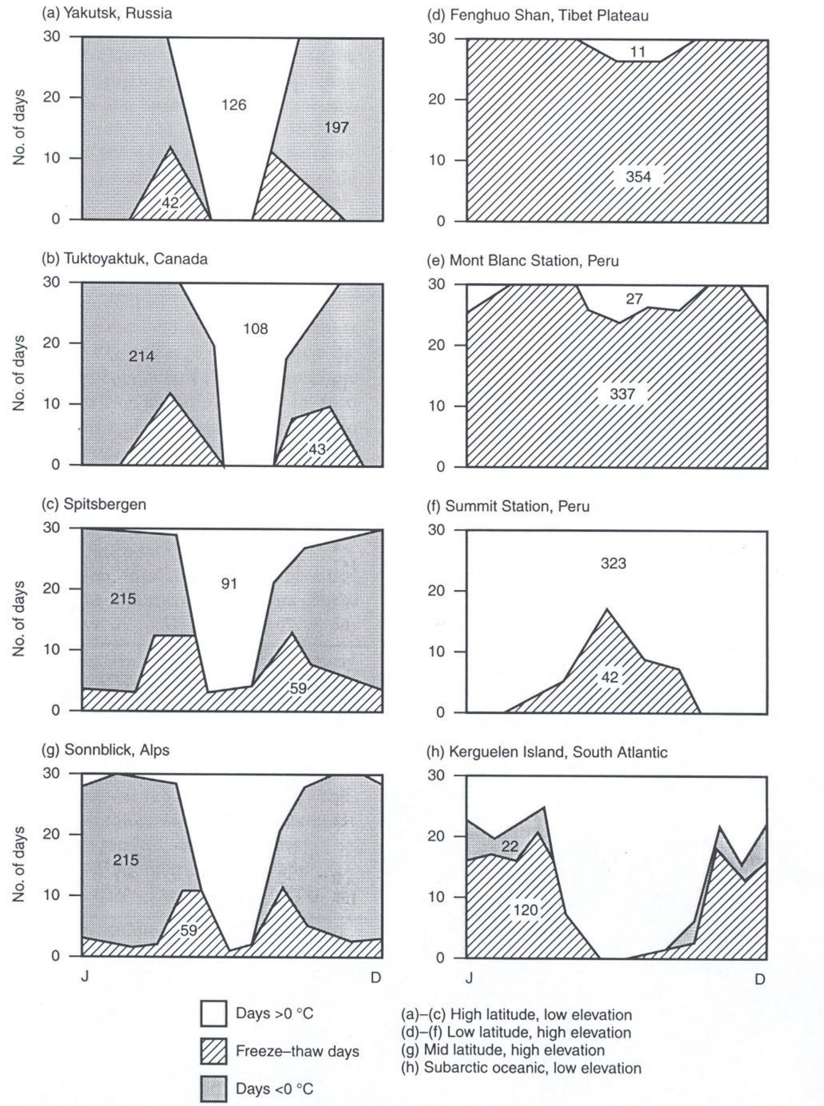
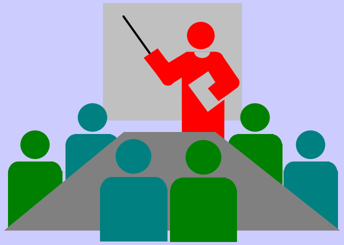
Periglacial climate types



igure 3.2 Freezing and thawing conditions in various periglacial environments of the world: (a) Yakutsk (lat. 62°01'N, long. 129°43'E, altitude 108 m): (b) Tuktoyaktuk (lat. 69°27'N, long 133°02'W, altitude <10 m); Mackenzie Delta (c) Spitsbergen (lat. 78°02'N, long. 14°14'E, altitude 7 m); (d) Fenghuo Shan Qinghai-Xizang (Tibet) Plateau, China; (lat. 34°20'N, long. 92°52'E, altitude 4800 m); (e) El Misti (Mont Blanc Station), South Peru (lat. 16°16'S, long. 71°25'W, altitude 4760 m; (f) El Misti (Summit Station), South Peru (lat 16°16'S, long. 71°25'W, altitude 5850 m). (g) Sonnblick, Austrian Alps (lat. 47°03'N; long. 12°57'E; altitude 3060 m); (h) Kerguelen Island (lat: 49°30'S; long. 69°30'E; altitude sea level). (Sources: (a), (c), (e) and (f) from Troll, 1944; (b) from AES records, Canada; (d) constructed from monthly means of air temperatures recorded at Fenghuo Shan by Northwest Railway Institute personnel).

H.M. French: The Periglacial Enviroment, 2007

Further notes about periglacial environments

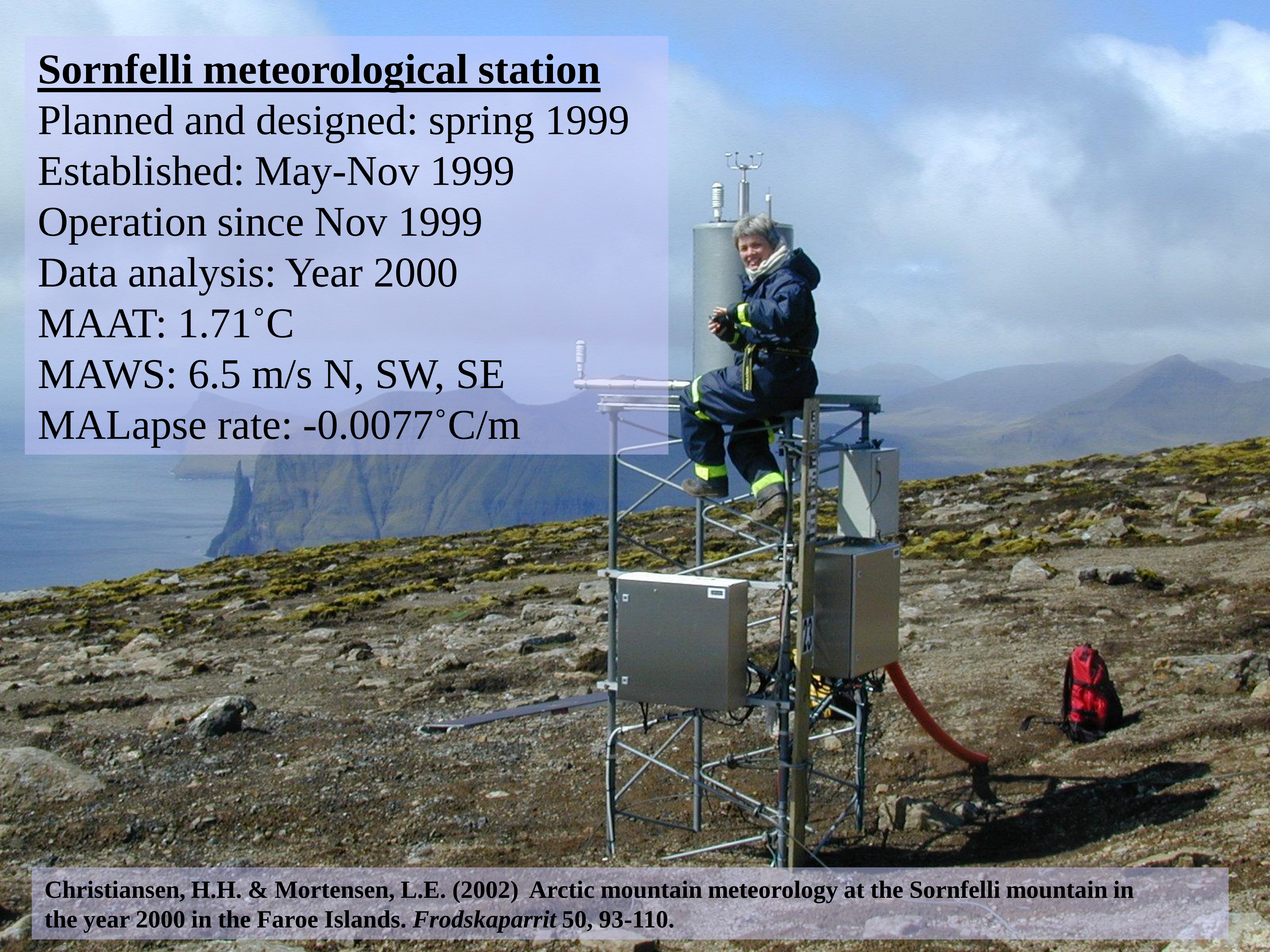


- Freezing and thawing of the ground
- Permafrost may or may not be present
- Solifluction and patterned ground of a frost-action nature frequent
- The most important ecological boundary associated with the delimitation of periglacial environments is presumably the treeline
- Regions with a mean annual air temperature (MAAT) below 3^{o}C (5^{o}C in windy regions) should be considered periglacial

The Arctic

(Greek: Arktos = Bear)

Figure 2. The limits of the Arctic according to various definitions.



Sornfelli meteorological station

Planned and designed: spring 1999

Established: May-Nov 1999

Operation since Nov 1999

Data analysis: Year 2000

MAAT: 1.71˚C

MAWS: 6.5 m/s N, SW, SE

MALapse rate: -0.0077˚C/m

Christiansen, H.H. & Mortensen, L.E. (2002) Arctic mountain meteorology at the Sornfelli mountain in the year 2000 in the Faroe Islands. *Frodskaparrit* 50, 93-110.

Modern altitudinal climate zonation

in the Faroe Islands

Potential permafrost zone 150-200 m above highest tops

High arctic (WM 5˚C) ---

5.5˚C WM 1.2˚C MAAT(856 m asl)

ET polar climate – arctic climate

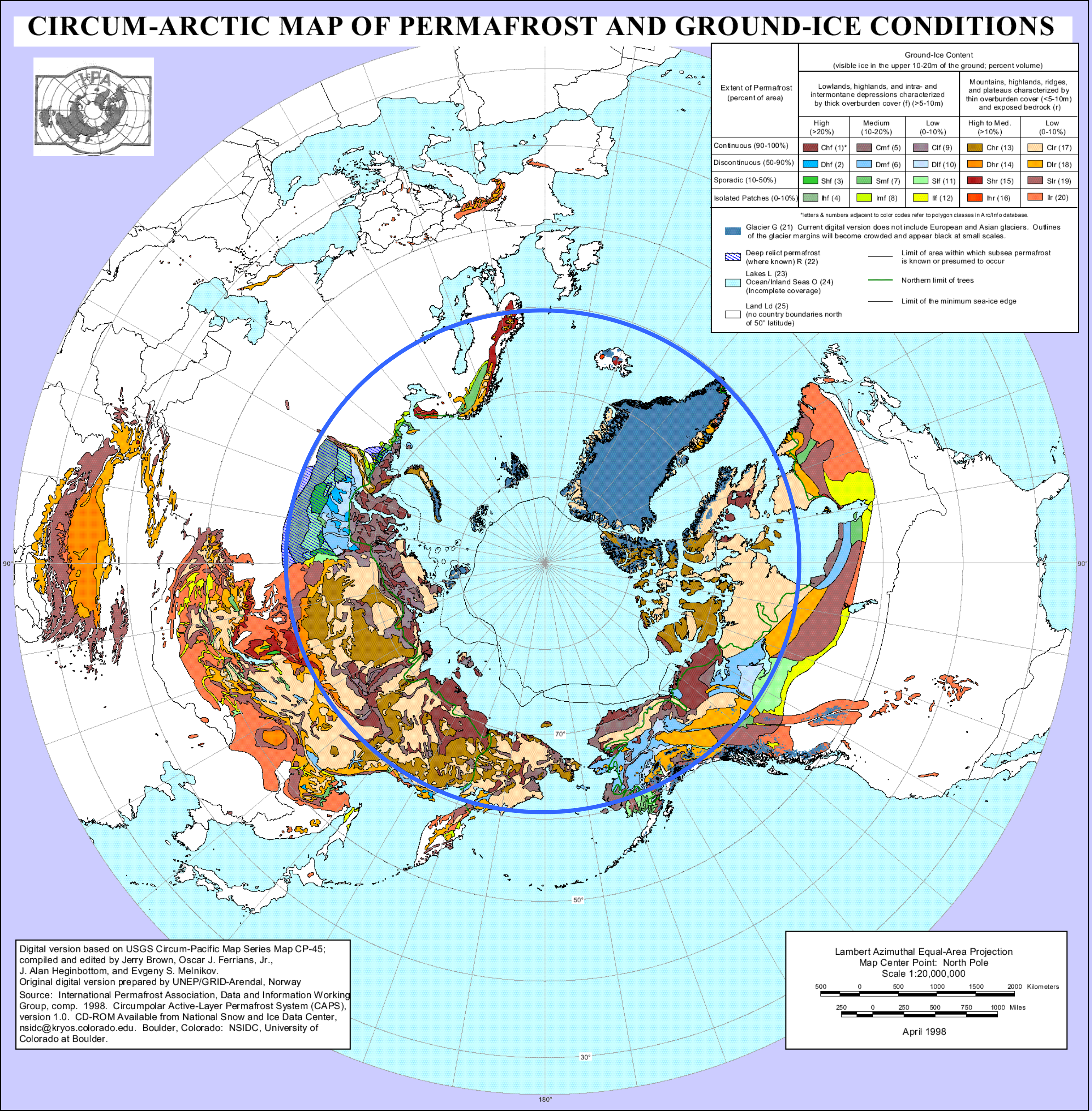
Periglacial zone from 250-450 m asl..

Low arctic (WM˚10 C, at 200 m asl)--------------------------------------

6.6˚C MAAT (33 m asl)

subarctic climate

WM 10.4˚C



The Polar zone

At 60ºN, so 6º south of the Arctic Circle

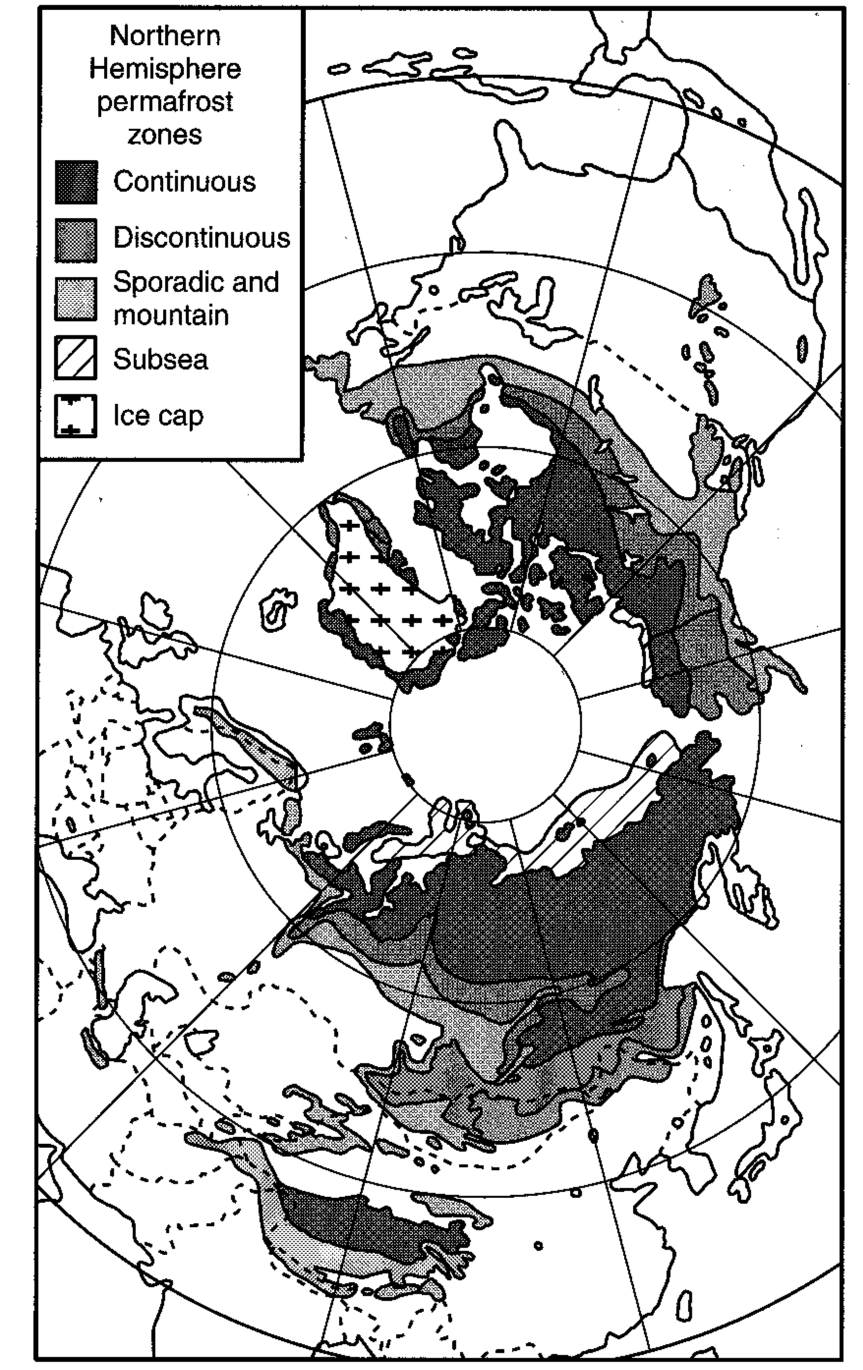
Permafrost

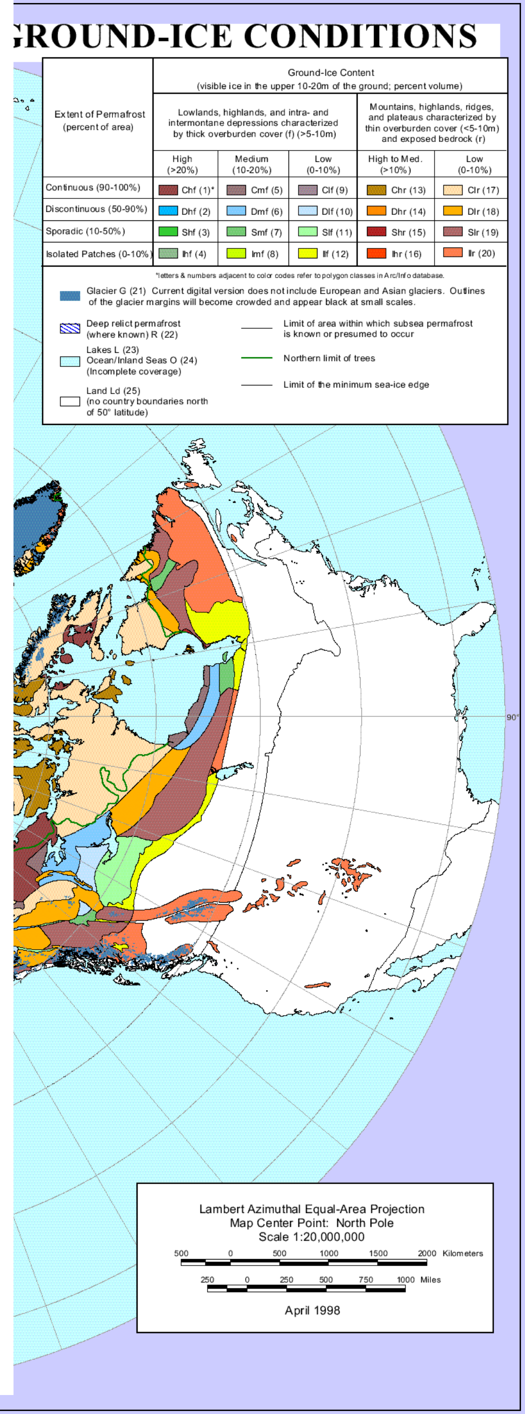
Definition:

Permafrost is defined on the basis of **temperature**: that is ground (i.e. soil, sediments, bedrock, etc.) that remains at or below 0^oC (i.e. the pressure melting point for pure ice) for at least two consecutive years. Moisture, in the form of water or ice, may or may not be present in permafrost

However:

Permafrost may not necessarily be frozen since the freezing point of included water may be depressed several degrees below 0^oC.





Distribution on Northern hemisphere

Permafrost alpine and arctic

Asymmetrical distribution

Zonation:
- Continuous
- Discontinuous
- Sporadic
- Patchy

Submarine

Permafrost importance:

In modern times, permafrost covers about 25% of the non-glaciated land surface

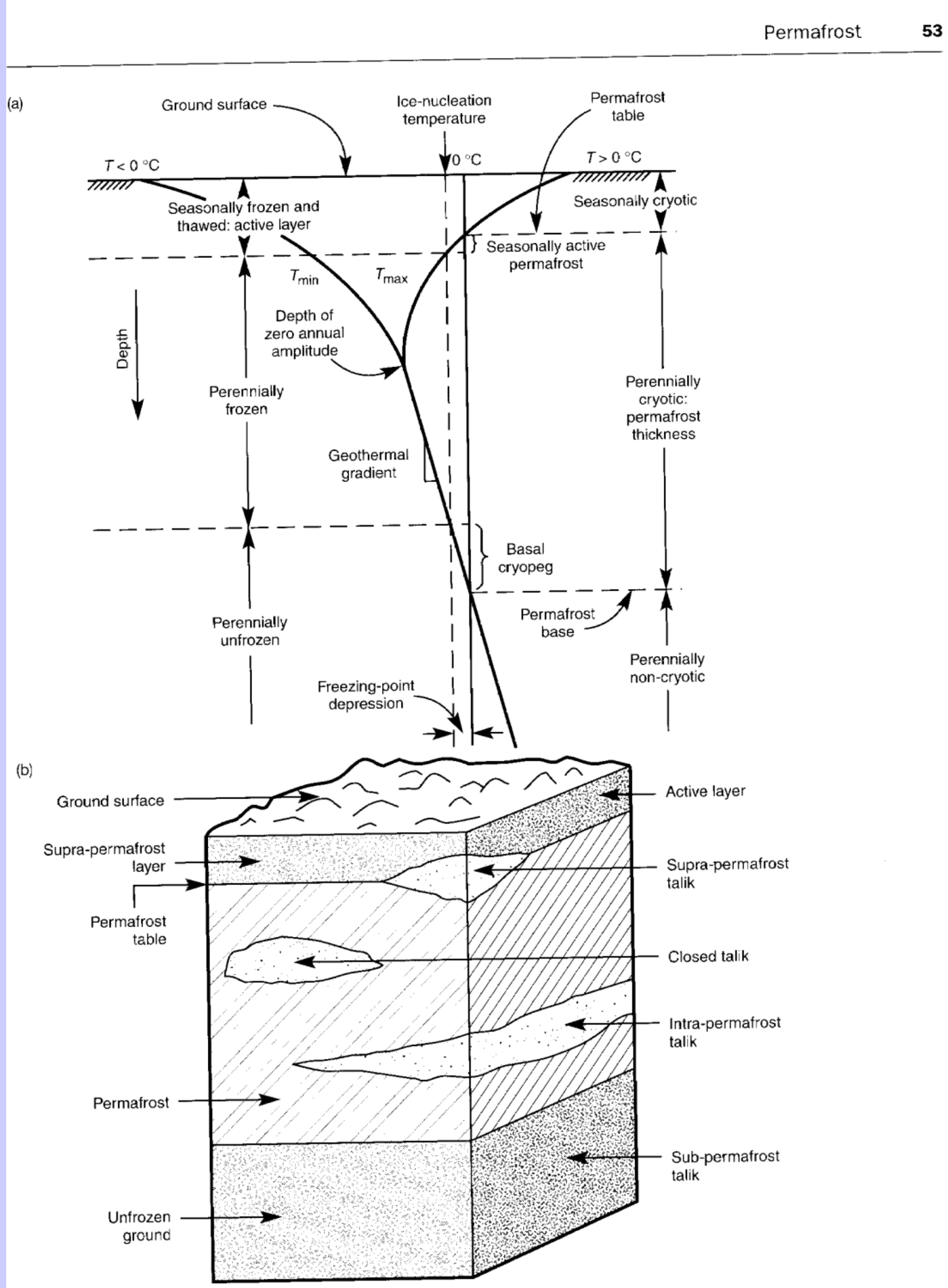
During the Quaternary glacial periods, permafrost covered about 50% of the non-glaciated land surface

Permafrost thickness and distribution varies with climate

A series of specific problems arise during construction work in permafrost regions

Permafrost temperature profile

Permafrost terminology



Permafrost temperature with time

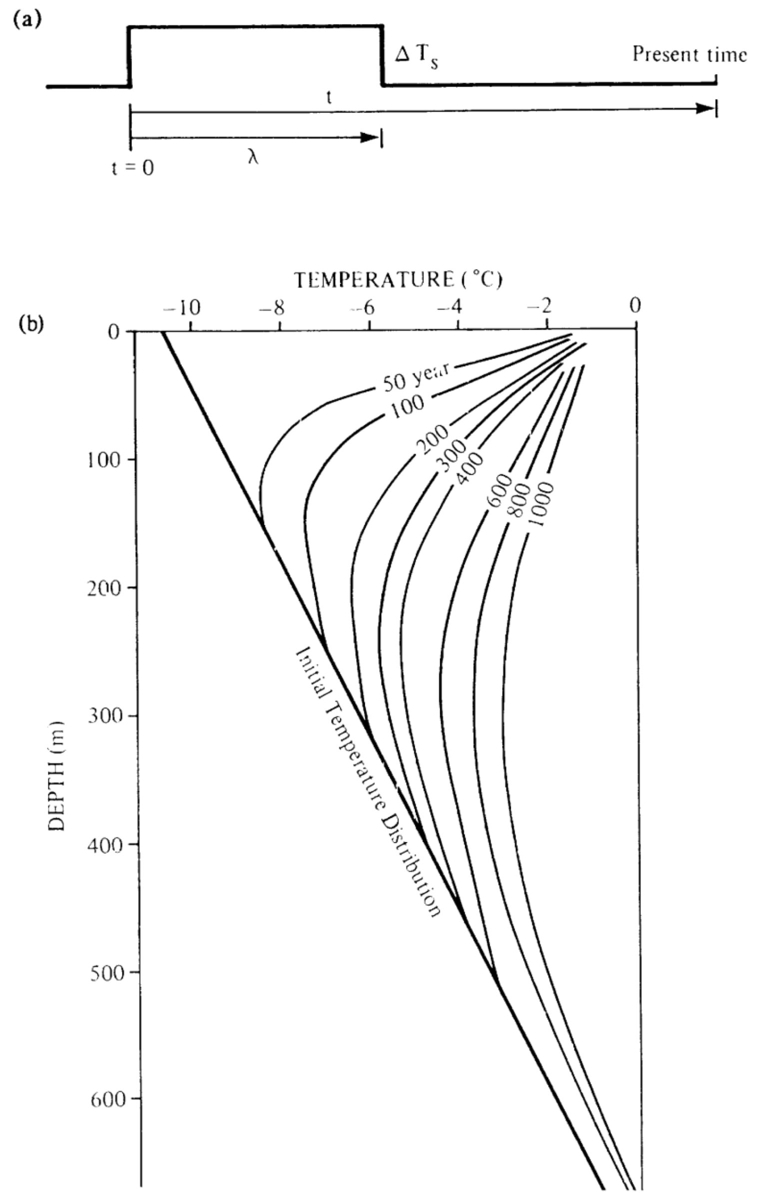


Figure 4.5 (*a*) Illustration of a step change model for climatic change. (*b*) Sequence of geothermal response to a surface temperature step change (from Molochuskin, 1973).

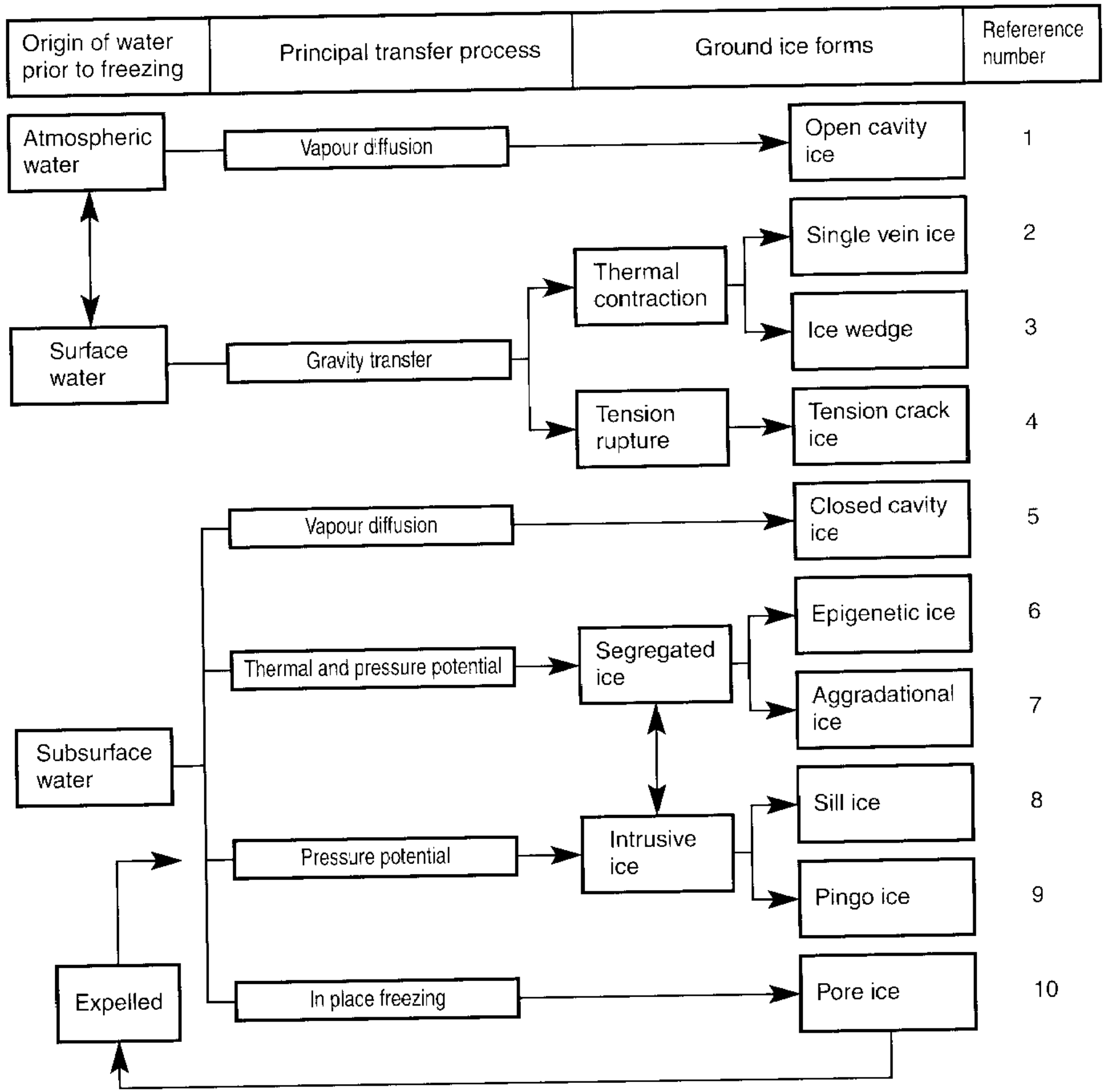
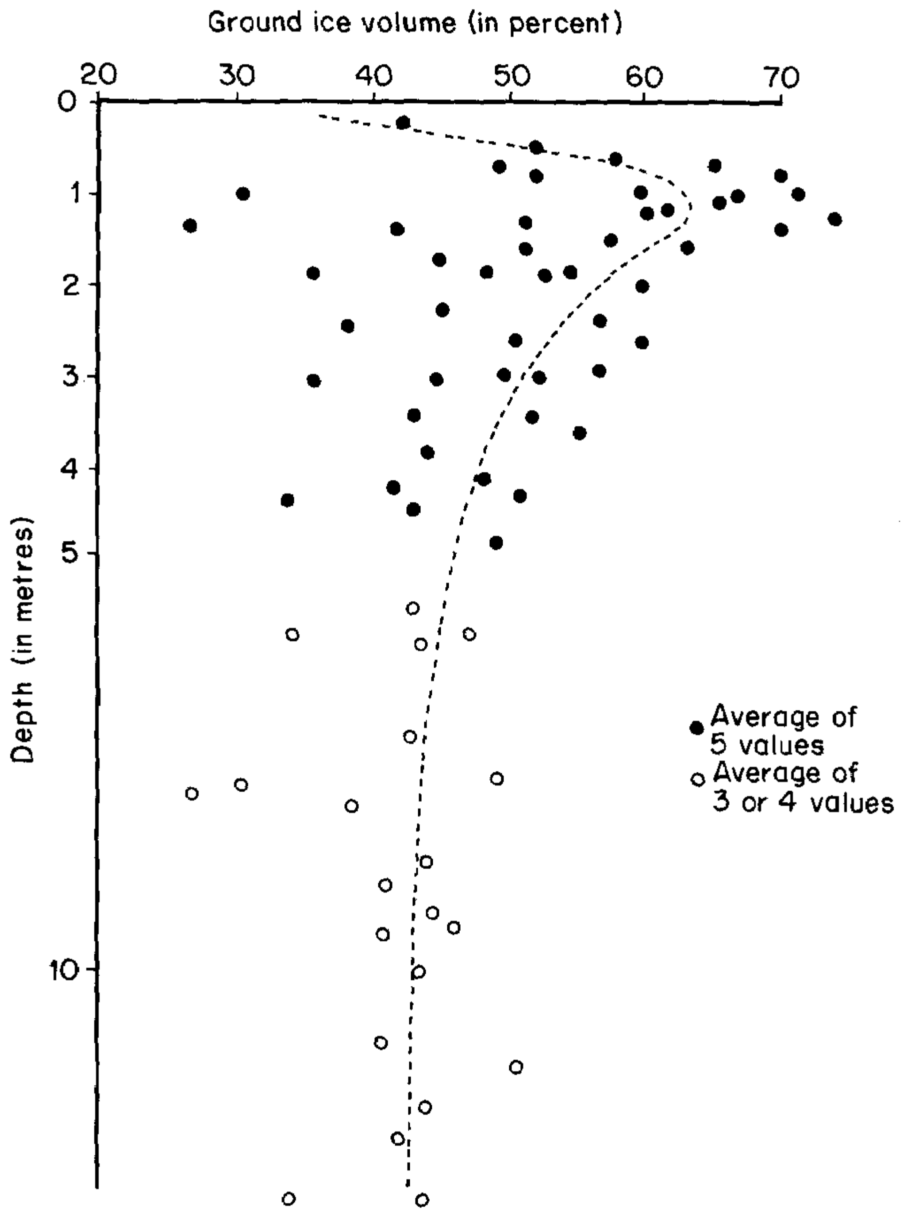


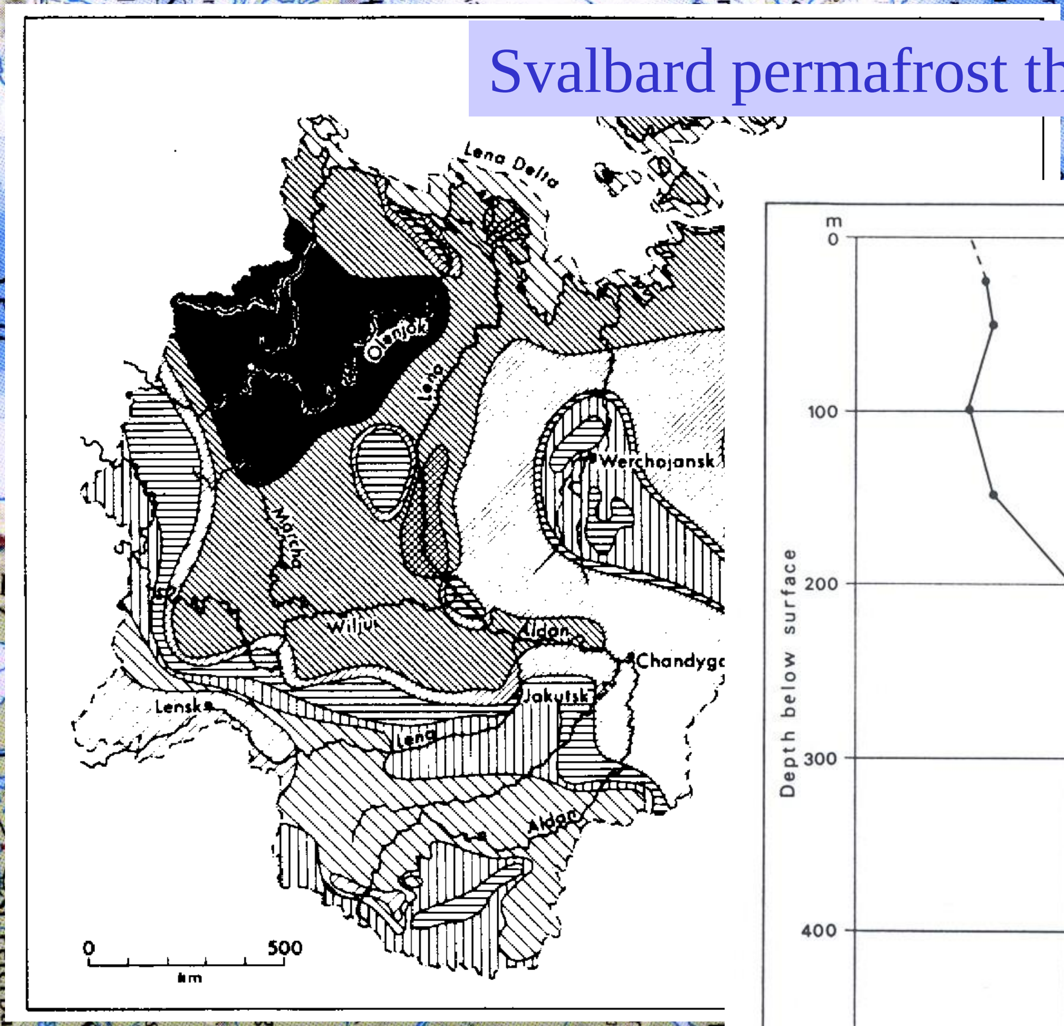
Figure 6.6 A genetic classification of ground ice (after Mackay, 1972b).

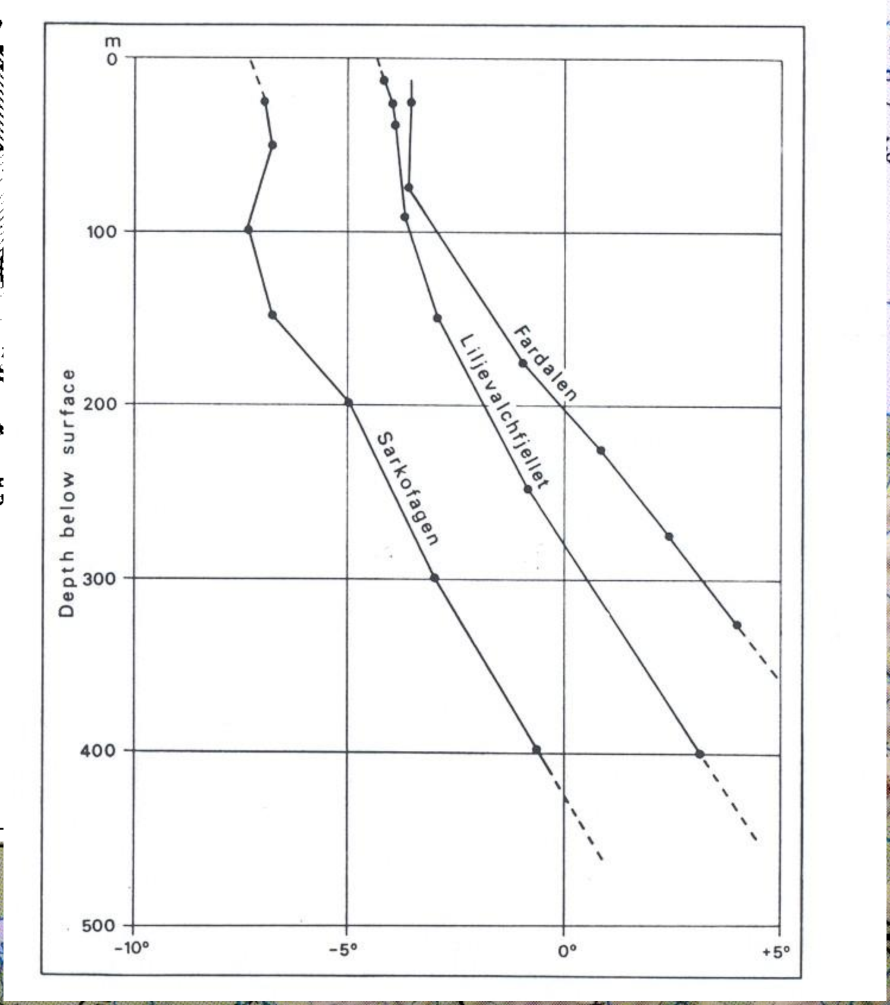
Ice content in the permafrost influence seal capacities and thawing rates



Permafrost thickness

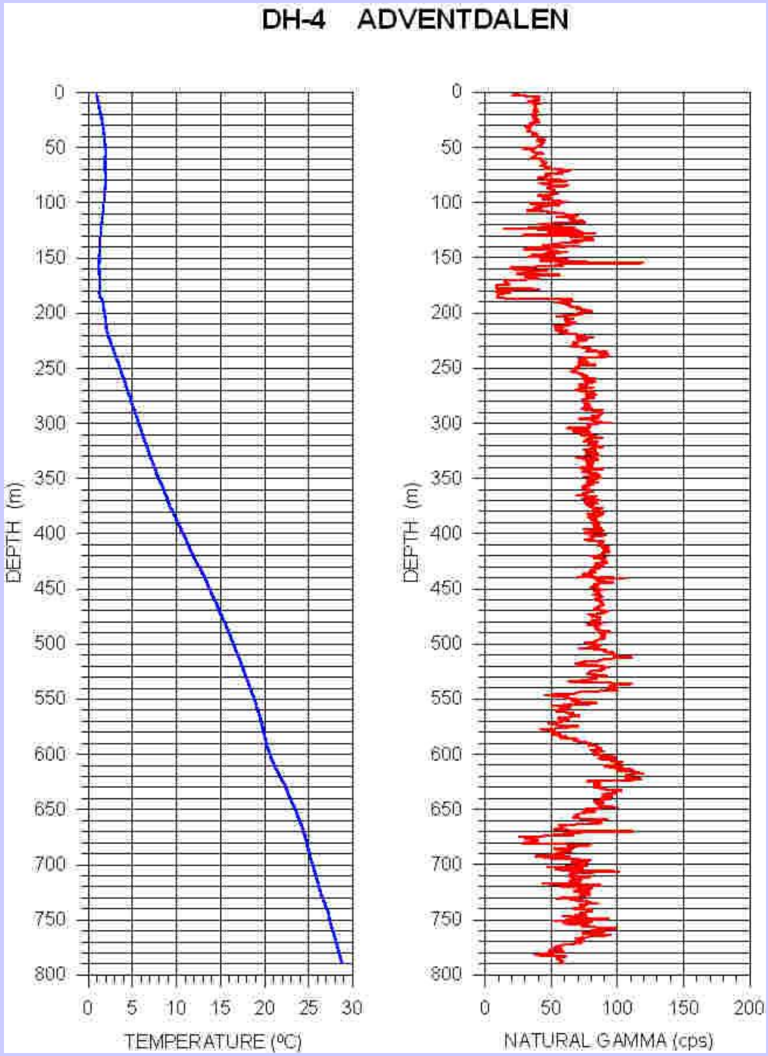
Svalbard permafrost thickness





Latest Svalbard permafrost thickness evidence

10 October 2009 CO_2 project well



Janssonhaugen permafrost borehole:

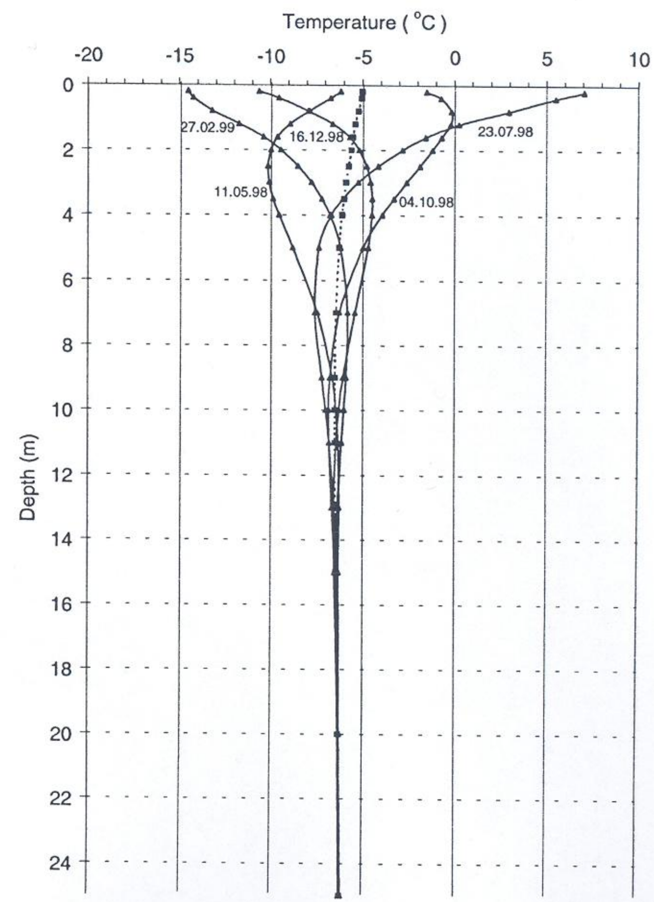
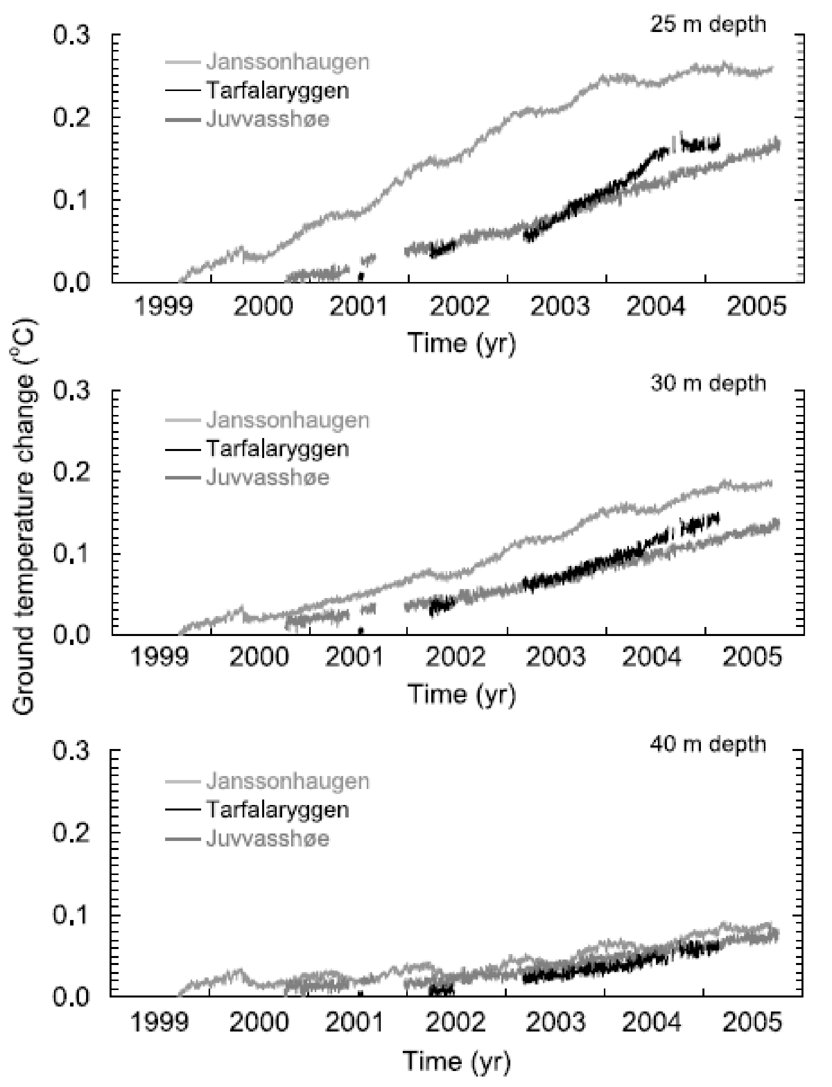


Fig. 3. Seasonal temperature profiles for the uppermost 20 m of the Janssonhaugen borehole during the first year after drilling. The year is divided into five readings with equal intervals (73 days). Dates are in dd.mm.yy. The dotted line represents the mean annual temperatures.

Janssonhaugen 102 m borehole permafrost temperature evidence



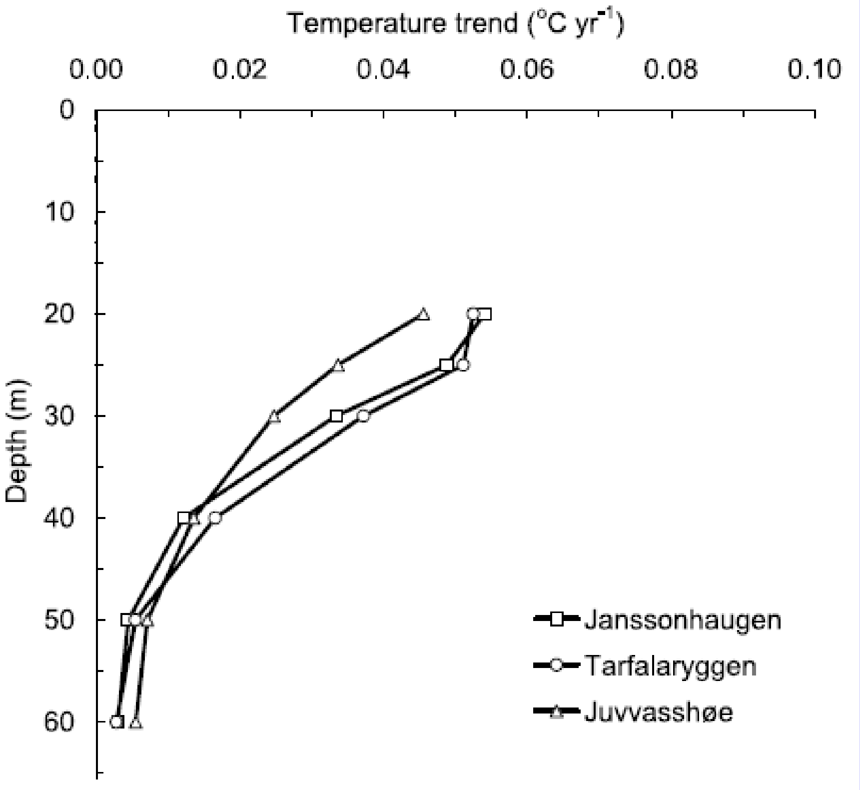


Figure 8. Observed linear trends in ground temperature as a function of depth. Statistically significant positive trends are found to 60 m depth at all sites. Time series at Janssonhaugen start in 1999, at Tarfalaryggen they start in 2001, and at Juvvasshøe they start in 2000, and they last for 6, 4, and 5 years, respectively.

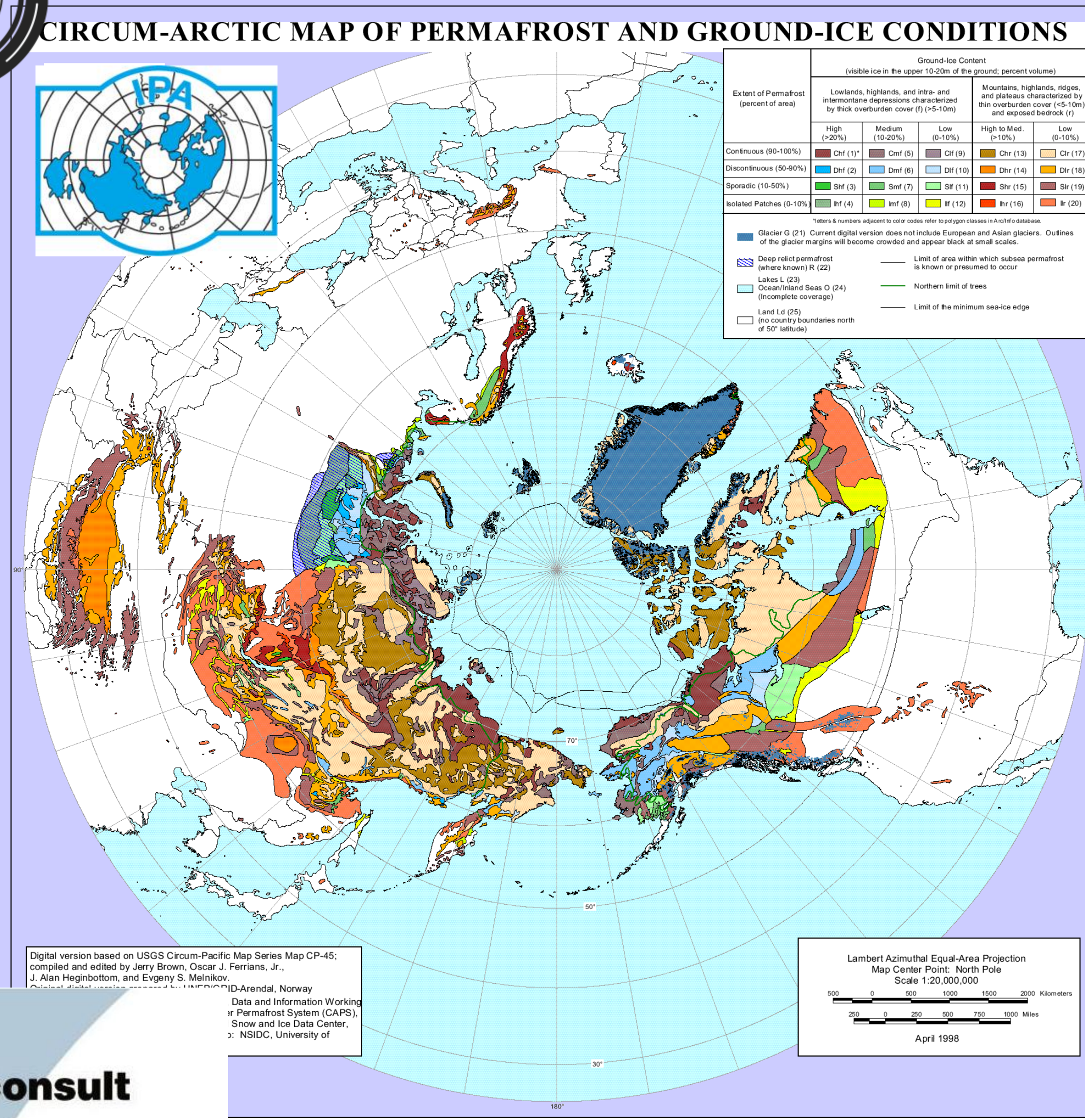
'Significant warming is detectable down to at least 60m depth, and present decadal warming rates at the permafrost surface are on the order of 0.04–0.07ºC/yr'

(Isaksen et al., 2007)

Permafrost Observatory Project: A contribution to the Thermal State of Permafrost in Norway and in Svalbard

<u>**Project focus:**</u>

1) **Permafrost temperatures in boreholes - snapshot**
2) **Permafrost landform activity**
3) **Permafrost observatories in Troms and in Svalbard**
4) **National permafrost database**
5) **Permafrost modelling – first permafrost map of Norway**
6) **Permafrost Int. University Course in Svalbard and Greenland**



NTNU Det skapende universitet

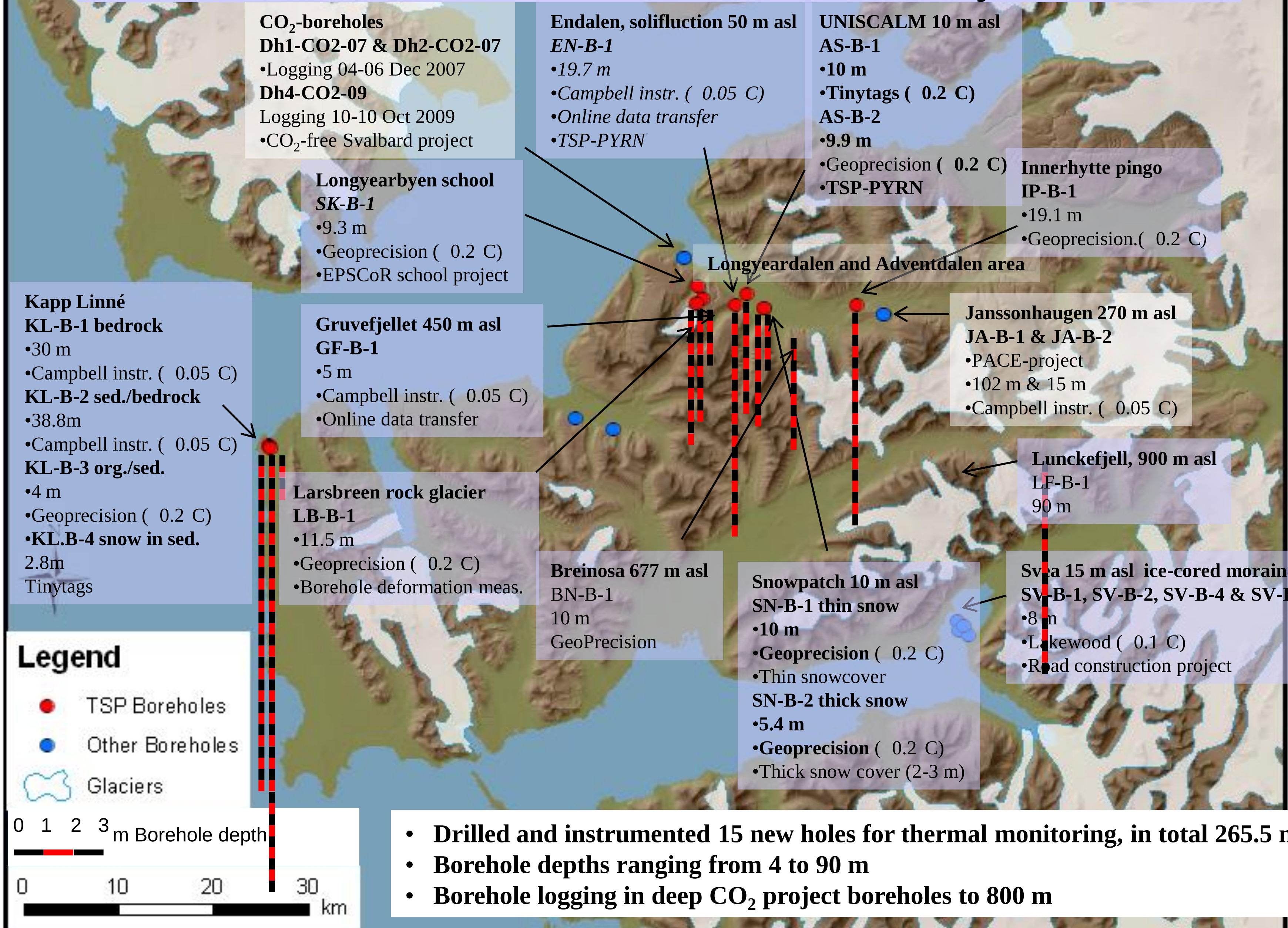
NGU Geologi for samfunnet siden 1858

Norwegian Meteorological Institute met.no

ICG International Centre for Geohazards

Opticonsult

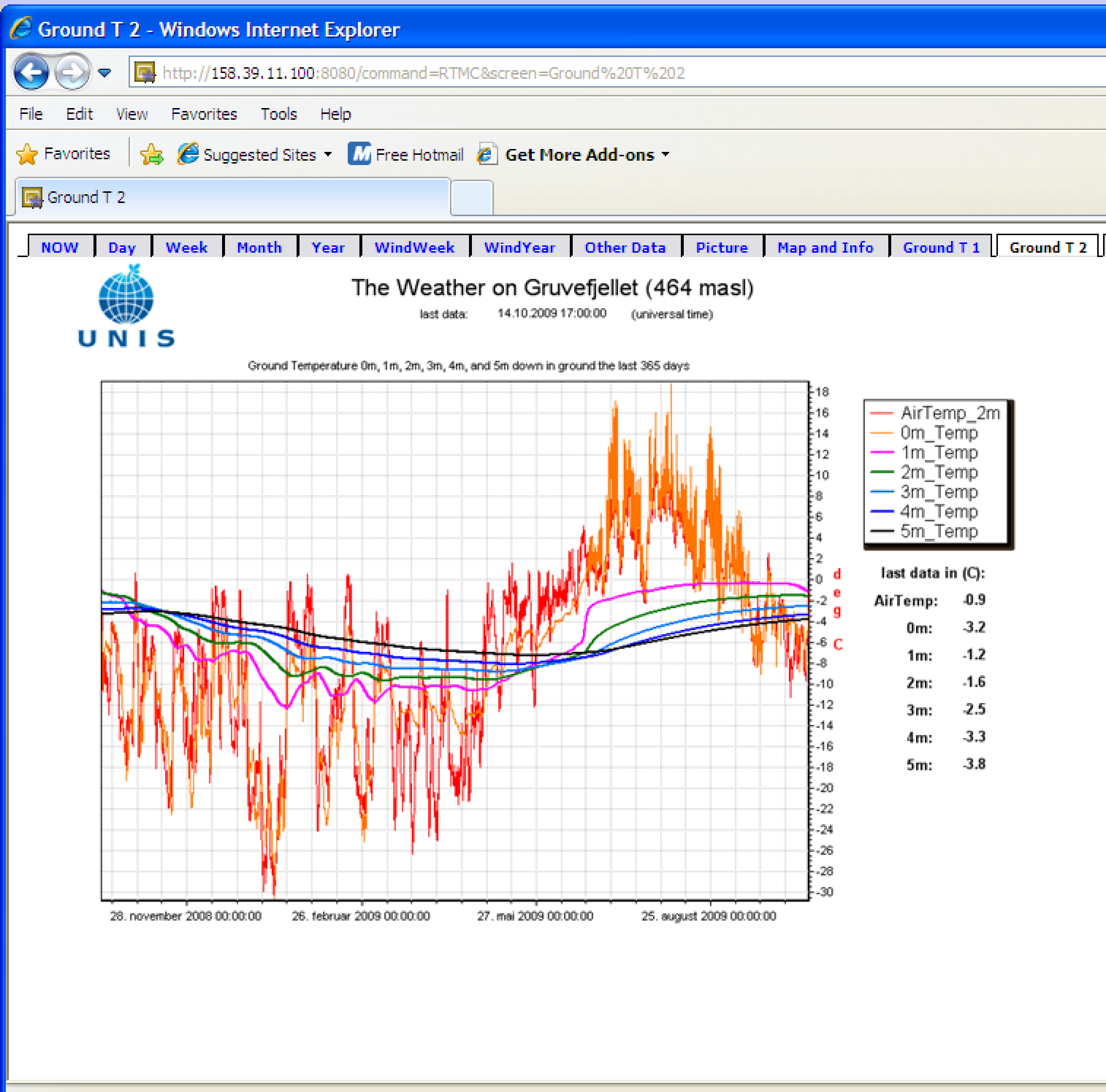
TSP Svalbard:
Nordenskiöldsland Permafrost Observatory, Svalbard

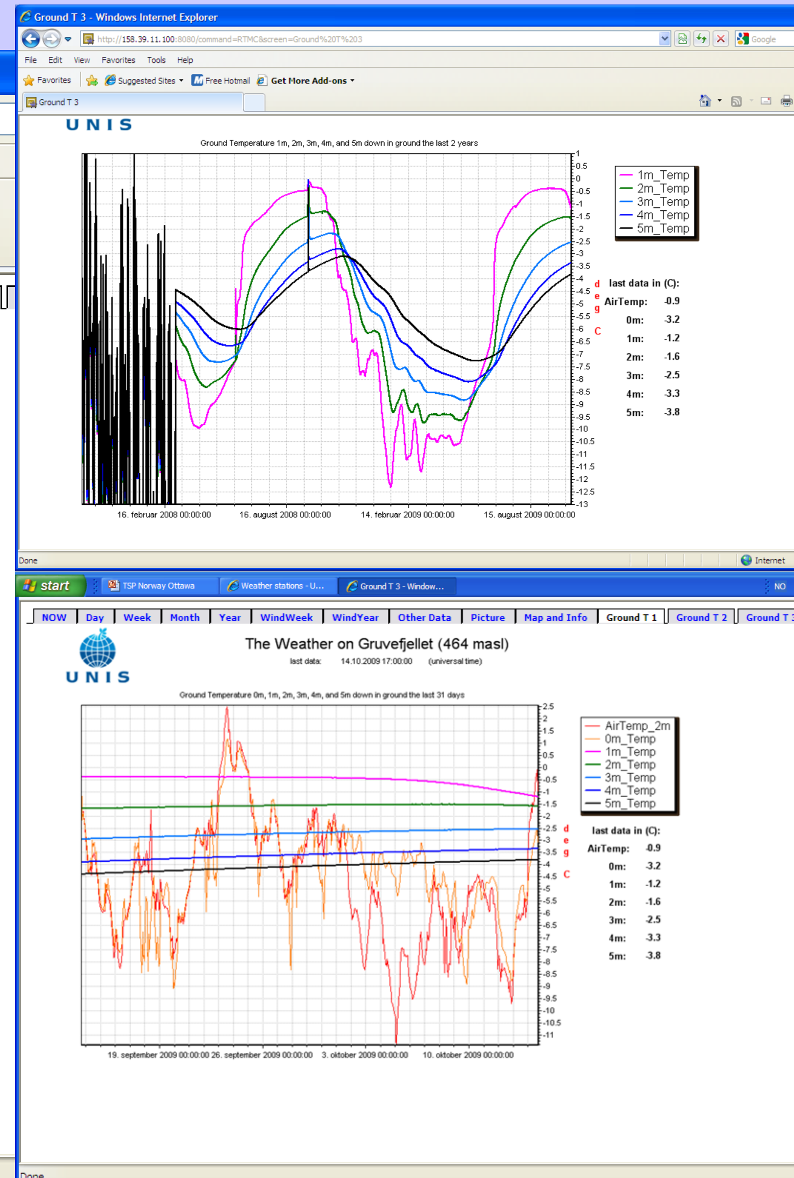


- **Drilled and instrumented 15 new holes for thermal monitoring, in total 265.5 m**
- **Borehole depths ranging from 4 to 90 m**
- **Borehole logging in deep CO_2 project boreholes to 800 m**

Permafrost boreholes drilled during winter 2008

Online permafrost temperatures – from two boreholes at (weather and permafrost stations)





UNIS students drilling to 3 m – ice content & temperature

Active layer definition

The active layer is defined as the top layer of ground subject to annual thawing and freezing in areas underlain by permafrost *(Glossary of Permafrost and Related Ground-Ice Terms, 1988)*

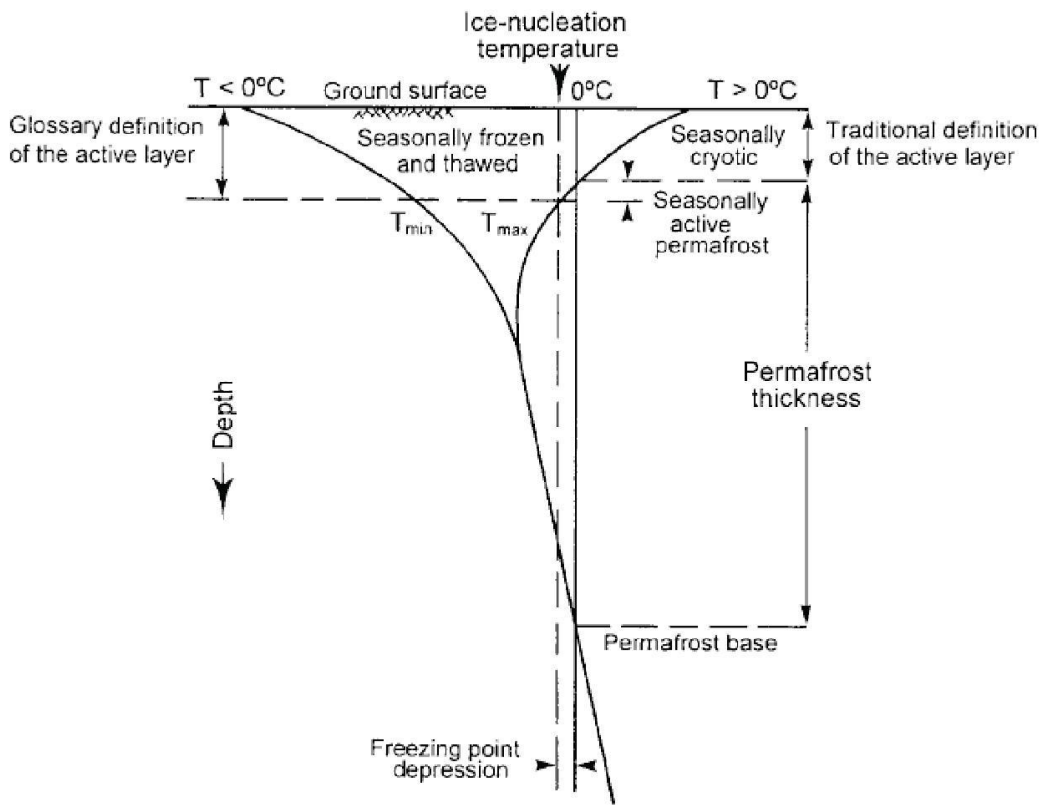


Figure 1. Selected terms used by the *Glossary* to describe the states of water and ground temperature in permafrost (after ACGR, 1988, Figure 2). Note that the active layer, as defined by Muller (1947), is described here as 'seasonally cryotic' ground.

(Burn, 1998)

Seasonal changes in the active layer

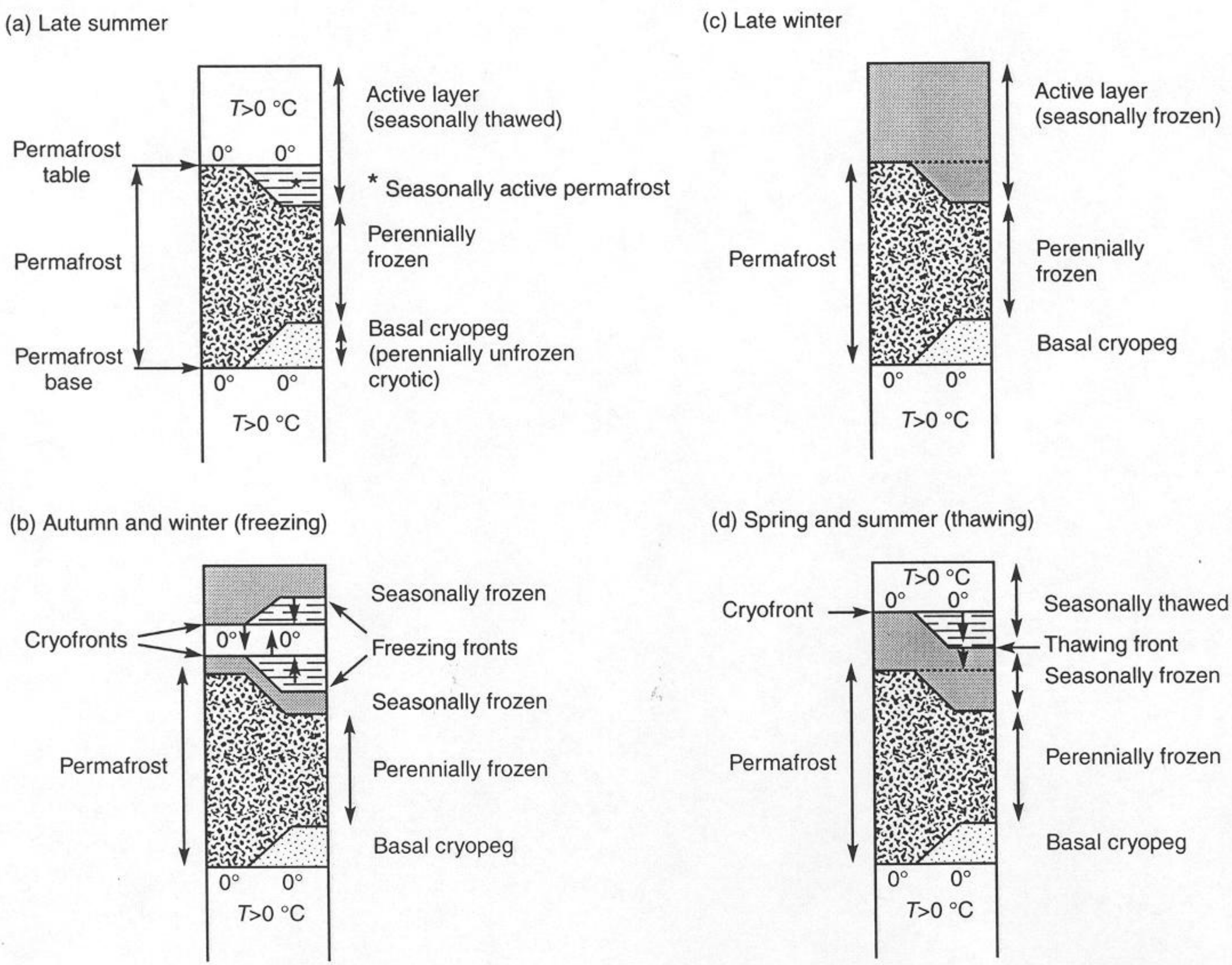
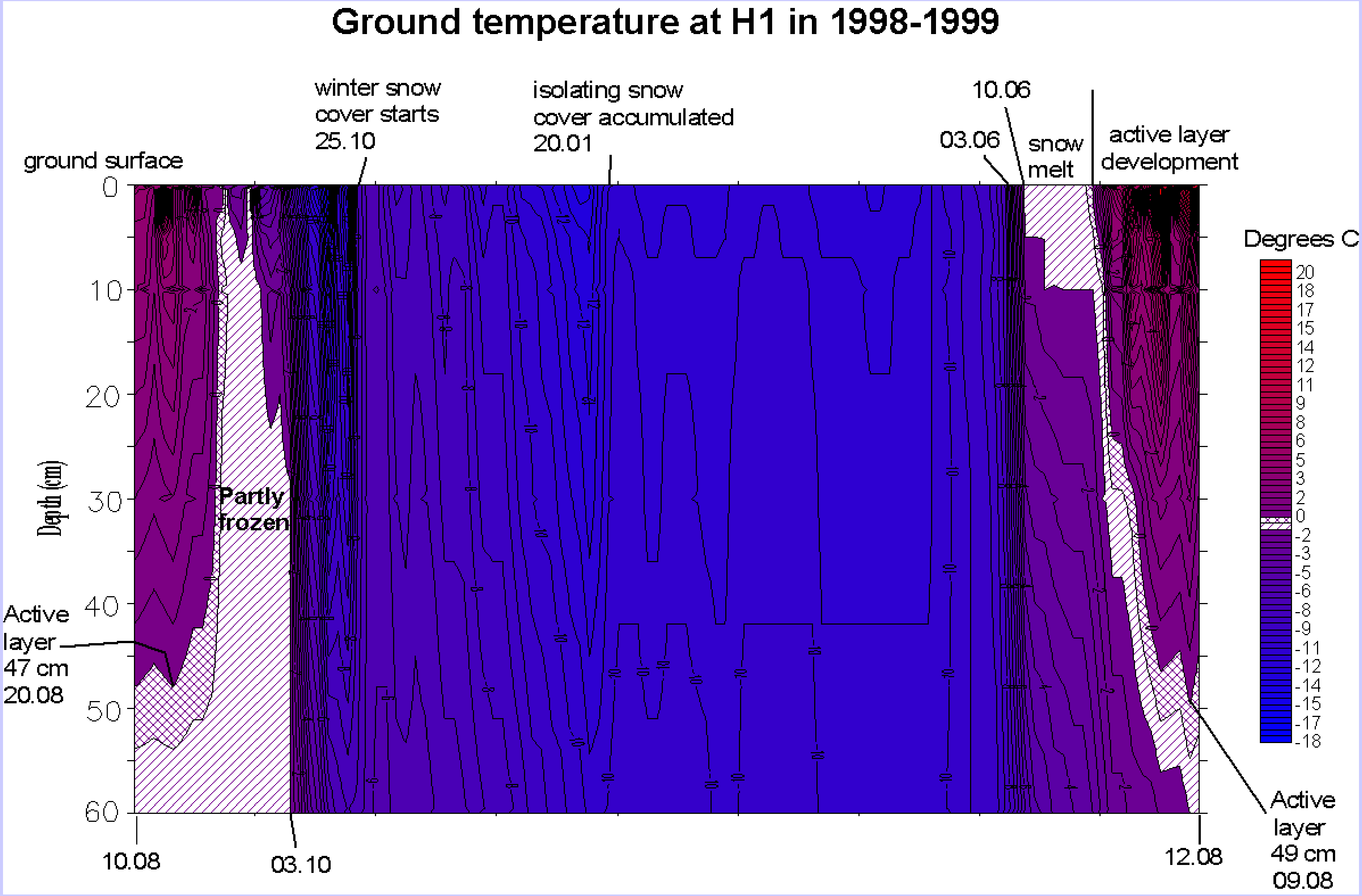


Figure 8.2 Seasonal changes (a–d) in the active layer. The temperature relative to 0 °C and the state of water are also indicated (*source*: ACGR, 1988).

Temperature measurements



Active layer thickness

Calculation:

-) Active layer thickness = $E\sqrt{TDD}$
(E = edaphic factor)

-) Active layer thickness = $\sqrt{\alpha P/\pi \log e \mid A_o/T_o \mid}$
(α = soil thermal diffusivity, P = period of temperature cycle
A_o= surface temperature amplitude, T_o= mean annual surface temperature)

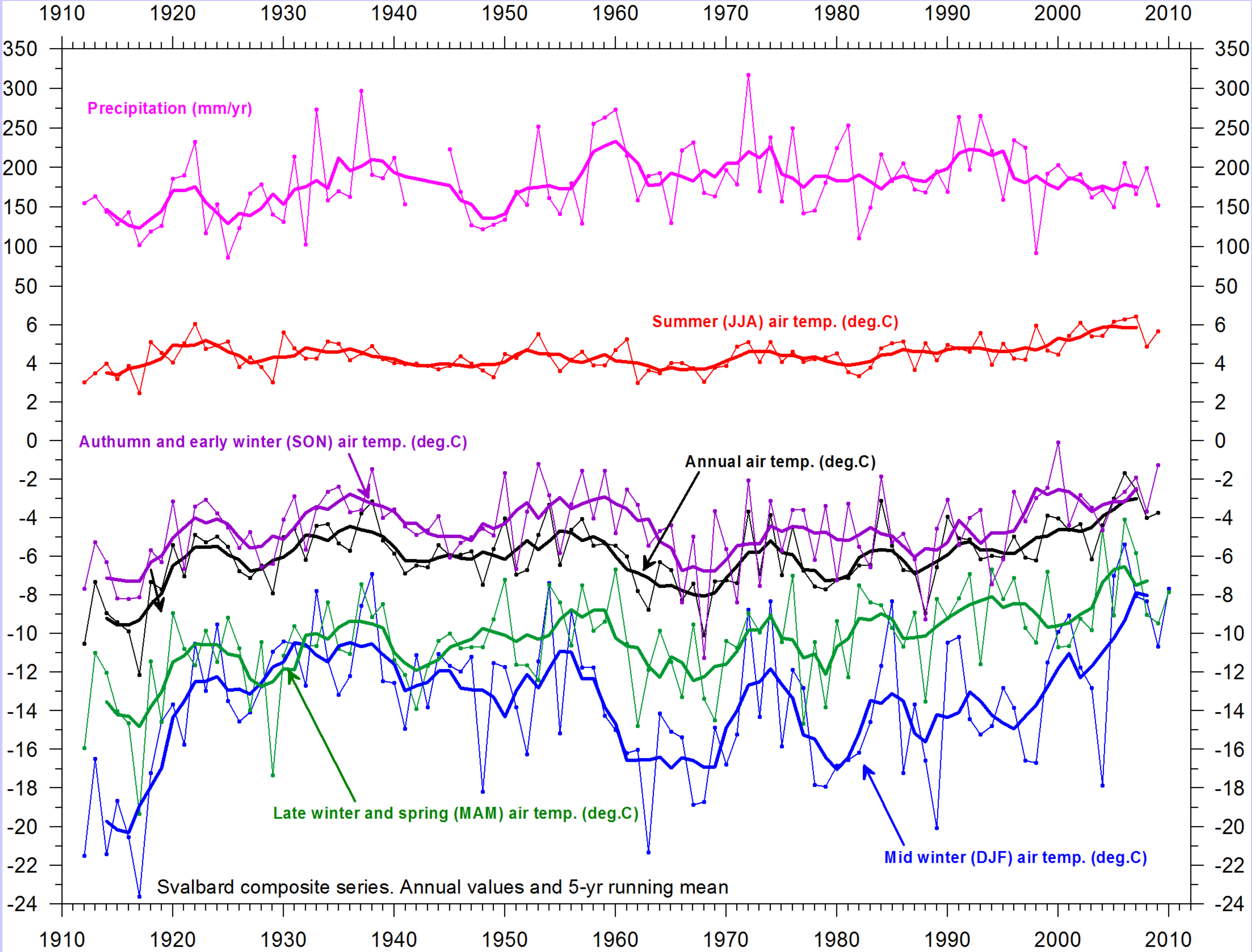
Monitoring:

-) Mechanical probing
-) Temperature measurements
-) Visual observations

UNISCALM: 100 x 100 m = 121 points, 10 gridsize

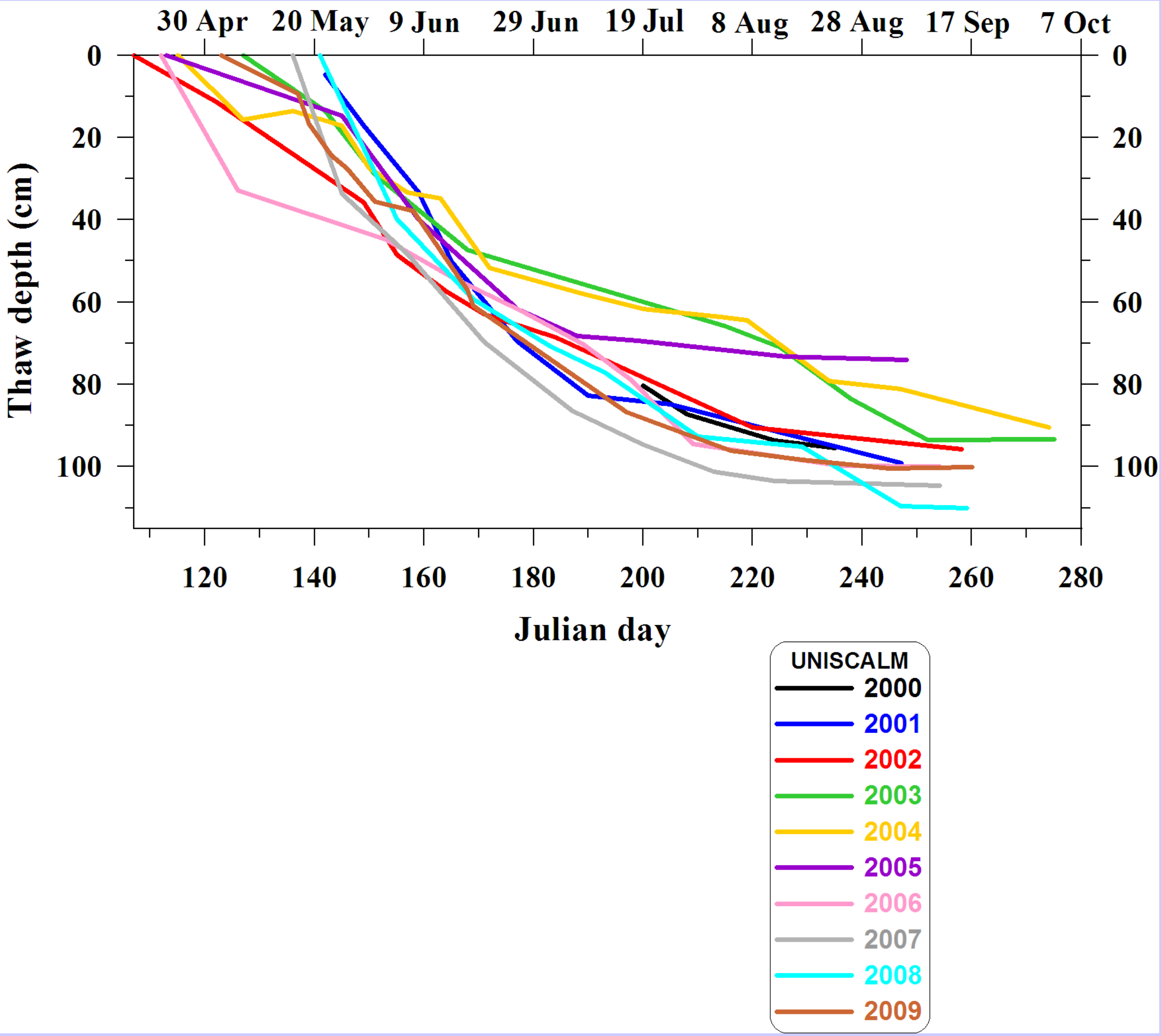
Flat and silt dominated loess deposits on fluvial terrace

Svalbard – a longer maritime high arctic meteorological record



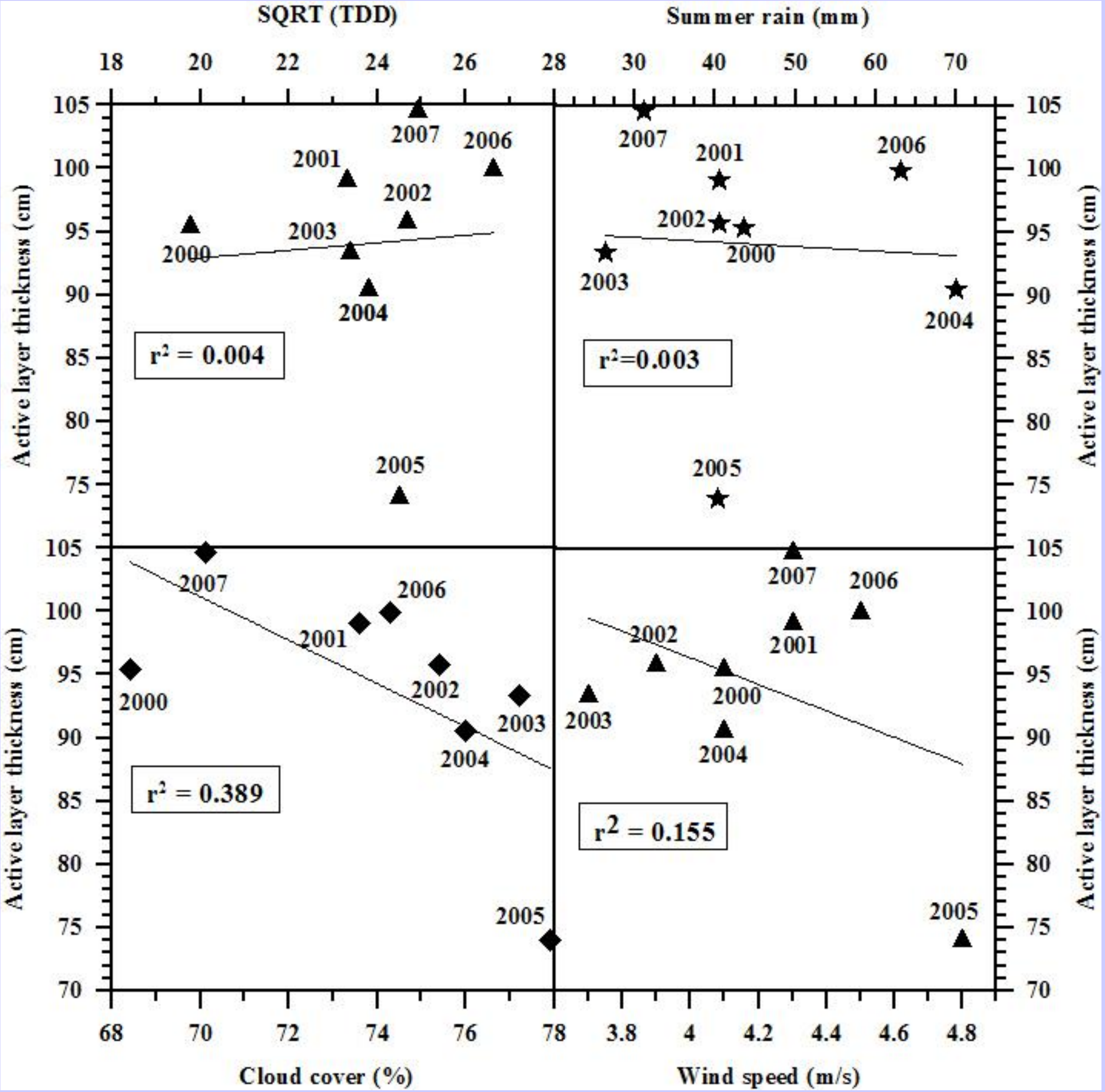
Thaw progression in the UNISCALM

Probed from 8 to 15 times annually

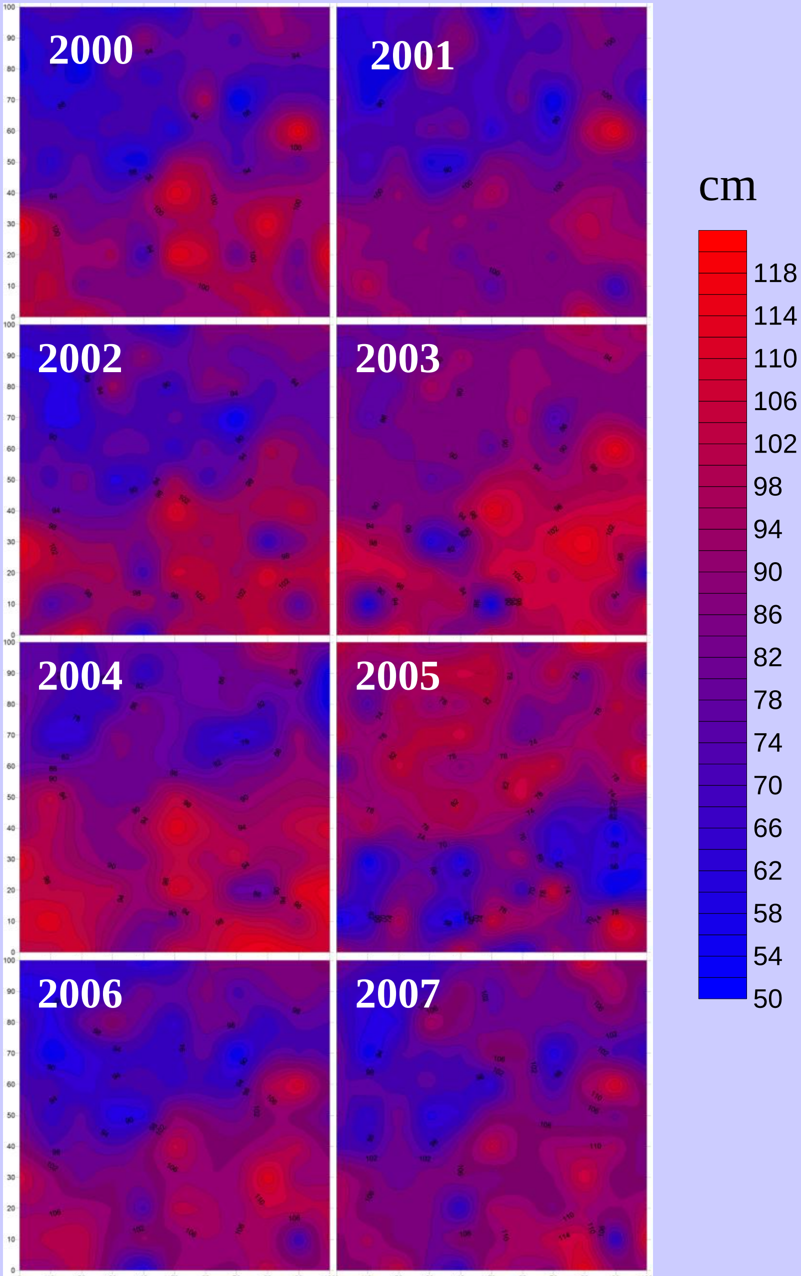


Active layer average: 94 cm, min: 74 cm, max: 105 cm

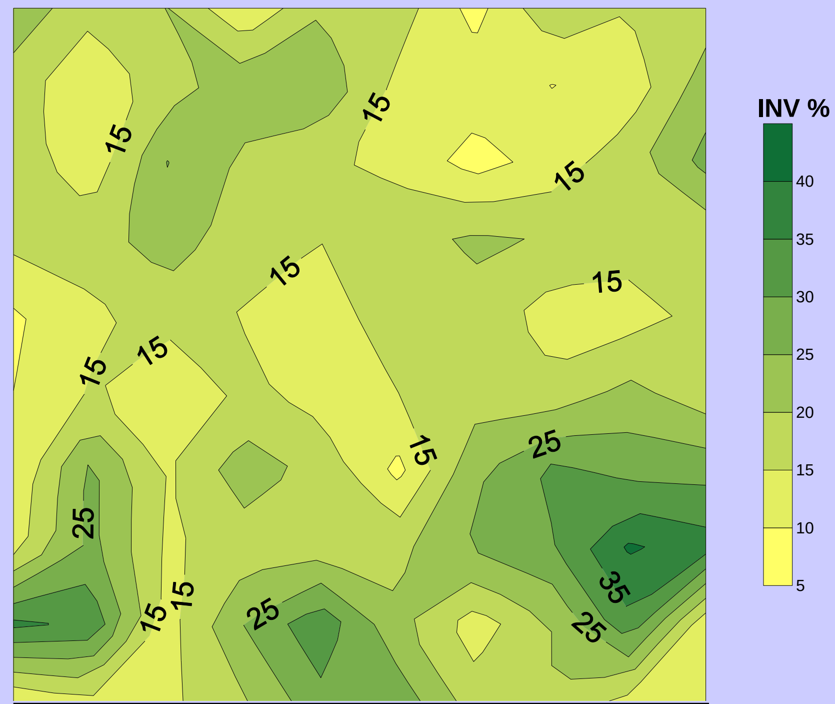
Meteorological control on active layer thickness



Interannual spatial variation in active layer thickness in the UNISCALM



Interannual grid node variability (INV) based on normalized variability index for each grid node over the 8 year measuring period



The Surface/Nival and Thermal Offsets

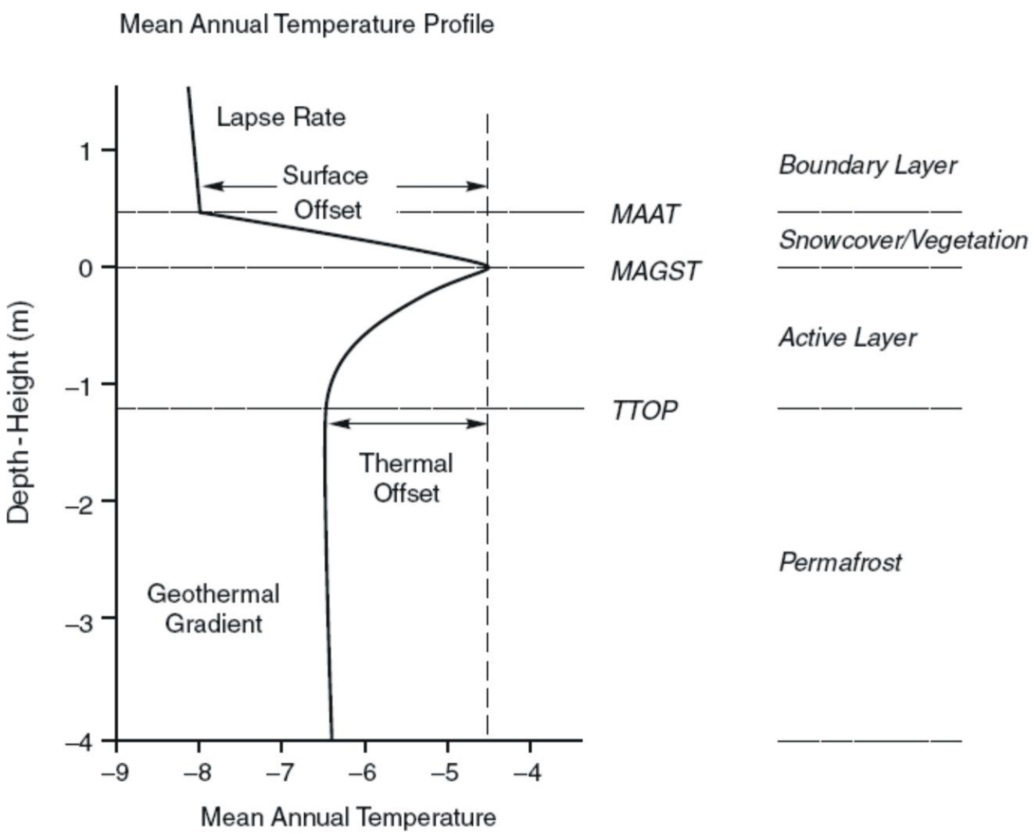
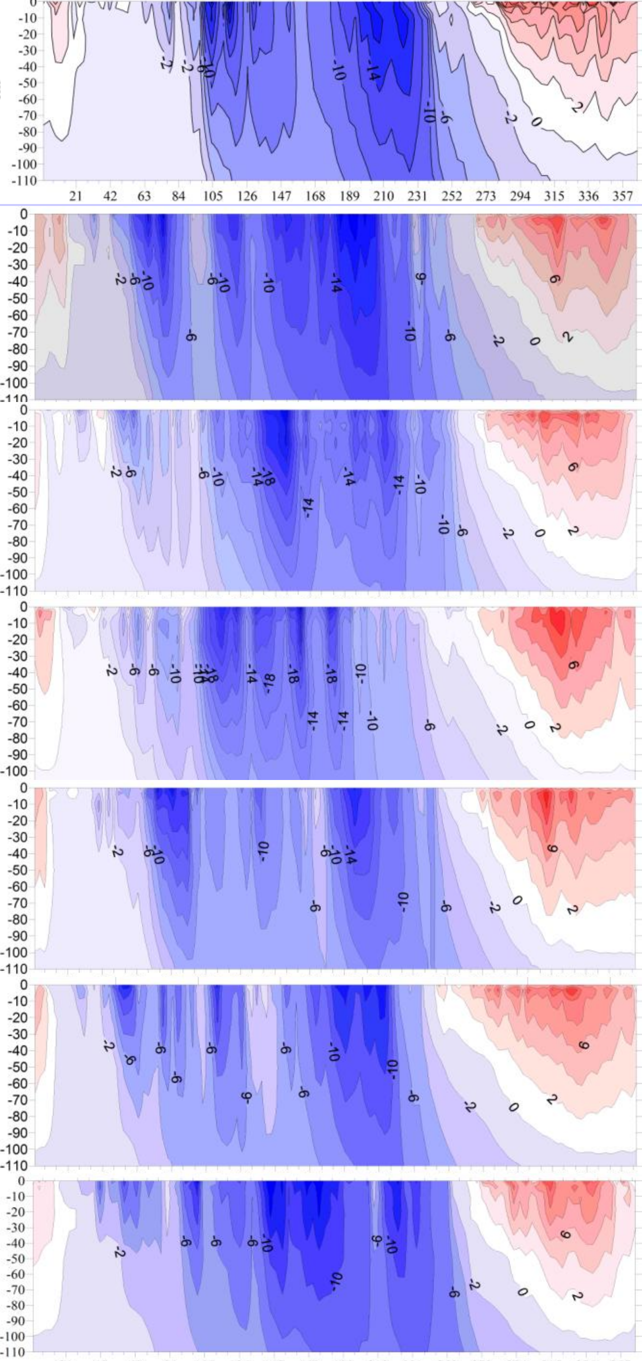


Figure 3 Schematic mean annual temperature profile through the surface boundary layer, showing the relation between air temperature and permafrost temperature.

Temperature of the active layer in UNISCALM in the sediment by 5 miniature temp. dataloggers



1 September to 31 August

2000
2001

2001
2002

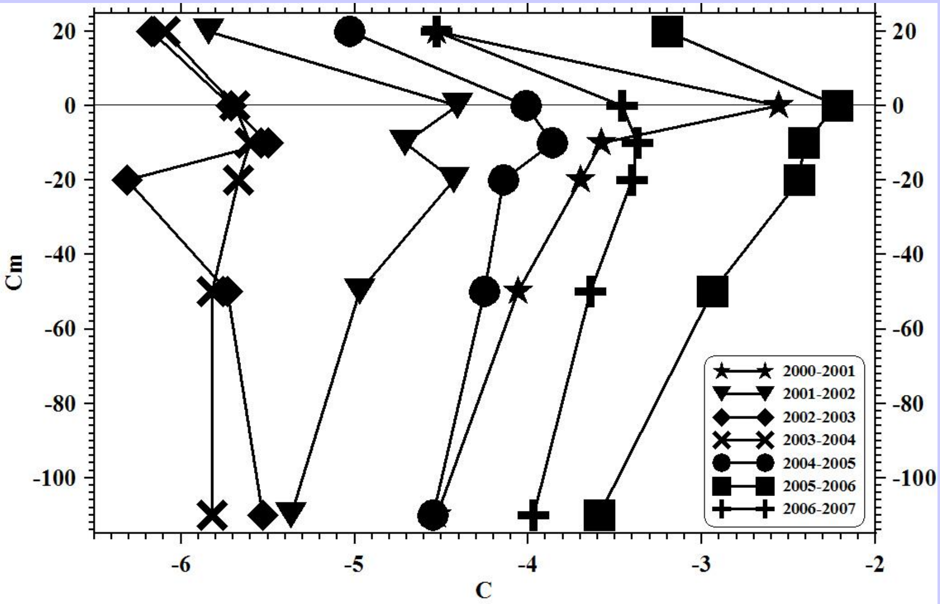
2002
2003

2003
2004

2004
2005

2005
2006

2006
2007

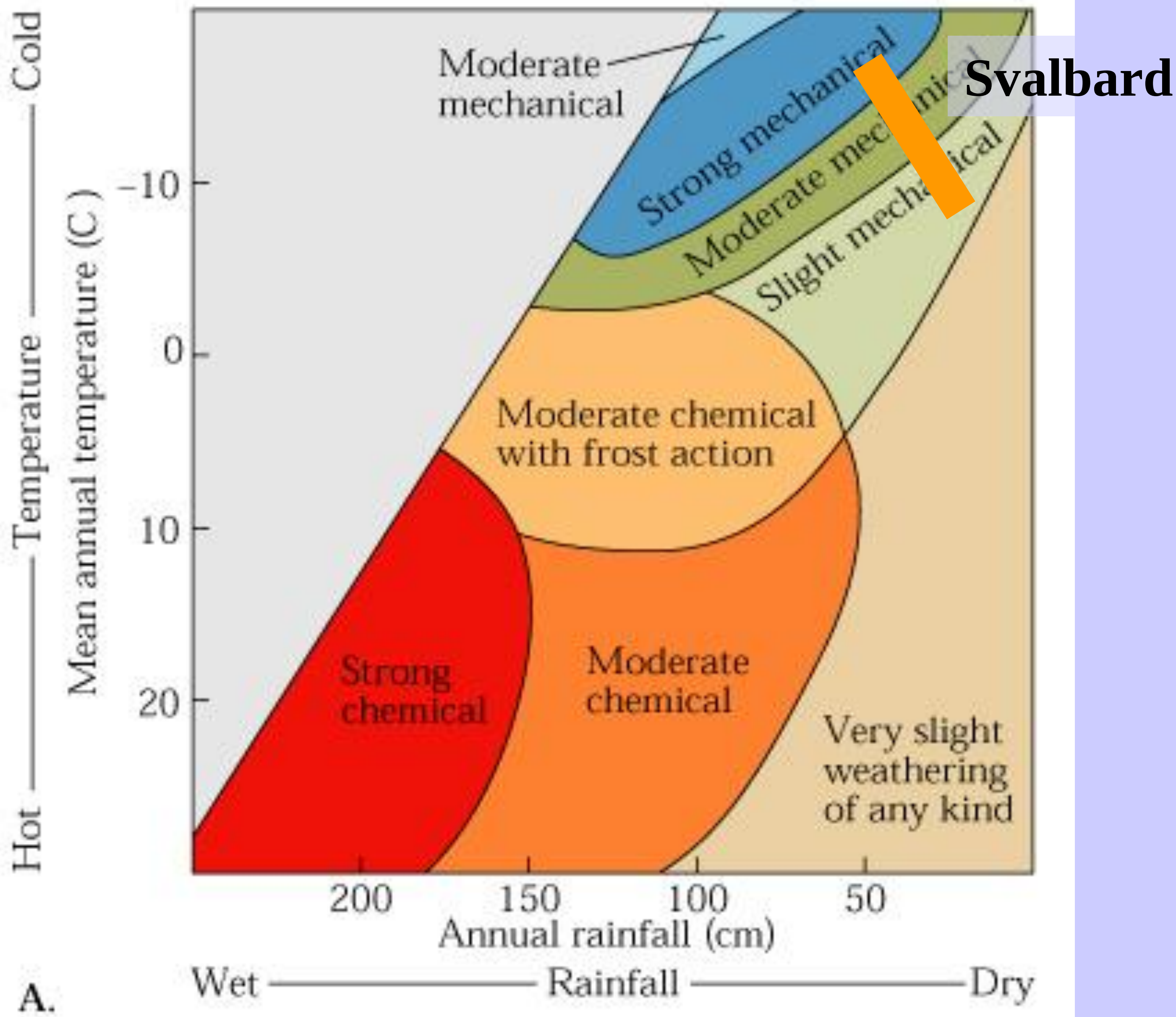


Large interannual variation of mean ground temperatures

Nival offset (Ground surface to 20 cm above ground):
Max: 2.0ºC, Min: 0.4ºC, Mean: 1.0ºC

Thermal offset (Ground surface to 110 cm top PF):
Max: 2.0 ºC, Min: 0.1ºC, Mean: 0.8ºC

(Christiansen & Humlum, 2008)



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’Cryogenic weathering is the combination of mechanico-chemical processes which cause the in situ breakdown of rock under cold-climate conditions’. (French, 1996)

Frost weathering is controlled by geology:

- Rocks with high porosity are frost sensitive
- Very permeable rocks are not frost sensitive
- Poorly consolidated rocks are frost sensitive
- Rock fracturing improve weathering

& by climate:

- Moisture is needed, a critical saturation level is needed
- Temperature (fast cooling but nature is slow 2 to 4°C/hour max, freeze/thaw cycles increase weathering)

Surface disturbance leading to subsidence - Thermokarst

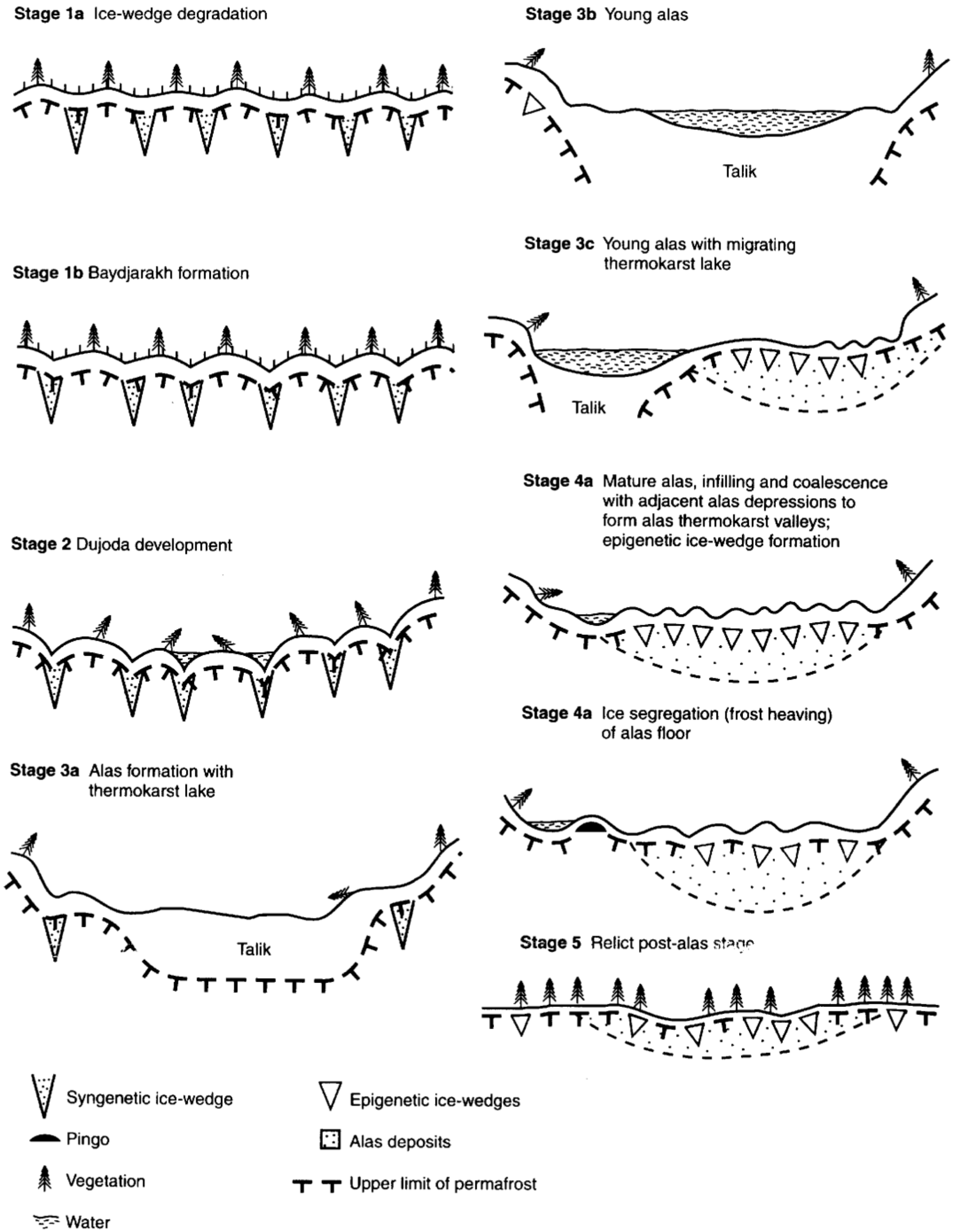


Figure 7.3 The sequence of development of alas thermokarst relief in central Yakutia, according to P. A. Soloviev (1973b).

<u>Controlling factors:</u>

Sediment type (ice content)

Increased continentality

Tree cutting/fires

Lateral water course erosion

<u>2 types of processes:</u>

Thermal erosion (horisontal)

Termokarst subsidence (vertical)

<u>Thermokarst landforms:</u>

Closed depressions

Hilly irregular terrain

Thaw lakes (oriented)

What are the controlling factors on thermokarst development ?

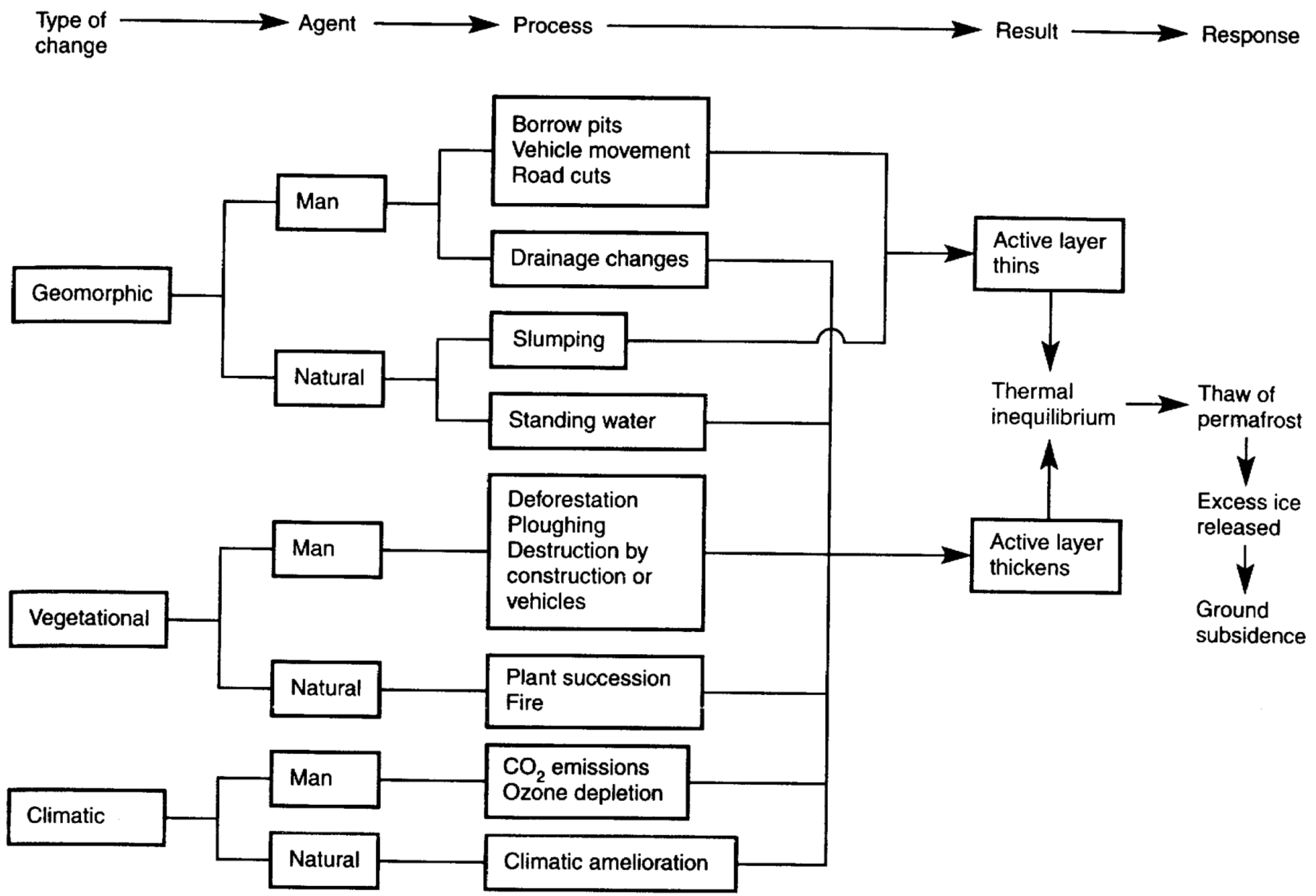
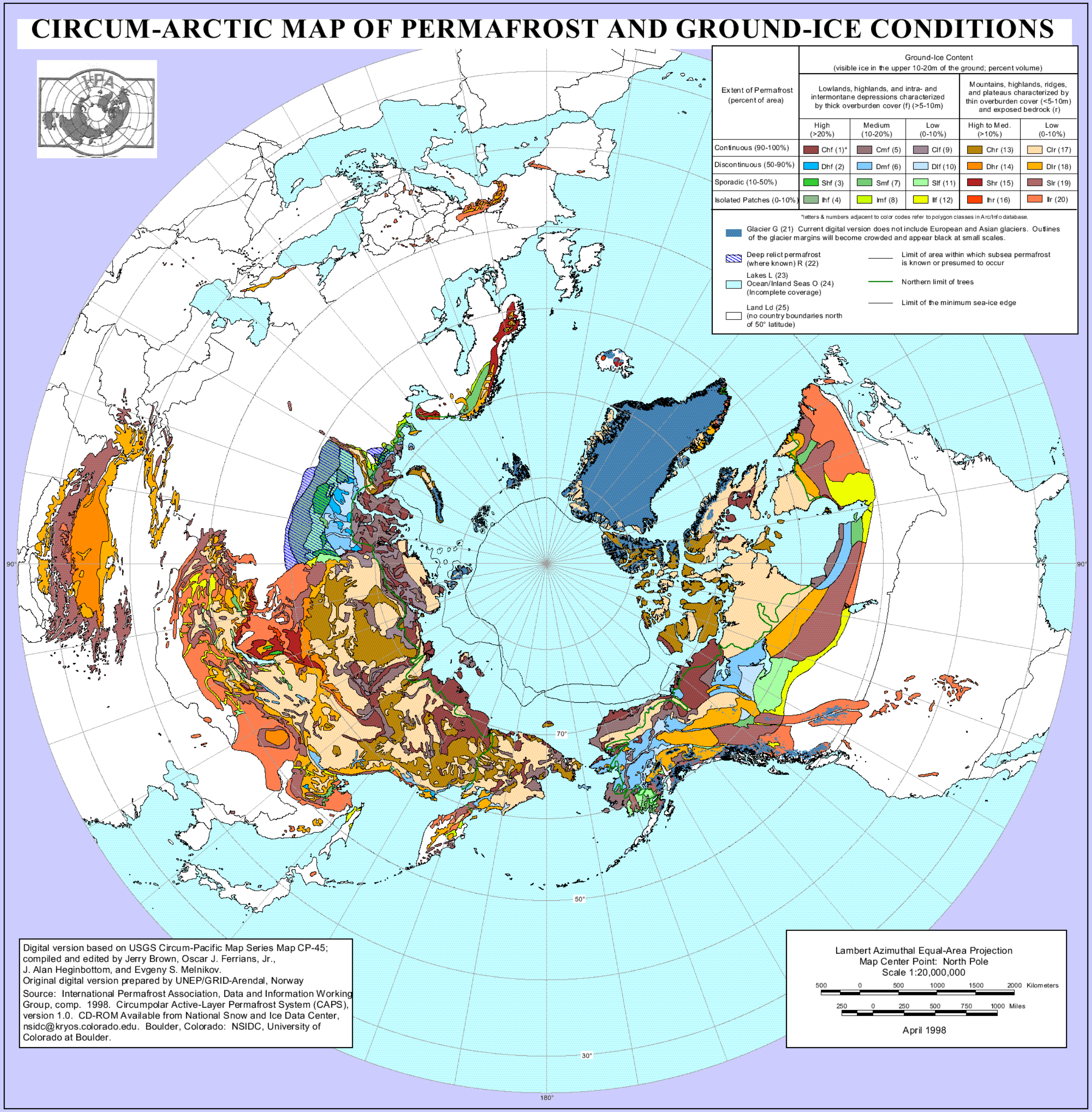


Figure 7.2 Diagram illustrating how geomorphic, vegetational and climatic changes may lead to permafrost degradation (modified from French, 1987c).

How can climatic changes affect permafrost ?
And the periglacial environment ?



Literature used in lecture:

French, H.M. **The Periglacial Environment**. 458 p,
Third Edition 2007.

Humlum, O.; Instanes, A. & Sollid, J.L. 2003.
Permafrost in Svalbard: a review of research history, climatic background and engineering challenges
Polar Research 22(2), 191–215.

Christiansen, H. H. & Humlum, O. 2008. **Interannual Variations in Active Layer Thickness in Svalbard. In** Kane, D.L. & Hinkel, K.M. (eds). 2008. *Ninth International Conference on Permafrost.* Institute of Northern Engineering, University of Alaska Fairbanks (2 Vols.), Vol. 1, p 257-262.

Christiansen, H.H. & Mortensen, L.E. (2002) **Arctic mountain meteorology at the Sornfelli mountain in the year 2000 in the Faroe Islands.** *Frodskaparrit* 50, 93-110.

Kottak, M., Grieser, J., Beck, C., Rudolf, B. & Ruber, F. (2006). **World Map of the Köppen-Geiger climate classification updated**. Meteorologische Zeitschrift, Vol. 15, No. 3, p 259-263.

Useful website:

http://ipa.arcticportal.org/

The Norwegian Permafrost database NORPERM was developed during IPY as part of the Geological Survey of Norways general borehole database system

You find all metadata and all data from all TSP Norway boreholes in the online NORPERM – as requested by the IPY Norway funding

http://www.ngu.no/kart/permafrost_svalbard/?lang=English

http://www.ngu.no/kart/permafrost/?lang=English