Periglacial geomorphology

GEG 2130

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Arctic definition
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Active layer
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Thermokarst
Climate Change

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Periglacial

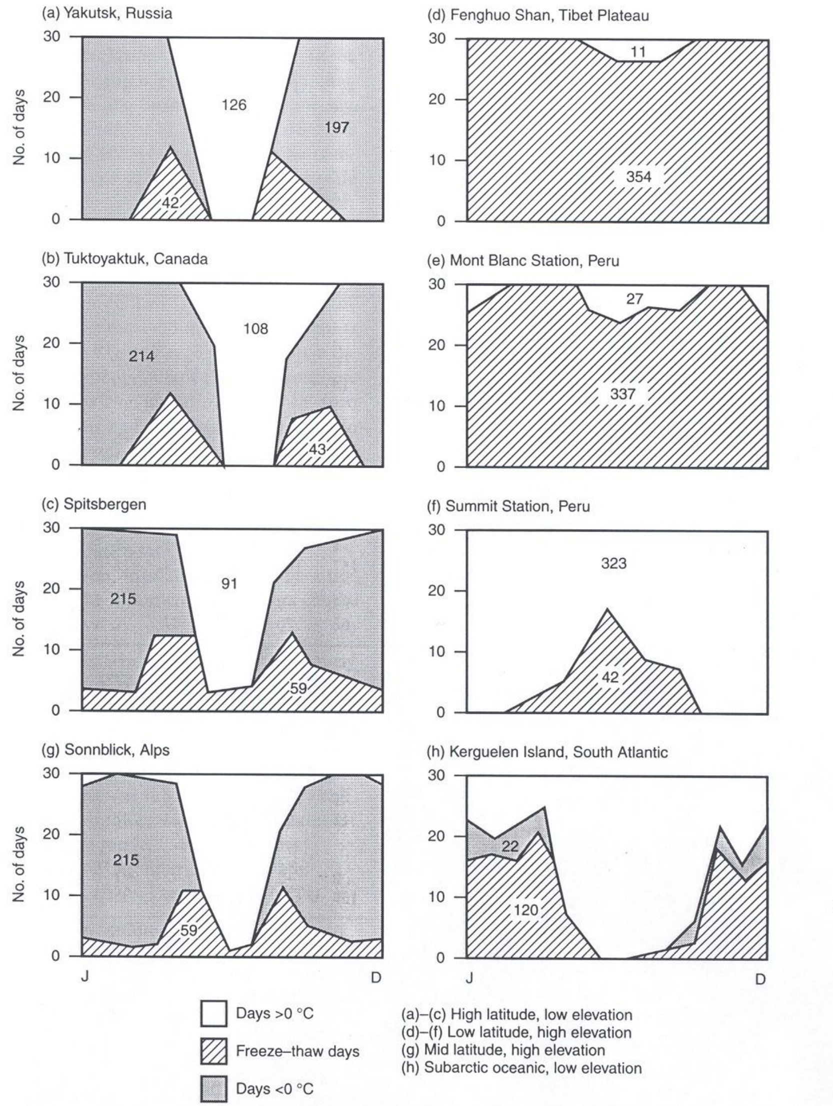
Definition:

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:

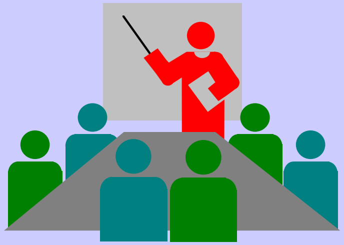
Periglacial environments may have permafrost but many periglacial regions have not.

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).

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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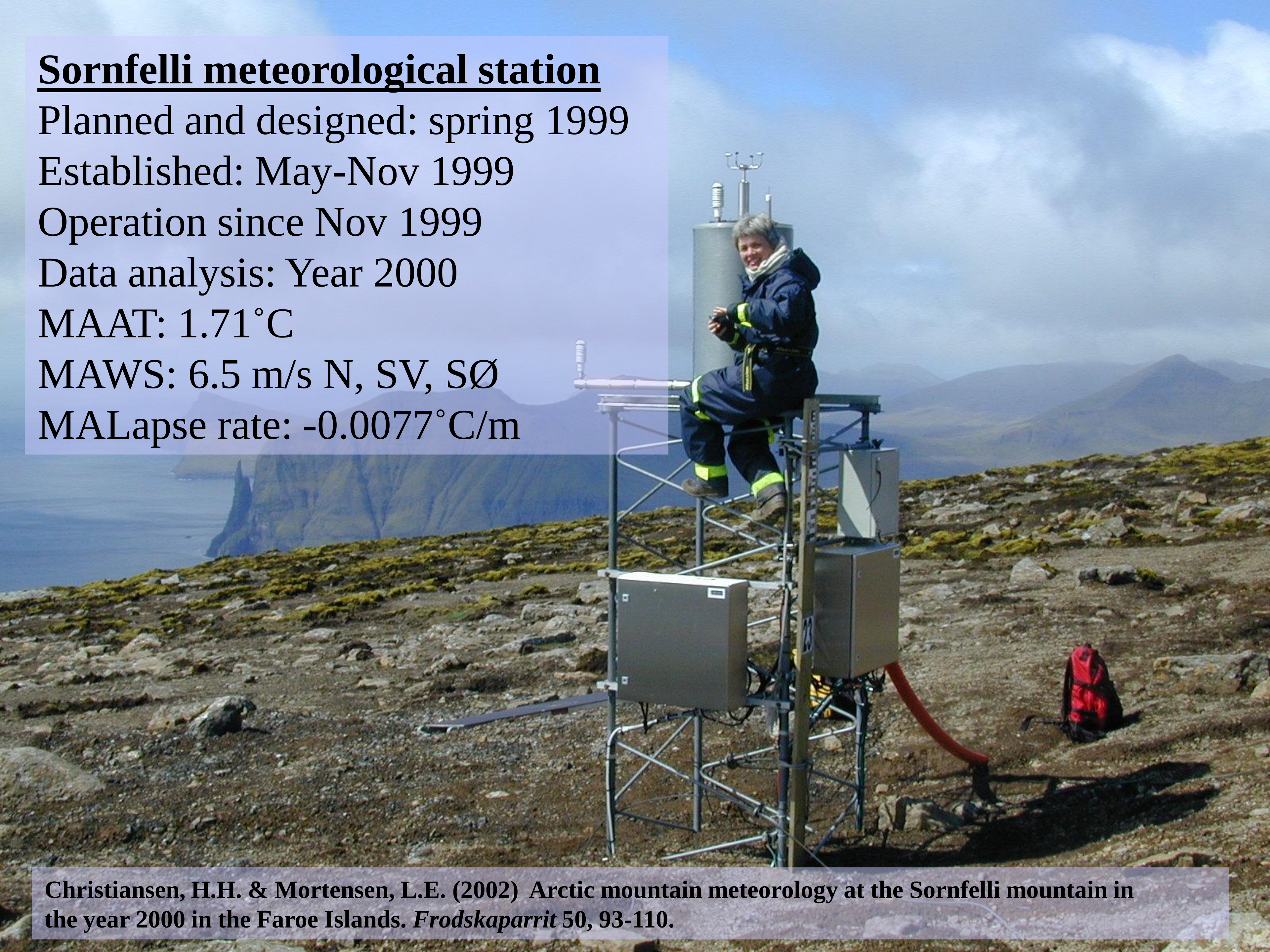
The Arctic

(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

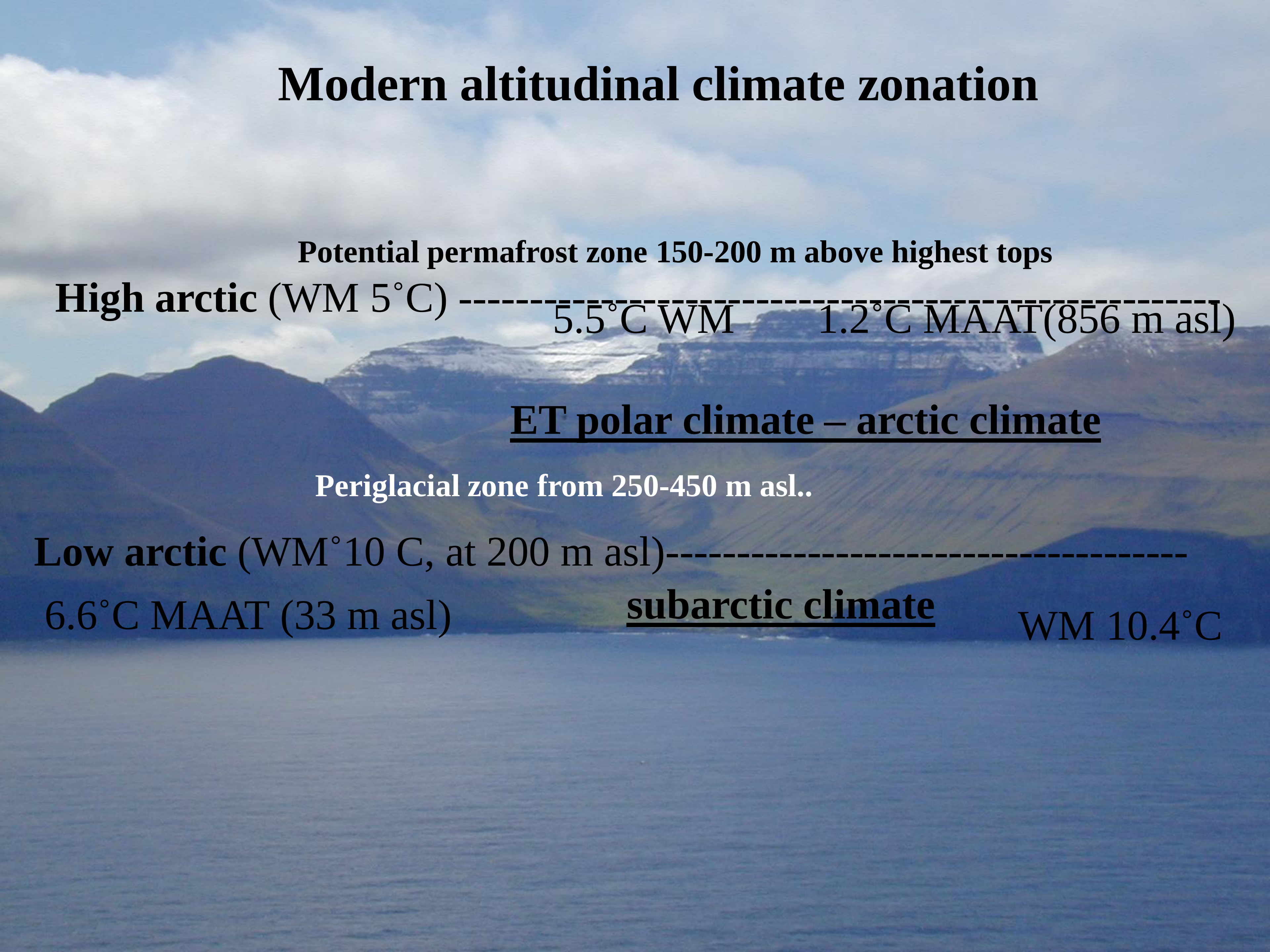
Data analysis: Year 2000

MAAT: 1.71˚C

MAWS: 6.5 m/s N, SV, SØ

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

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..

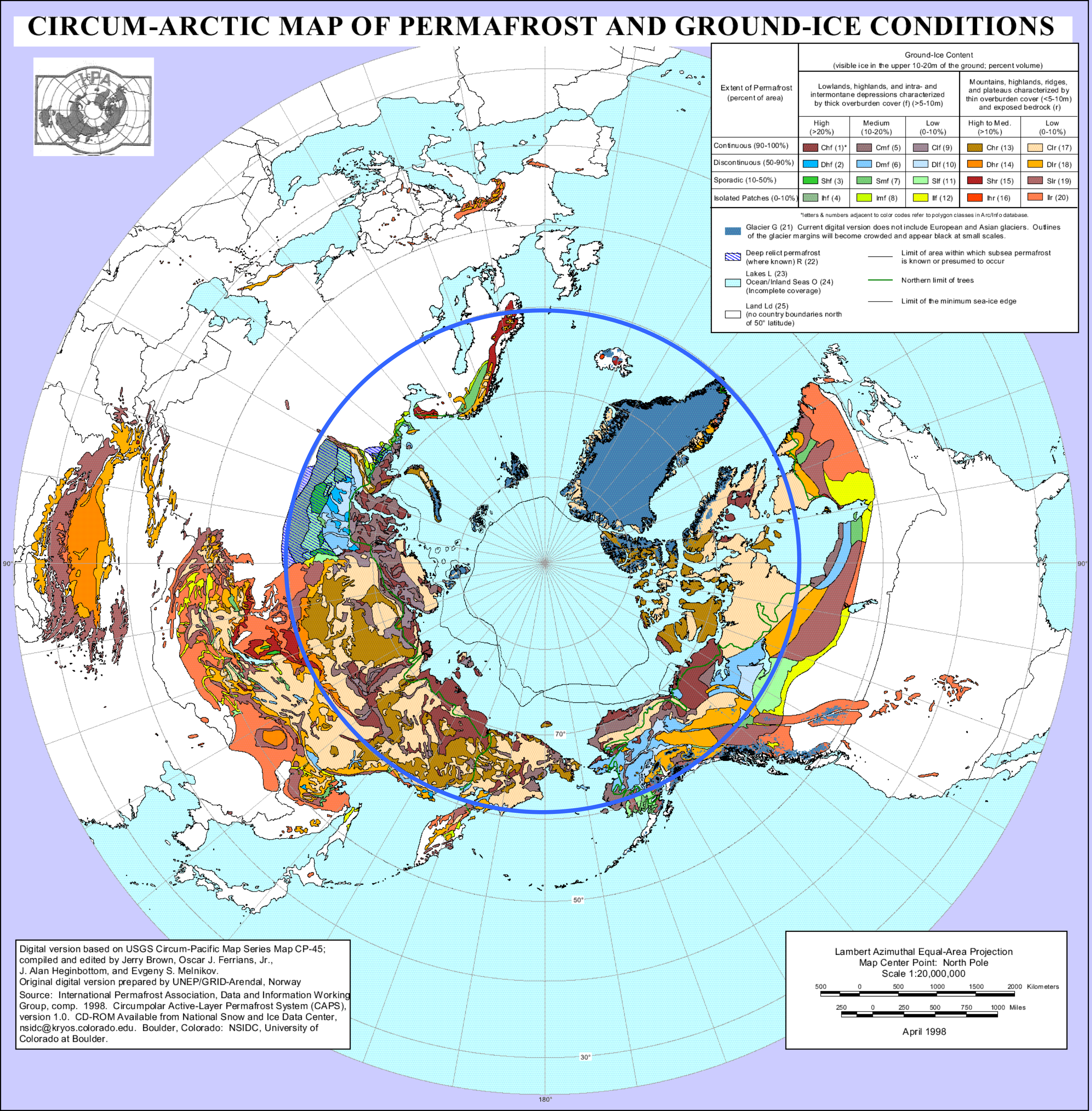
Low arctic (WM˚10 C, at 200 m asl)---

6.6˚C MAAT (33 m asl)

subarctic climate

WM 10.4˚C

The Polar zone



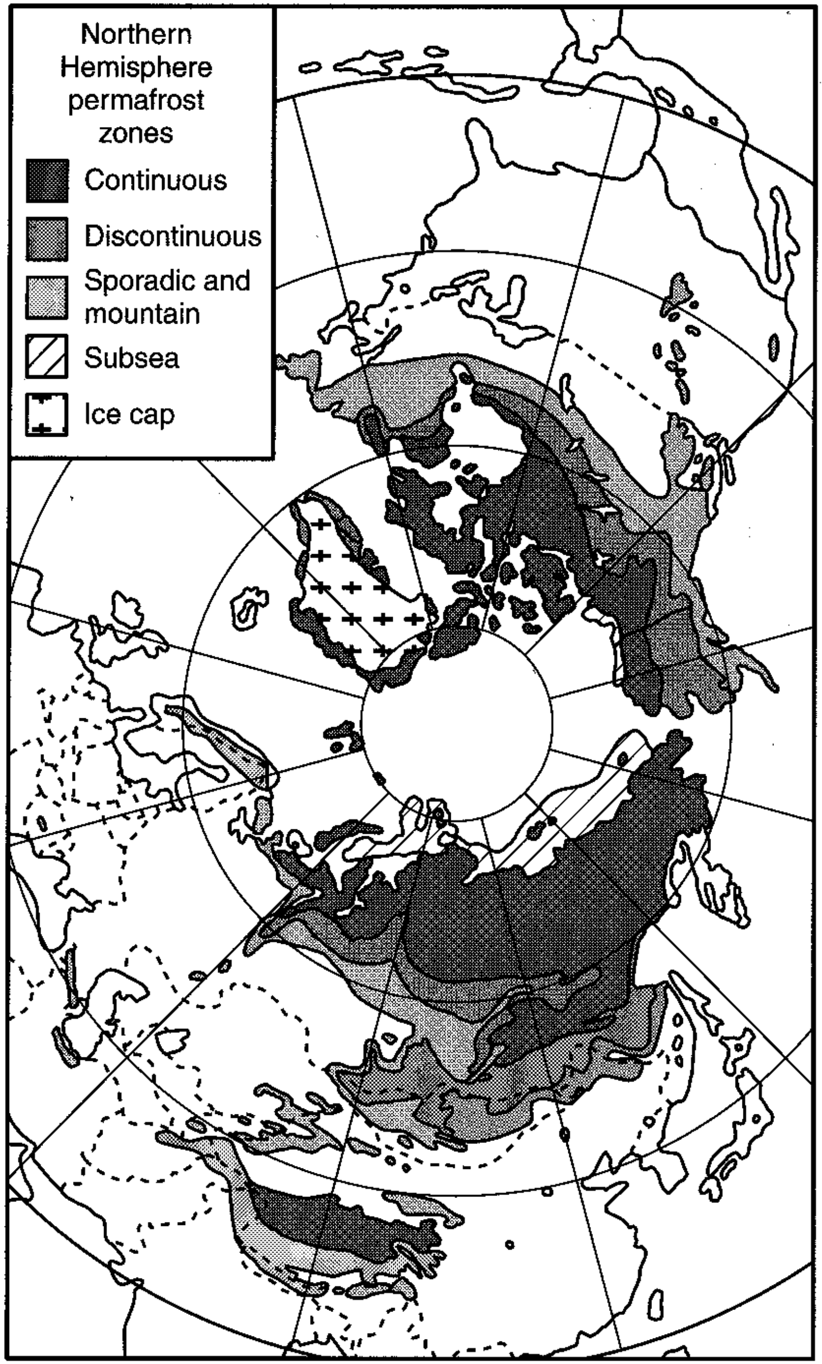
Permafrost

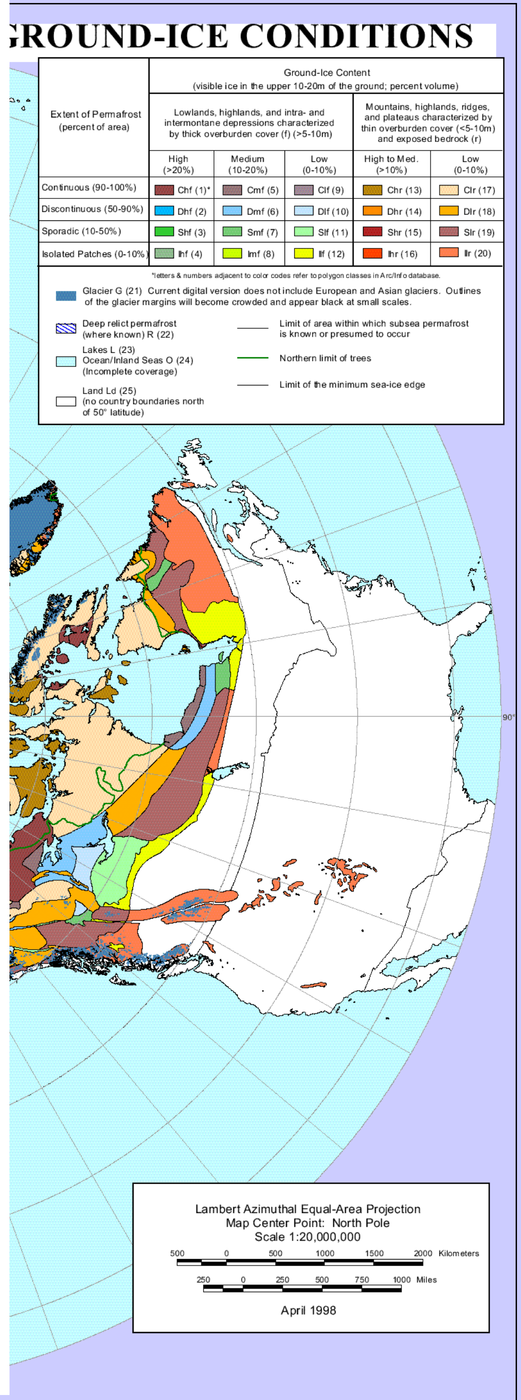
Definition:

Permafrost is defined on the basis of **temperature**: that is ground (i.e. soil, sediments, bedrock, etc.) that remains at or below 0^{o}C (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^{o}C.





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

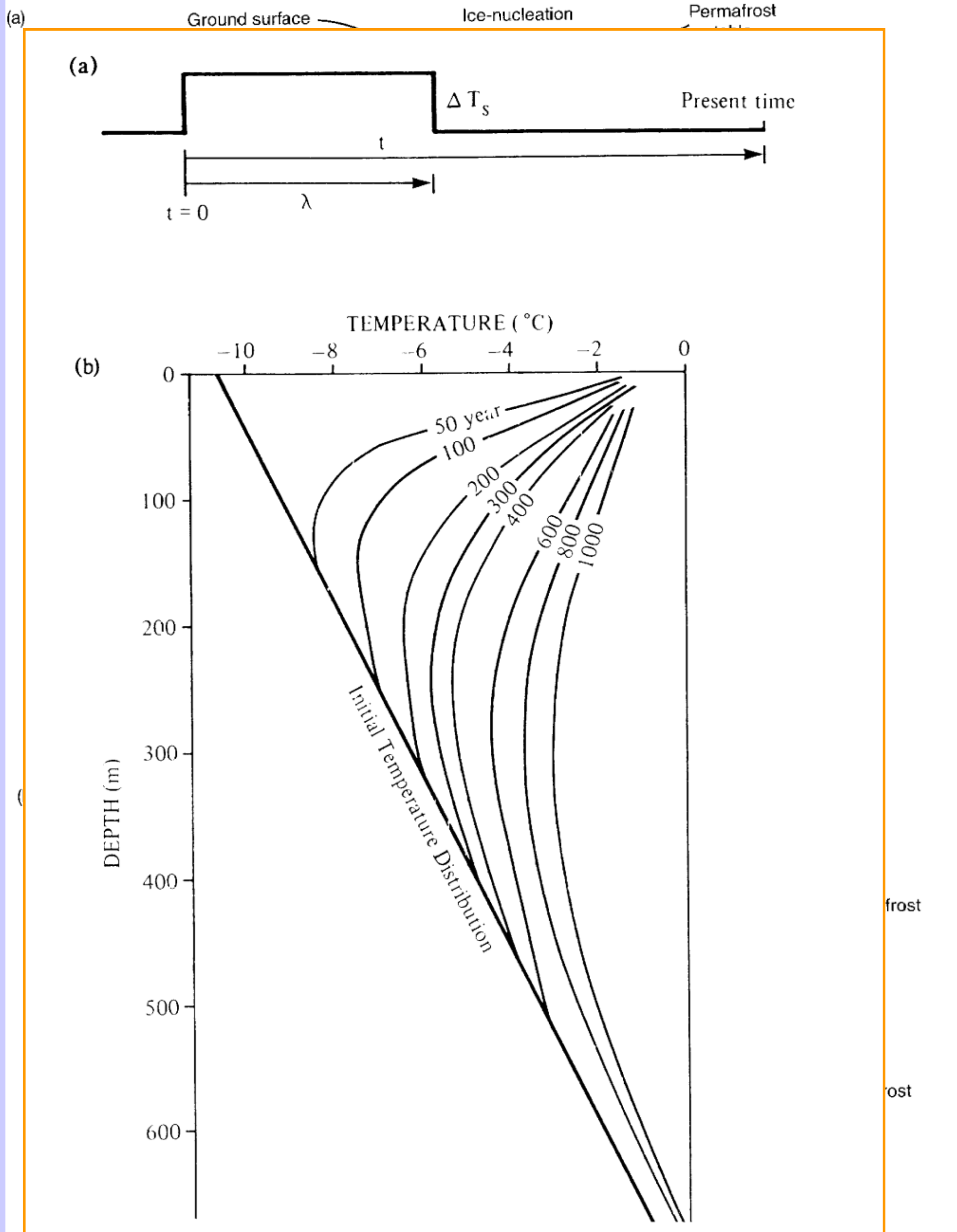


Figure 4.5 (*a*) Illustration of a step change model for climatic change. (*b*) Sequence of geothermal response to a surface temperature step change (from Molochuskin, 1973).

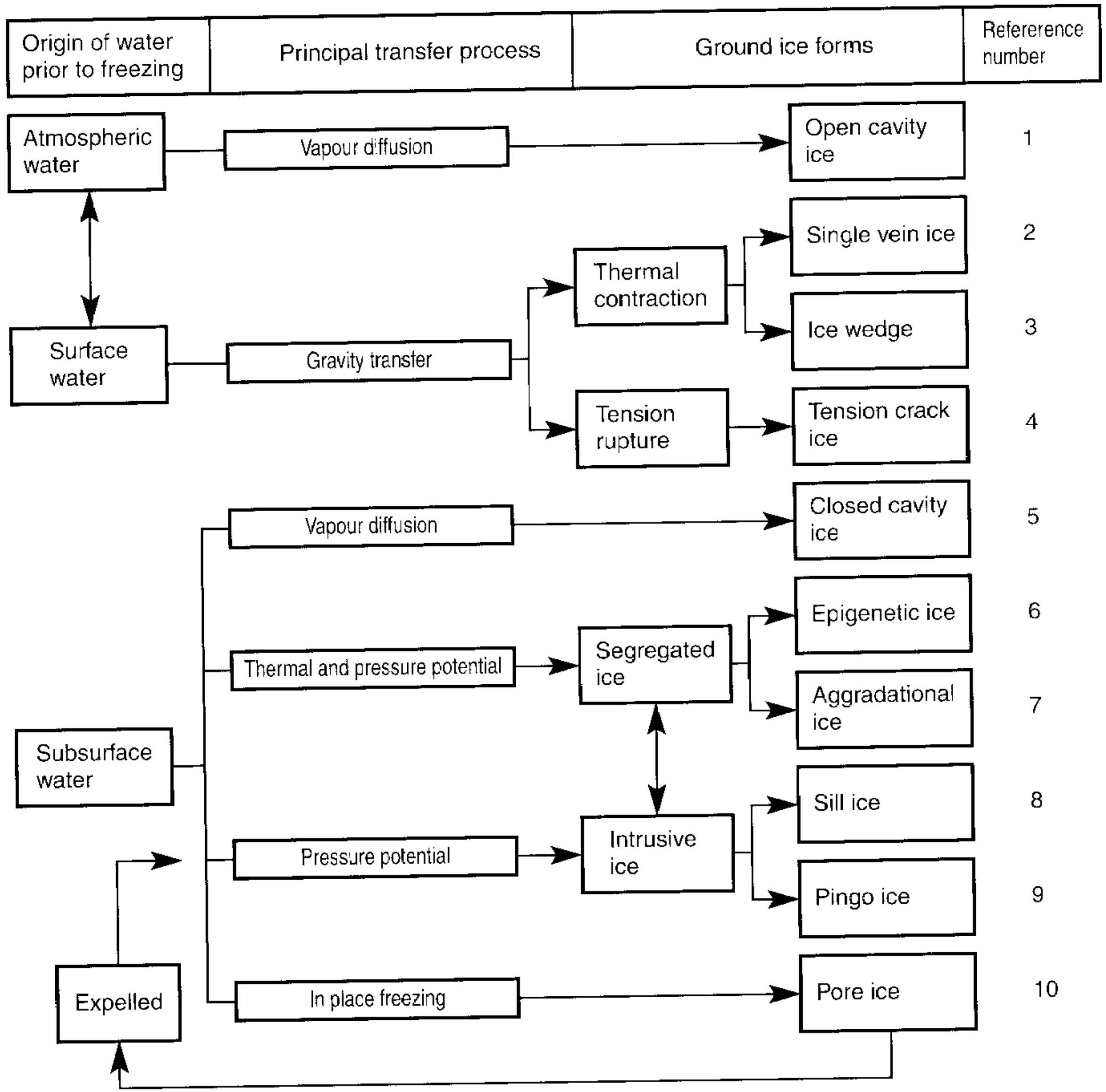
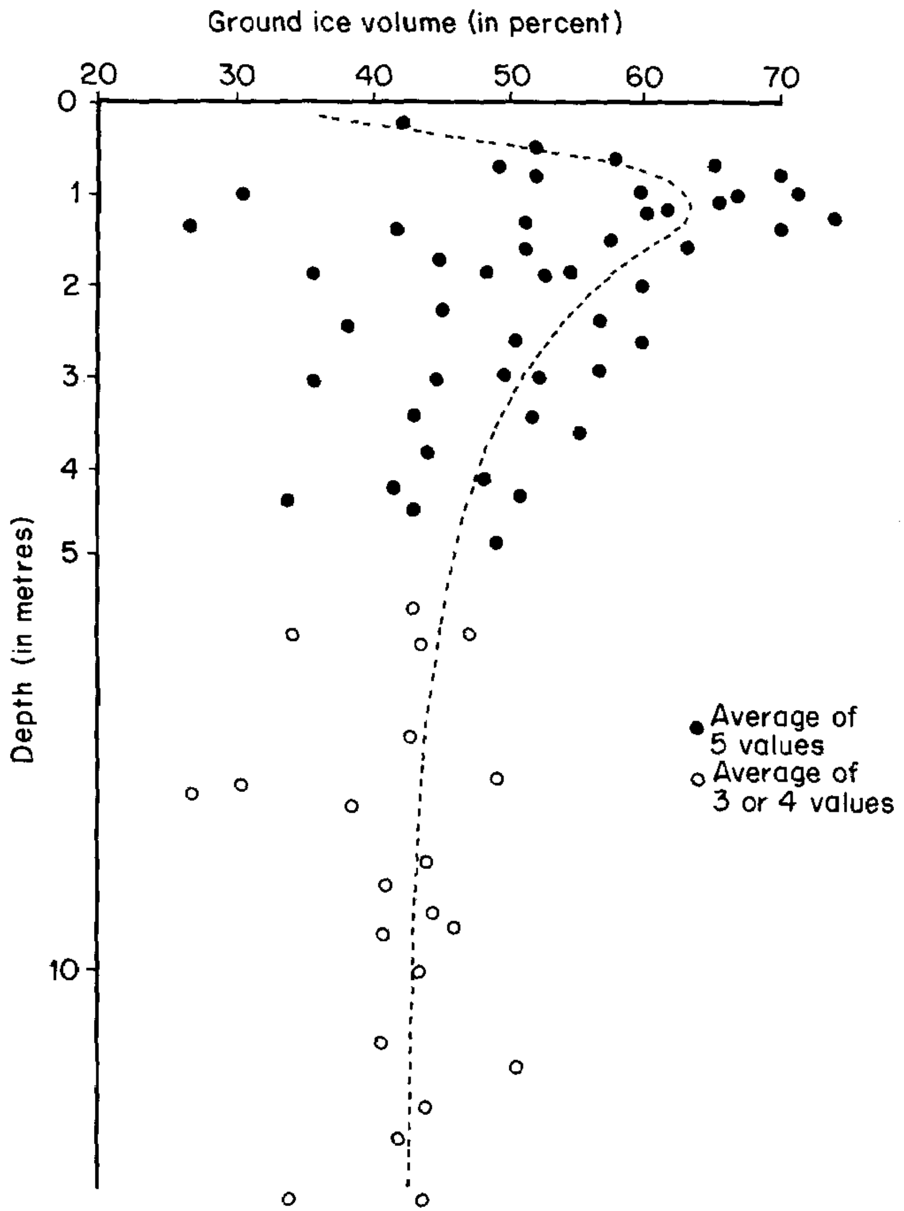
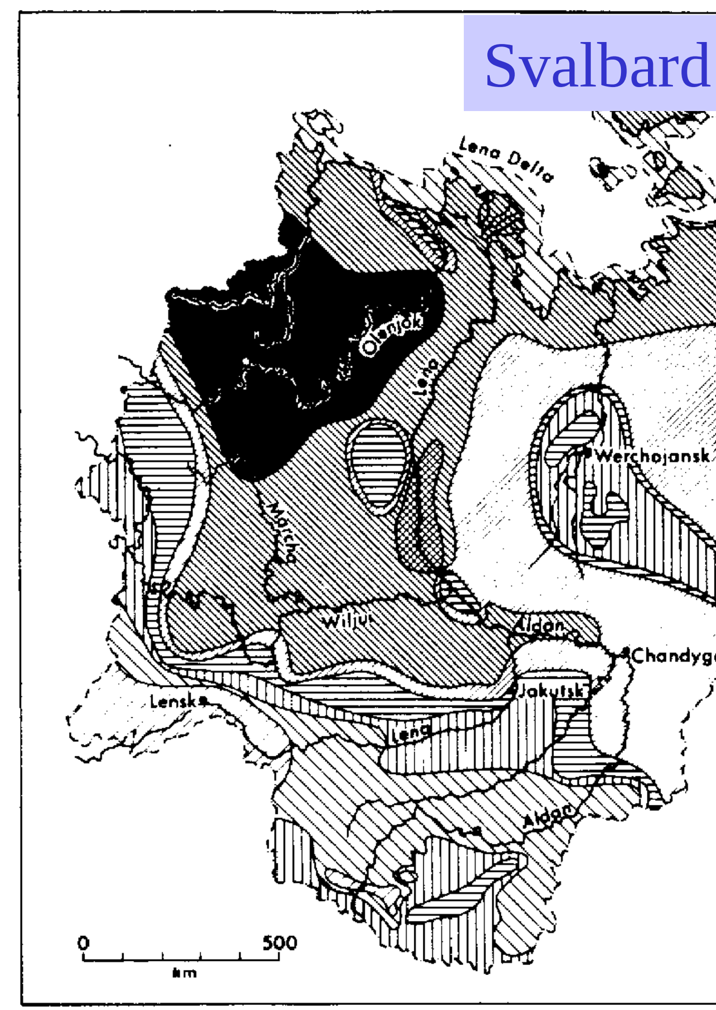


Figure 6.6 A genetic classification of ground ice (after Mackay, 1972b).

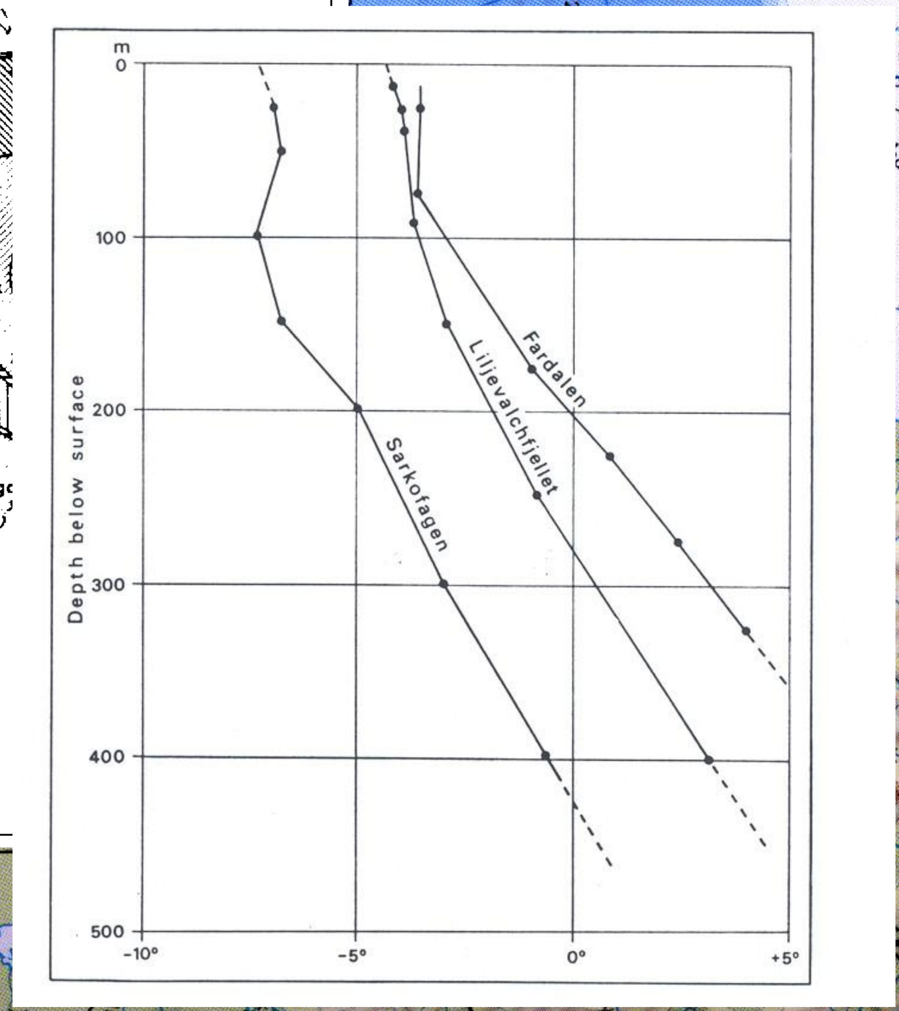
Ice content in the permafrost influence seal capacities and melting rates



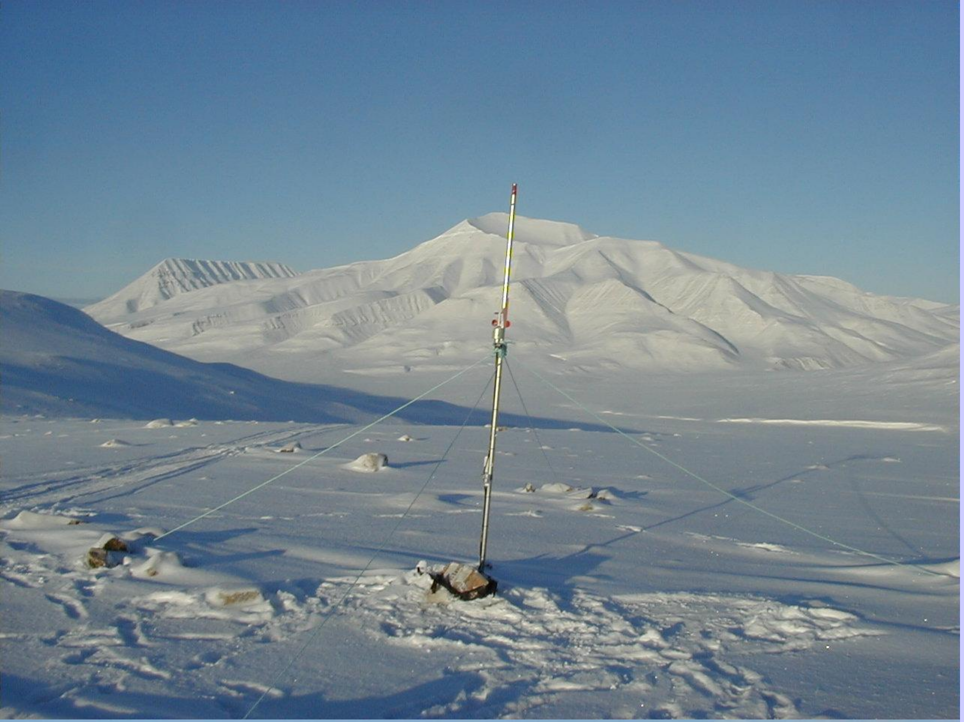
Permafrost thickness



Svalbard permafrost thickness



Janssonhaugen permafrost observatory:



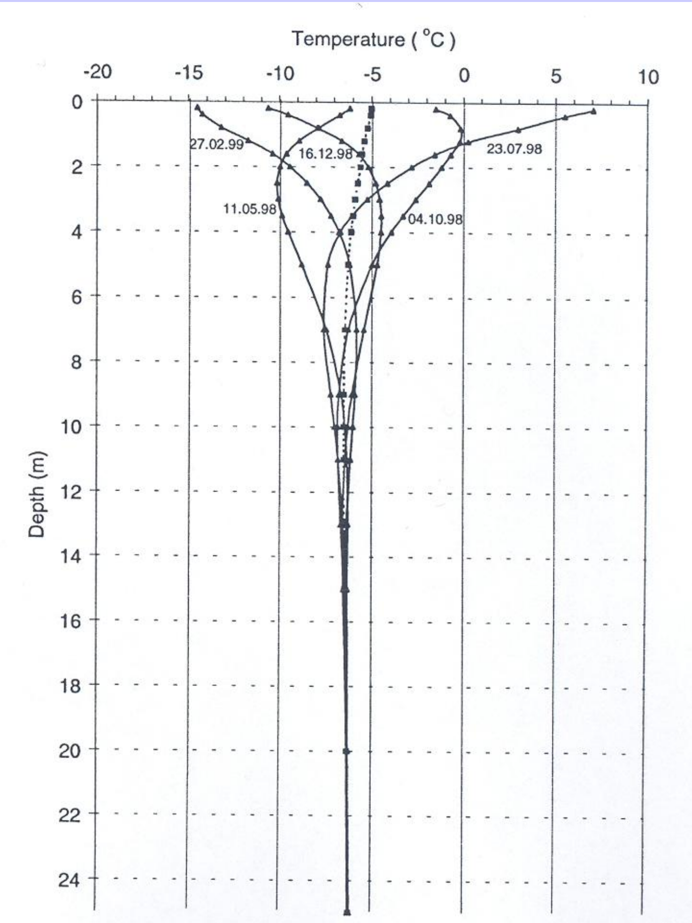
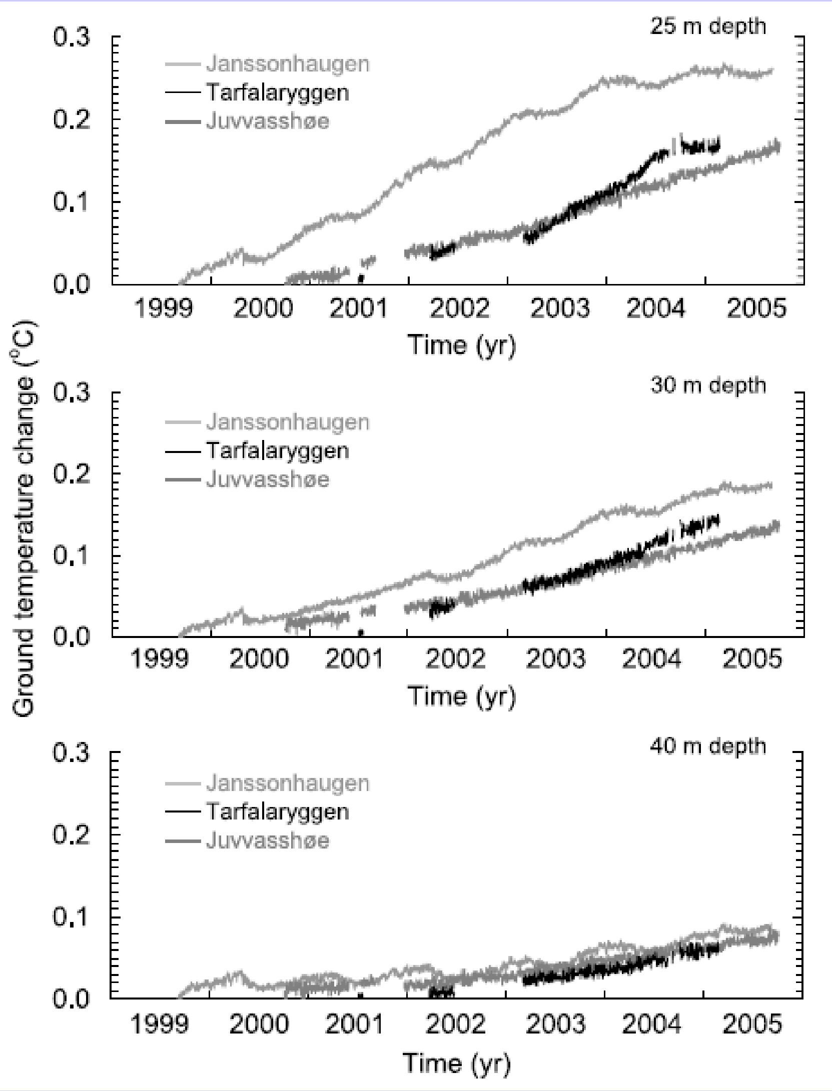


Fig. 3. Seasonal temperature profiles for the uppermost 20 m of the Janssonhaugen borehole during the first year after drilling. The year is divided into five readings with equal intervals (73 days). Dates are in dd.mm.yy. The dotted line represents the mean annual temperatures.

Janssonhaugen 102 m borehole permafrost temperature evidence



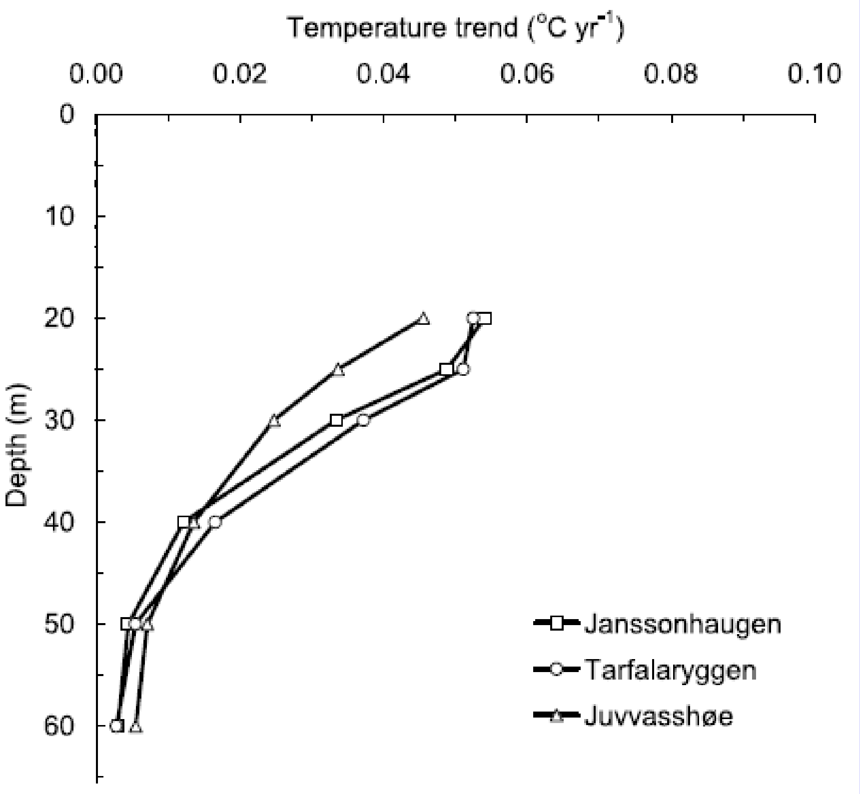


Figure 8. Observed linear trends in ground temperature as a function of depth. Statistically significant positive trends are found to 60 m depth at all sites. Time series at Janssonhaugen start in 1999, at Tarfalaryggen they start in 2001, and at Juvvasshøe they start in 2000, and they last for 6, 4,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

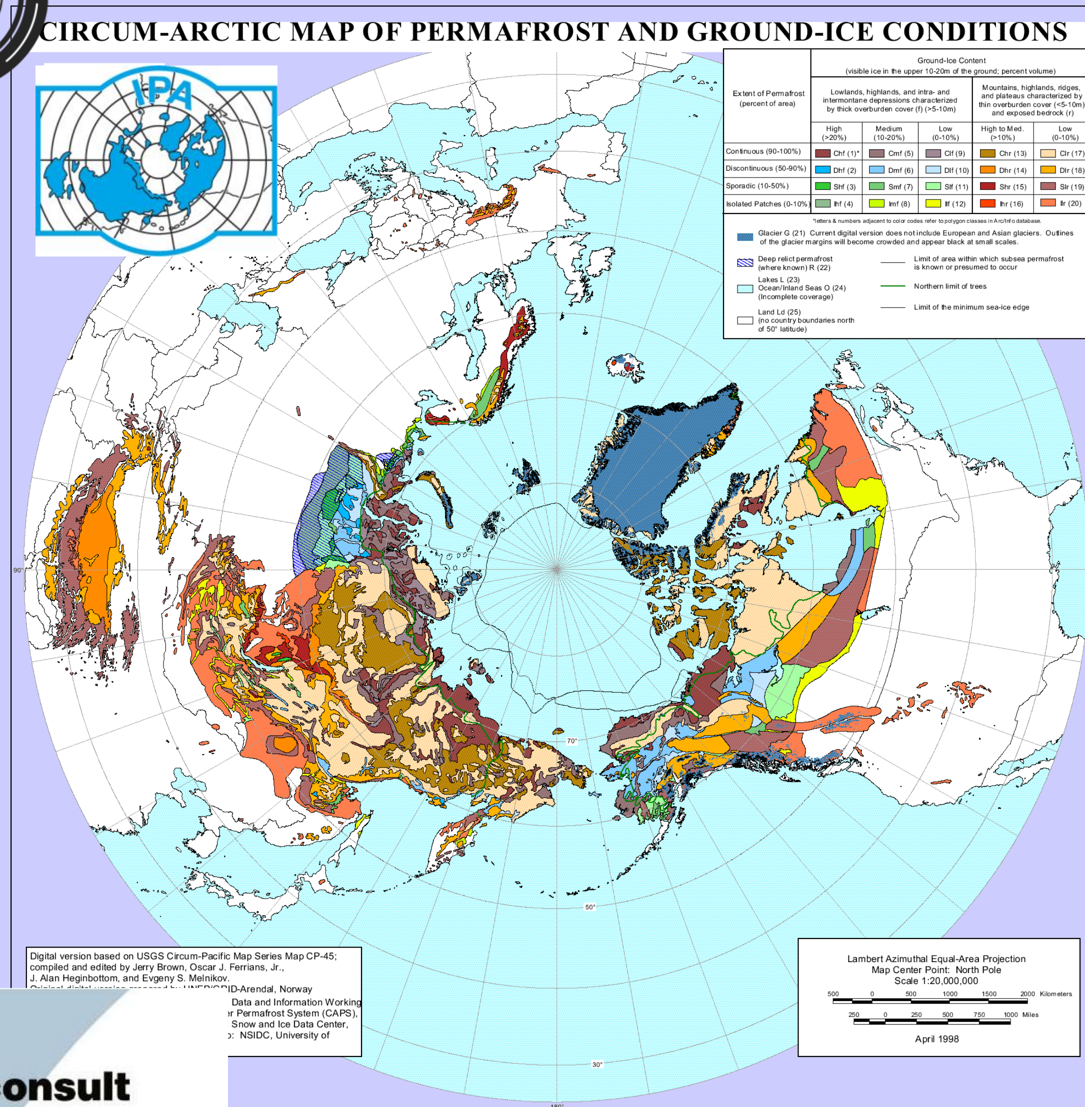
'Significant warming is detectable down to at least 60m depth, and present decadal warming rates at the permafrost surface are on the order of 0.04–0.07ºC/yr'

(Isaksen et al., 2007)

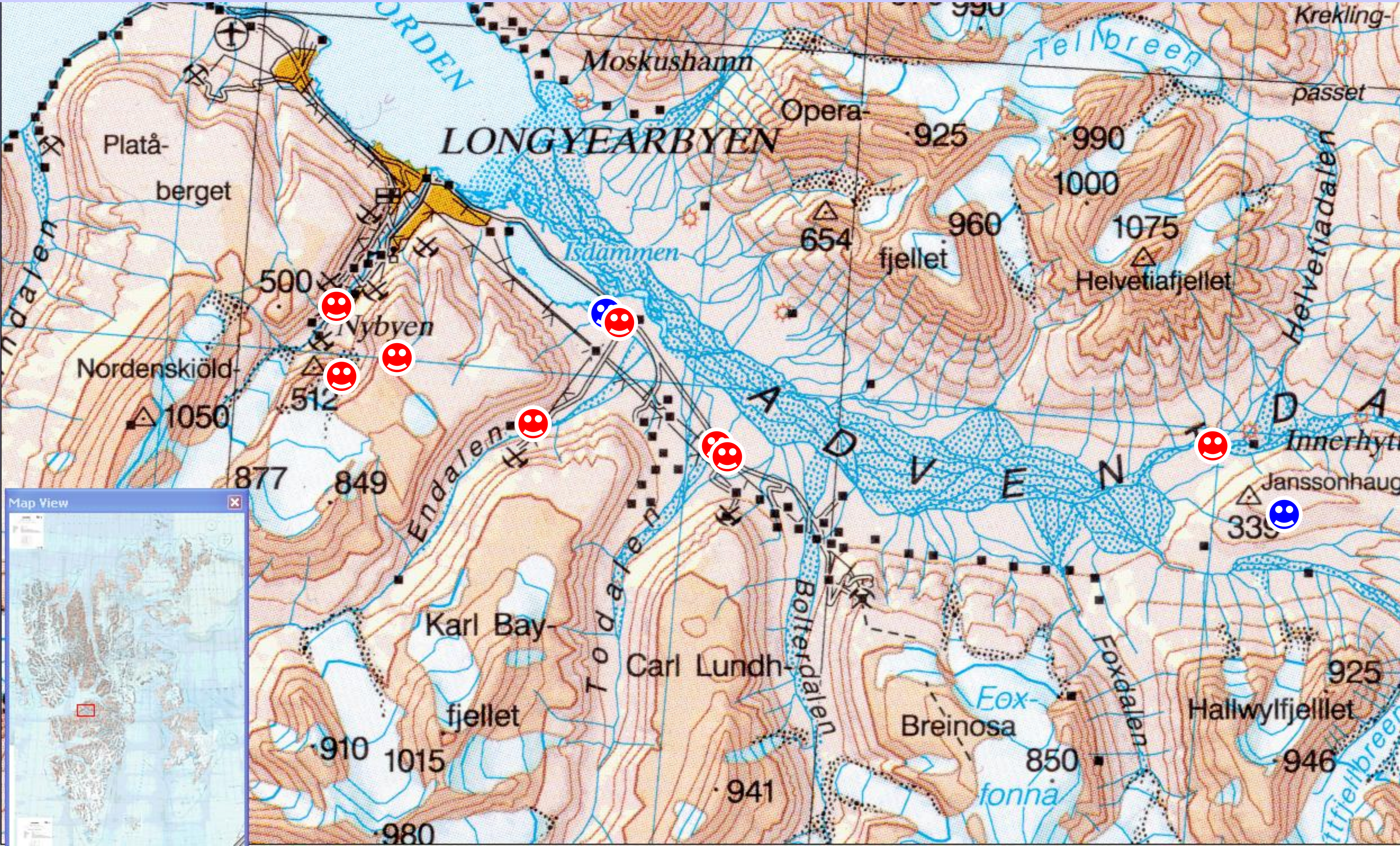
Permafrost Observatory Project: A contribution to the Thermal State of Permafrost in Norway and in Svalbard

Project focus:

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



TSP Norway 8 new and 2 existing boreholes Longyearbyen -Adventdalen



Permafrost boreholes drilled during winter 2008

Now online permafrost temperatures in Svalbard from www.unis.no

UNIS students drilling to 3 m – ice content & temperature

Borehole name	Depth (m)	Present instrumentation	Best instrumentation
Kapp Linne 1	**30**	2 * Geoprecision (0, 0.25, 0.5, 1, 2, 3, 4, 5, 7, 10, 10.25, 10.5, 11, 12, 13, 14, 15, 17, 20m)	Termistorstreng (+/- 0.01 degC)
Kapp Linne 2	**38.8**	-	Termistorstreng (+/- 0.01 degC)
Kapp Linne 3	**4**	-	Miniloggere/ 1 * Geoprecision
Longyearbyen skole	**9.8**	1 * Geoprecision (0, 0.25, 0.50, 1, 2, 3, 4, 5, 7, 9m)	1 * Geoprecision
Gruvefjellet	**5**	Koblet til online værstasjon (0, 1, 2, 3, 4, 5m)	Koblet til online værstasjon
Larsbre-steinbreen	**11.5**	1 * Geoprecision (1, 2, 3, 4, 5, 6, 7, 8, 9, 11m)	1 * Geoprecision
Pingo	**19.1**	2 * Geoprecision (0, 0.25, 0.5, 1, 2, 3, 4, 5, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19m)	2 * Geoprecision
Endalen	**19.7**	-	Termistorstreng (+/- 0.01 degC)
Snøleie 1	**5.4**	-	1 * Geoprecision
Snøleie 2	**10**	-	1 * Geoprecision
Gml. Nordlysst.	**9.9**	-	1 * Geoprecision
Ny-Ålesund	**10**	-	1 * Geoprecision
Colesbukta 1	**6**		-
Colesbukta 2	**28**	-	1-2 * Geoprecisio

Permafrost database NORPERM

NGU Geologi for samfunnet siden 1858

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)*

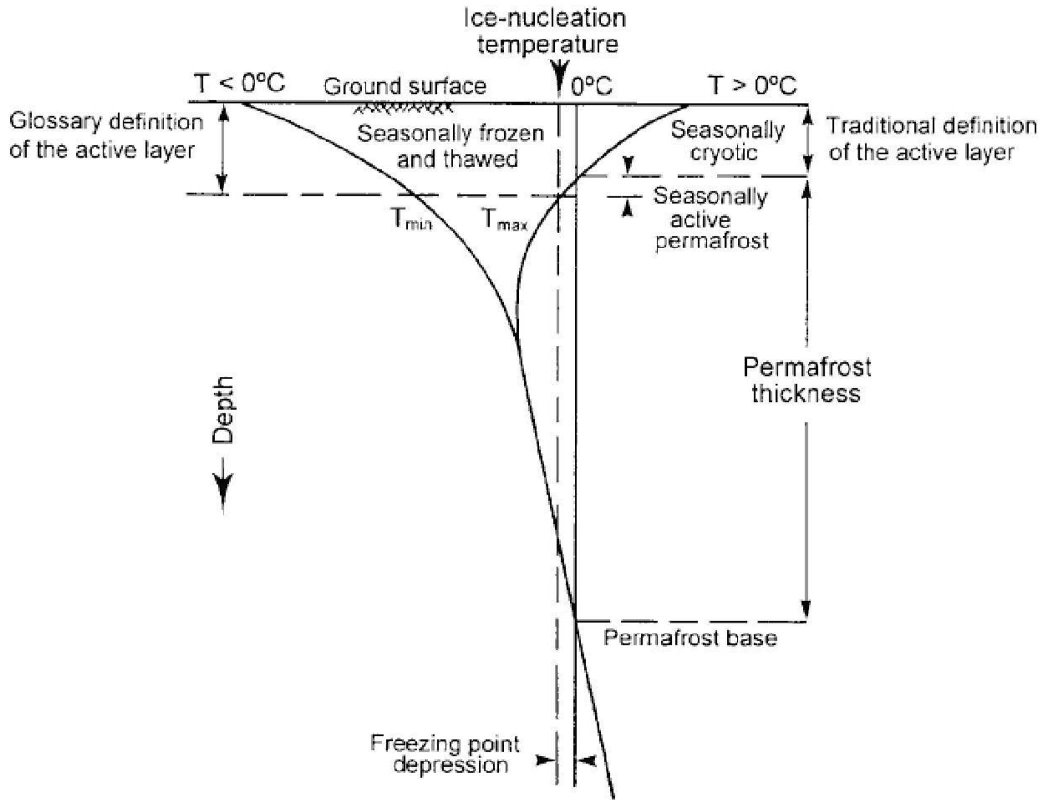


Figure 1. Selected terms used by the *Glossary* to describe the states of water and ground temperature in permafrost (after ACGR, 1988, Figure 2). Note that the active layer, as defined by Muller (1947), is described here as 'seasonally cryotic' ground.

(Burn, 1998)

Seasonal changes in the active layer

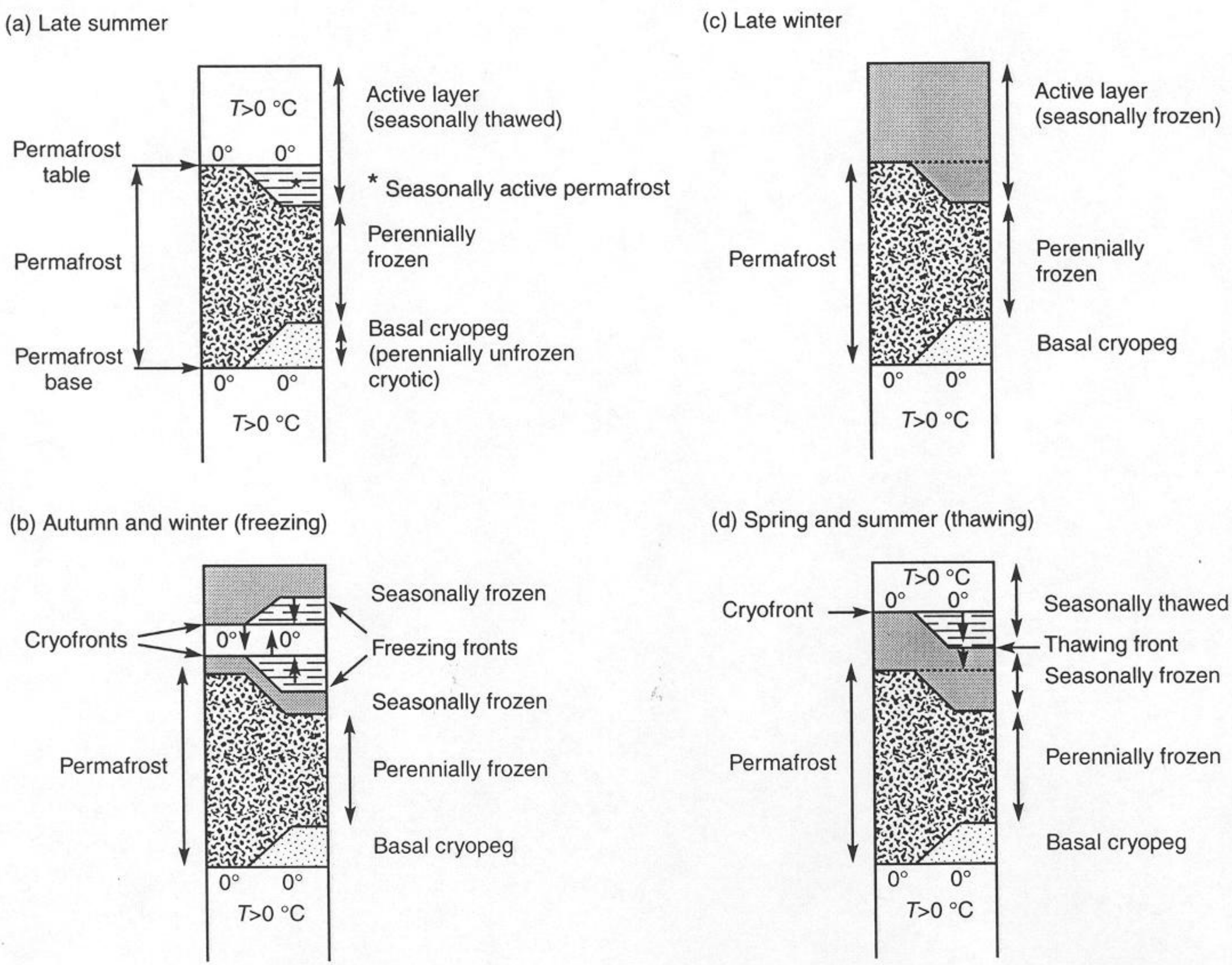
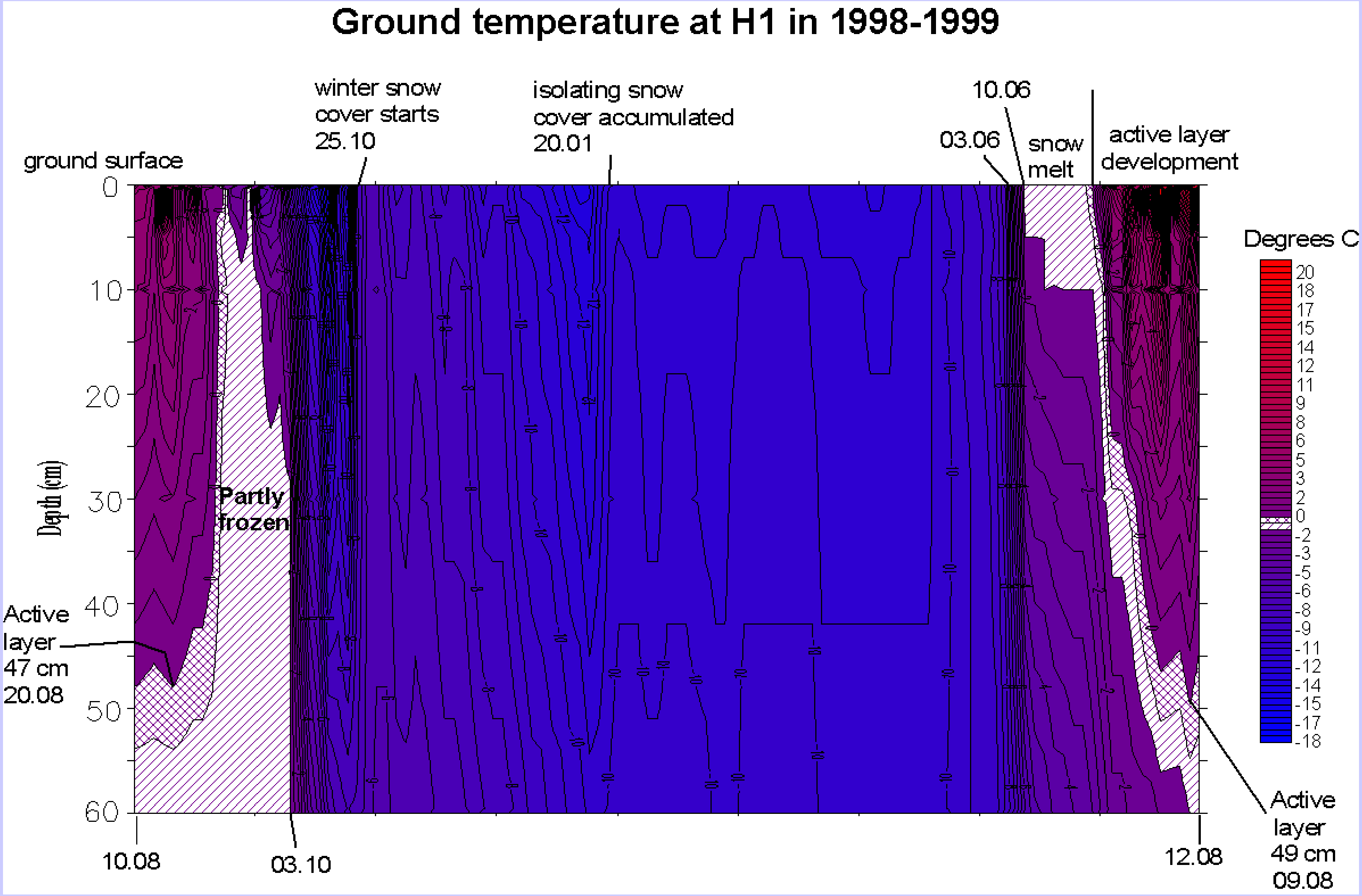


Figure 8.2 Seasonal changes (a–d) in the active layer. The temperature relative to 0 °C and the state of water are also indicated (*source*: ACGR, 1988).

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)

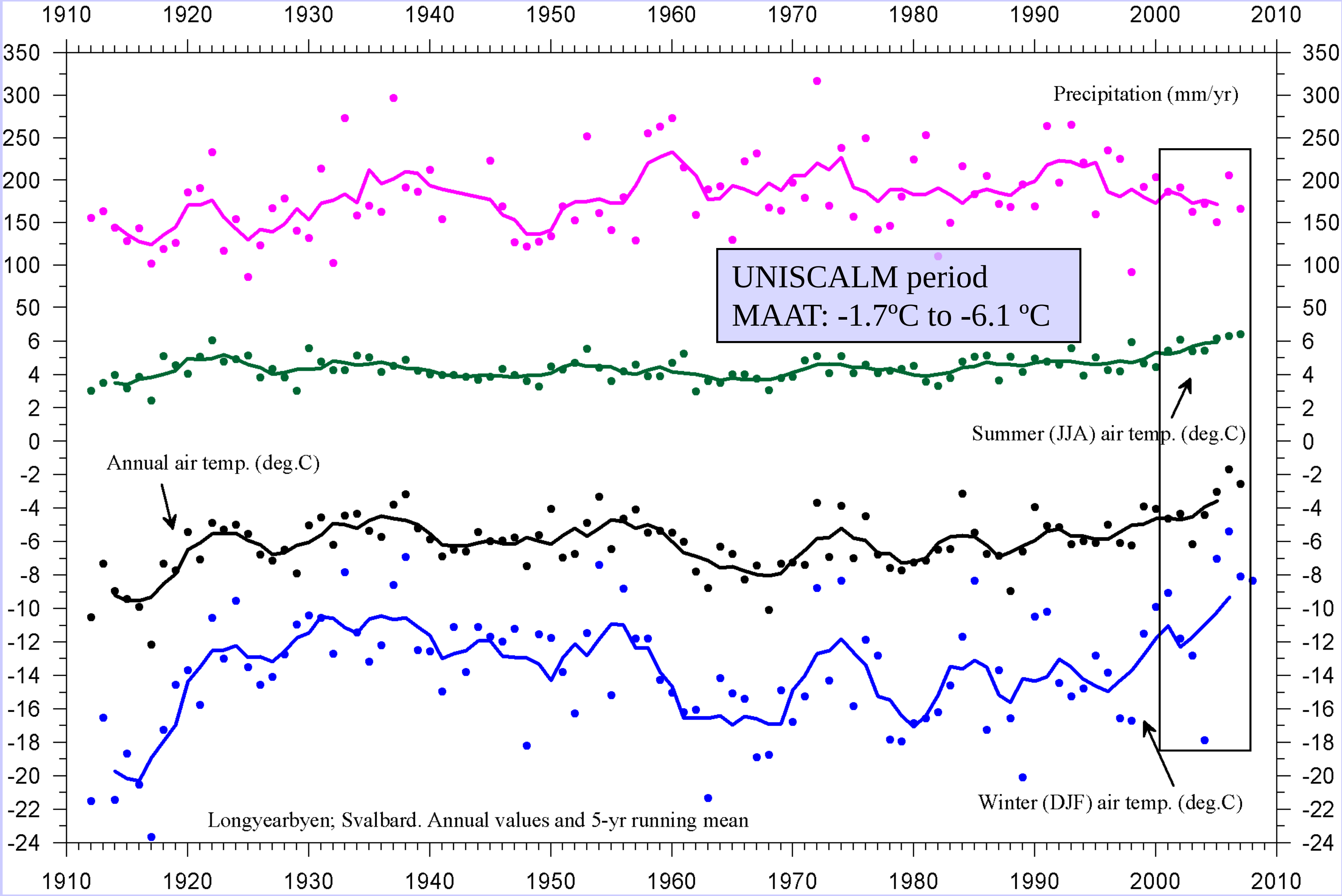
Monitoring:

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

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

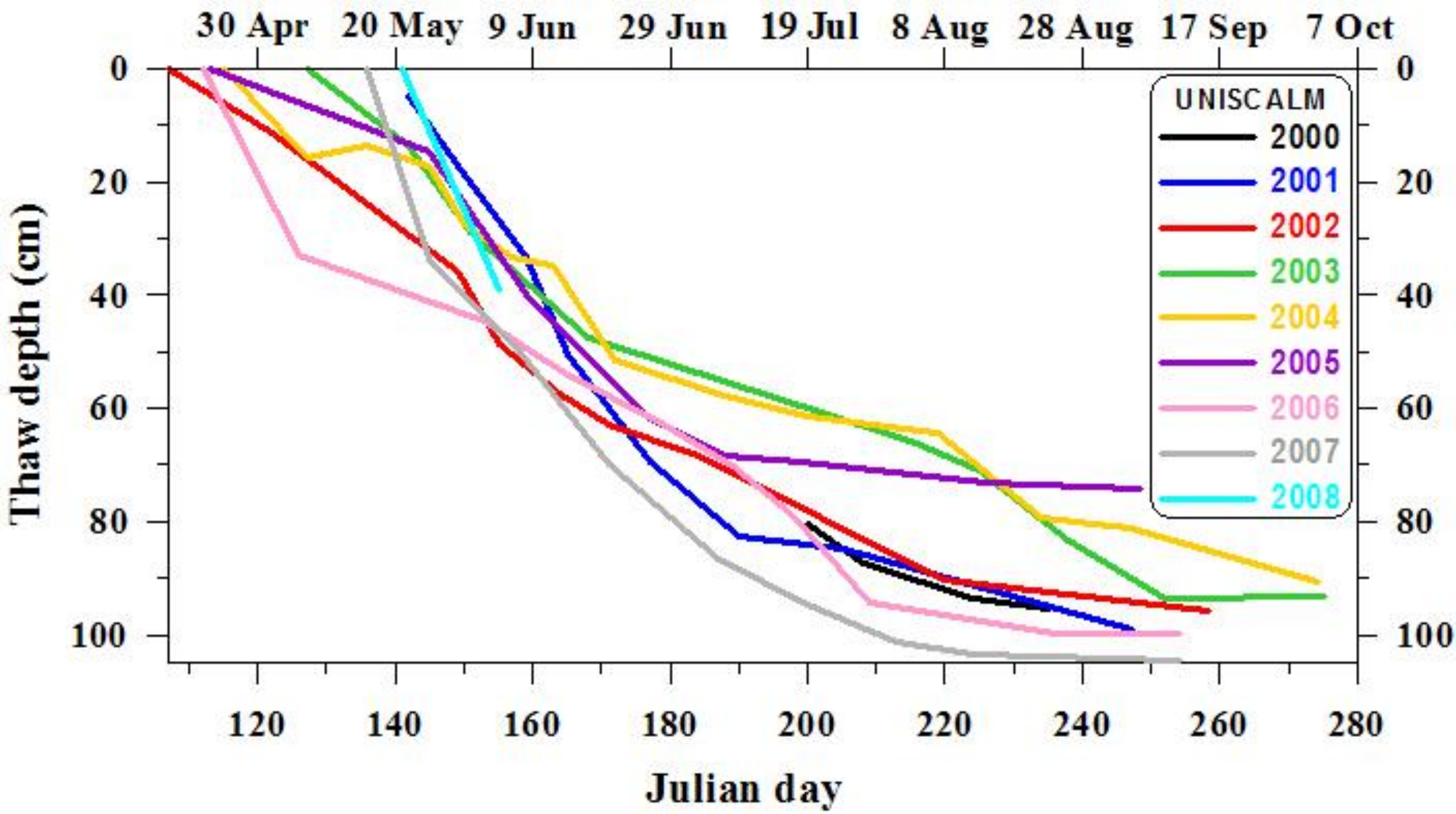
Flat and silt dominated loess deposits on fluvial terrace

Svalbard – a very martime high arctic setting – Longyearbyen met. station



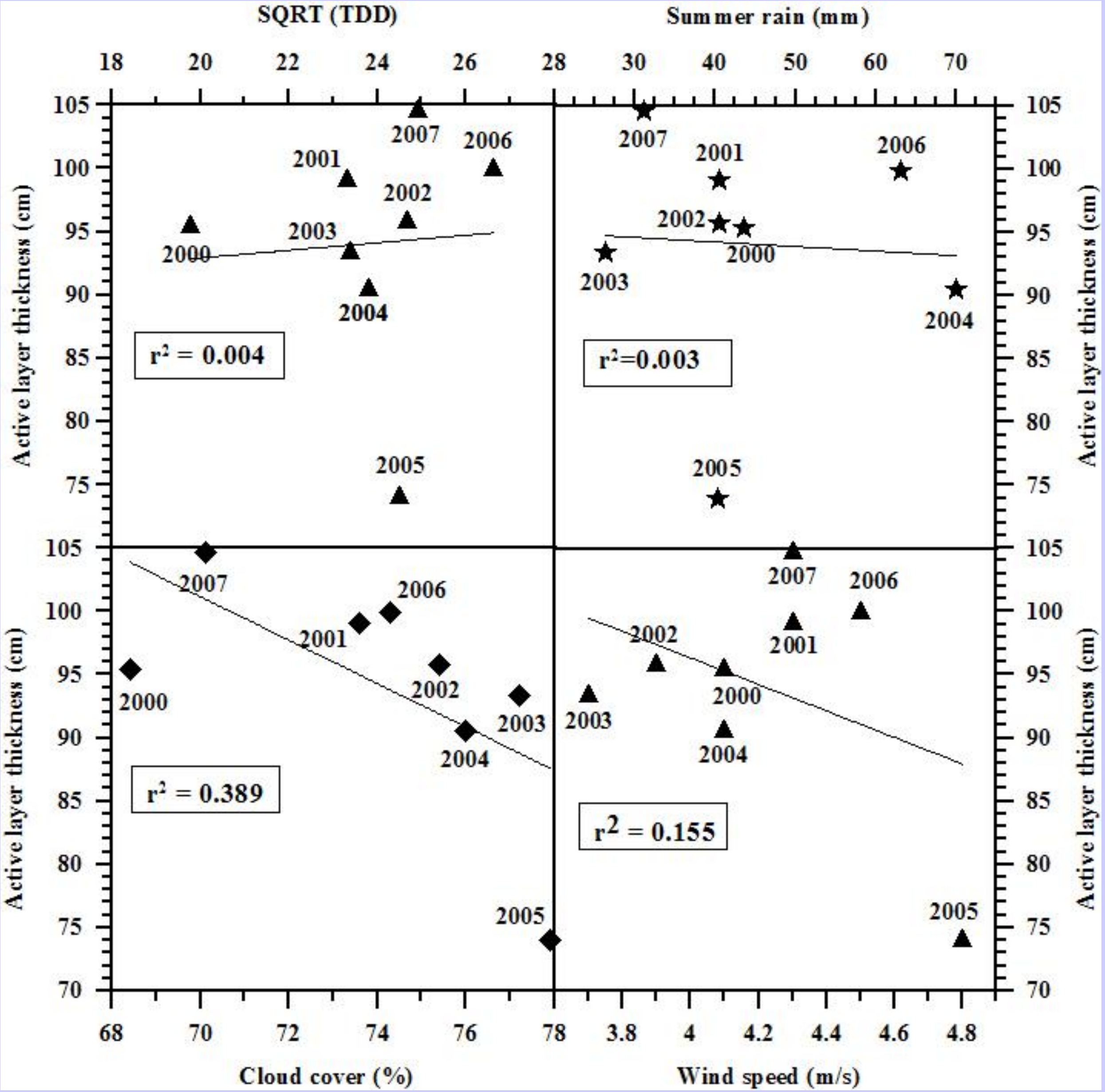
Thaw progression in the UNISCALM

Probed from 8 to 15 times annually

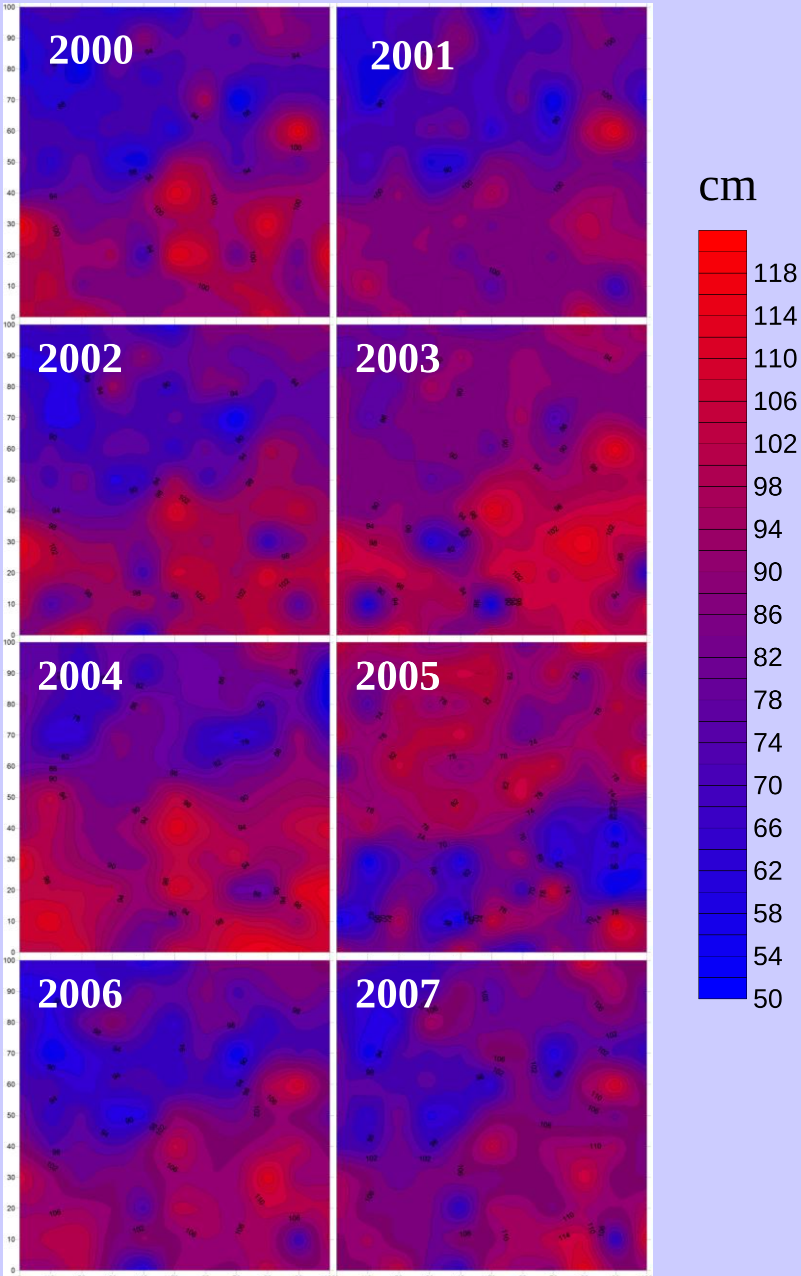


Active layer average: 94 cm, min: 74 cm, max: 105 cm

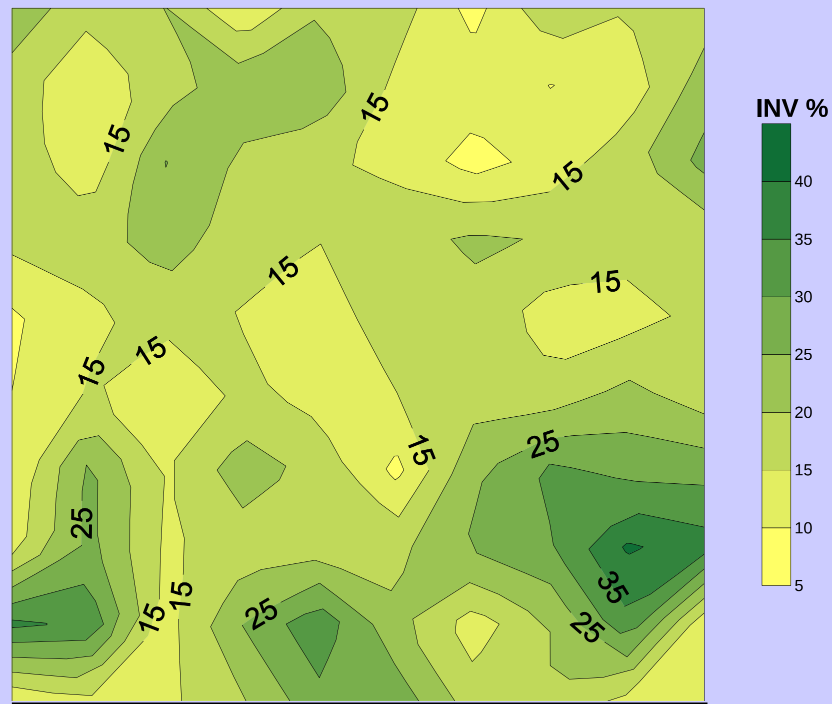
Meteorological control on active layer thickness



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

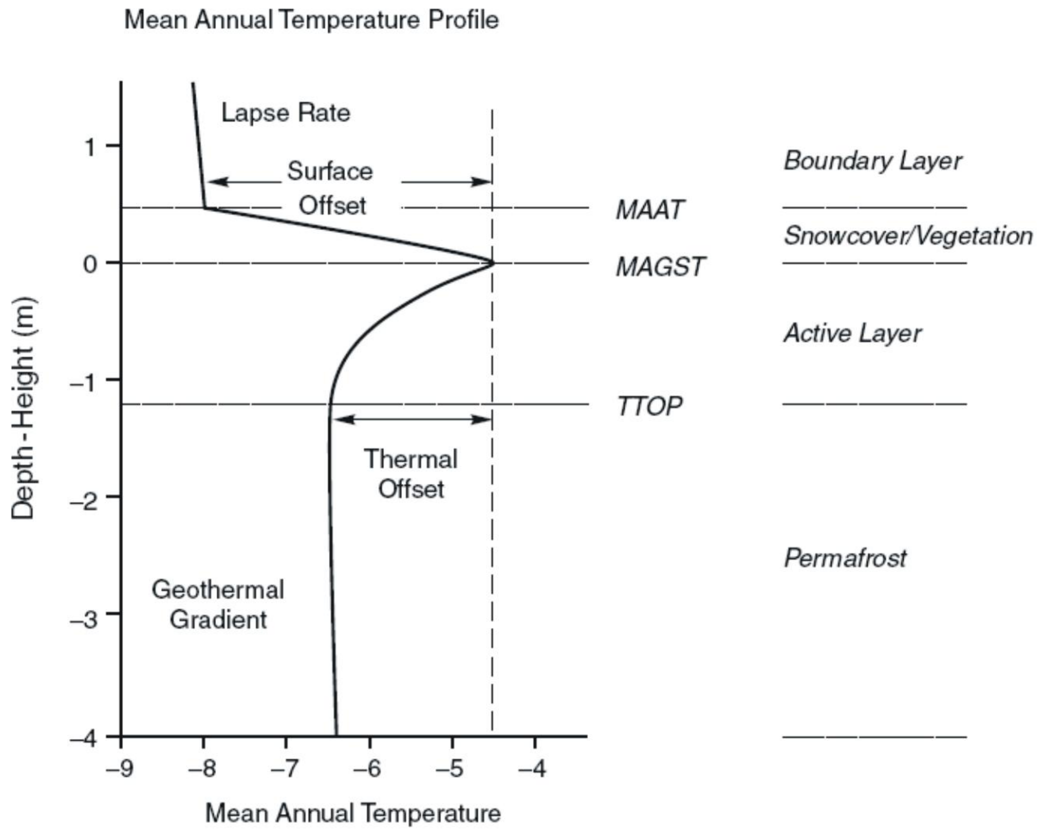
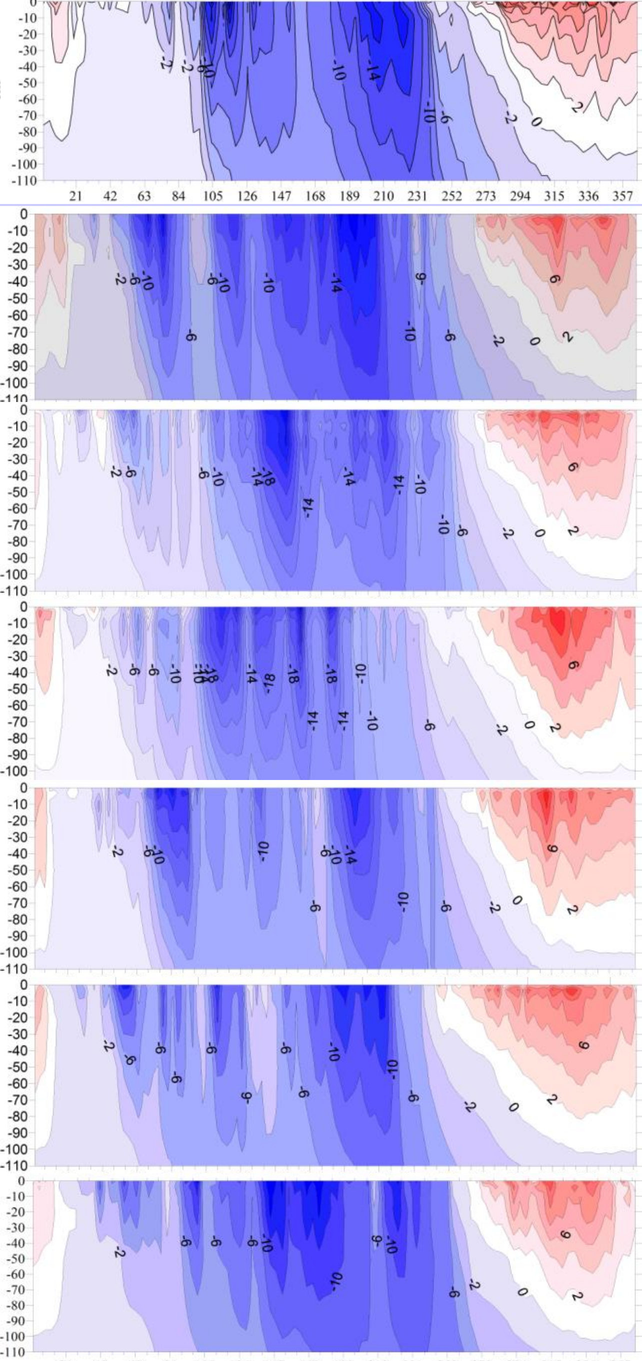


Figure 3 Schematic mean annual temperature profile through the surface boundary layer, showing the relation between air temperature and permafrost temperature.

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



2000
2001

2001
2002

2002
2003

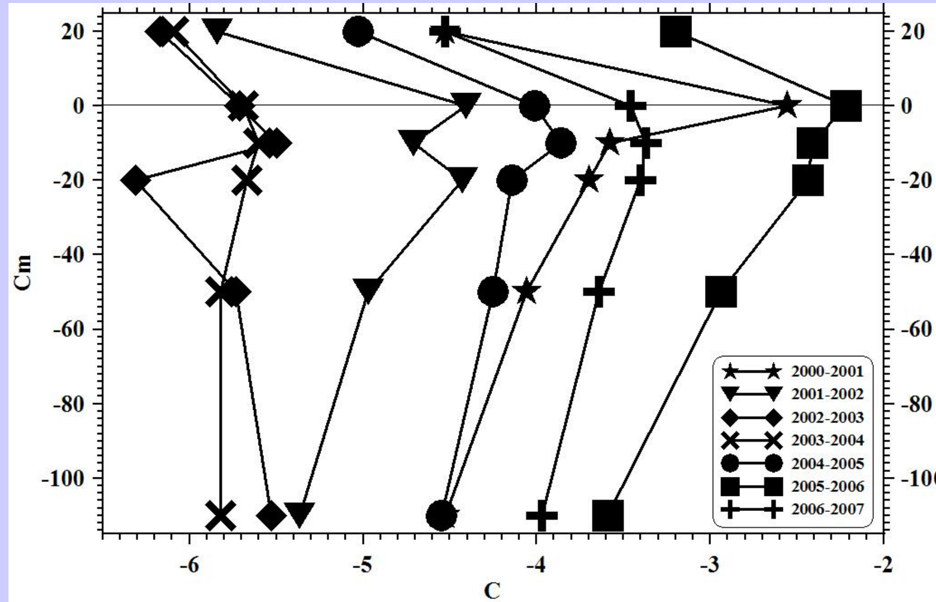
2003
2004

2004
2005

2005
2006

2006
2007

1 September to 31 August



Large interannual variation of mean ground temperatures

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

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

Summing up:

-) Upper 40 cm thawing until mid June, winter and spring controlled, while the lower thawing is summer controlled.

-) Interannual active layer variation (0.3 m) as large in sediments as in sandstone rock – no large transient layer influence, as less ice in permafrost top.

-) Interannual active layer variation mainly controlled by meteorology - mainly cloud cover (radiation) and air temperature.

-) Large interannual spatial variability in active layer thickness (INV) for UNISCALM data, but not in ground thermal data profile, so local variability, need to be careful with direct climatic causes only.

-) Clear nival and thermal offsets even with only 20-30 cm snow and hardly any vegetation.

-) Fairly warm permafrost top, 0ºC to -2ºC in summer, and no significant two-sided freezing.

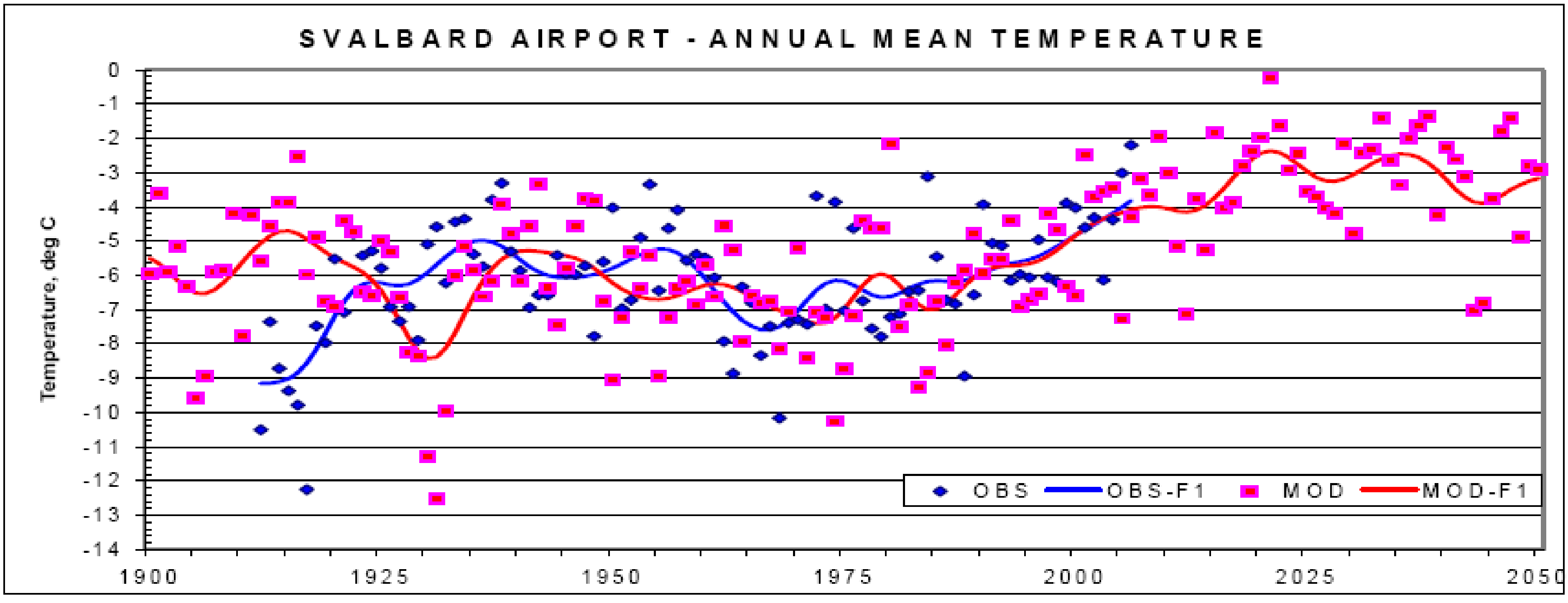
-) UNISCALM is very susceptible to meteorological variations like over the last 8 years.

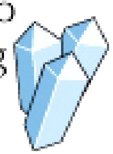
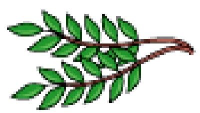
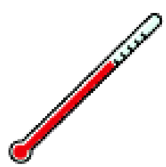
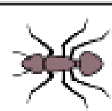
Permafrost as a seal:

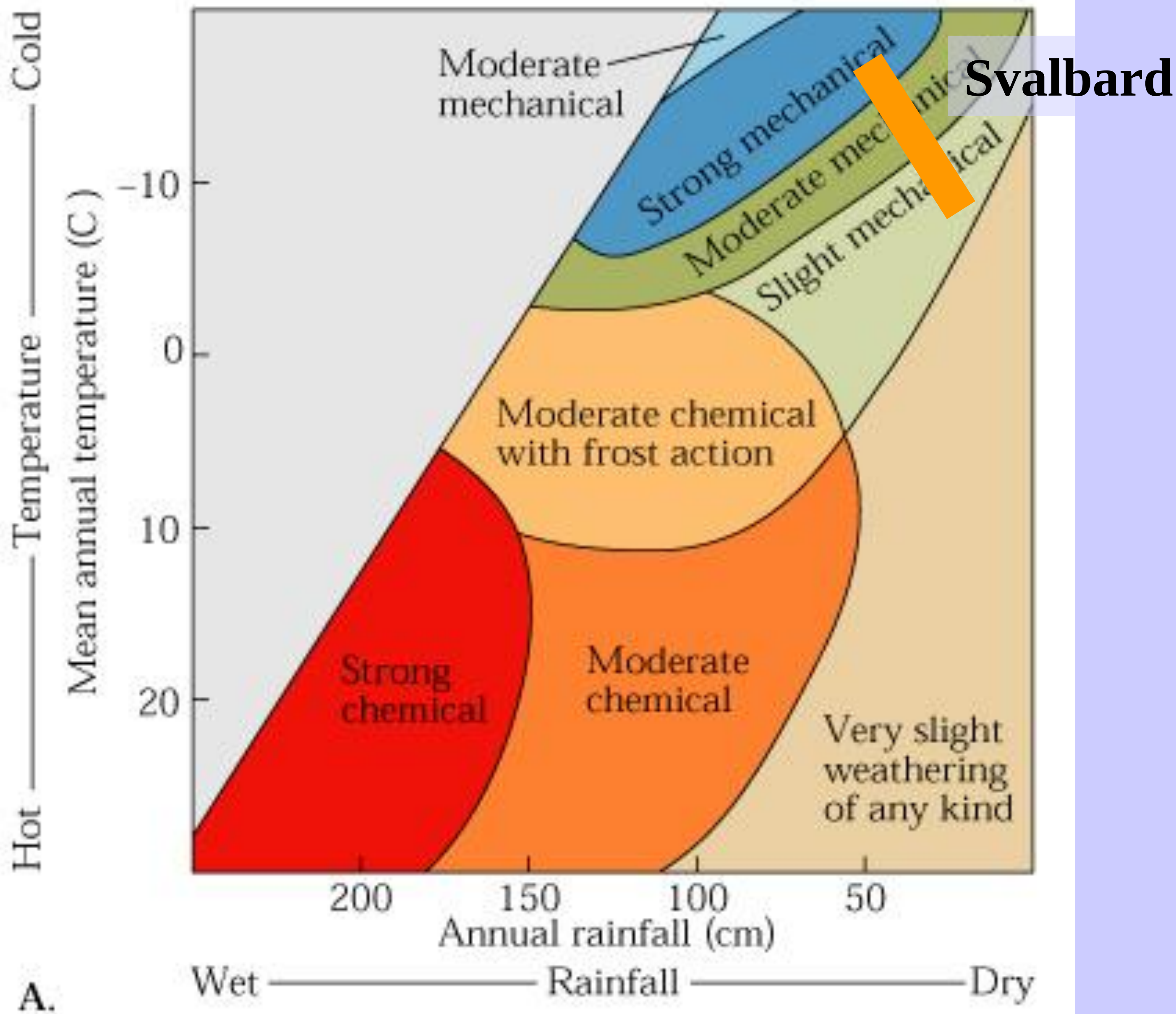
-) No permafrost generally below the glaciers

-) Not a lot of permafrost in the sea

-) Melting rate of permafrost of app. 300 m during a glaciation 30000 yr



	Rate of Weathering Slow ⟶ Fast		
Mineral resistance to chemical weathering 	High (e.g., quartz)	Intermediate (e.g., mica, feldspar)	Low (e.g., calcite, olivine)
Frequency of joints 	Few joints (meters apart)	Intermediate (0.5-1.0 meters apart)	Many (centimeters apart)
Depth of regolith 	Zero	Shallow	Deep
Steepness of slope 	Steep	Moderate	Gentle
Vegetation 	Sparse	Moderate	Dense
Temperature 	Cold (average about 5°C)	Temperate (average about 15°C)	Warm (average about 25°C)
Rainfall 	Low (<40 cm/y)	Intermediate (40–130 cm/y)	High (>130 cm/y)
Burrowing animals 	Rare	Frequent	Abundant


Svalbard
Moderate mechanical
Strong mechanical
Moderate mechanical
Slight mechanical
Moderate chemical with frost action
Strong chemical
Moderate chemical
Very slight weathering of any kind
Cold
Temperature
Hot
Mean annual temperature (C)
−10
0
10
20
200
150
100
50
Annual rainfall (cm)
Wet
Rainfall
Dry
A.

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

<u>Frost weathering is controlled by geology:</u>

- **Rocks with high <u>porosity</u> are frost sensitive**
- **Very <u>permeable</u> rocks are not frost sensitive**
- **Poorly <u>consolidated</u> rocks are frost sensitive**
- **Rock <u>fracturing</u> improve weathering**

<u>& by climate:</u>

- **<u>Moisture</u> is needed, a critical saturation level is needed**
- **<u>Temperature</u> (fast cooling but nature is slow 2 to 4°C/hour max, no minimum most occur from 0 to -6°C, freeze/thaw cycles increase weathering)**

Surface disturbance leading to subsidence - Thermokarst

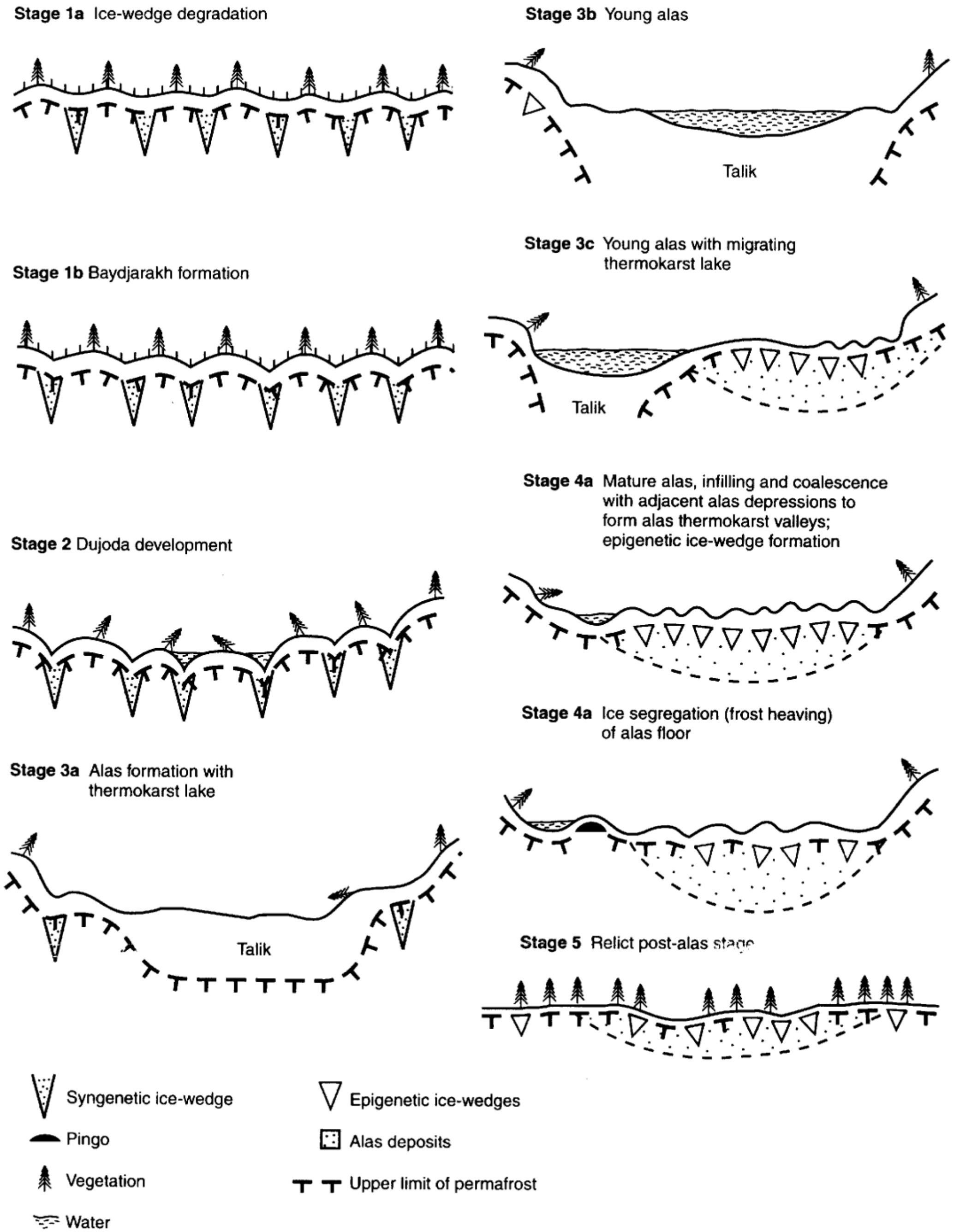


Figure 7.3 The sequence of development of alas thermokarst relief in central Yakutia, according to P. A. Soloviev (1973b).

<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 ?

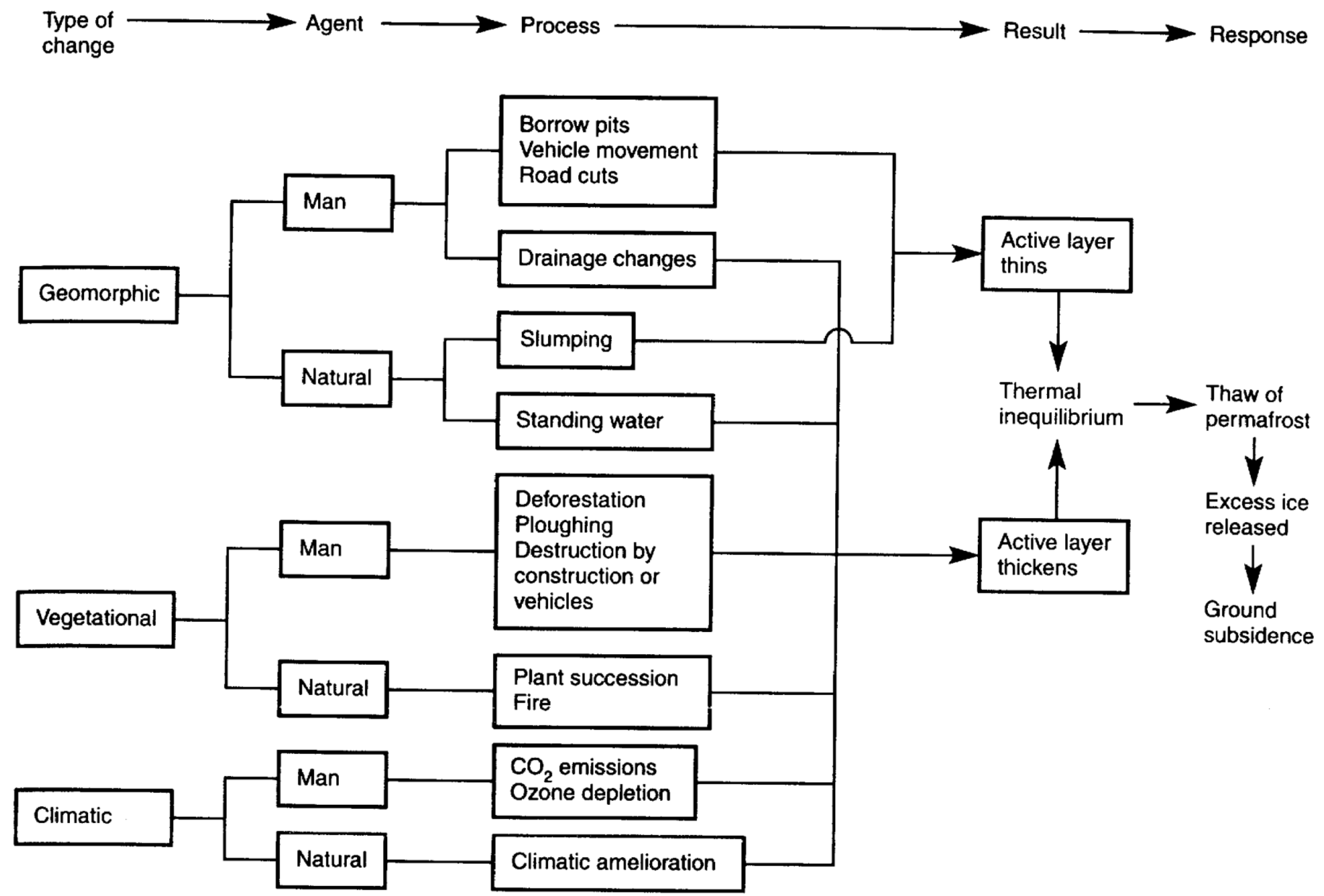
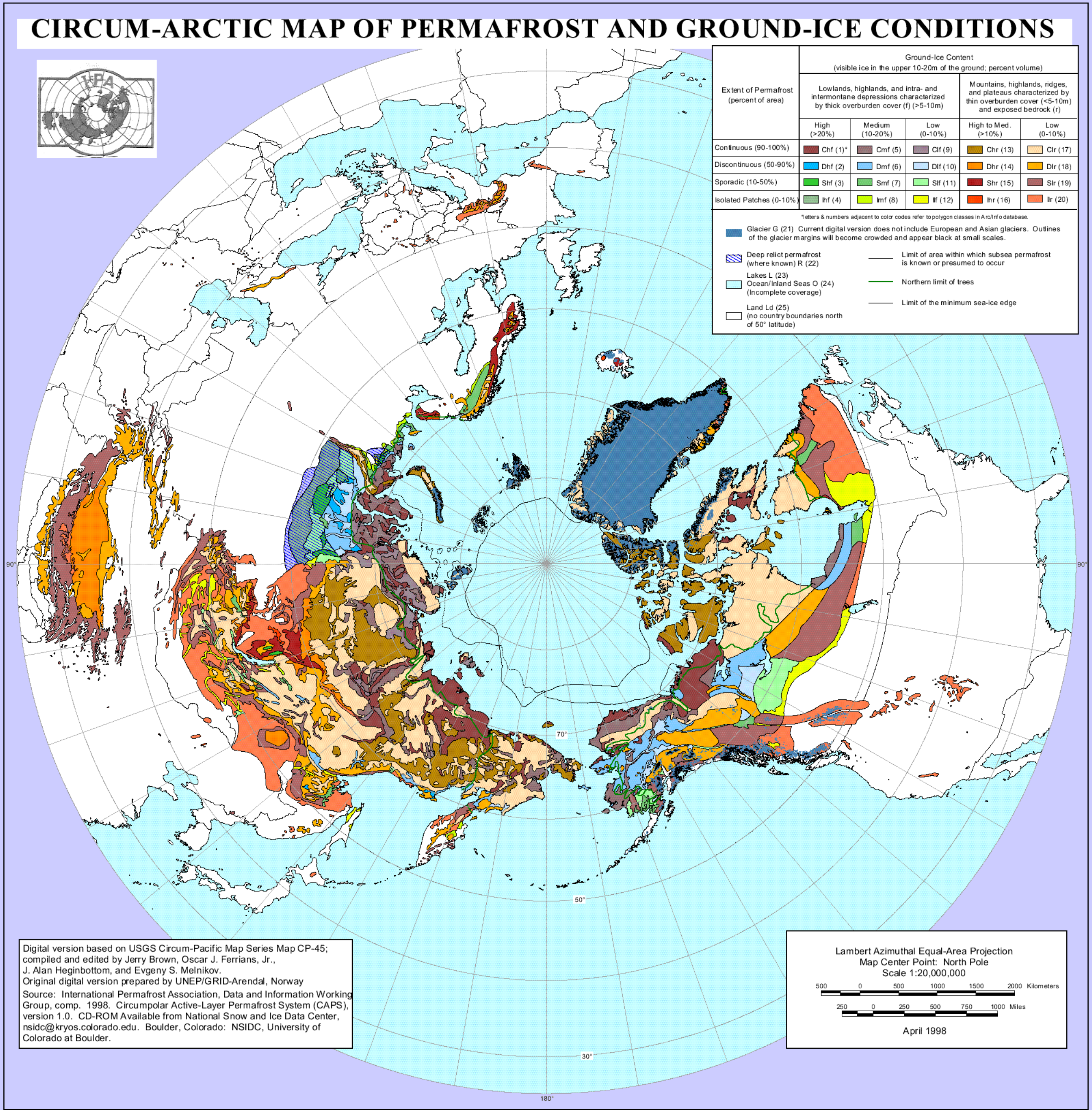


Figure 7.2 Diagram illustrating how geomorphic, vegetational and climatic changes may lead to permafrost degradation (modified from French, 1987c).

How can climatic changes affect permafrost ?



Suggestions for readings:

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.