Change in snow regime and its effect on the nutrient cycling in forest soils

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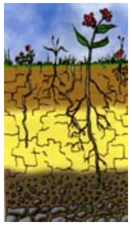
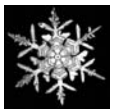




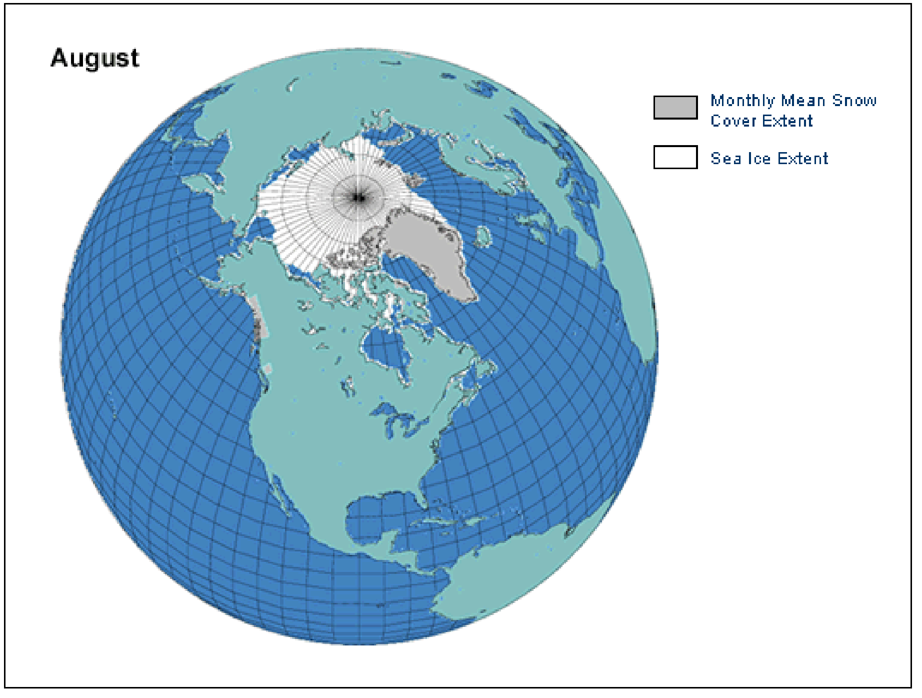
Summary

1. **Soil and snow: connected systems**
2. **The snow cover under a changing climate**
3. **Change in snow regime and the nutrient cycling (N) in forest soils**

3.1. Lack of snowcover

3.2. Increased density of the snowcover

The length of the snow-cover period varies each year and is dominated by the seasonal cycle. The extent of the snow-covered area in the northern hemisphere ranges each year from an average minimum of 3.6 million square kilometres in August, to an average maximum of 46.8 million square kilometres in late January.



World distribution of snowcover

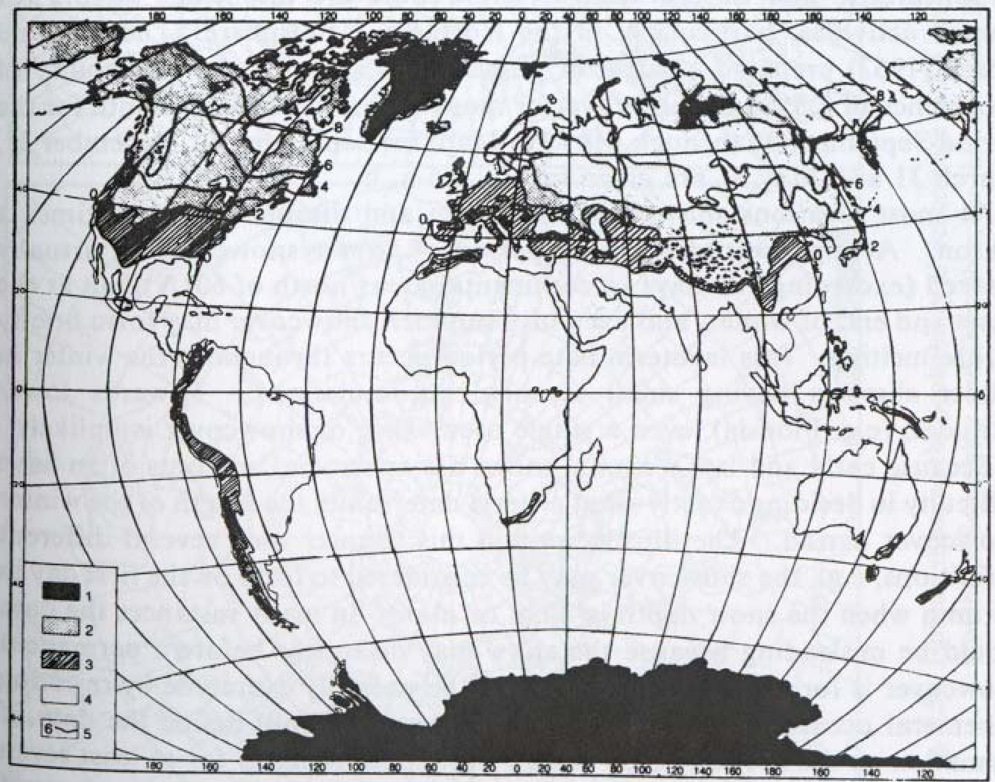
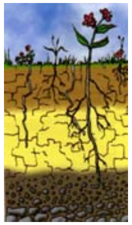
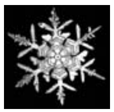


Fig. 5.4 World distribution of snowcover (Rikhter, 1945).
1. Permanent cover of snow and ice. 2. Stable snowcover of varying duration forms every year. 3. Snowcover forms almost every year, but is not stable. 4. No snowcover. 5. Duration of snowcover (months).

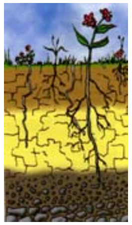
Over 30% of Earth's land surface has seasonal snow

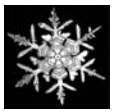
1. Soil and snow: connected systems





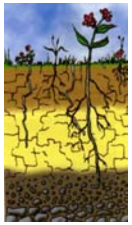
"The two domains, soil and snow, are obviously connected, and perhaps continuous, system" (Guymon GL, 1978).

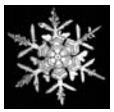




The Rock Analogy

"It could be useful to view the snowcover as a type of sedimentary rock composed of consolidated layers of deposited minerals in their solid state (ice) – thus ***a snowcover is analogous to a sedimentary rock*** *formed of ice, the mineral whose principal property is its temperature (McKAY & Adams, 1981)".* **But…..**

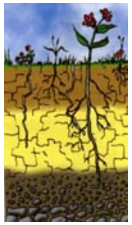


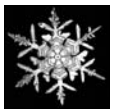


The Soil Analogy

*" As the rates of snowcover metamorphism (transformation) are very rapid, the **"rock analogy"** is not useful for describing the dynamic nature of a snowcover. For this purpose **snow might be considered as being more like soil**, which is also characterized by layering of particles of different grain size, shapes…but which, contains appreciable quantities of air and water and which is highly dynamic…. ! (McKAY & Adams, 1981)".*

1. Soil and snow: connected systems





*“ Keeping the **soil analogy**, the snowcover is a network of solid particles (ice) enclosing voids or pores of varying size. The horizons which make up a soil profile are in some ways analogous to strata encountered in a snowcover. Snow, like soil, is a medium for life, a sheltered extension of the atmosphere. Also like soil it is a substrate for life” (McKAY & Adams, 1981).*

The formation of snow

An understanding of snowfall formation helps to better understand the structure and properties of the snow covers which may influence the soil properties.

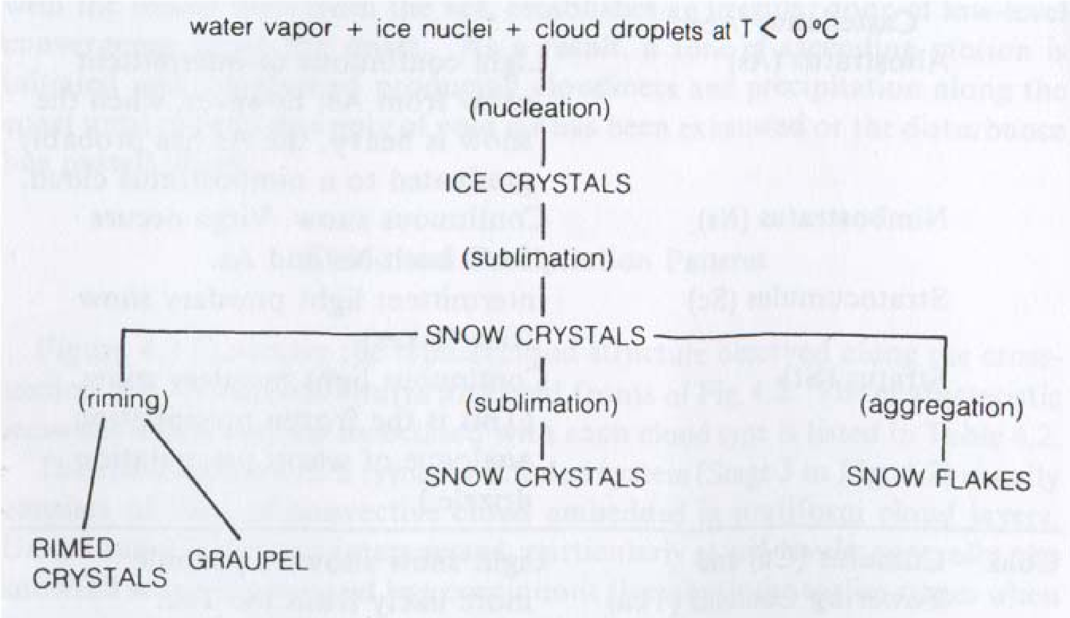
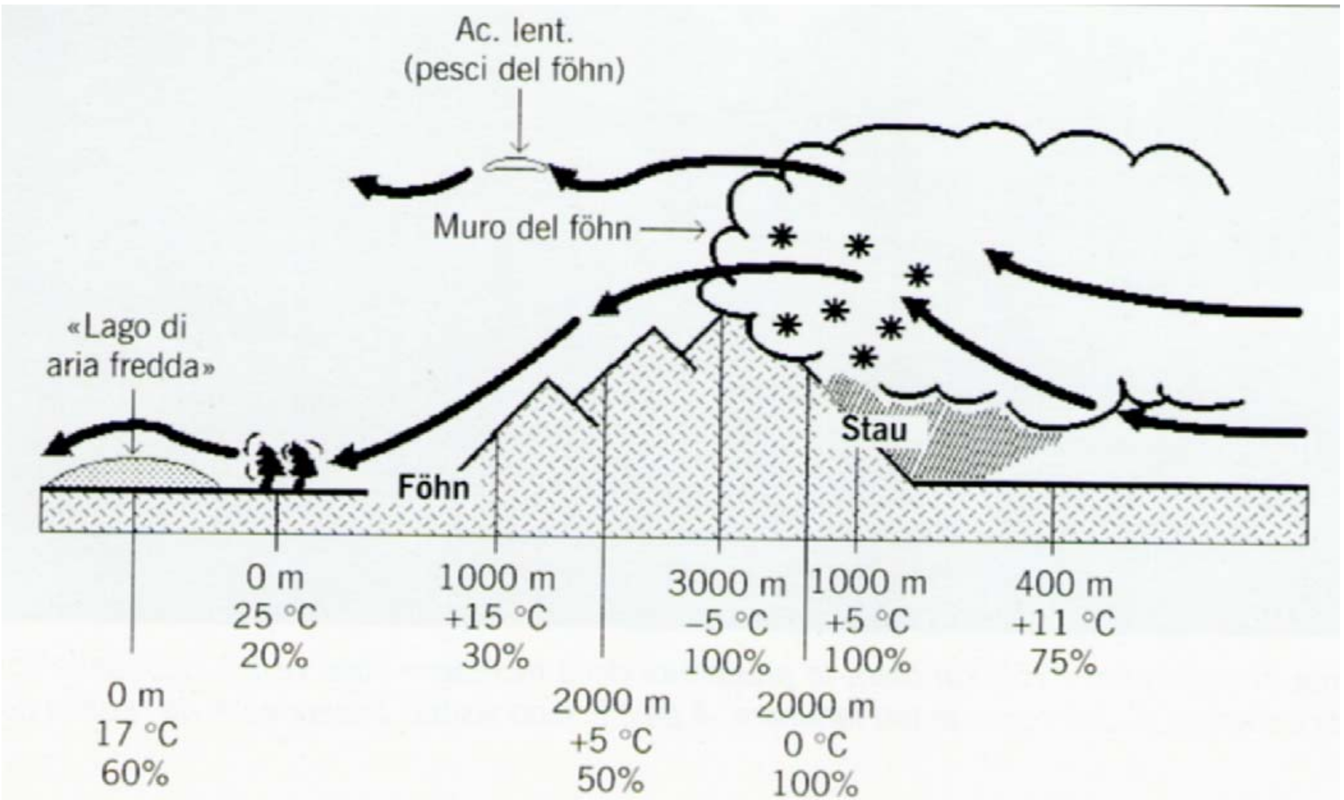


Fig. 4.4 Flow diagram of the formation of different types of snow.

The formation of snow

Initially a cloud is formed by condensation of the water vapor in an ascending region of warm moist air.



Giovanni Kappenberger, Jochen Kerkmann *Il tempo in montagna*

The formation of snow

- Once the cloud temperatures drop below freezing, conditions are suitable for forming snow.
- **Ice nuclei** are particles which causes the formation of ice through either the direct freezing of cloud droplets or the freezing of water deposited as a vapor onto the particle’s surface.
- The major source of ice nuclei in the atmosphere is the earth’s surface from which dust is raised by the wind. **Clay-silicate particles** are one of the most common and most efficient natural ice-nucleating agents.

The formation of snow

The basic habit (shape) of an ice crystal is determined mainly by the temperature at which it grows:

-10 – 20 °C

dendrites

0 – 4 °C

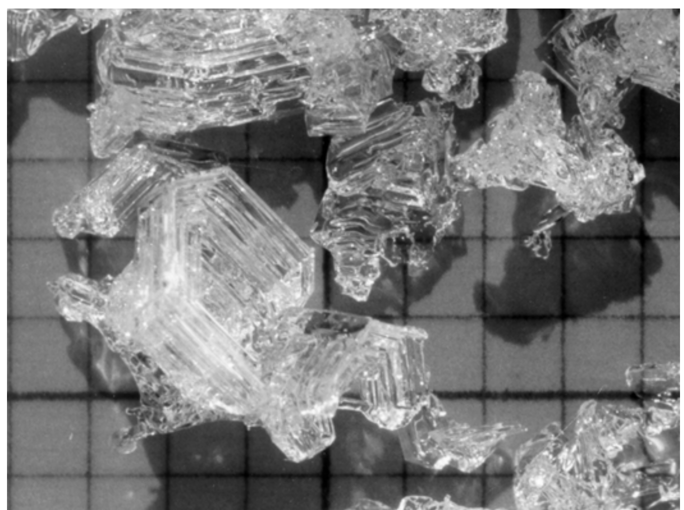
plates

www.its.caltech.edu/˜atomic/snowcrystals

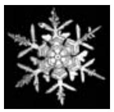
Snow metamorphism

After the snow is deposited particles shapes are modified by a process known as metamorphism.

1. Low temperature gradient metamorphism
2. High temperature gradient metamorphism



Depth hoar crystals



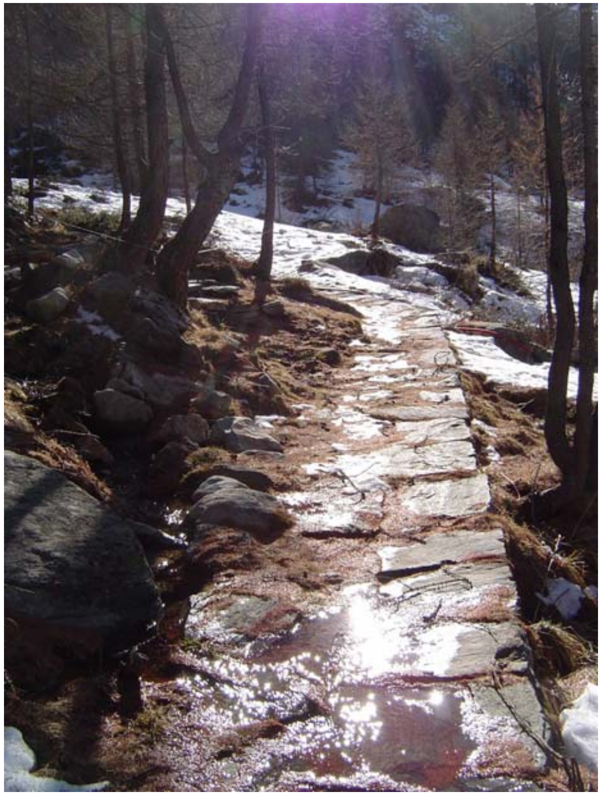
Snow cover structure

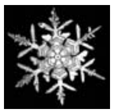
- An important characteristic of snow covers is the stratification of their physical structure.
- Snow stratification results from successive snowfalls over the winter and processes (metamorphism) that transform the snow cover between snowfalls.
- A new snowfall creates a new surface layer that will undergo various transformations before being buried by the next snowfall.


2.4 – 18 kg ha-1

Snow/Soil interactions

- Snow is a reservoir of water, released into the soil in a short time (Italian Alps, 2000 m, SWE=320 mm).





Snow/Soil interactions

- Snow is a reservoir of nutrients. During the spring melt period, meltwaters deliver nutrients to the soil, up to 2-4 kg ha^{-1} of N within a period of a few weeks.
- 50 to 80 per cent of the solute species are eluted in the first 30 per cent of melt water (**ionic pulse**).
- **Preferential elution** from snow to soil in the sequence SO_4^{2-}>NO_3^->Cl^- was confirmed from field and laboratory measurements.

Profiles of nutrient species

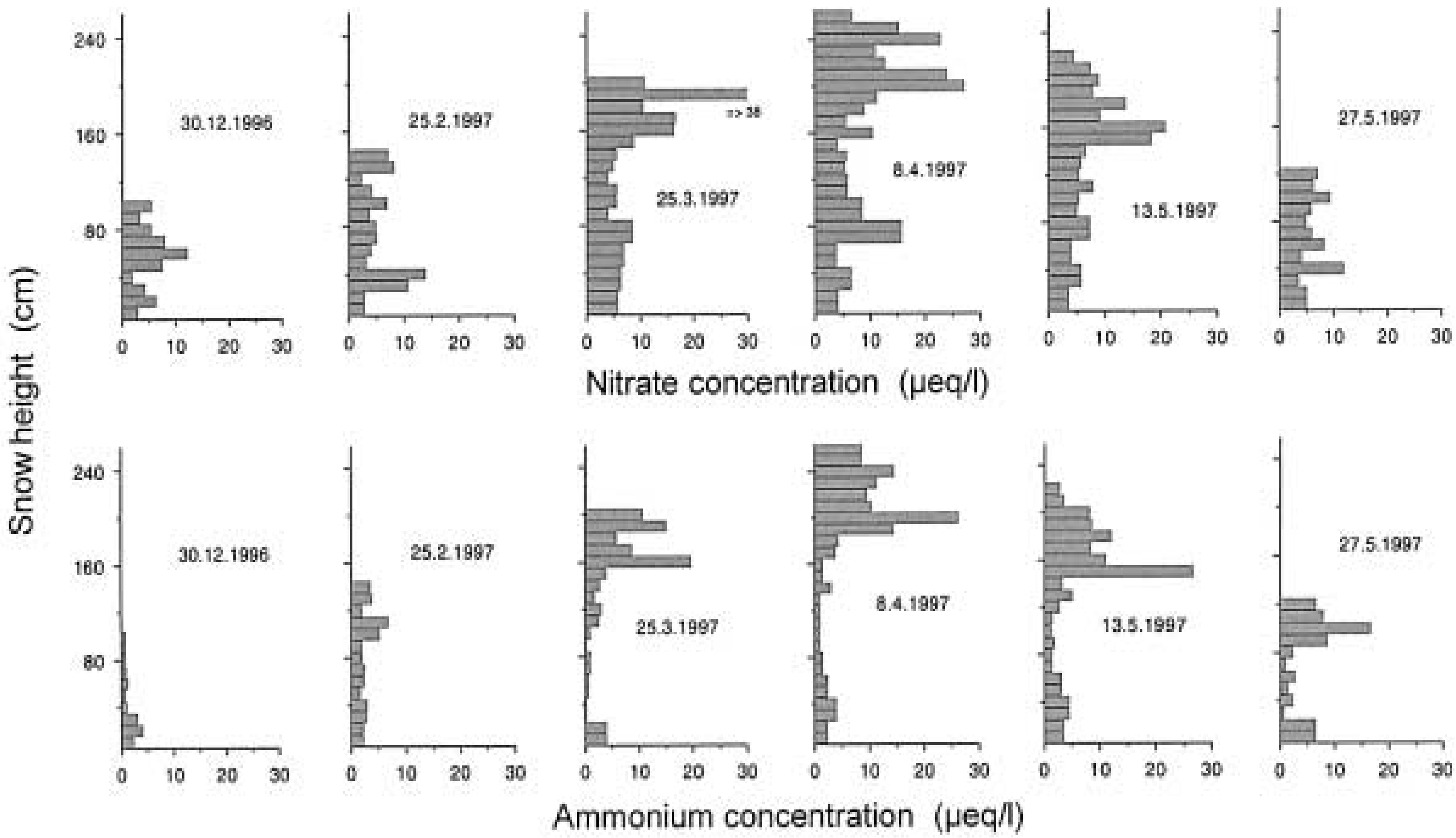


Figure 3. Profiles of two nitrogen species through the winter season. Data from sampling near Lake Gossenkölle at 2400 m elevation in the Tyrolean Alps. Note the strong enrichment in the top layers that were deposited in a well mixed atmosphere in April and May. The simultaneous growth of both snow cover and concentration causes a marked increase of total nutrient load (µeq m^{-2}) in the spring months

Ionic Pulse

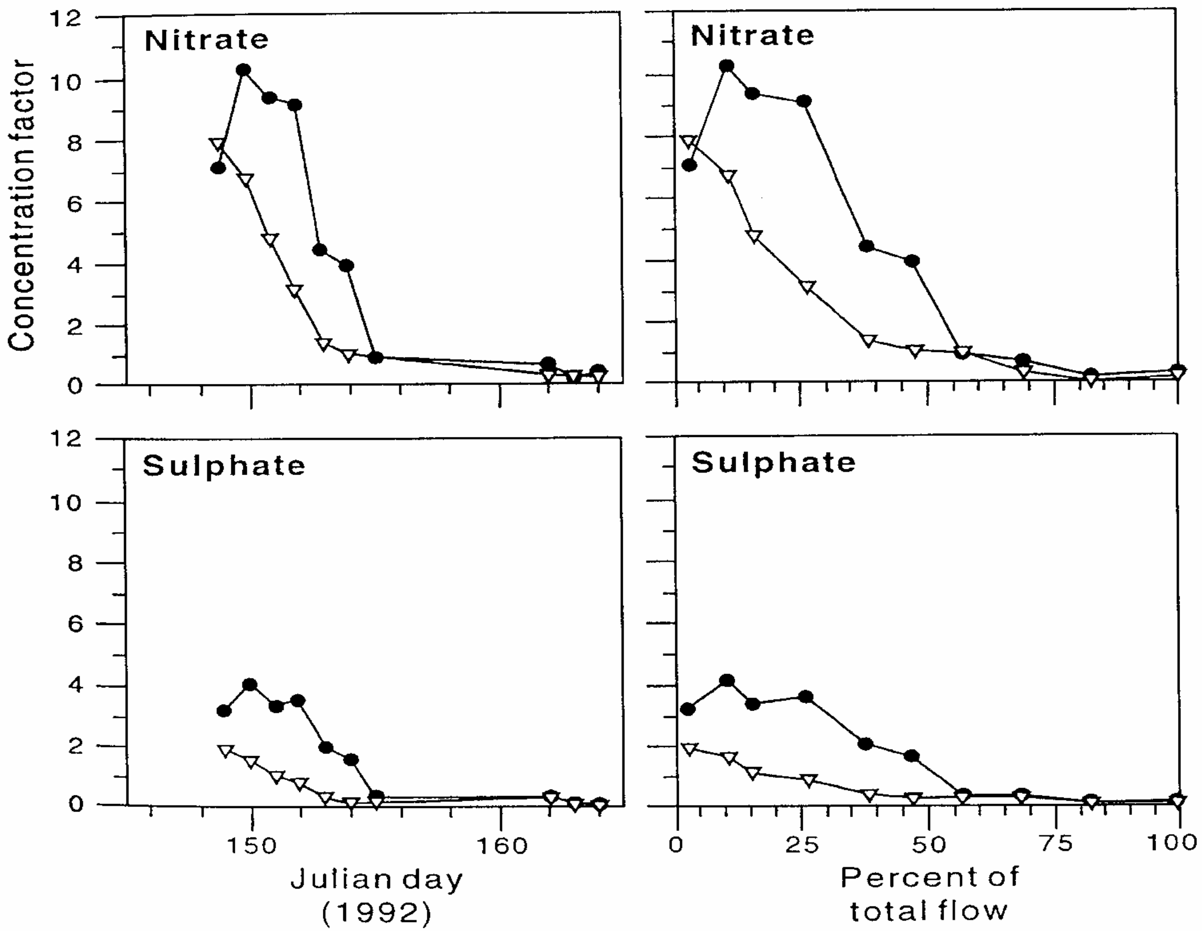


Figure 3.6. The impact of flow rate on the concentration factor of SO_4^{2-}, NO_3^-, and Cl^- in snowmelt. Open symbols denote high rates; closed symbols denote low flow rates (after Marsh and Pomeroy, 1993).

Preferential Elution

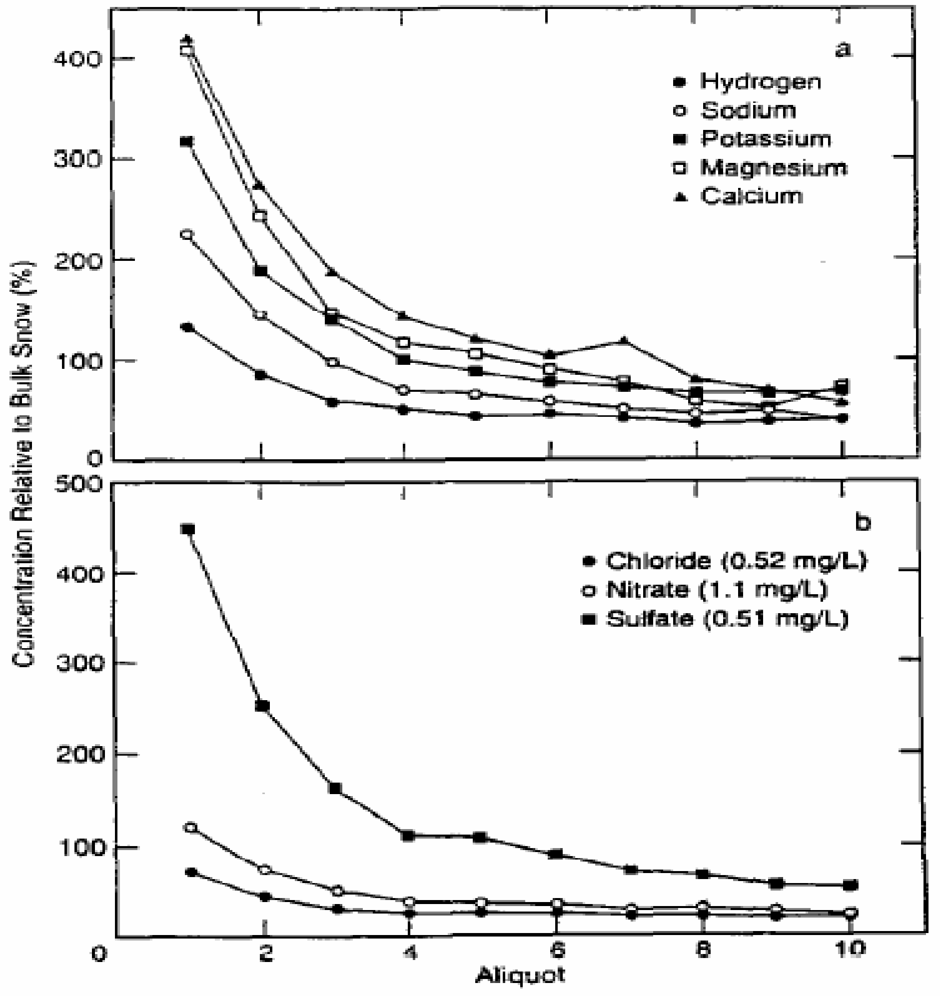
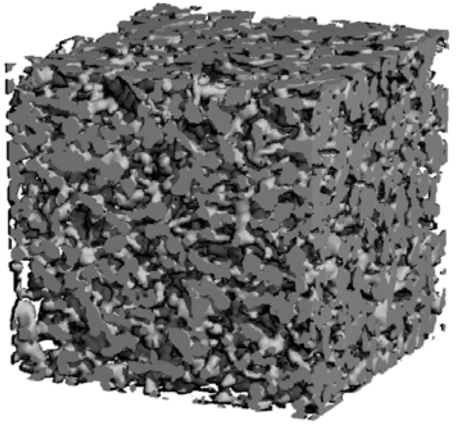


Fig. 3. Concentrations of (a) cations and (b) anions in sequential eluate aliquots for natural snow elution. Values have been normalized to bulk snow concentrations.

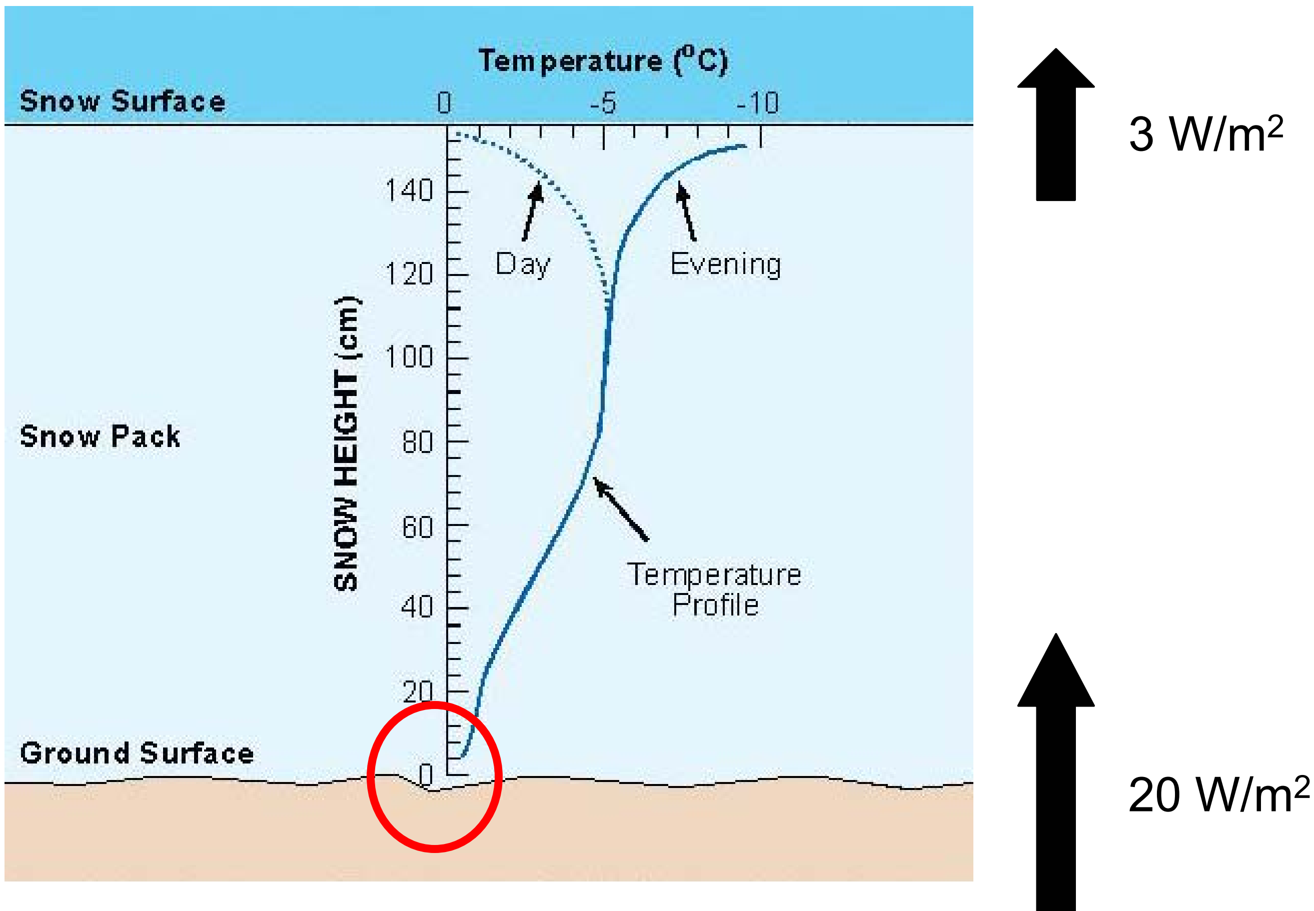
Snow/Soil interactions

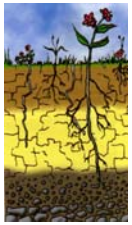
- As a porous medium with a large air content, snow has a high insulation capacity and plays an important role protecting soil from severe winter temperatures.
- The thermal conductivity of a snow cover is low compared with soil surfaces and varies with **snow depth** and **snow density**.

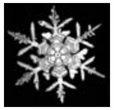


Snow insulation effect

- Low thermal conductivity of snow







Soil life under snow

- Soil respiration

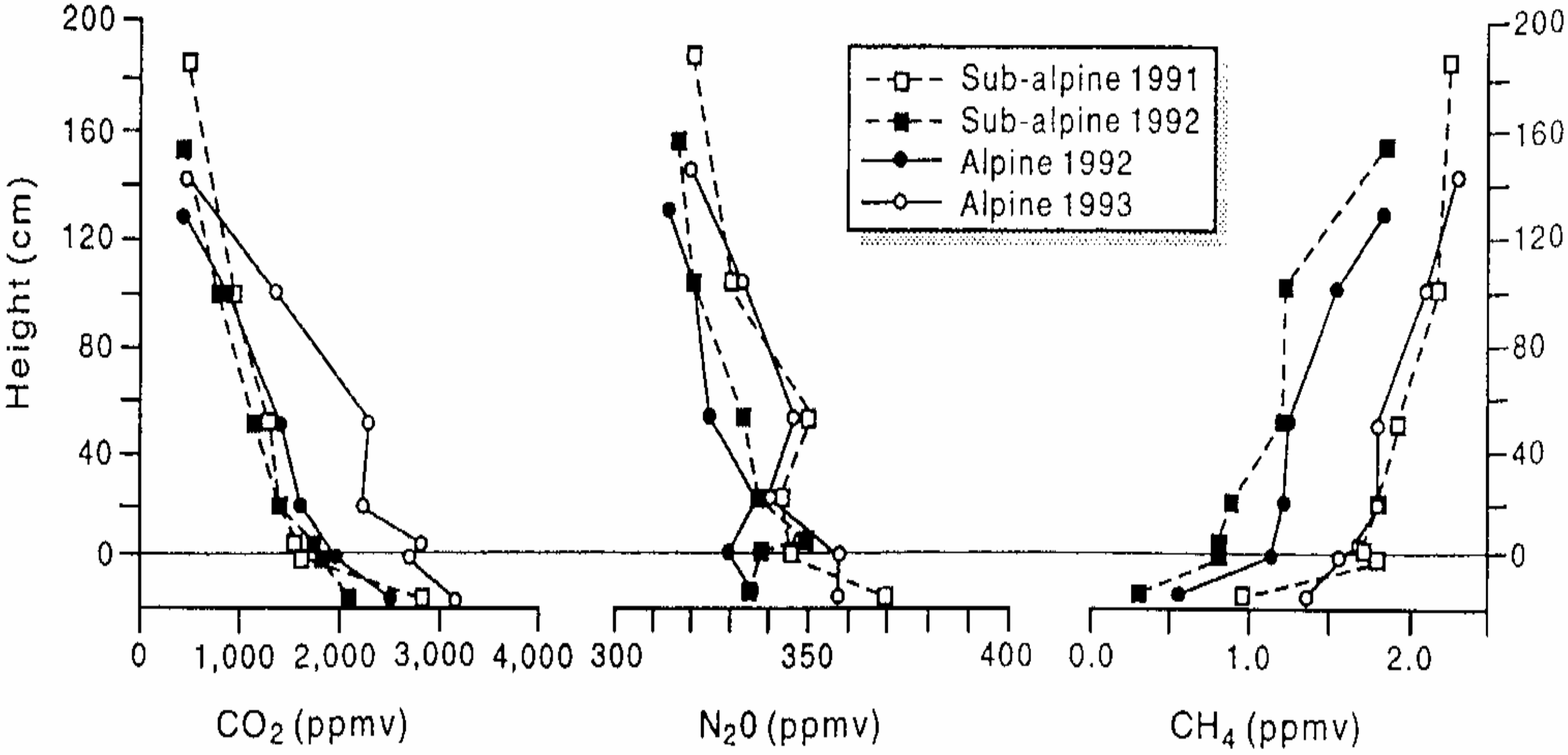
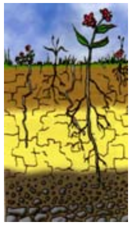
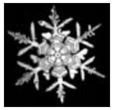


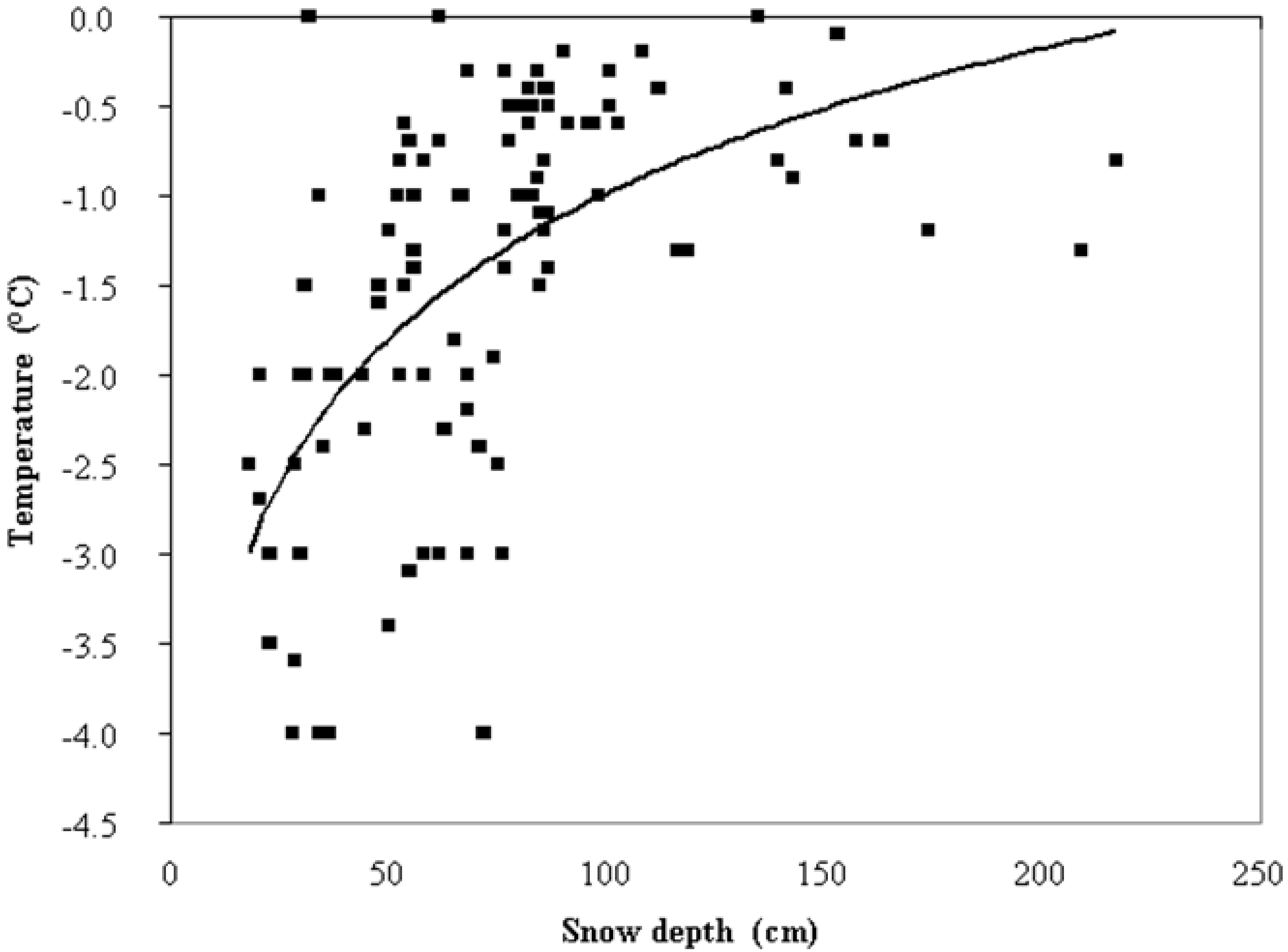
Figure 3.4. Profiles of the gaseous concentration of CO_2, N_2O, and CH_4 in alpine snow cover (after Sommerfeld, Mosier, and Musselman, 1993).

Snow depth

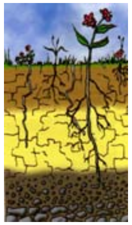


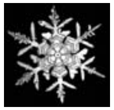


Snow depth


0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
Temperature (°C)
0
50
100
150
200
250
Snow depth (cm)

1. Soil and snow: connected systems





Alpine Tundra

Niwot Ridge, Colorado (40°03’N; 105°35’W), 3500-4085 m, LTER site

MAAT: -3.5°C

Annual precipitation: 1050 mm

Cryochrepts

Altered snow regime by snow fences (Walker et al., 1999; Brooks and Williams, 1999)

Niwot Ridge - COLORADO

The wind action

Alpine Tundra

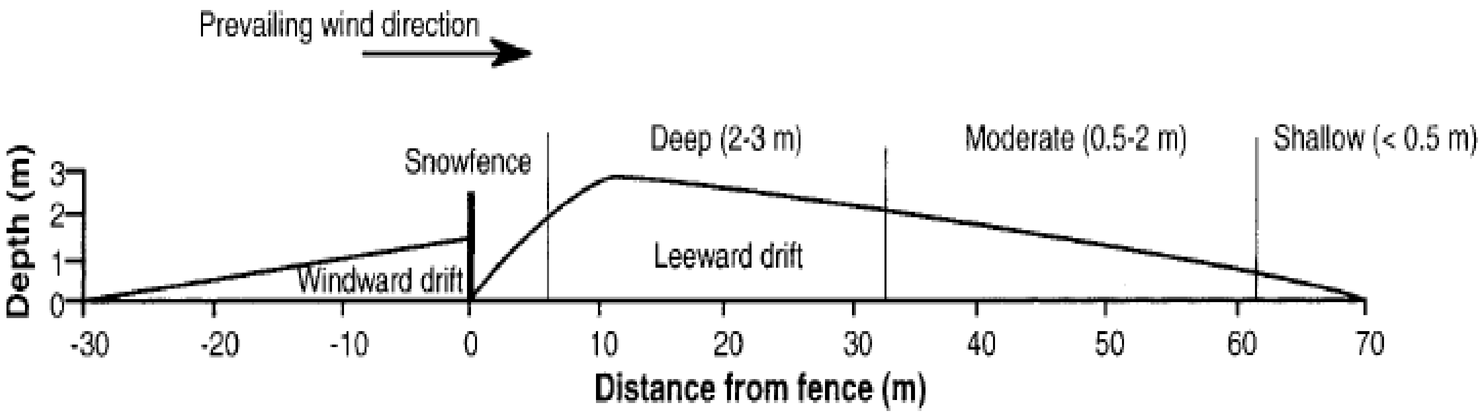
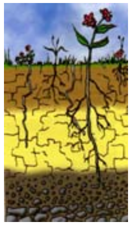
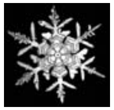
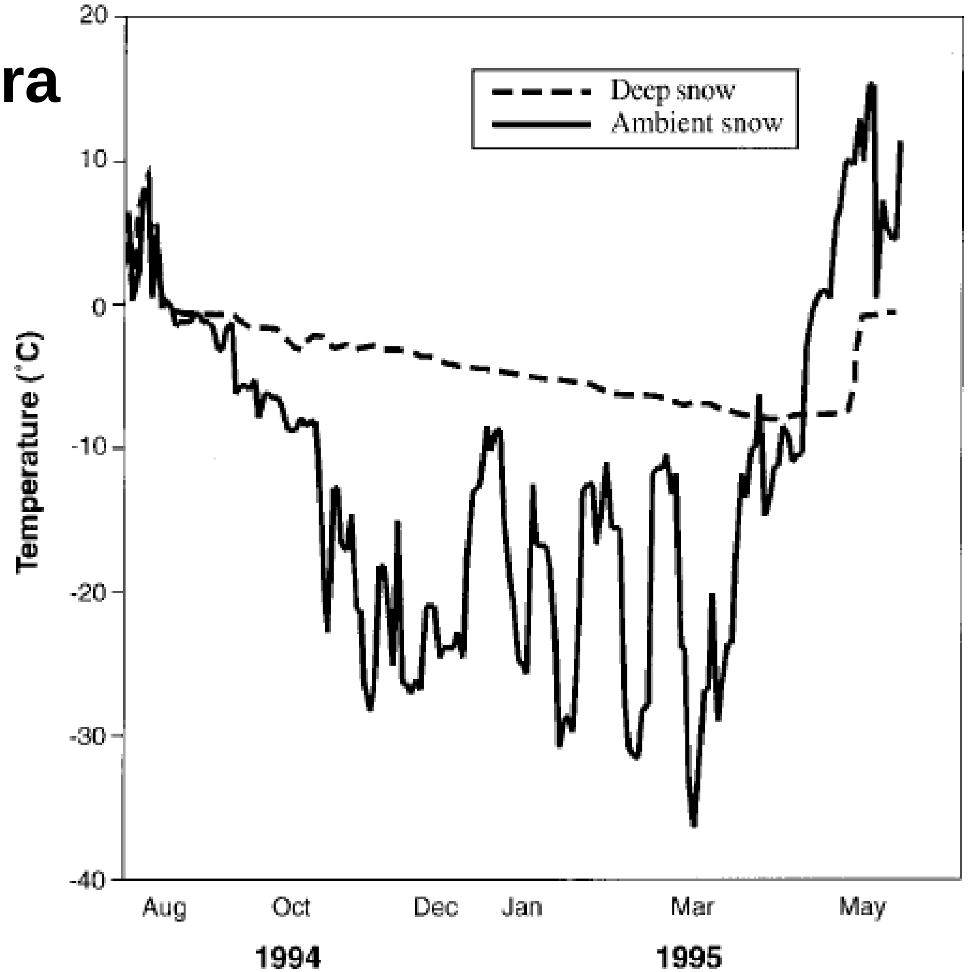


Figure 3. Experimental drift profile. The shape and depth profile of the actual experimental drifts varies somewhat from this theoretical profile, particularly early in the season. Once the drift has filled, however, the shape and depth are quite similar to what is shown here

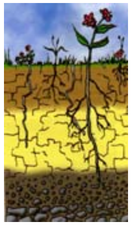


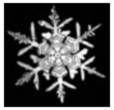


Alpine Tundra



Soil surface temperatures beneath the Toolik Late dry-site fence and control plots, winter 199-1995. Temperatures were recorded every 48 minutes using Hobo temperature logging devices (Onset Computer Corporation, Pocasset, MA). A very similar pattern was found at Niwot Ridge





Alpine Tundra

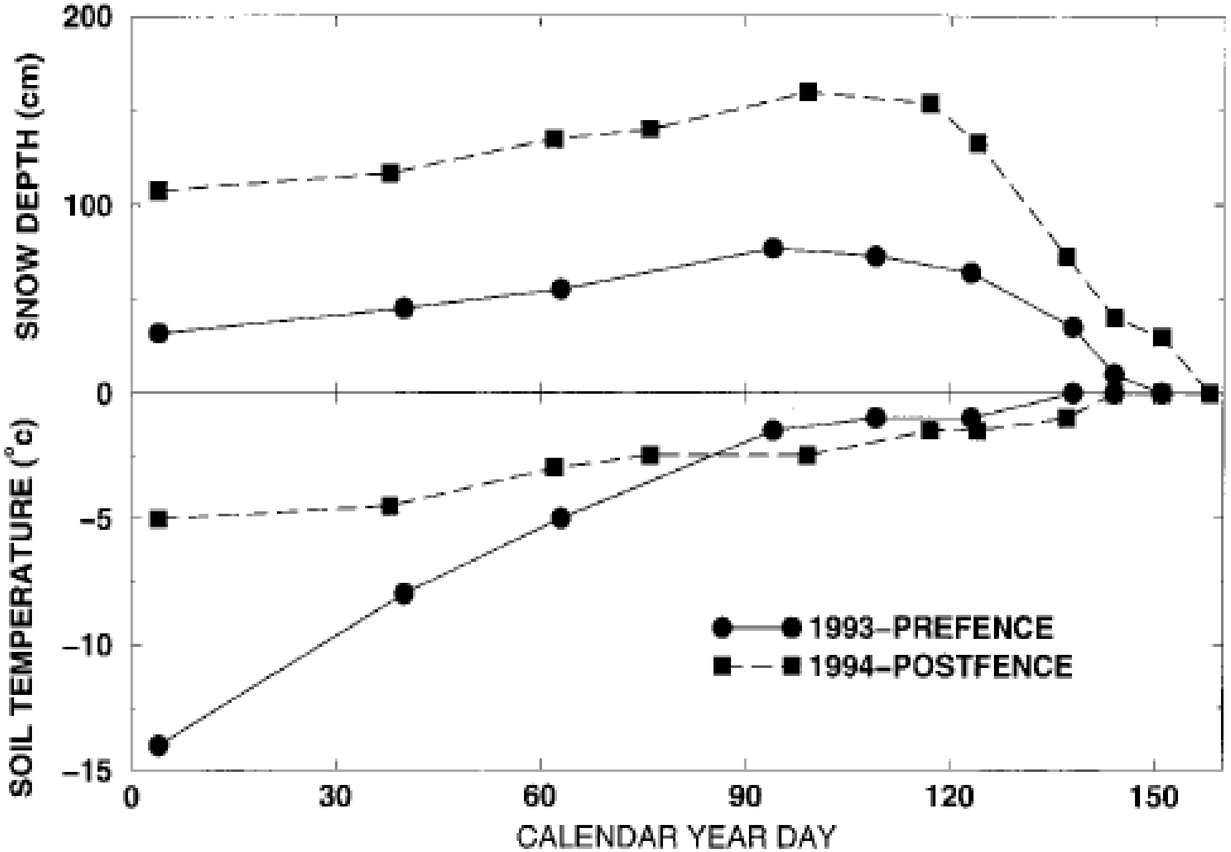
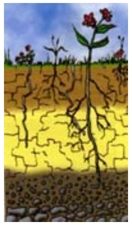
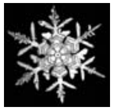
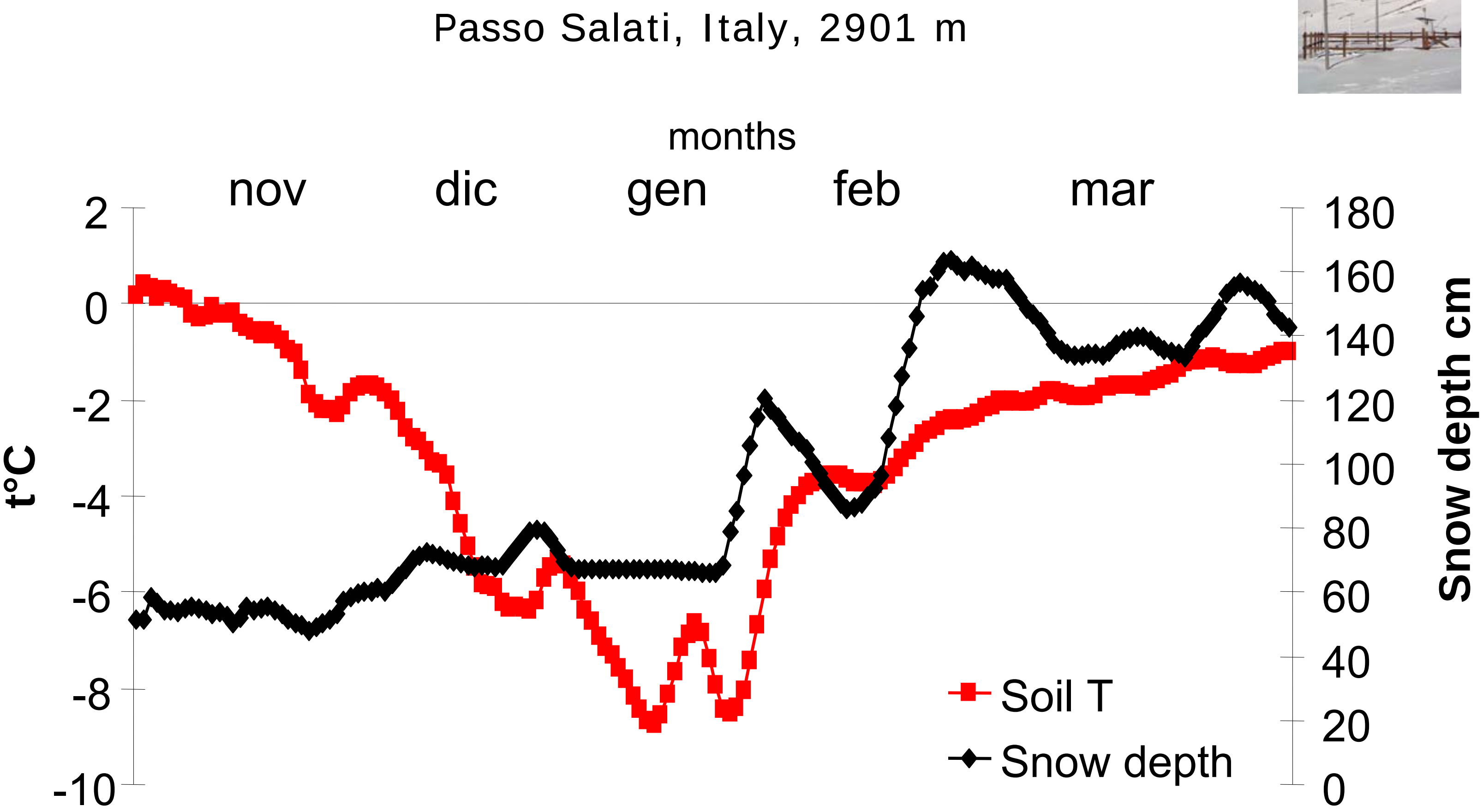


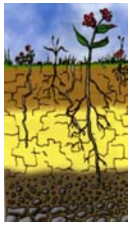
Figure 3. Time series of soil temperature and snow depth before (1993) and after (1994) installation of a snowfence (n . 3)

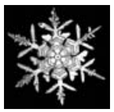




The rate of soil freezing/warming

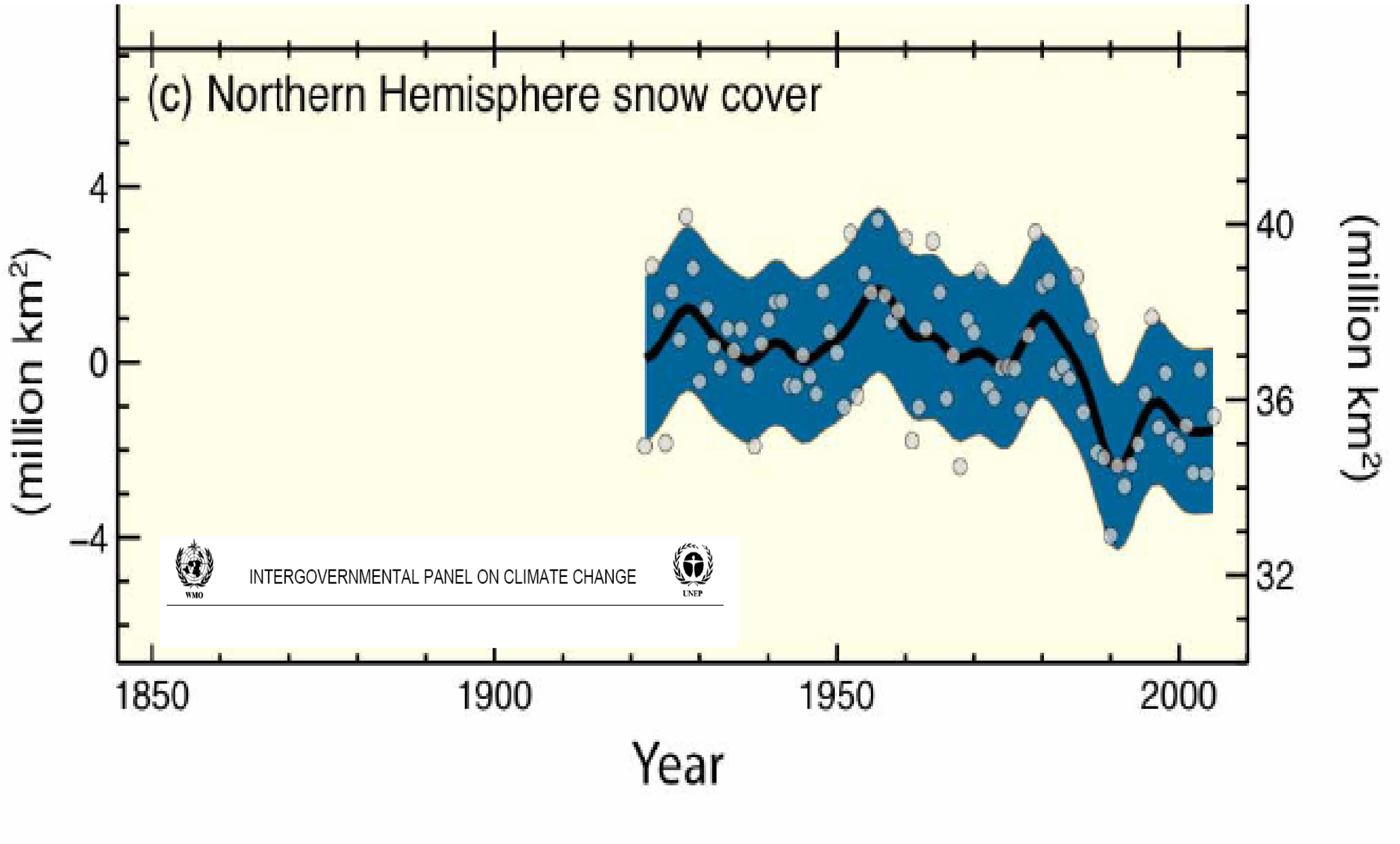


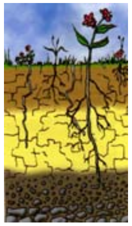




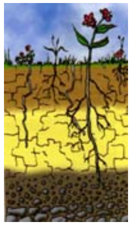
- As an indicator of climatic change, snow is an interesting variable, because it is dependent not only on temperature but also on precipitation.

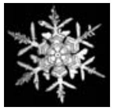
- There has been much concern expressed in recent years that the run of mild winters with relatively **little snow in the Alps** (particularly during the critical vacation periods) in the latter part of the 1980s and the early 1990s may already be a sign of the anthropogenic signal on climate change (Beniston, 1997).


(c) Northern Hemisphere snow cover
(million km²)
4
0
−4
40
36
32
(million km²)
1850
1900
1950
2000
Year
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
WMO
UNEP



- In the Alps **the phenomenon was most marked at low to medium elevation sites**. At high elevations, little difference in snow depth and duration have been observed with respect to the long- term mean.
- This is related to the fact that snow which accumulates in the early part of the season will be less sensitive to warm periods during the winter at higher elevations. This is not the case at lower elevations, which can be subject to extended periods of temperatures above the freezing point (Beniston, 1997).





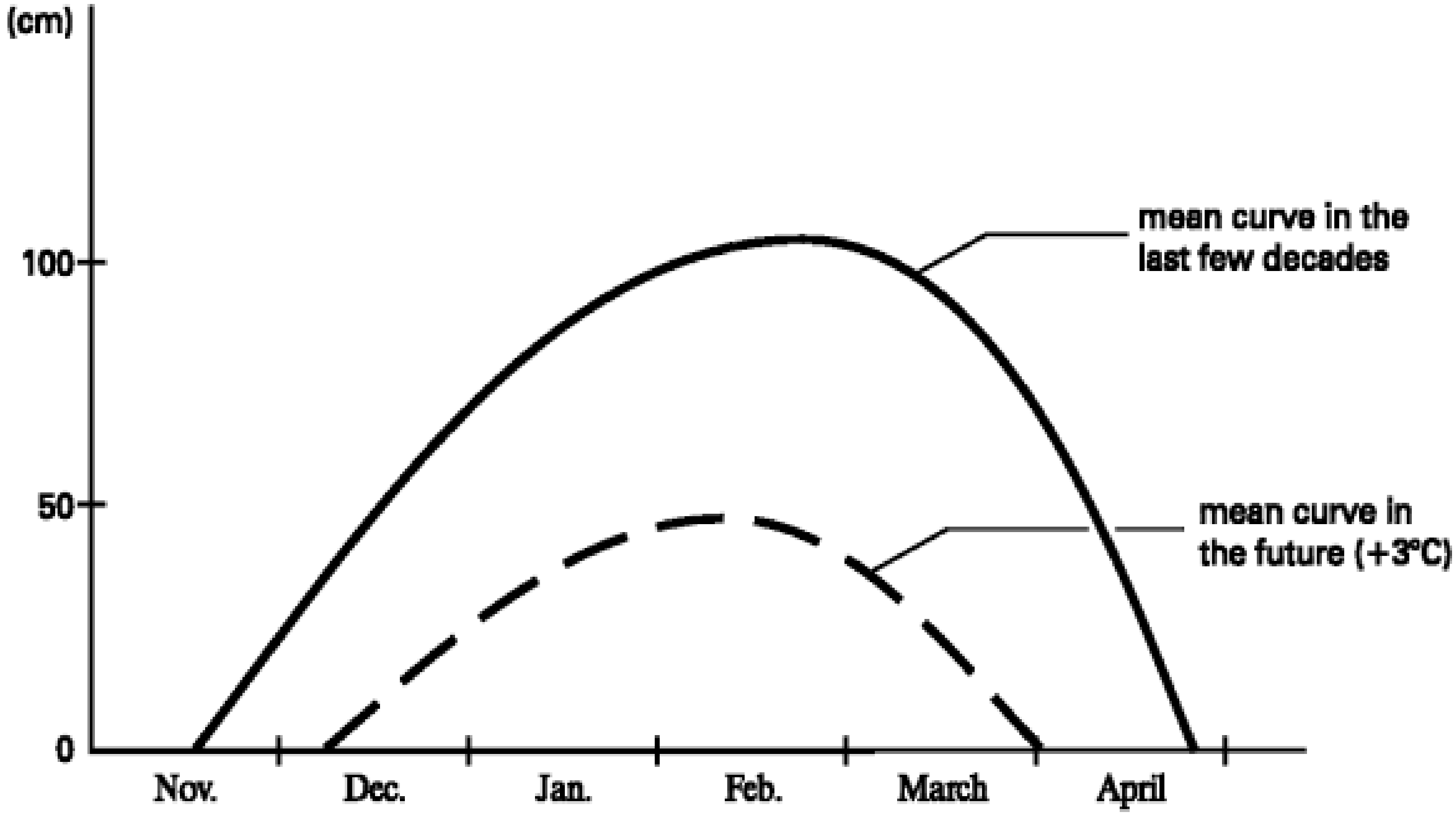
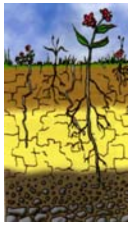
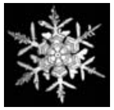
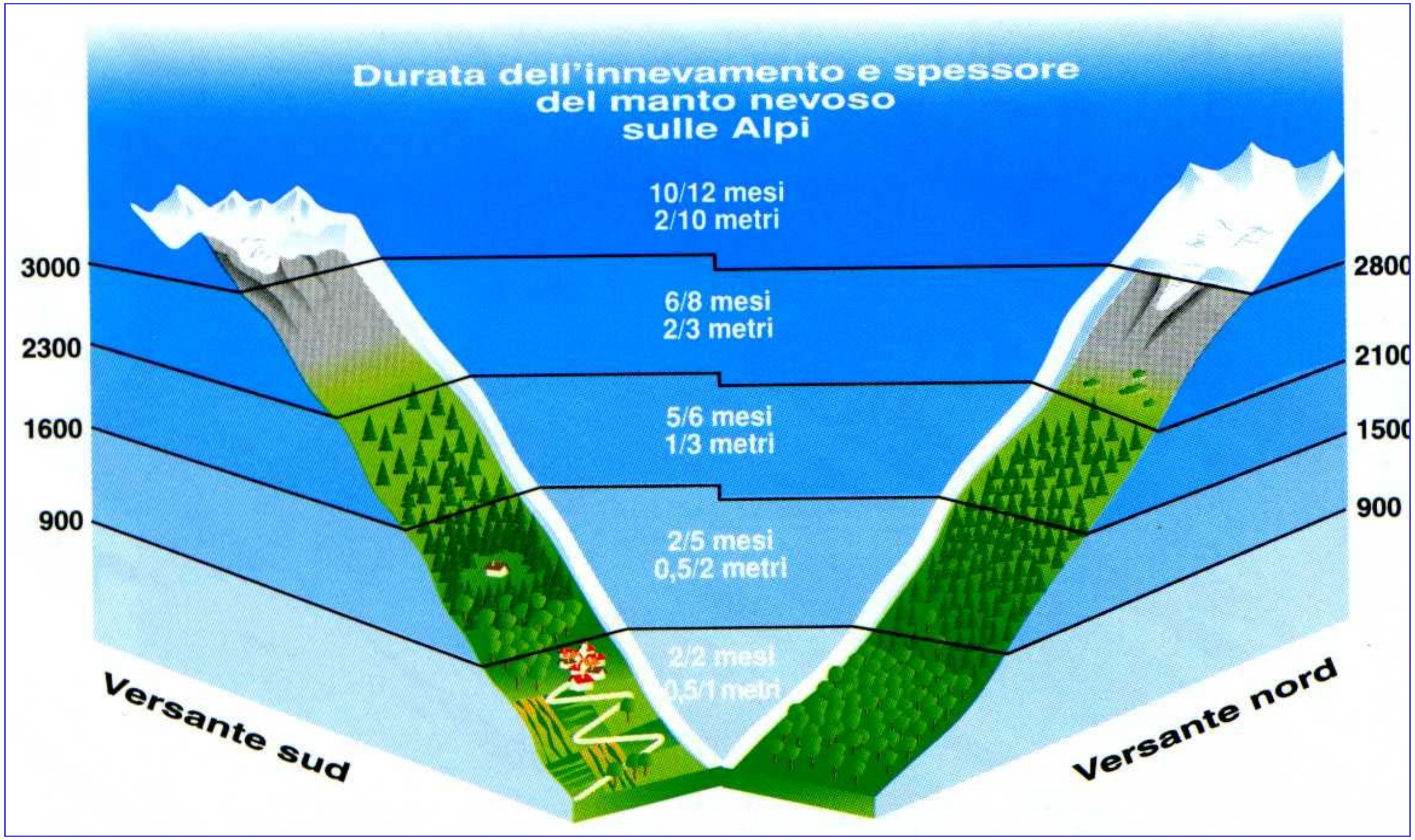
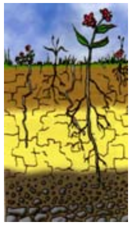


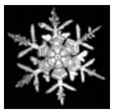
Figure 5 Snow depth and duration of snow cover at an altitude of 1500m in the last decades and in the future (schematic illustration). *Source*: Foehn, 1991






Durata dell'innevamento e spessore
del manto nevoso
sulle Alpi
10/12 mesi
2/10 metri
6/8 mesi
2/3 metri
5/6 mesi
1/3 metri
2/5 mesi
0,5/2 metri
2/2 mesi
0,5/1 metri
3000
2300
1600
900
2800
2100
1500
900
Versante sud
Versante nord

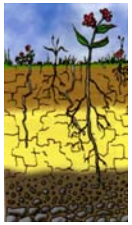


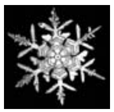


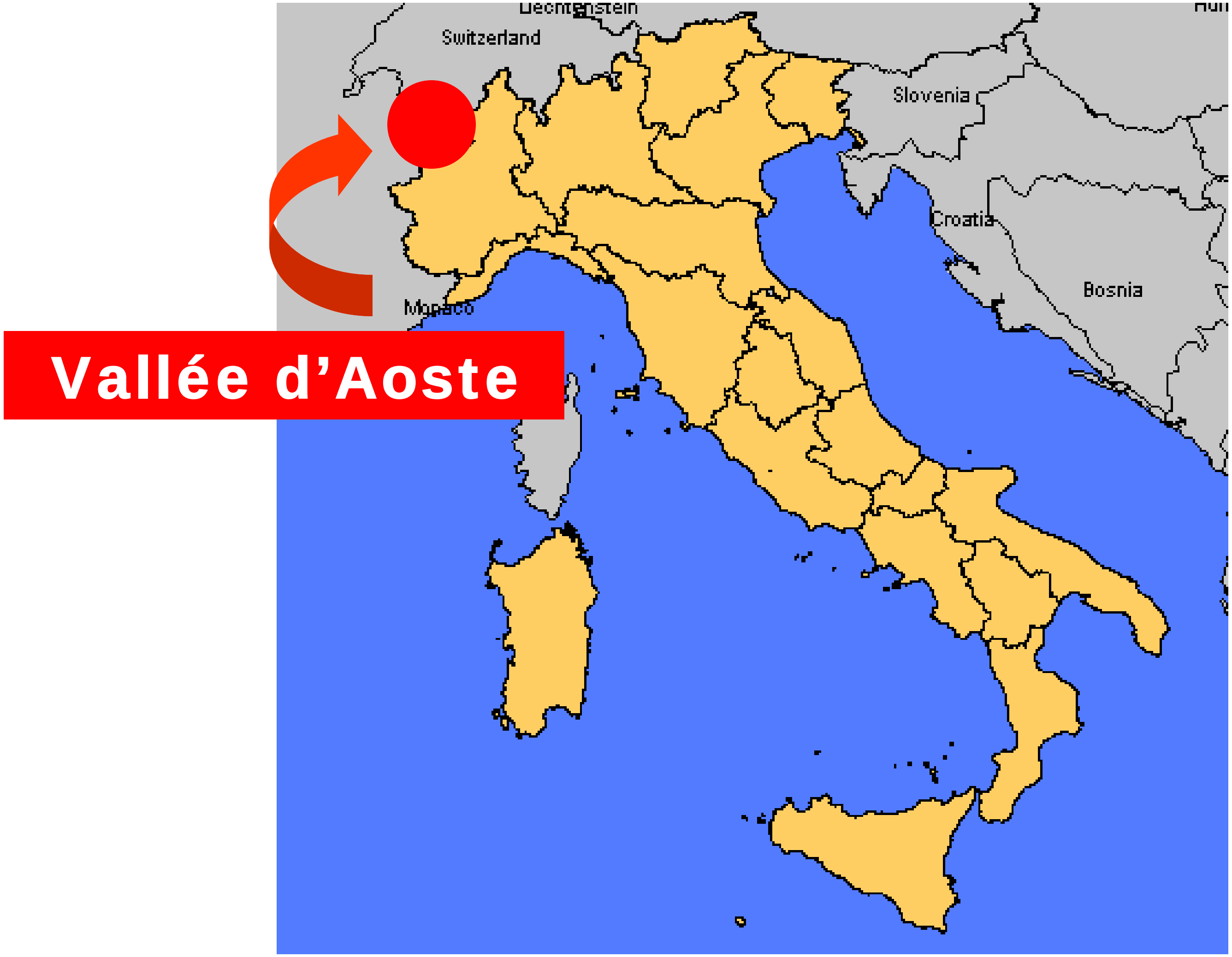
Lack of snowcover: Snow removal experiments

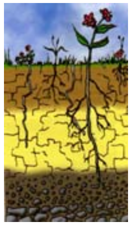
- Roofs
- Shovelling

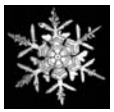
3. Snow regime and nutrient cycling in forest soils











Montane forest soils

Valle del Lys, Italy (45°03’N; 7°E), montane forest (*Larix decidua*), 1450 m

MAAT: +4°C

MAP: 1100 mm

Inceptisols

Winter 2003-2004: Altered snow regime by snow shovelling

Forest soils

Topsoil characteristics

	Larch (L)
pH_{H2O}	5.9
Rocks[a]	520
Density[b]	1.25
Fine earth	
Clay[c]	60
Silt[c]	220
Sand[c]	720
C_{org}[c]	12
N_{tot}[c]	0.5
P_{tot}[d]	581
C/N	24
CEC ($cmol_c^+ kg^{-1}$)	30
BS (%)	46

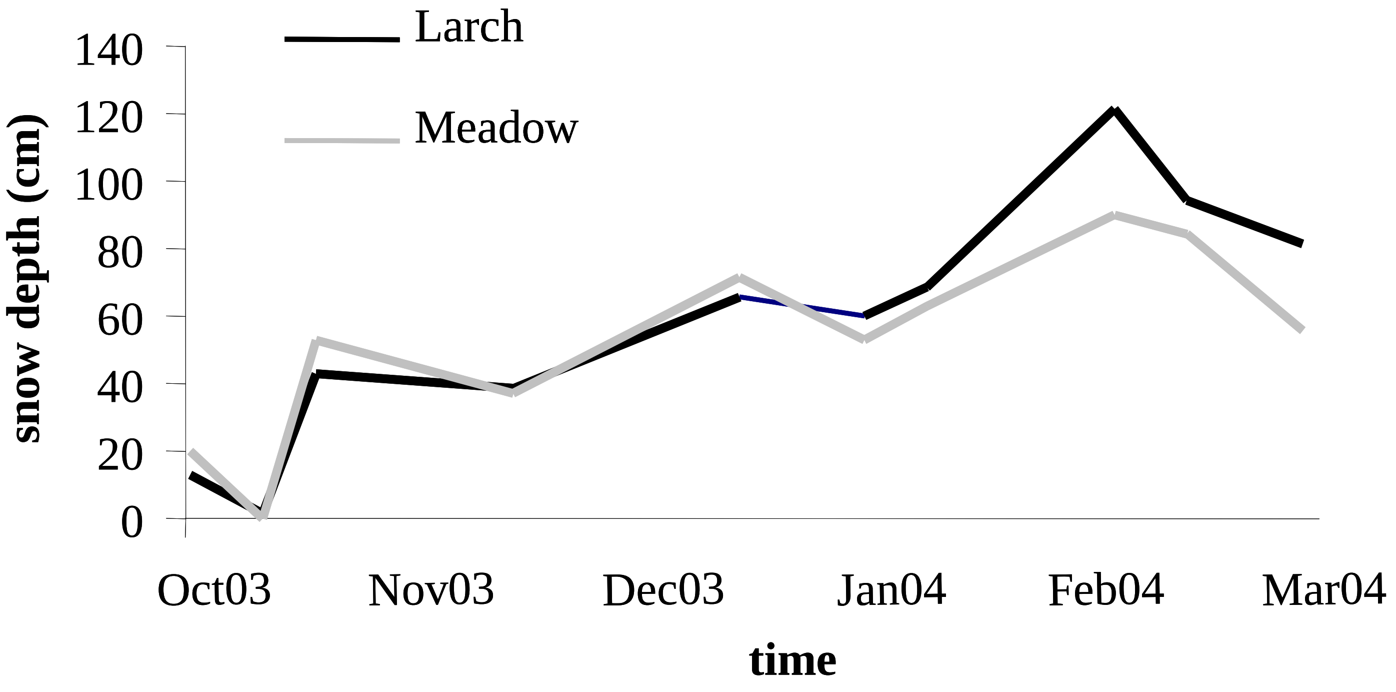
[a] Properties are given as $g\ kg^{-1}$ of bulk soil
[b] Properties are given as $g\ cm^{-3}$ of bulk soil
[c] Properties are given as $g\ kg^{-1}$ of fine earth
[d] Properties are given as $mg\ kg^{-1}$ of fine earth

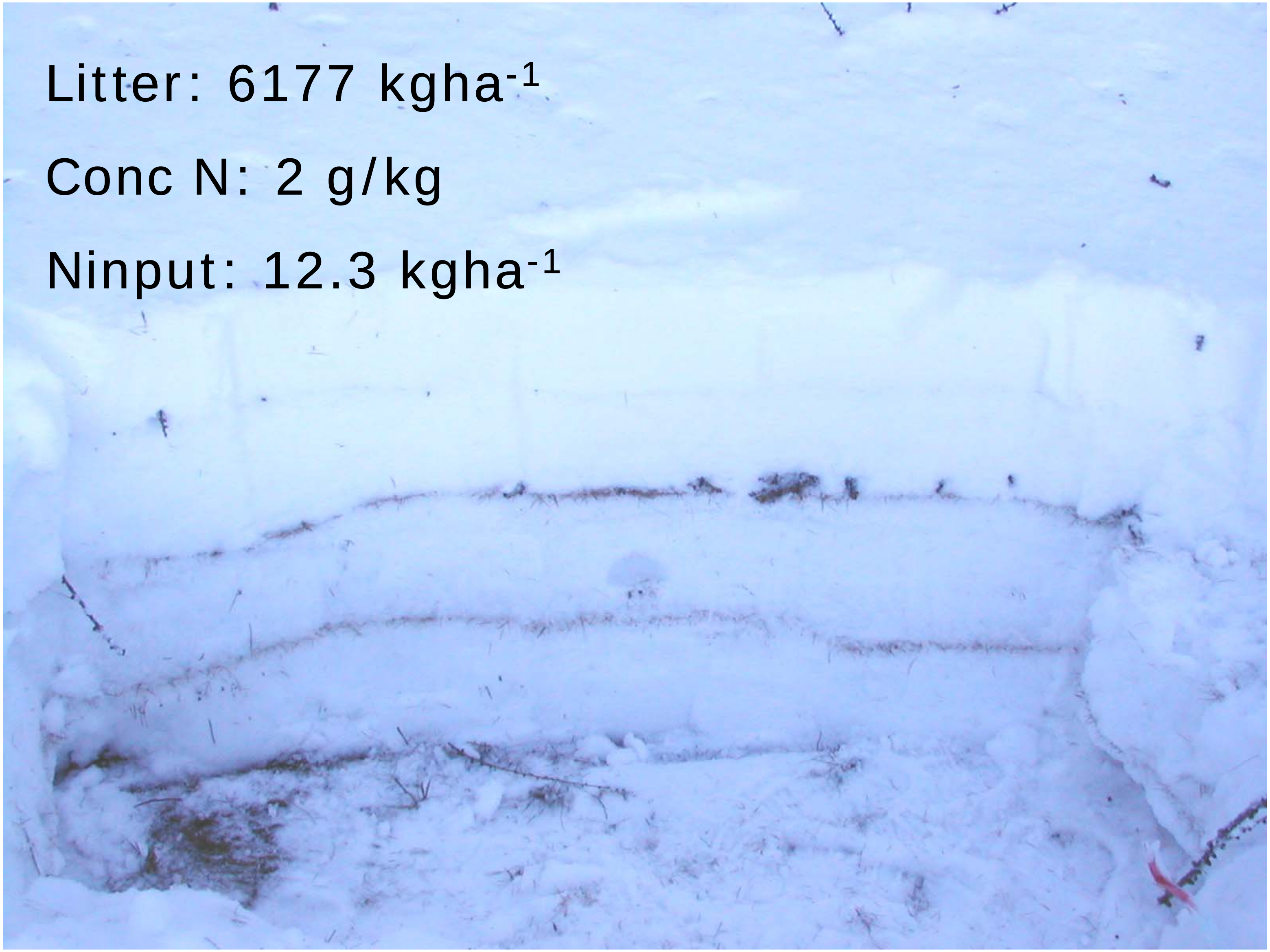
Forest soils

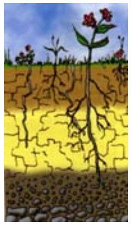
Winter 2003-2004: The snow removal site

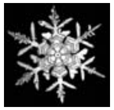
Forest soils

Winter 2003-2004: The undisturbed site



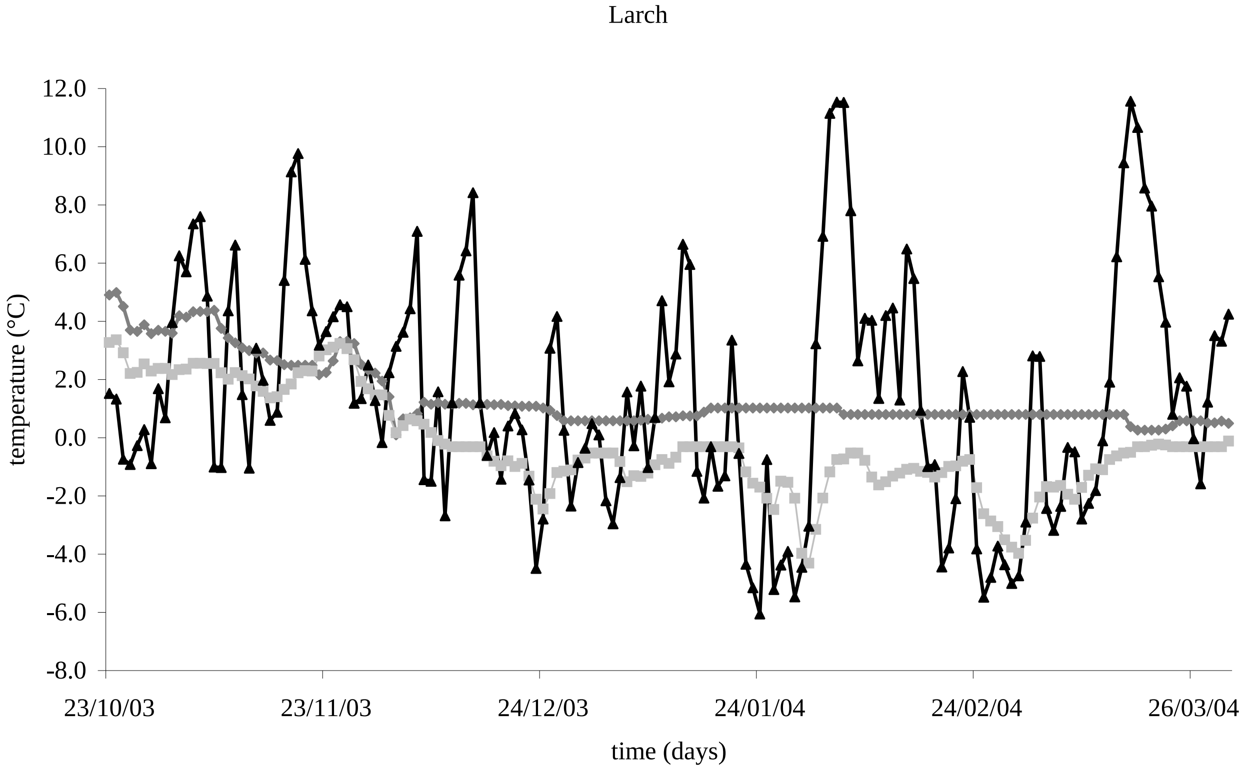

Litter: 6177 $kgha^{-1}$
Conc N: 2 g/kg
Ninput: 12.3 $kgha^{-1}$

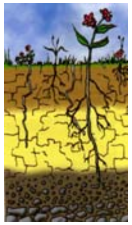




Forest soils

Winter 2003-2004: Soil temperature

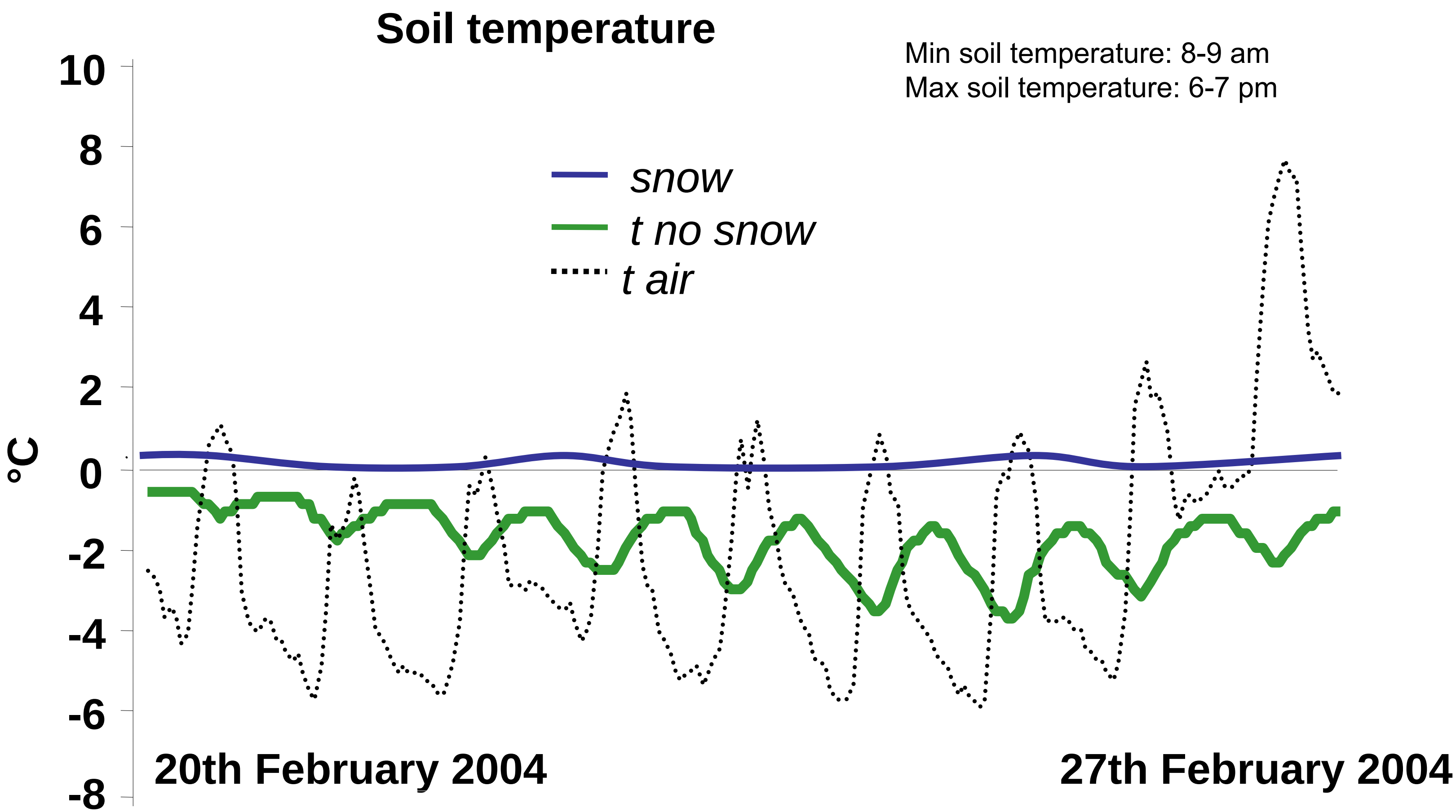


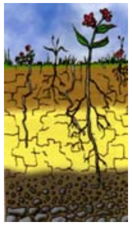


Forest soils

Min air temperature: 6-7 am
Max air temperature: 3-4 pm

Min soil temperature: 8-9 am
Max soil temperature: 6-7 pm



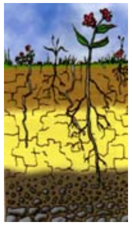


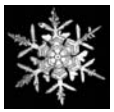
Forest soils

- During the winter 2003-2004 our snow removal manipulation produced relatively **mild freezing events** (soil temperatures seldom decreased below –4°C) but the effects were significant…

With snow


Without snow





Forest soils

New Hampshire, USA (43°56’N; 71°45’W), *Fagus grandifolia, Acer saccharum*, 1015 m, LTER site

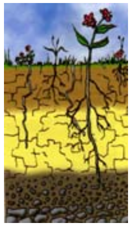
MAAT: +3°C

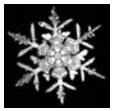
Annual precipitation: 1050 mm

Haplorthods

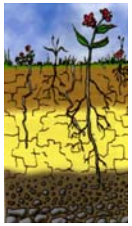
Altered snow regime by shovelling (Groffman et al., 1999, 2001)

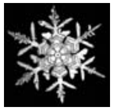
3. Snow regime and nutrient cycling in forest soils



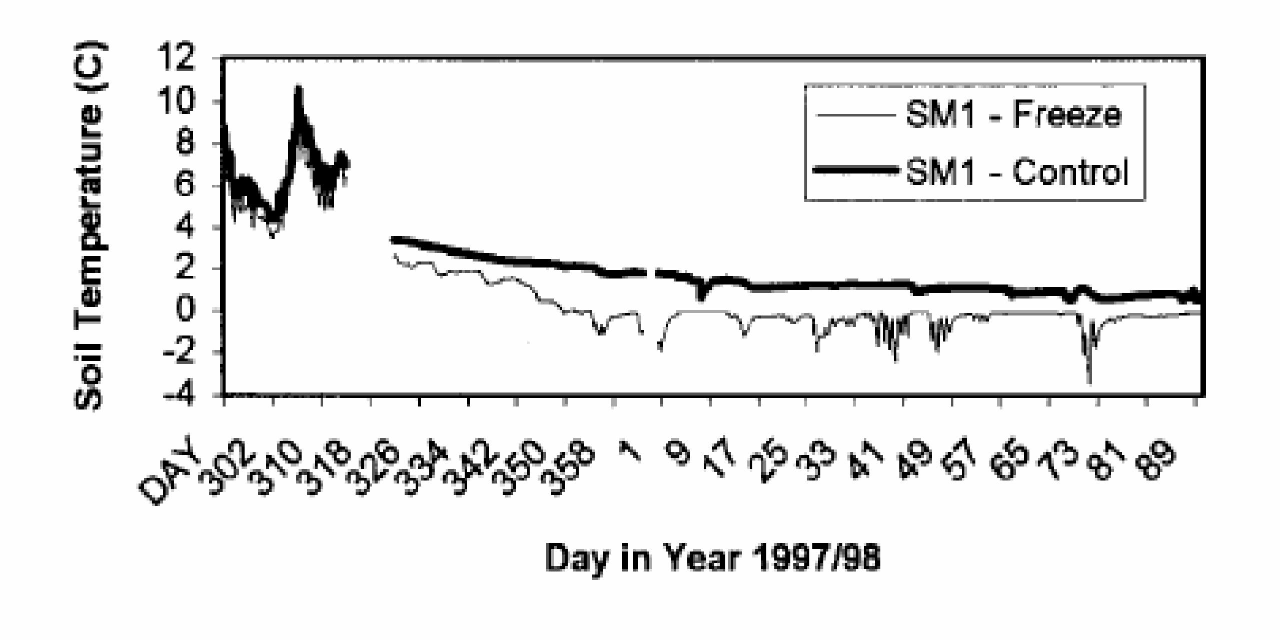


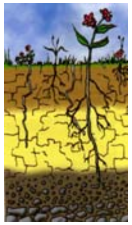
3. Snow regime and nutrient cycling in forest soils

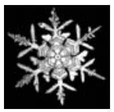




Forest soils

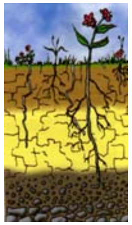


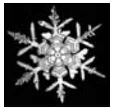




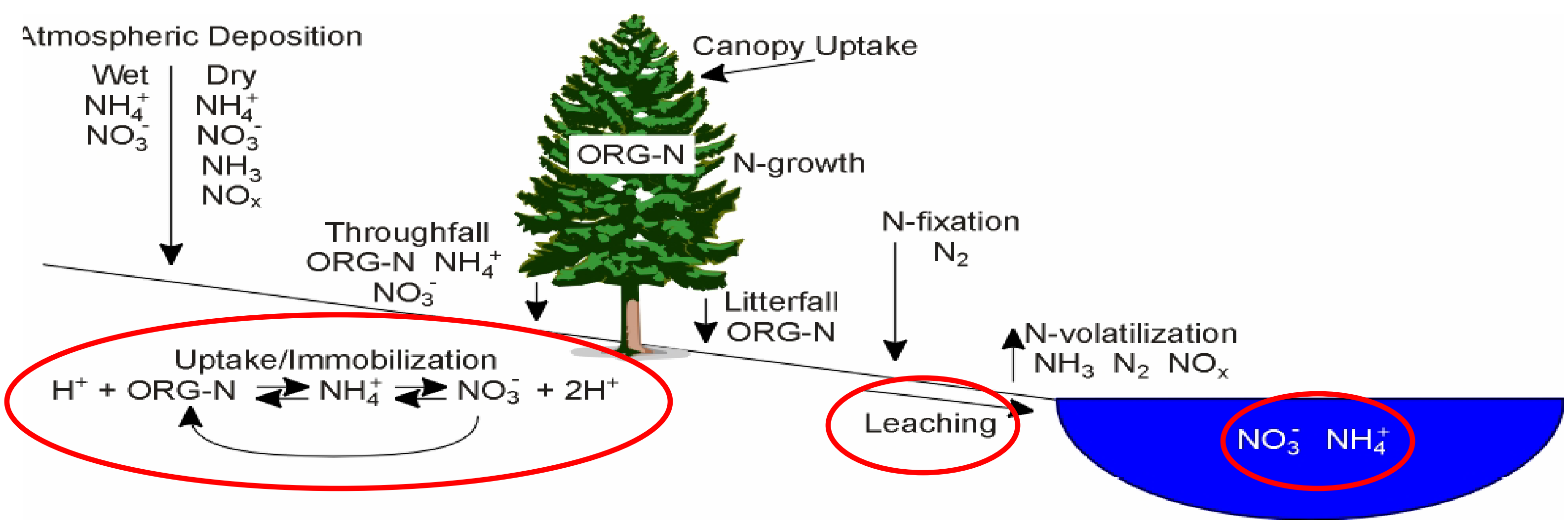
- A lack of snow cover results in colder soil temperatures, more extensive soil freezing, and an increase in freeze/thaw cycles.

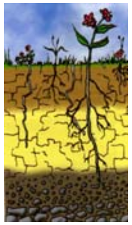
- Previous studies have suggested that these stresses result in root and microbial mortality, releasing labile organic carbon (C) and nitrogen (N) to soil (via root and microbial death) and increasing soil moisture and available N (via reduced uptake by trees and microbes) (Pilon et al., 1994; Boutin and Robitaille, 1994).



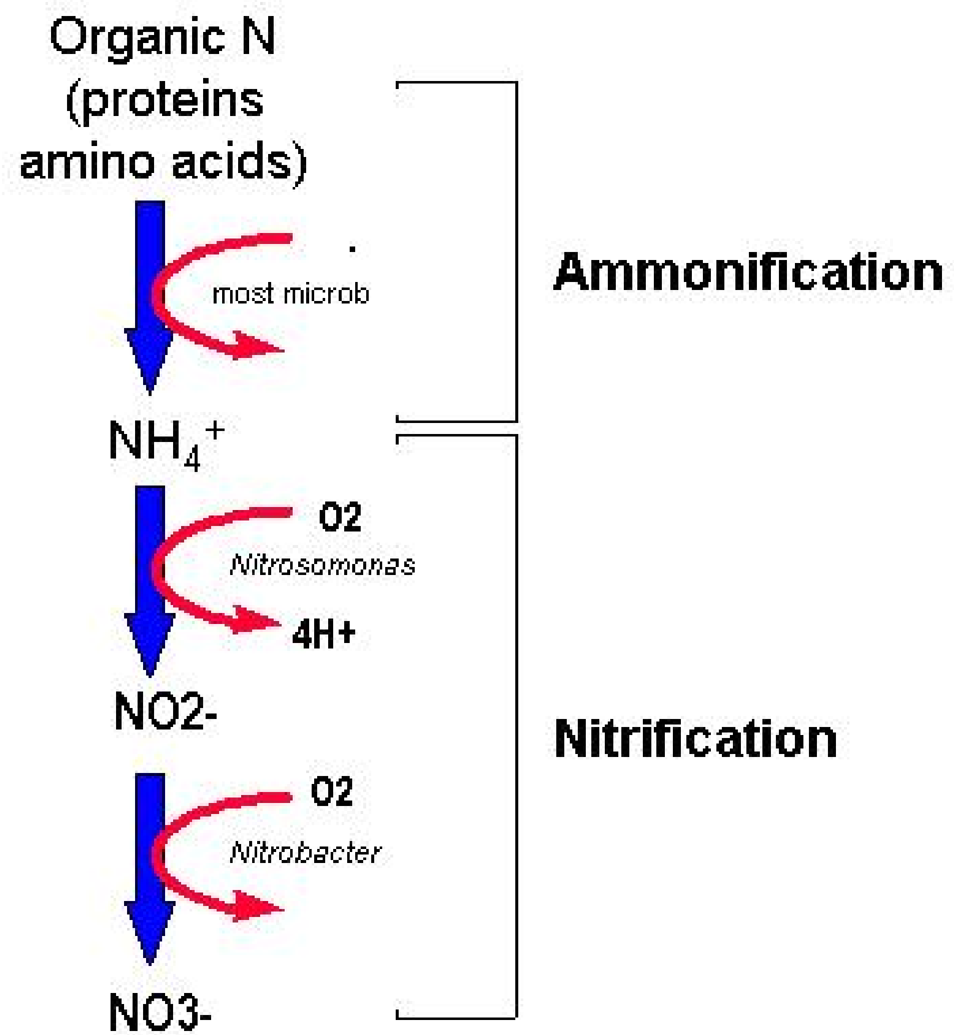


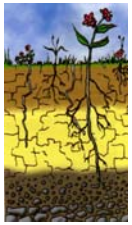
- These changes lead to nitrate (NO_3^-) and cation leaching losses and acidification of drainage waters (Skogland et al., 1988; Christensen and Christensen, 1991; DeLuca et al., 1992; Brooks et al.,1995; 1996).

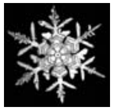




Net N mineralization





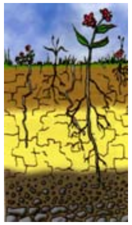


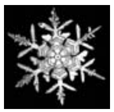
Forest soils

Topsoil characteristics

	Larch (L)
$N\text{-}NH_4^{+a}$	12.0b
$N\text{-}NO_3^{-a}$	4.1b
DON^a	207.0b
$N_{micr}{}^a$	340.0b
DOC^a	115.0a
$C_{micr}{}^a$	1470b
C/N_{micr}	4.3a

[a]Properties are given as mg kg^{-1} of fine earth
Different letters in the same rows indicate significant differences between means ($p<0.05$)



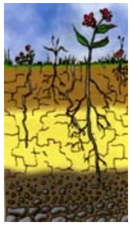


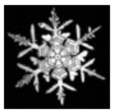
Forest soils

- *Buried bag technique* (Eno, 1960; Adams et al., 1989)
- Soil temperature sensors: UTL-1

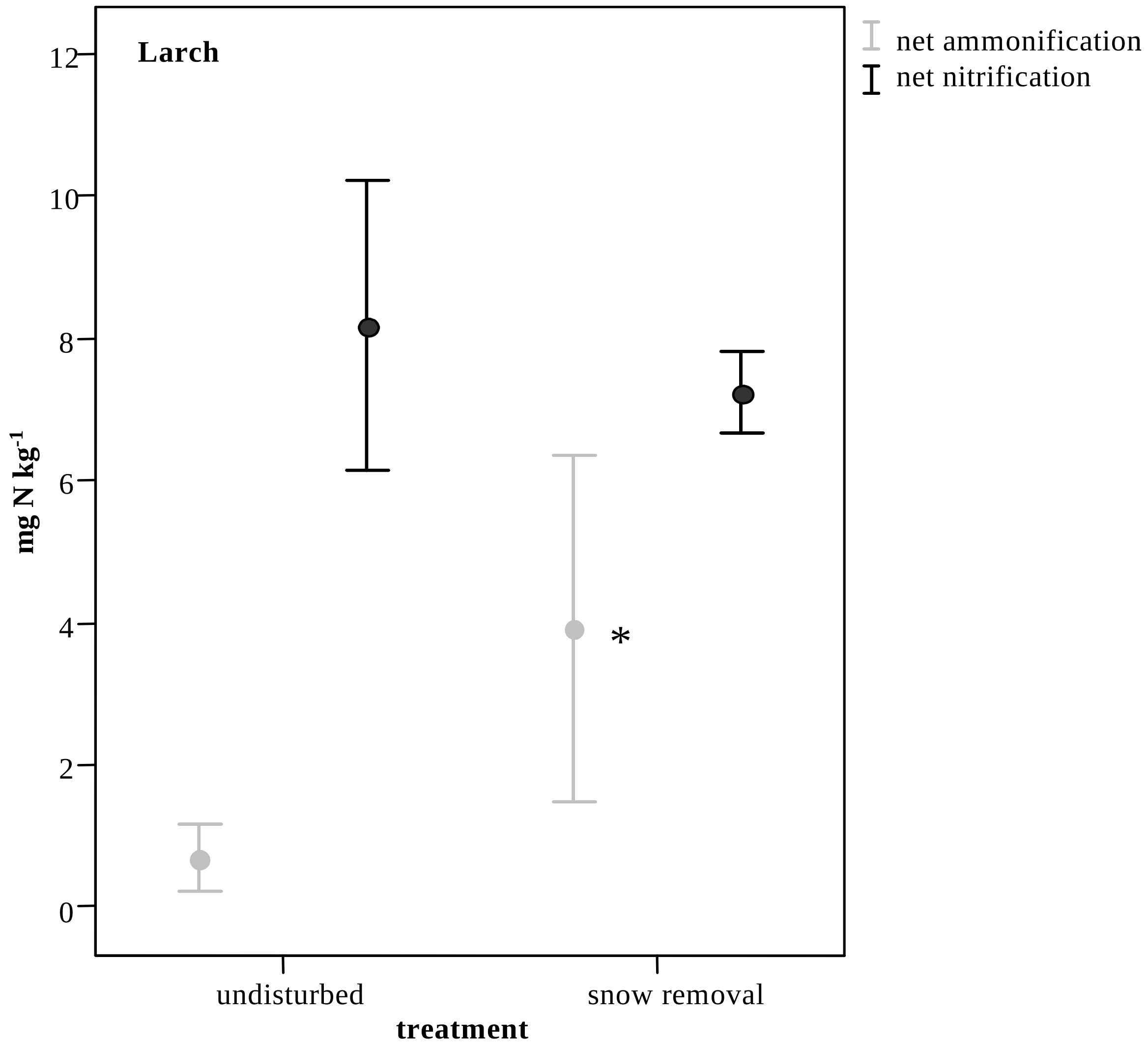
▪Net ammonification:
$(N\text{-}NH_4^+)_{\mathbf{f}} - (N\text{-}NH_4^+)_{\mathbf{i}}$

▪Net nitrification:
$(N\text{-}NO_3^-)_{\mathbf{f}} - (N\text{-}NO_3^-)_{\mathbf{i}}$





Montane forest soils



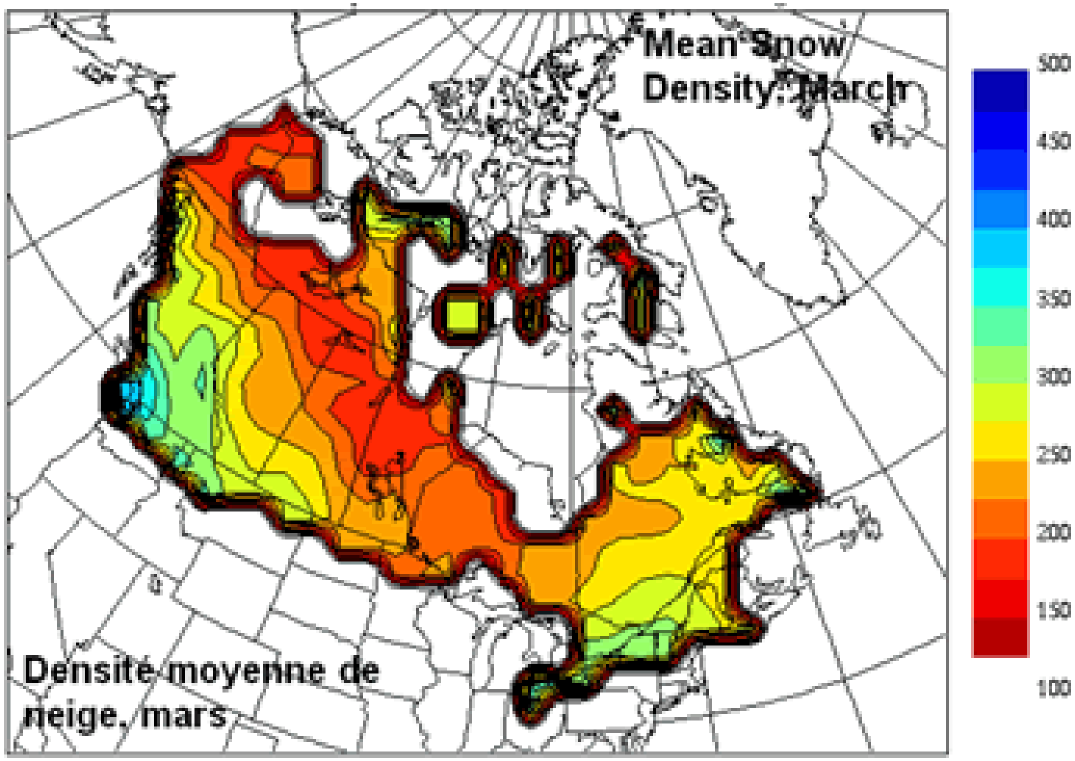
Not only the **depth** but also the quality of the snowcover may affect the nutrient cycling:

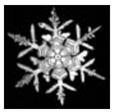
The snow cover density

50 – 100 kgm^{-3}

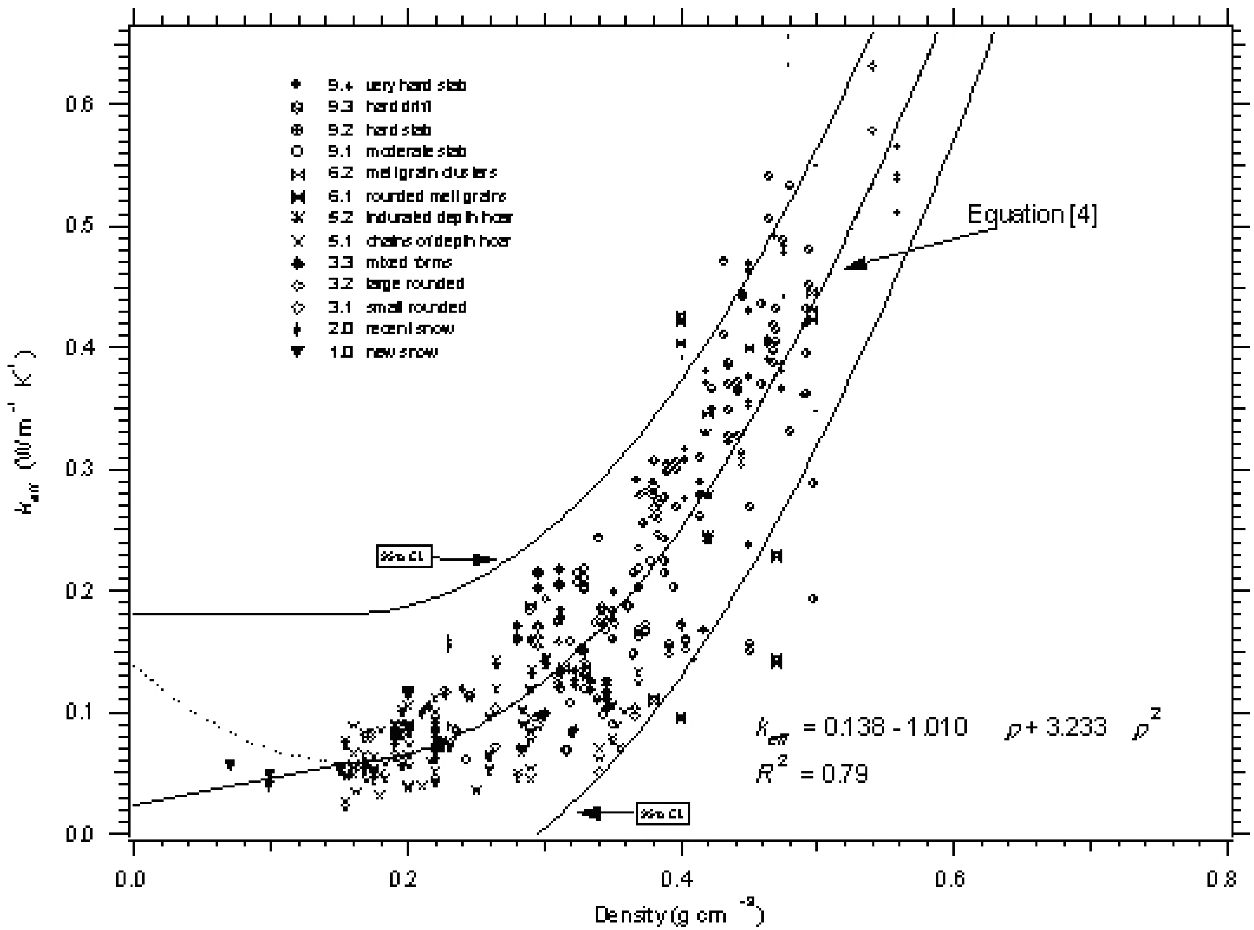
200 - 300 kgm^{-3}

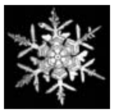
The density of snow (usually expressed in units of kilogram per cubic metre) is a measure of the mass per unit volume of snow, and is an indicator of the compactness of a snowpack.





- A typical thermal conductivity for dry snow with a density of 100 kgm^{-3} is 0.045 W m^{-1} k^{-1}





- In temperate mountain regions, the snowpack is often close to its melting point, so that it may respond rapidly to apparently minor changes in temperature. As warming progresses in the future, **regions where snowfall is the current norm will increasingly experience precipitation in the form of rain** (*Beniston*, 2003), with episodes of rain on snow.

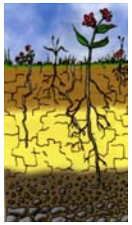
Altered snow properties

Increased snow density by grooming

SLF ENA SNV PNL

Swiss Federal Institute for Snow and Avalanche Research (Davos-CH)

LNSA



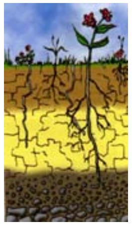
Soils:

- 3 different forest covers:

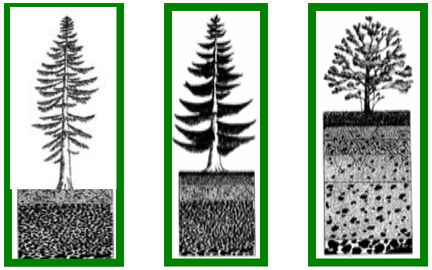
Alder (*Alnus viridis*) (**A**)

Spruce (*Picea abies*) (**F**)

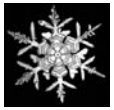
Larch (*Larix decidua*) (**L**)

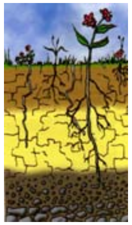


Topsoil characteristics



Soil	USDA	pH H_2O	clay	silt %	sand	C/N
(A)	Typic Udorthent	4.4	2	19	79	14
(F)	Spodic Dystrudept	4.9	5	29	66	11
(L)	Mollic Eutrocryept	6.5	3	31	66	12



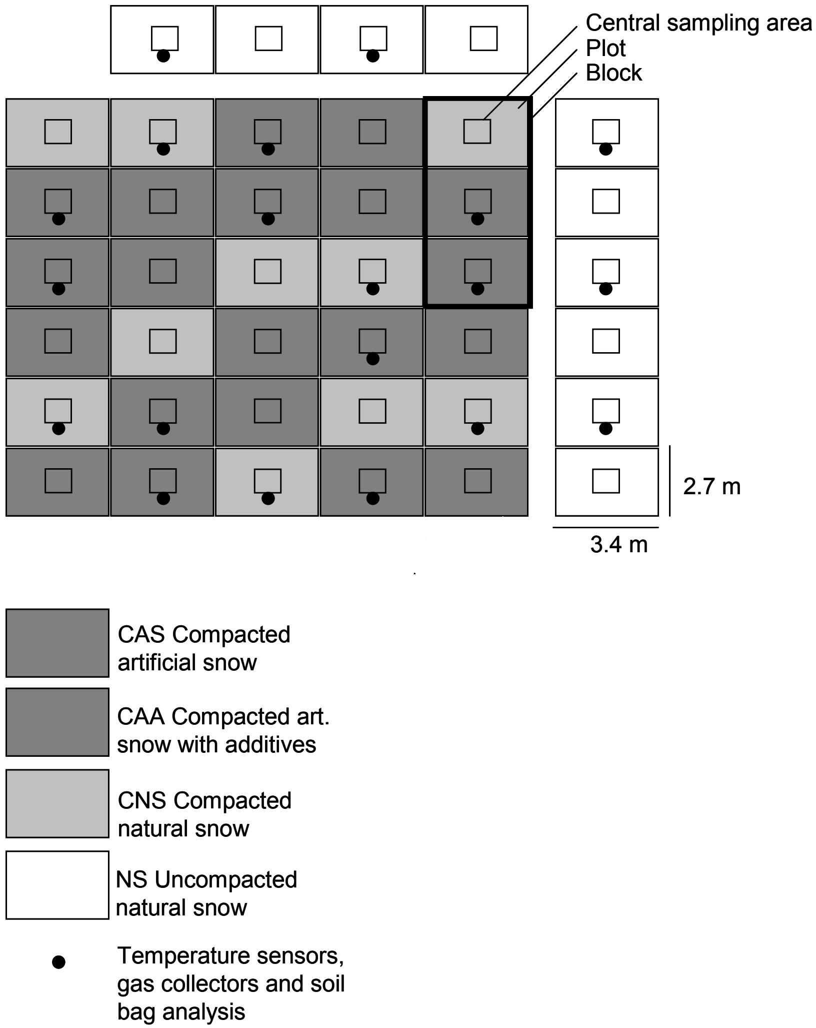


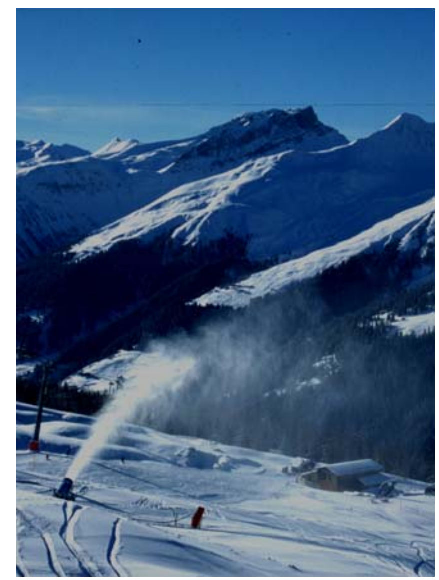
Experimental site

- Davos (CH)
- 1530 m
- MAAT: +2.7 °C

- *Buried bag technique* (Eno, 1960; Adams et al., 1989)
- 5-10 cm depth

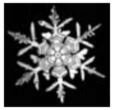
Experimental site



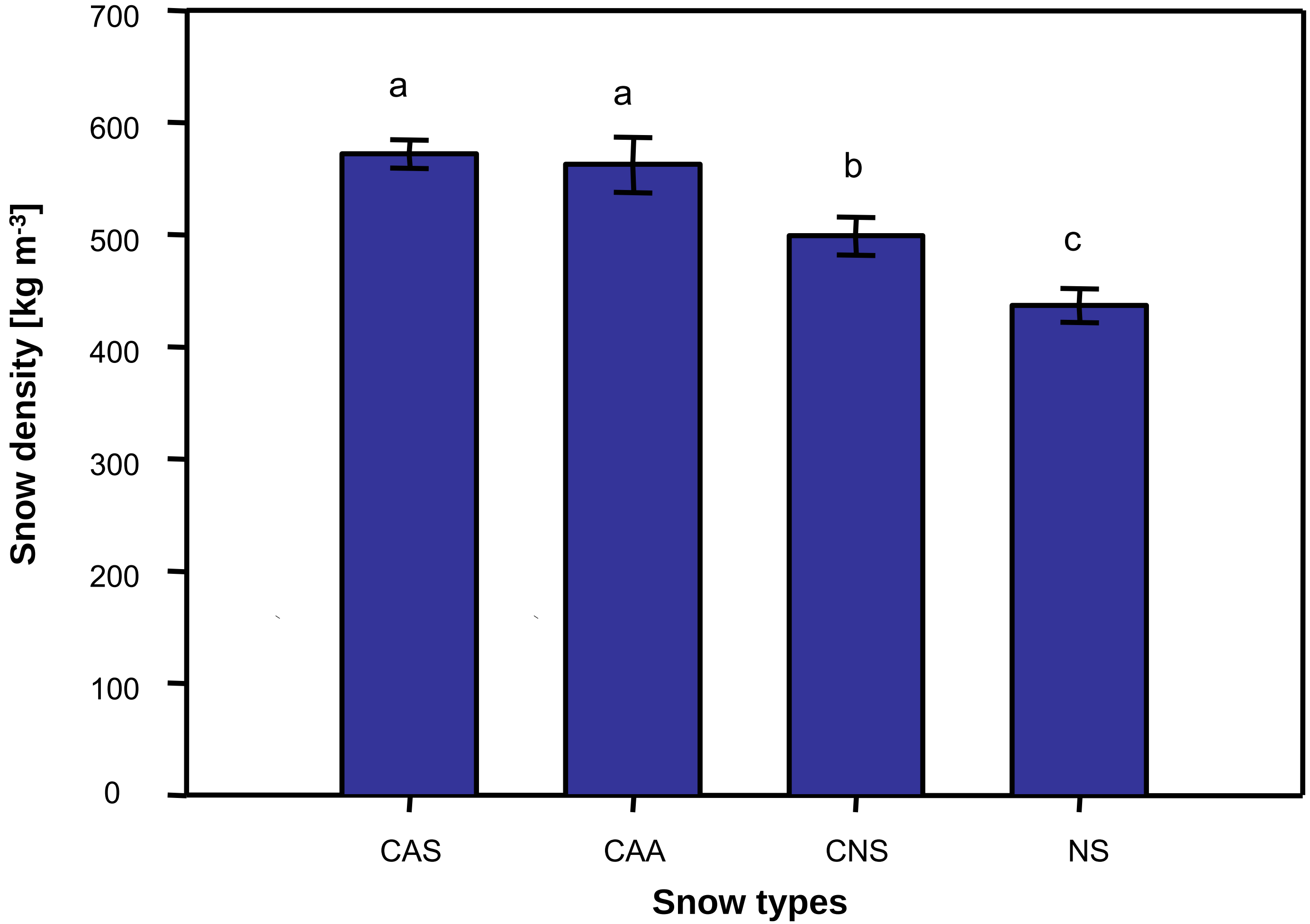


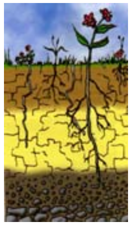
Snow characteristics

- CAS: artificial snow groomed
- CAA: artificial snow with additivies groomed
- CNS: natural snow groomed
- NS: natural snow not groomed

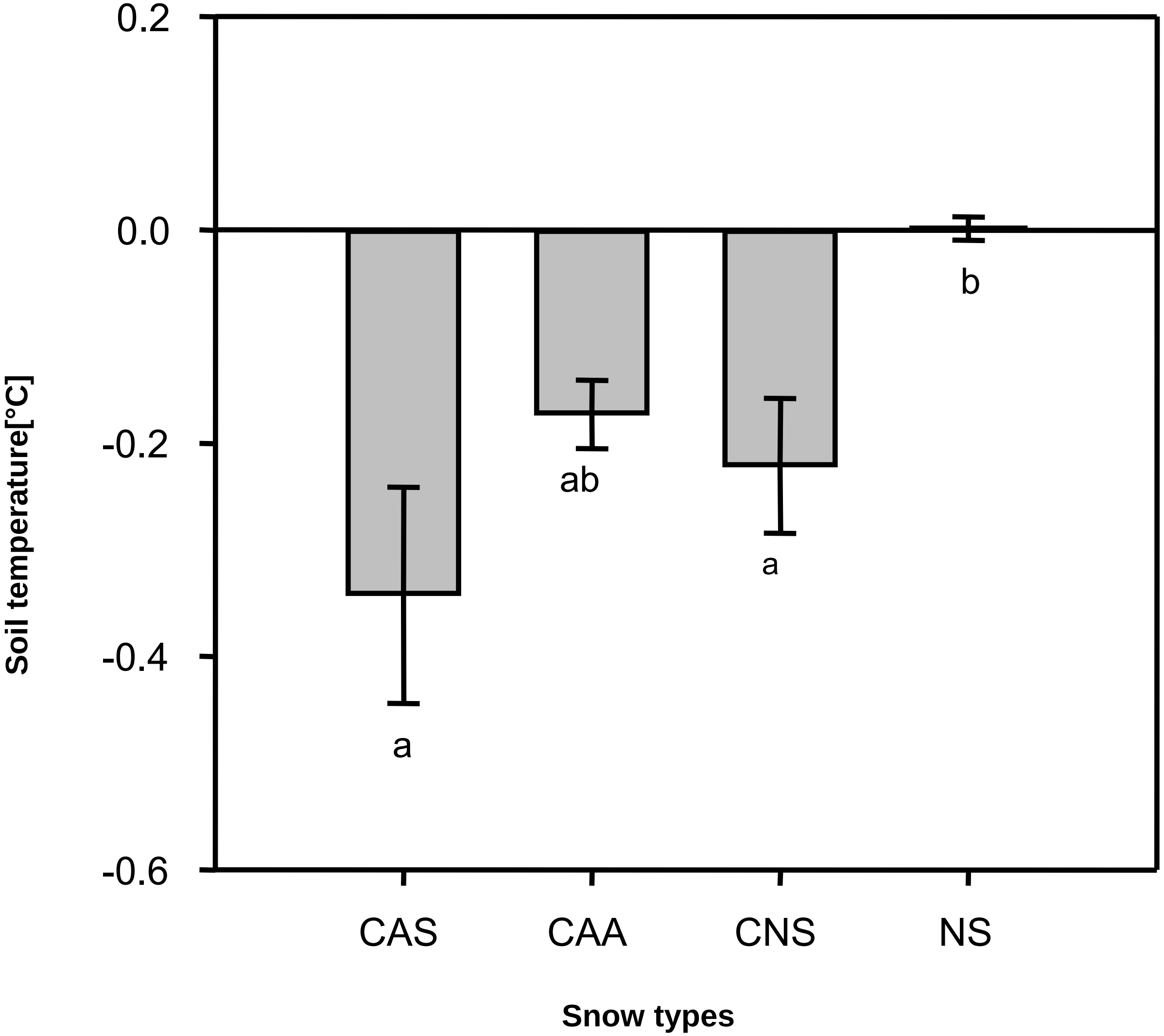


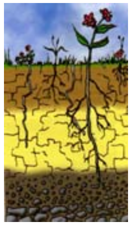
Snow density



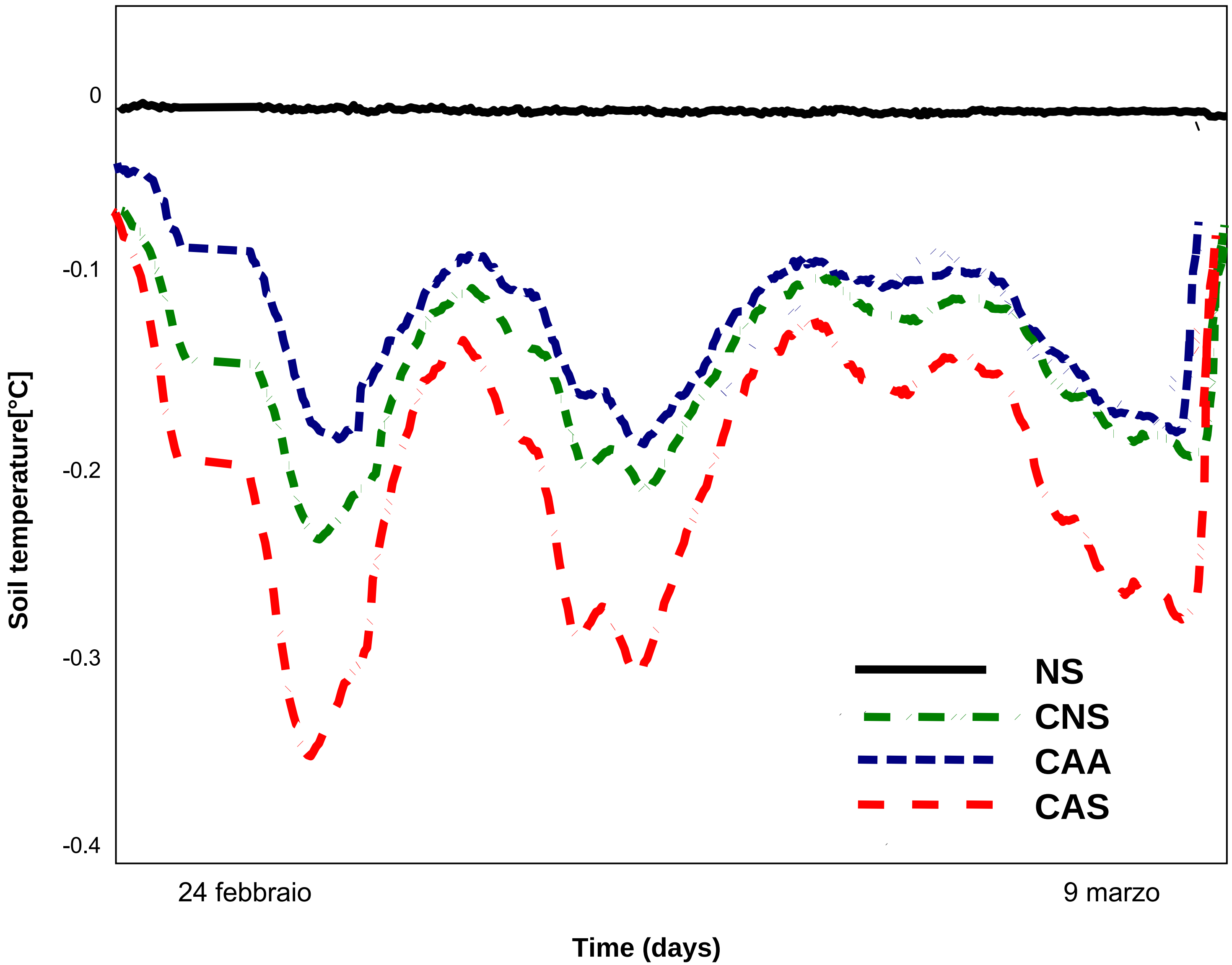


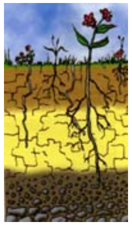
Soil temperature





Soil temperature



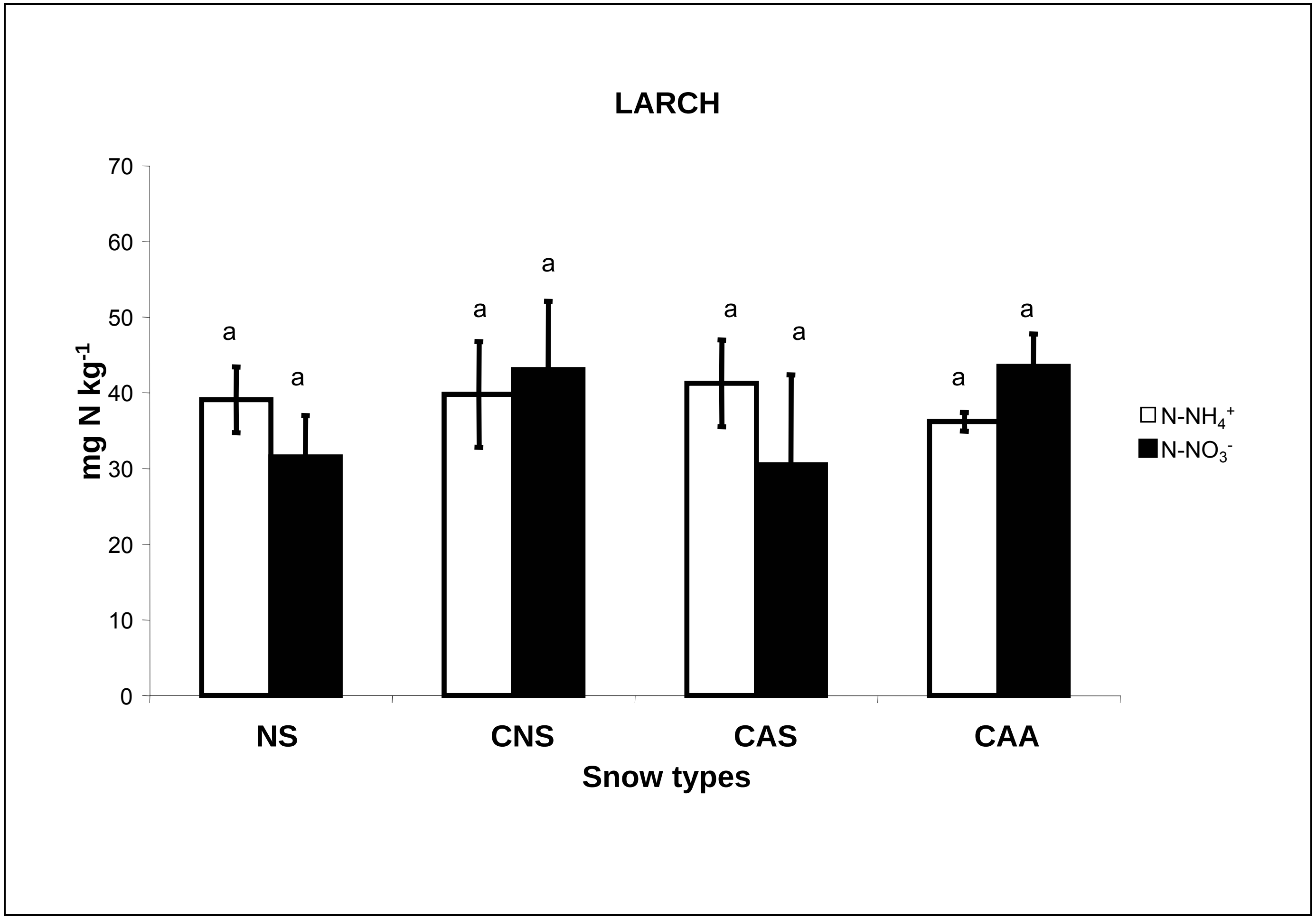


N forms

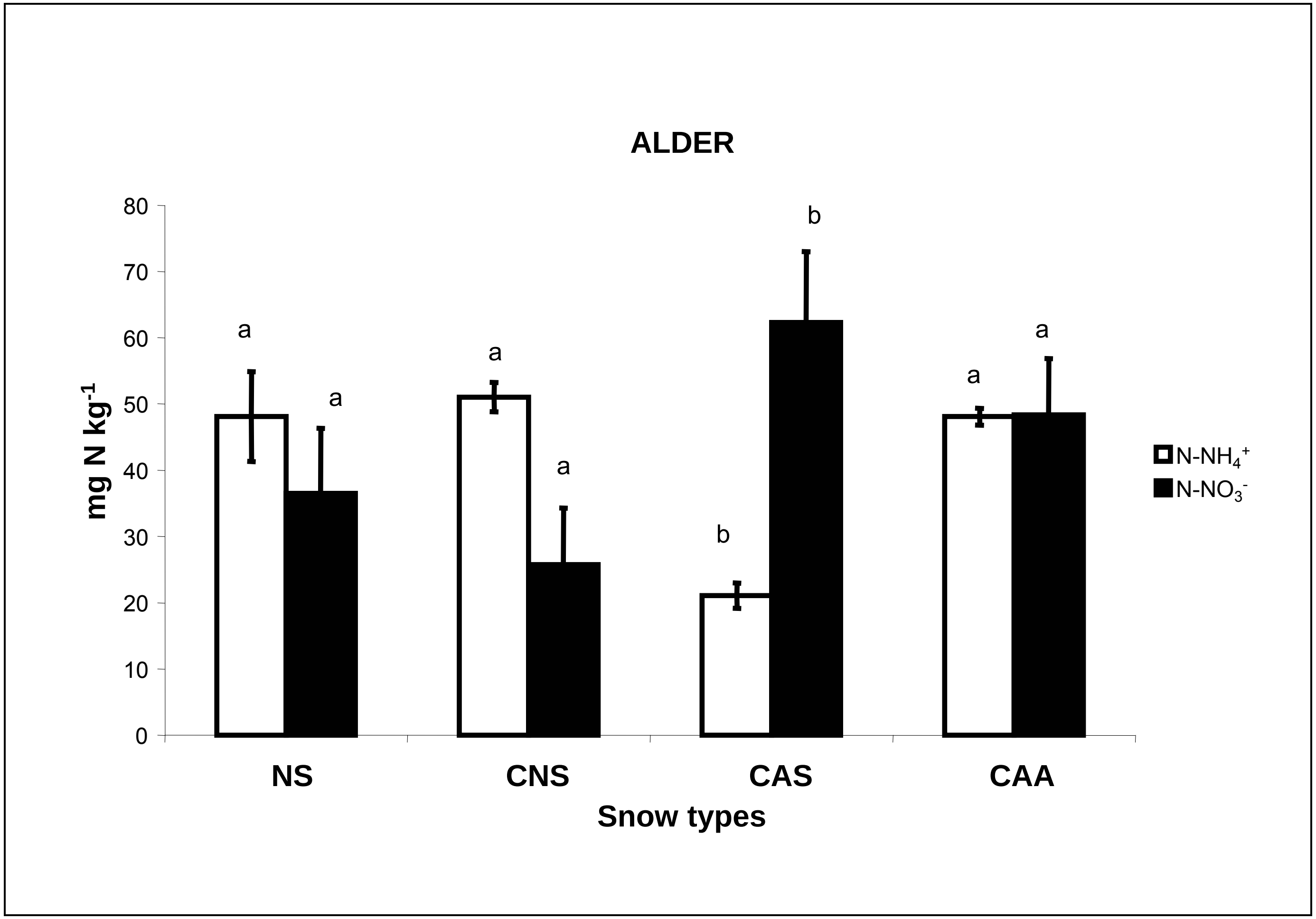
- Autumn 2000

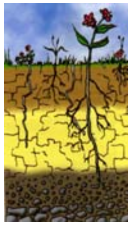
Suoli	USDA	N_{tot}	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$
		g kg^{-1}	mg N kg^{-1}	
(A)	Typic Udorthent	7.4	15.8	21.4
(F)	Spodic Dystrudept	1.5	21.8	9.3
(L)	Mollic Eutrocryept	5.2	23.6	16.3

Net ammonification and net nitrification

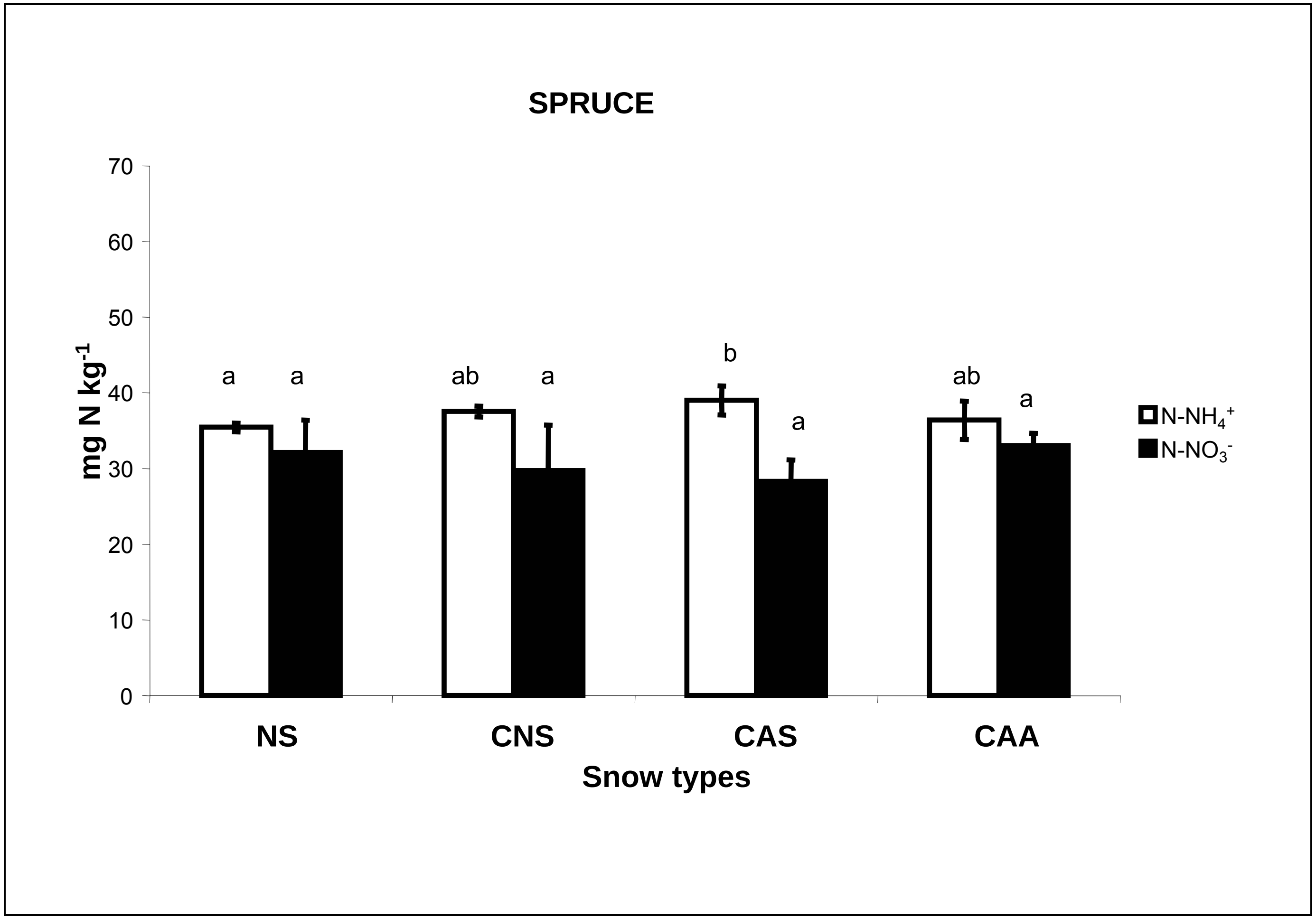


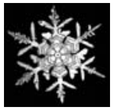
Net ammonification and net nitrification

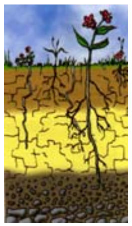




Net ammonification and net nitrification

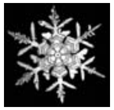


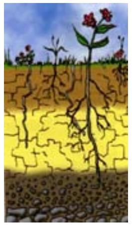




Conclusions (1)

- In all soils, under an undisturbed snow cover, the net N mineralization during winter was positive (34-42 kgNha^{-1}).
- Soil N production during winter was 10-15 fold higher than the Input from the snowmelt (2-3 kgNha^{-1}).





Conclusions (2)

- The increase of snow density caused a reduction of soil temperature (mild freezing), less important than that recorded without snow cover.
- Mild soil freezing determined an increase of net ammonification and net nitrification.

Colder soils in a warmer world?

Thanks for your attention!

www.lnsa.unito.it

michele.freppaz@unito.it