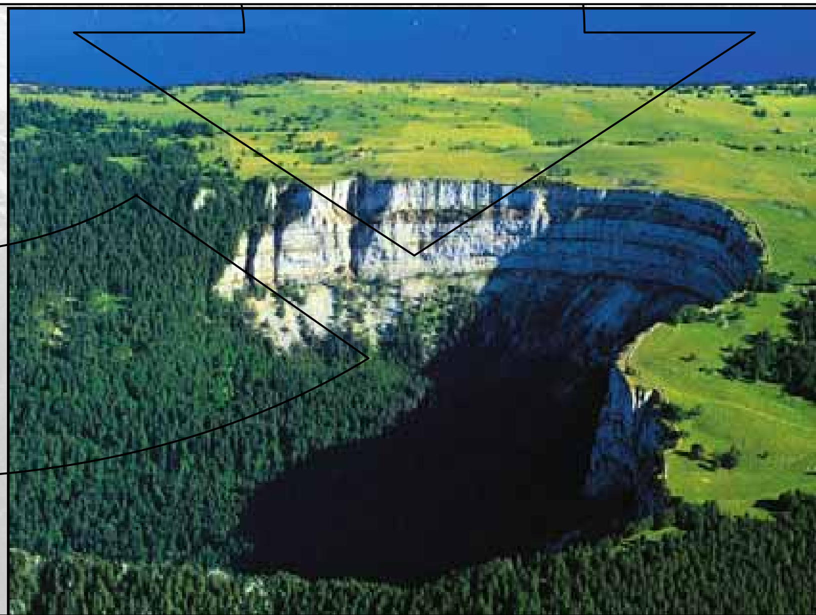
**TransAlaska Pipeline** (North of Brooks Range, Alaska) (*S. Morard 2008*)

**Qinghai-Tibet Railway** (Beiluhe test-station (~4600 m), discontinuous permafrost)
(*R. Delaloye 2006*)

**Roquefort Caves** (France) (***flickr.com/photos/darque/2612698321/***)

**Creux-du-Van** (1250 m., MAAT +5°C, Jura Mountains, CH)
(*http://www.dcs.bbk.ac.uk/pmaa08/photos/*)

## Which characteristic do they share?



# Which characteristic do they share?

They all use **natural air circulation mechanism** to (over)cool the ground…

# Air circulation in a low elevation debris accumulation and its implications on ground thermal regime and ecosystems

UNIVERSITAS FRIBURGENSIS

FACULTY OF SCIENCE GEOSCIENCES

IPROMO

*International Programme on Research and Training on Sustainable Management of Mountain Areas*


**<u>Sébastien MORARD</u>, Reynald DELALOYE**

Geography, Department of Geosciences, University of Fribourg, Switzerland.


**August 2nd. 2008**

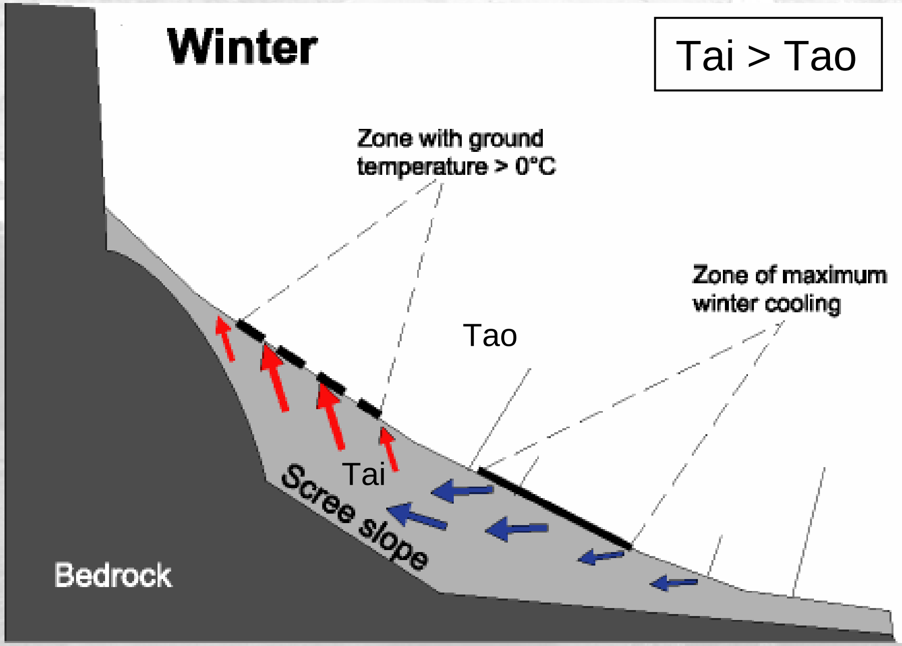
# CONTENT

- **What is** air circulation (“chimney effect”) ?
- Effects on ground surface **thermal regime** ?
- **Occurrence** and **frequency ?**
- Which **processes** ?
- Implications on **ecosystems** ?
- And at **depth** ? **Extra-zonal permafrost** ?

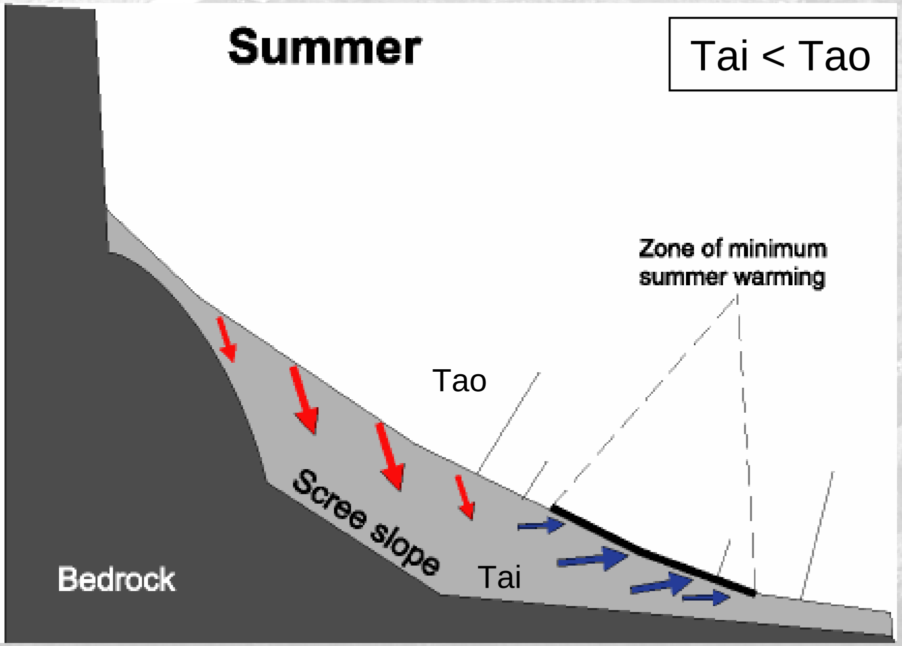
# THE MECHANISM OF AIR CIRCULATION - CONCEPT

- Controlled by the **thermal gradient** between the surrounding air and the ground air.
- Flow direction seasonally reverses.
- The process leads to a **strong annual negative anomaly** of the ground temperature in the lower part of the slope

⇒ **"*Cold reservoir*" effect** (*stored in rock and ice, not in air !*).




Ascent of relatively warm light air and cold air aspiration (as a consequence)




Gravity discharge of relatively cold dense air

# HISTORICAL BACKGROUND

*« Un berger observa que pendant les grandes chaleurs, ses **brebis** allaient toutes mettre le nez contre terre de préférence sur certaines places, (…) au pied d'une montagne tout **couvert de débris anguleux, d'où sortait un vent frais*** » ...

(DeSaussure Horace-Bénédict, 1796).


## ⇒ ''Milk houses''

(Cysat, Johan Leopold, 1661).

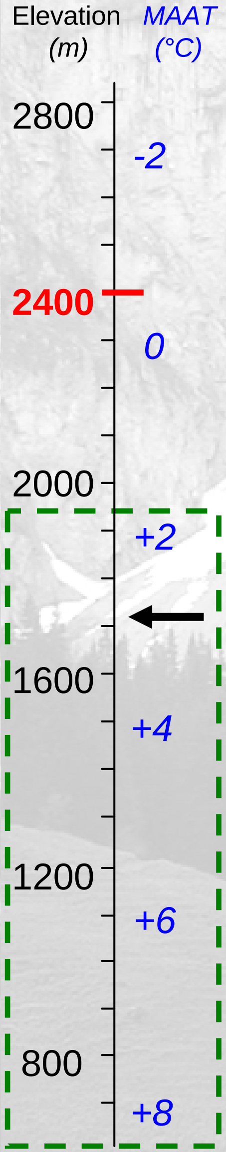
« (…) ***le lait s'y conservait** pendant trois semaines sans se gâter, la viande un mois, et les cerises d'une année à l'autre* ».

(DeSaussure Horace-Bénédict, 1796).

*« (…) den Wohnhäusern entfernt an den Bergabhang hingebaut seien, so erfährt man, daß an dieser Stelle **während des Sommers ein eiskalter Wind aus dem Boden** hervordringe, der das Hüttchen ganz kühl erhalte, und Milch und Fleisch während eines Monats und Kirschen ein ganzes Jahr lang vor Sauerwerden und Fäulniß schütze. »*

(Keller Ferdinand, 1839).

# INTRODUCTION




- **Very cold ground conditions** (negative thermal anomalies) are frequent at (extrem) low elevation :

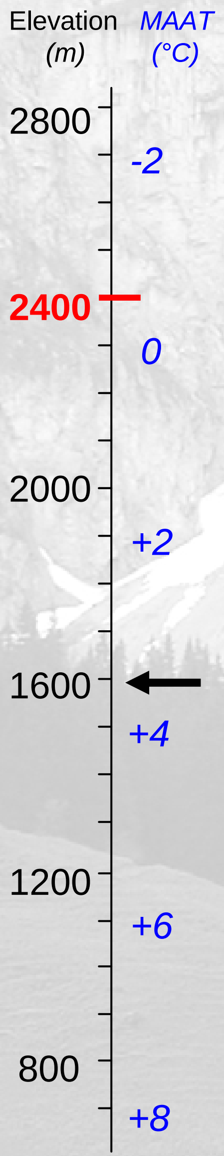
  - and sometimes **sporadic permafrost**…

  - …consecutive to **air circulation** within **talus slopes.**

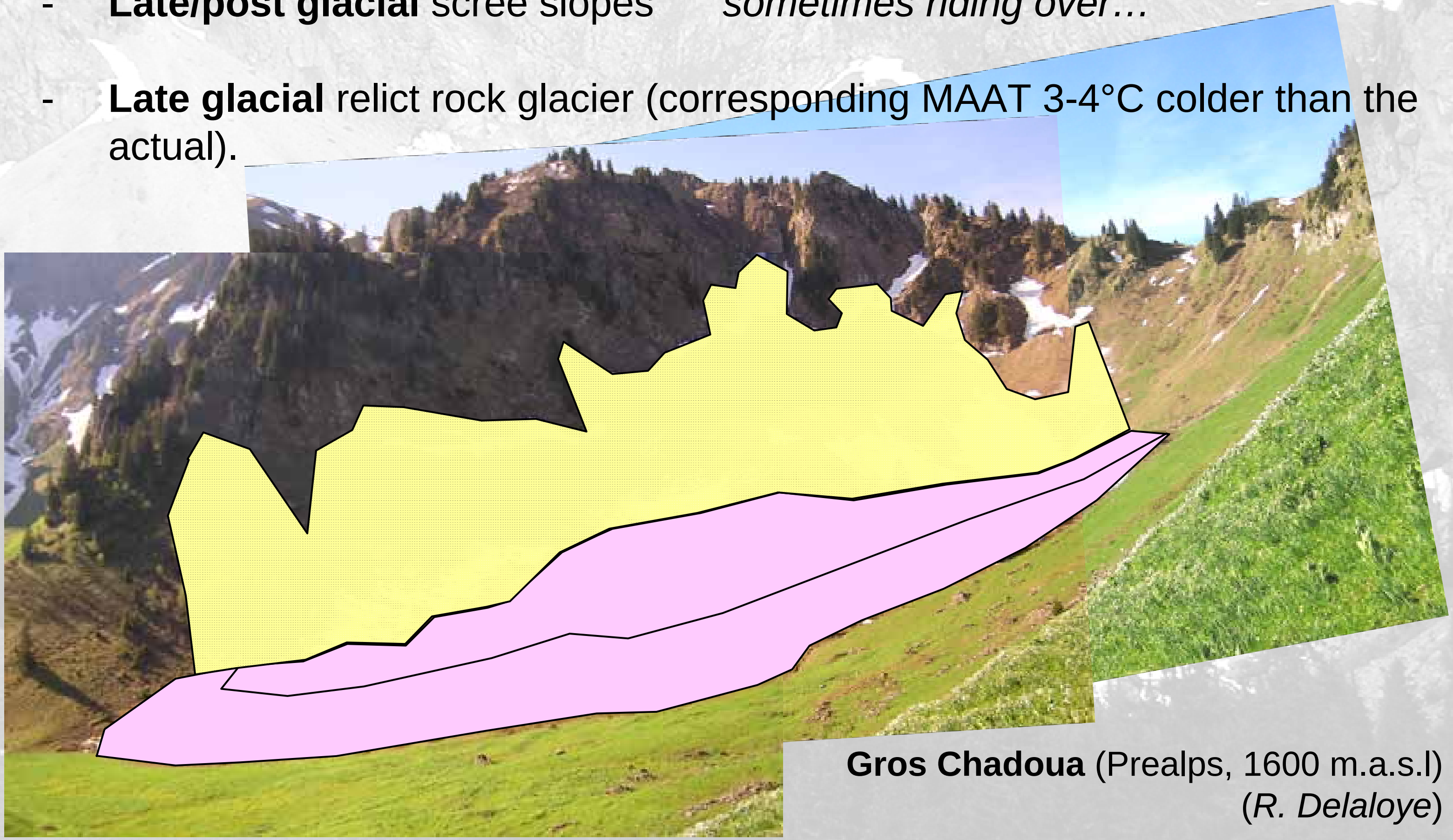
→ *Several publications, especially for the last decade (e.g. Wakonnig 1996, Molenda 1996, Gude & al. 2003, Delaloye et al. 2003, Delaloye & Lambiel 2005, Morard et al. 2008, …)*

Bois des Arlettes (1750 m., NW, Prealps, CH) (*S. Morard 2005*)

# SITES CHARACTERISTICS




- Between **400 to >1500 meters** below the regional permafrost limit.
- Two different geomorphological features:
  - **Late/post glacial** scree slopes *sometimes riding over…*
  - **Late glacial** relict rock glacier (corresponding MAAT 3-4°C colder than the actual).



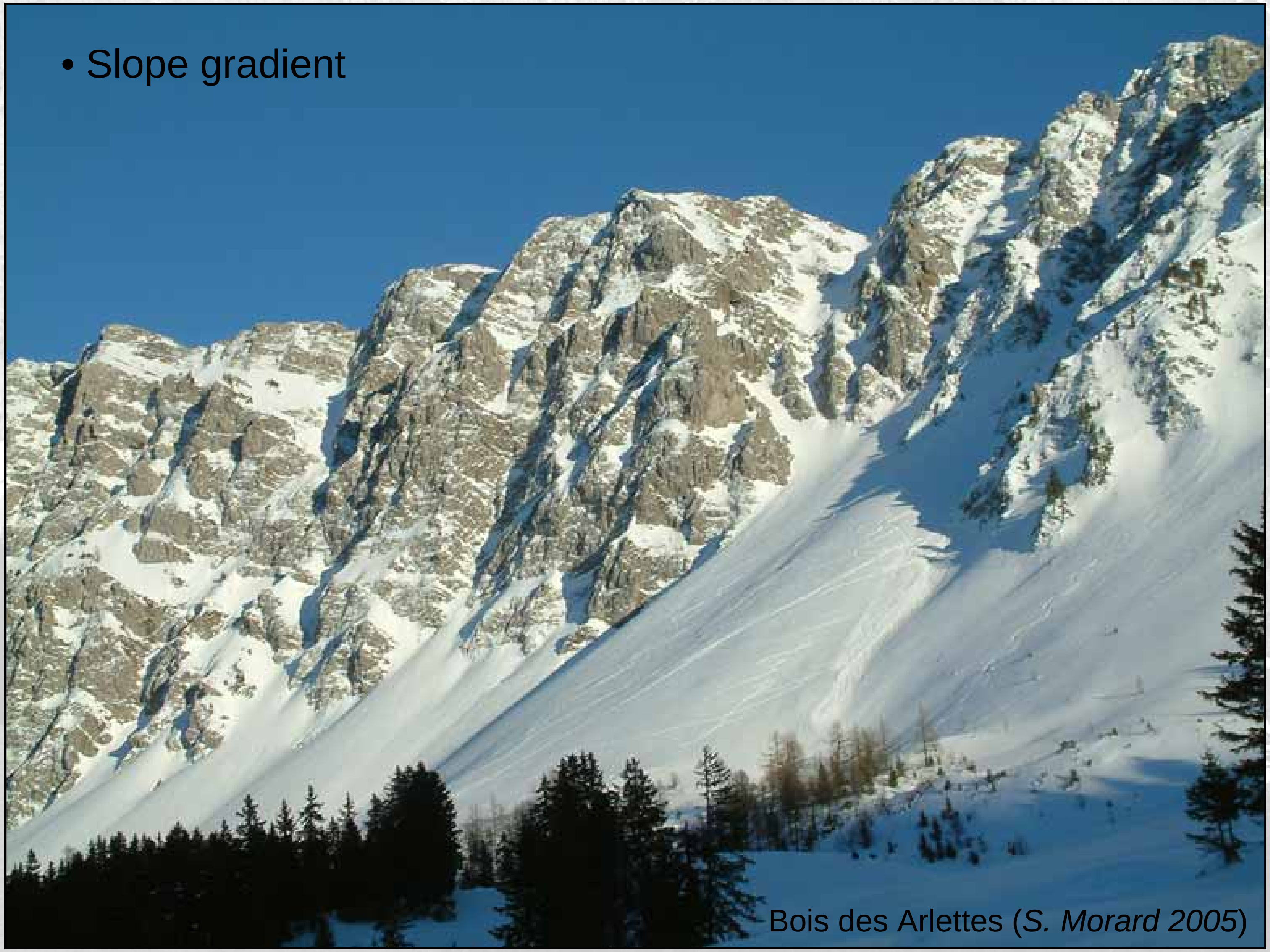
**Gros Chadoua** (Prealps, 1600 m.a.s.l)
(*R. Delaloye*)

# METHODS USED

*At the ground surface…*

- **Frequent field observations and temperature measurements** (*with handy thermometer*).
- **Ground surface temperature recording** (*UTL*).
- **“BTS” mapping** (*to detect winter thermal anomalies*).
- Wind velocity, pressure, humidity…

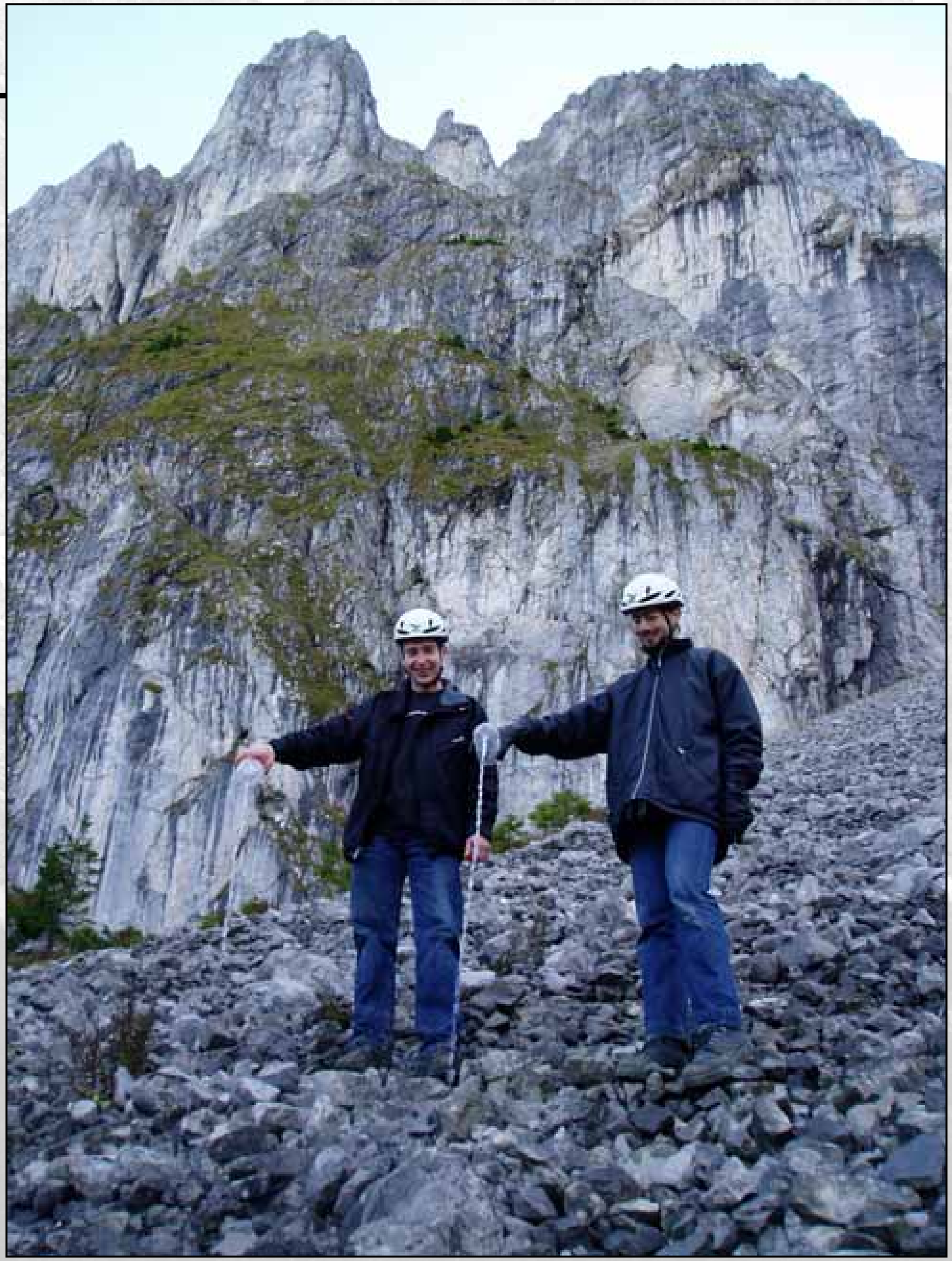
# FIELD WORK LIMITATIONS…




Bois des Arlettes (*S. Morard 2005*)

# FIELD WORK LIMITATIONS…

- Slope gradient
- Unstable terrain
- Block falls…



Dreveneuse-du-Milieu (left) and Gourd-de-la-Plâne (right) (*S. Morard*)

# FIELD WORK LIMITATIONS…

- Avalanches
- Field assistants…


Le Larzey (left) and Bois des Arlettes (right) (*S. Morard*)

# FIELD WORK LIMITATIONS…

- Meteorological conditions…

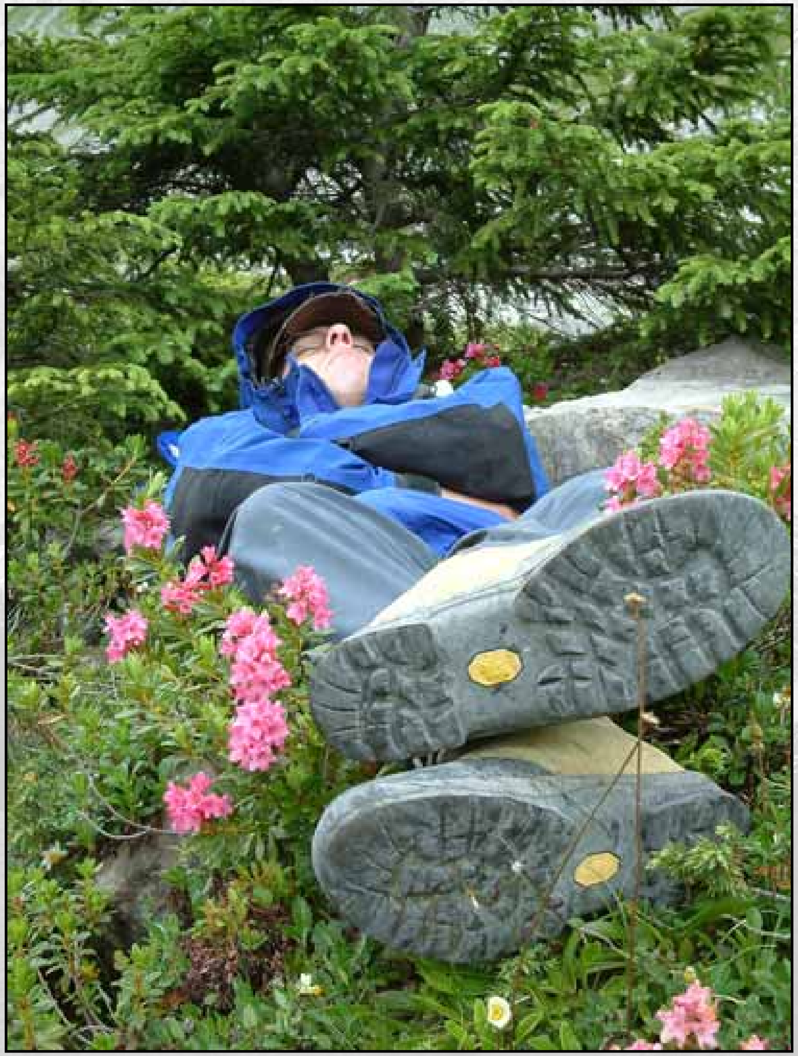
Combe de Châtillon (*S. Morard, summer 2005*)

# FIELD WORK LIMITATIONS…

- Dense vegetation

Gourd-de-la-Plâne (left) and Dreveneuse (right)
(*S. Morard*)

# BUT ALSO…



# BUT ALSO…

# METHODS USED

*At the ground surface…*

- **Frequent field observations and temperature measurements** (*with handy thermometer*).
- **Ground surface temperature recording** (*UTL*).
- **“BTS” mapping** (*to detect winter thermal anomalies*).
- Wind velocity, pressure, humidity…

# EFFECTS ON GROUND SURFACE THERMAL REGIME ?

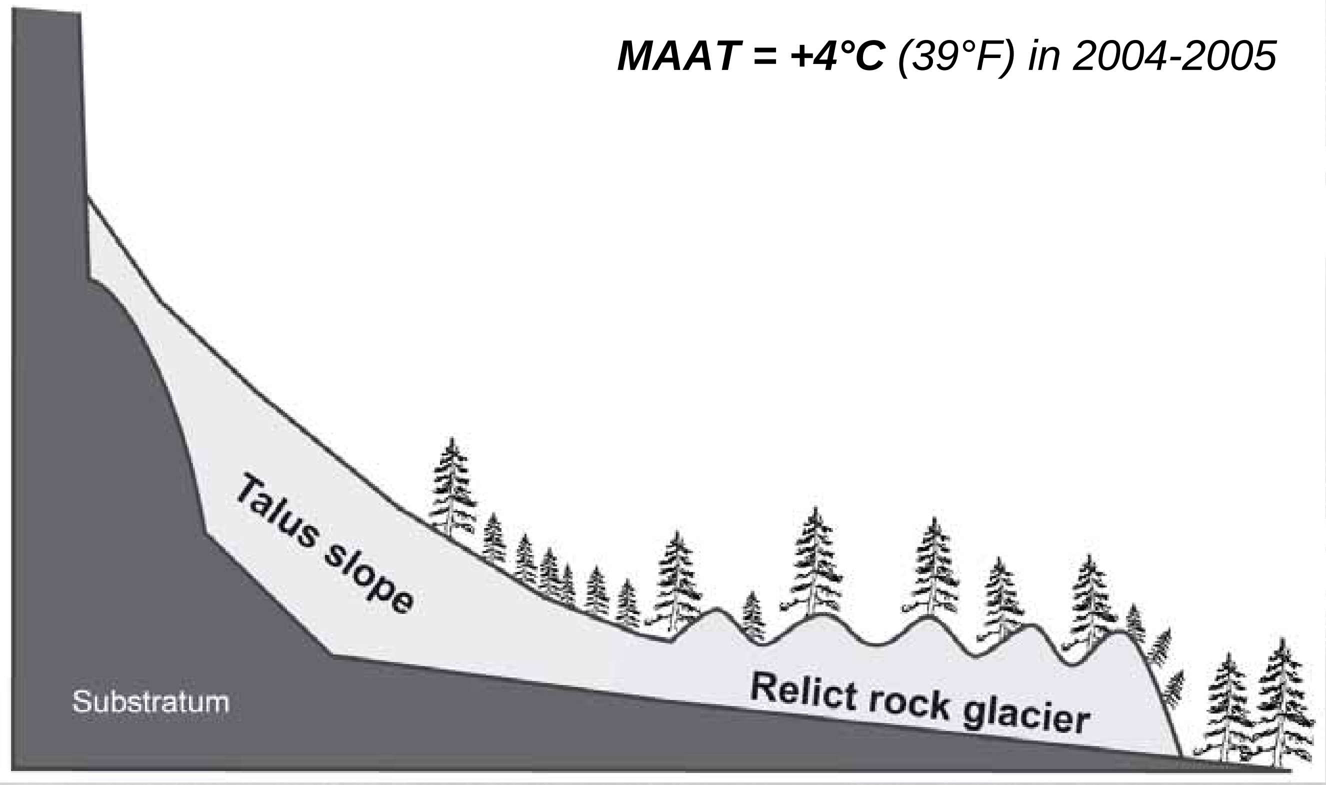
1) Autumn and early winter

2) Winter

3) Snowmelt period

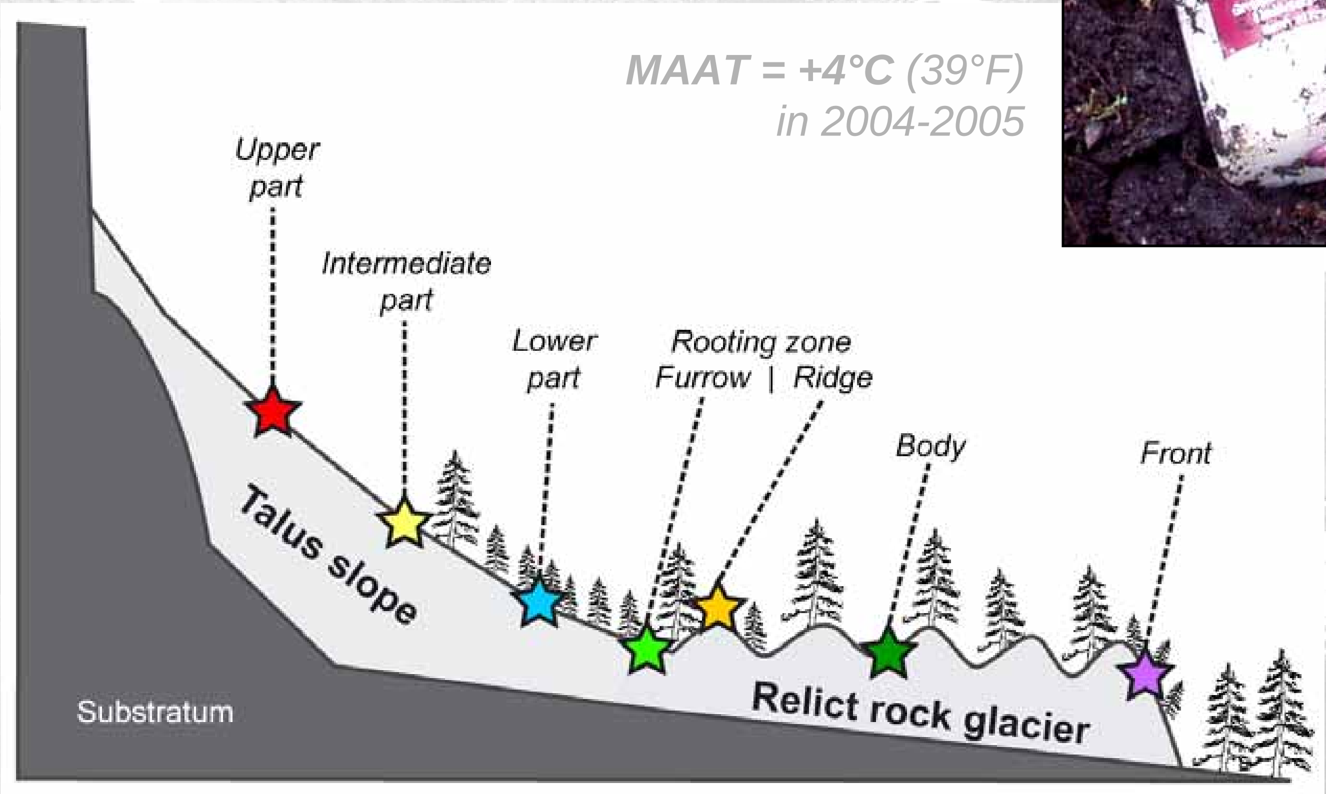
4) Summer

***MAAT = +4°C** (39°F) in 2004-2005*



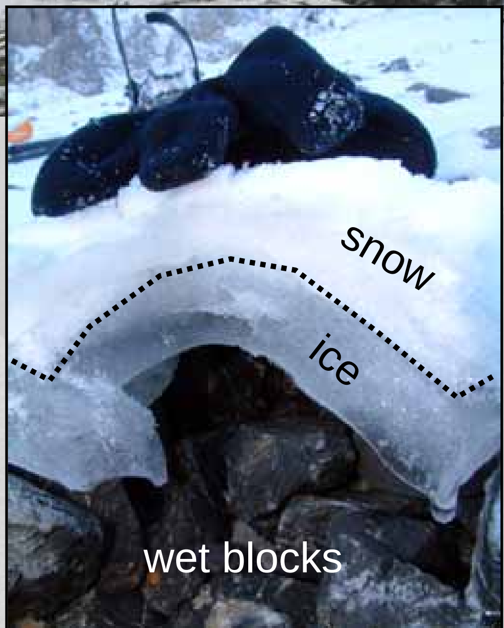
# THERMAL AND VISUAL EVIDENCES

…along a longitudinal cross profile




# AUTUMN AND EARLY WINTER (reversibility)

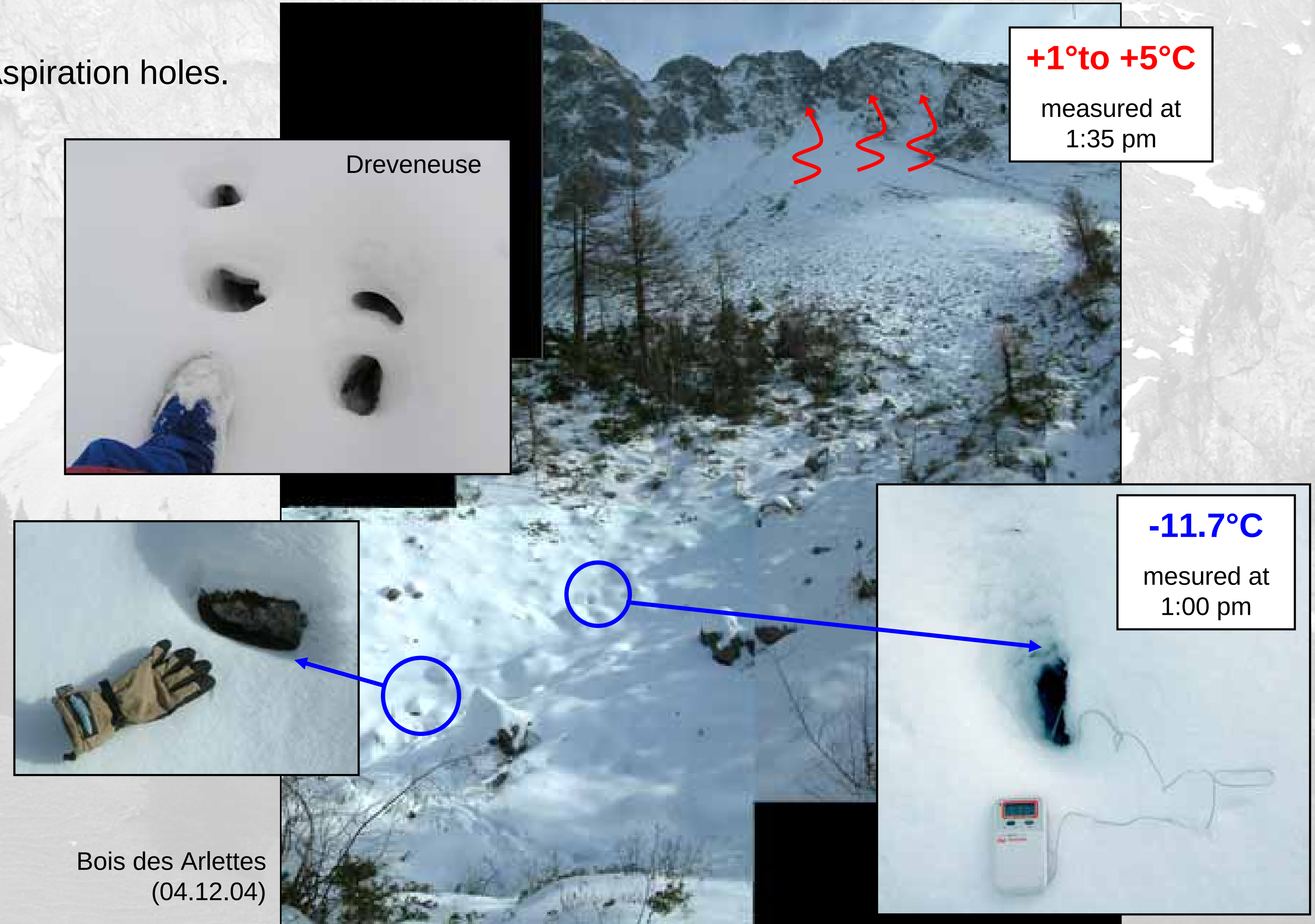
- Snowmelt windows (*outflow of warm air*).
- Hoarfrost and, sometimes, condensation fog.
- Basal icing of the snow cover, *when outside temperature rises* !





# AUTUMN AND EARLY WINTER (reversibility)

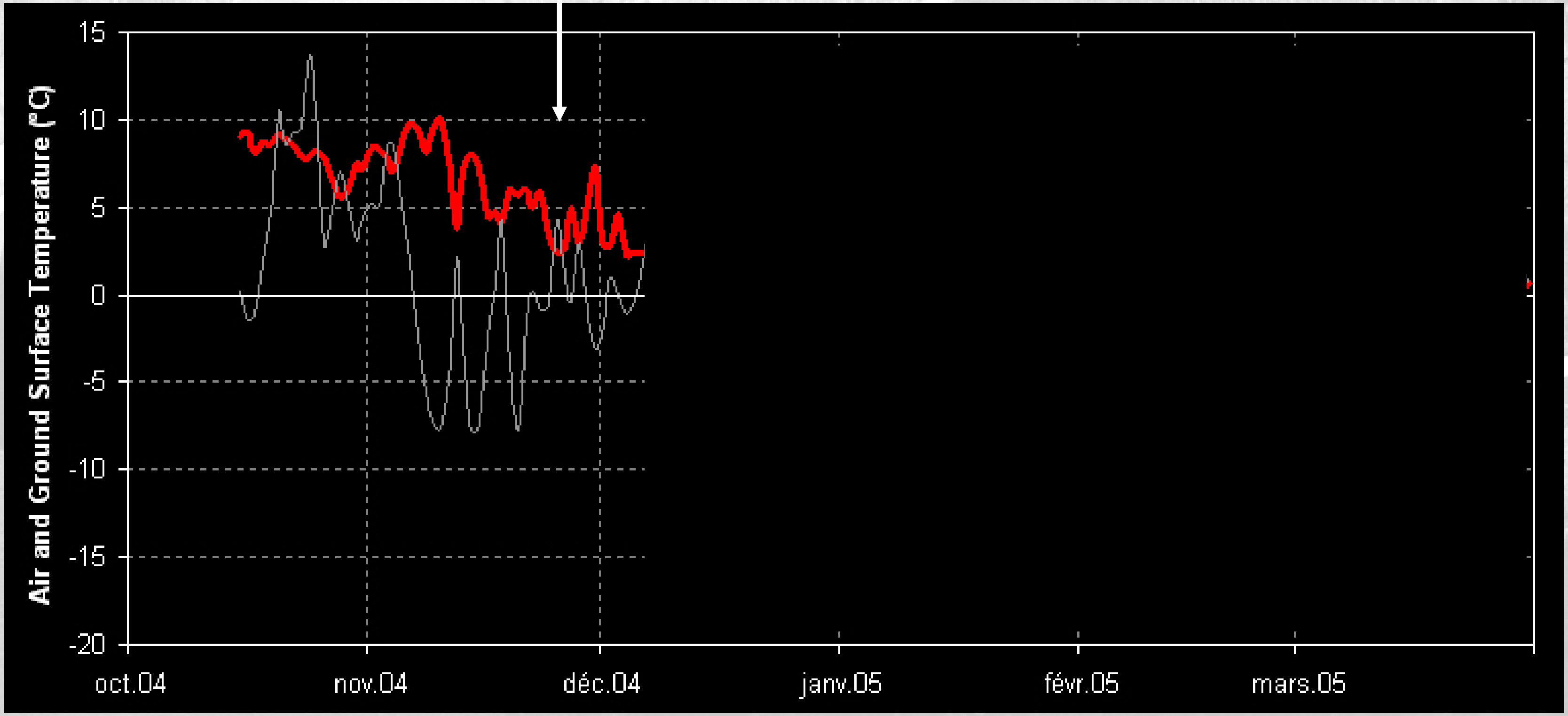
- Aspiration holes.




Bois des Arlettes
(04.12.04)

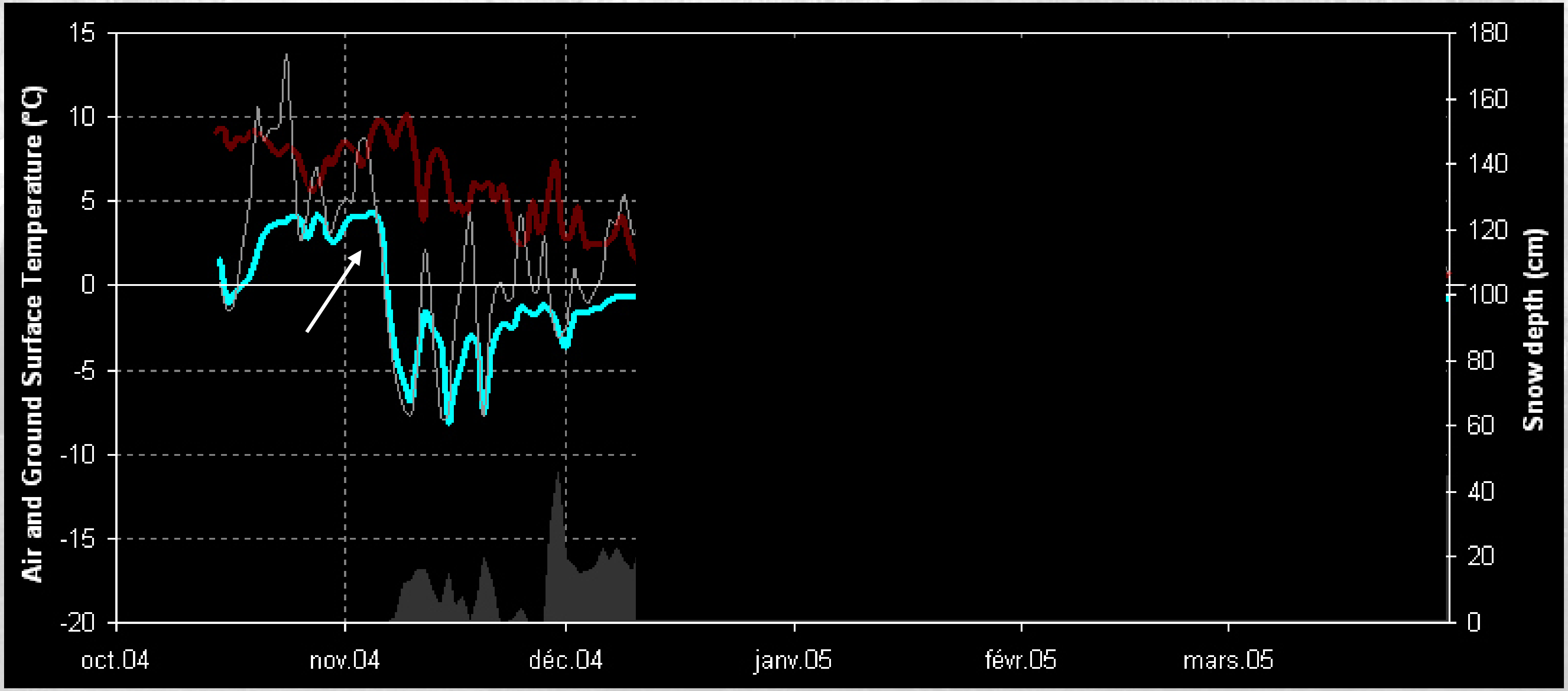
# AUTUMN AND EARLY WINTER (reversibility)


- **Expelling of warmer air** (snowmelt windows)…
- which provokes…

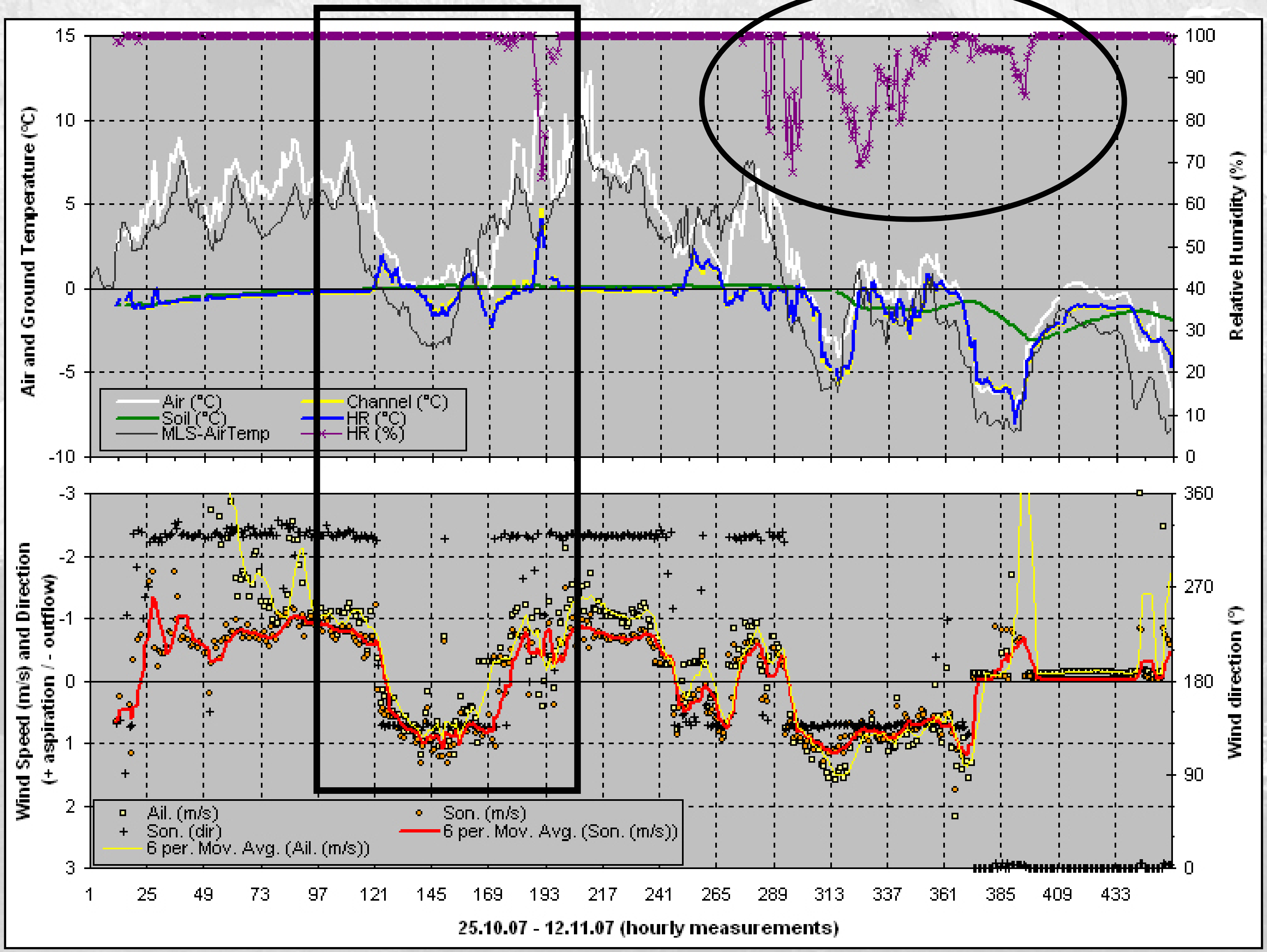


# AUTUMN AND EARLY WINTER (reversibility)


- **Reversibility of the ventilation system** when the external air temperature < ~ +5.5°C.
- **Rapid cooling (+4°C to -6.8°C)** due to aspiration of colder air.
- Aspiration holes.



# AUTUMN AND EARLY WINTER (reversibility)



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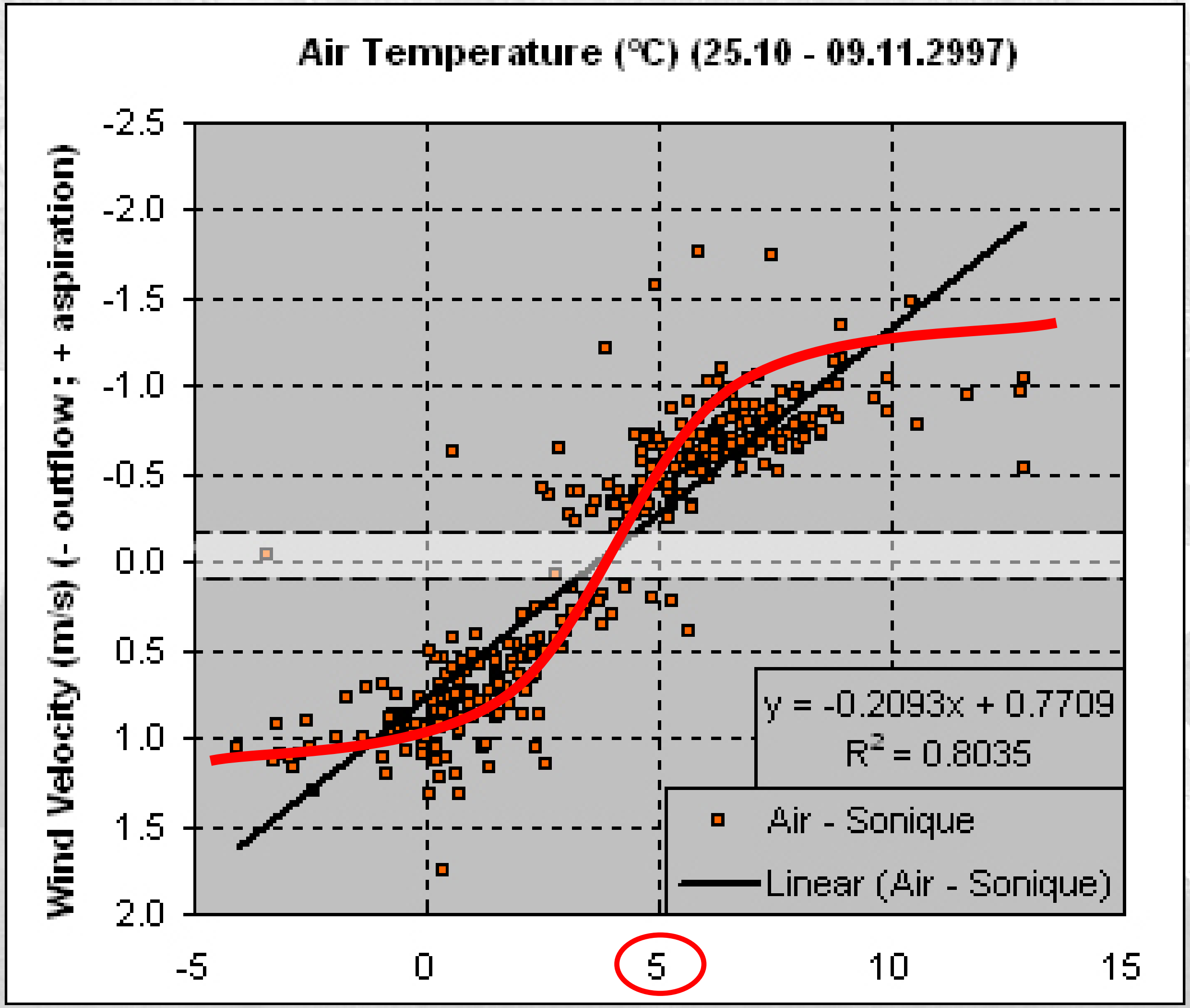

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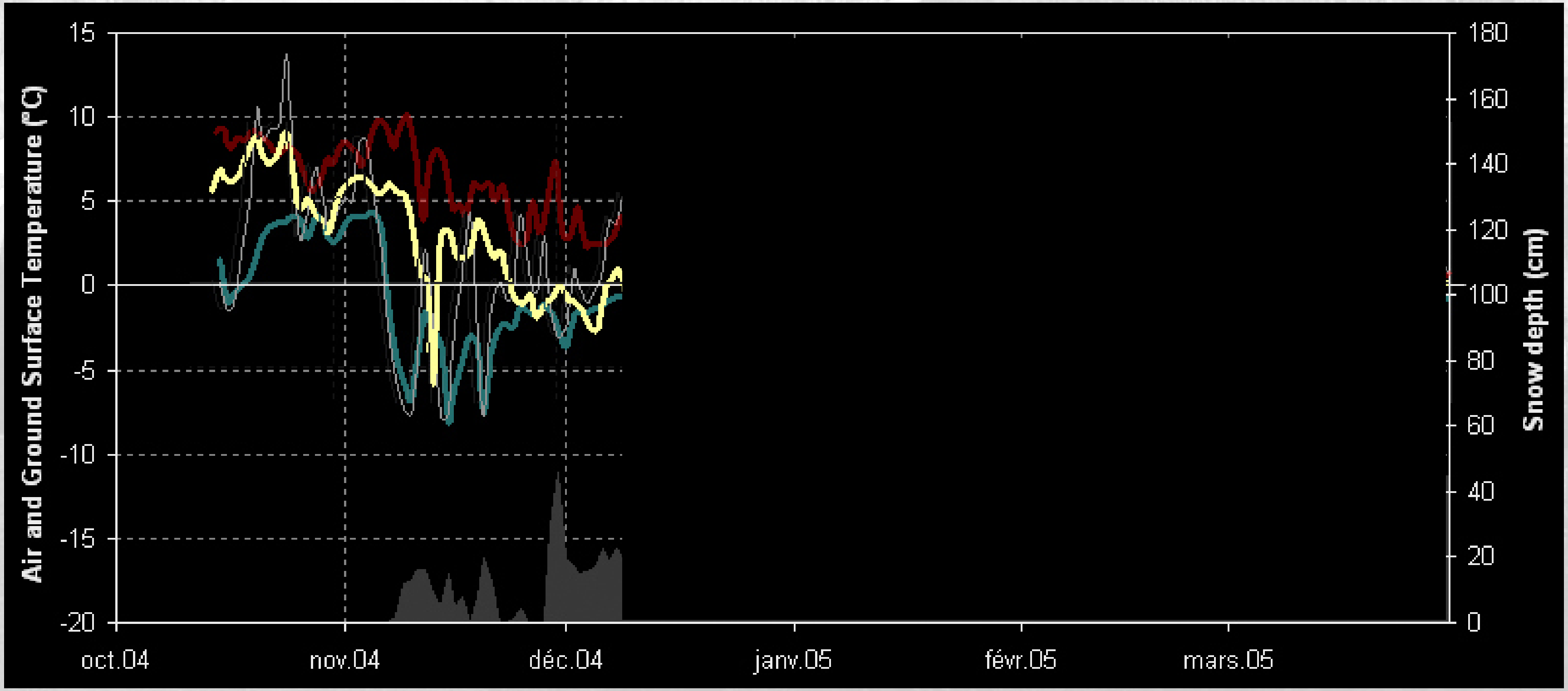
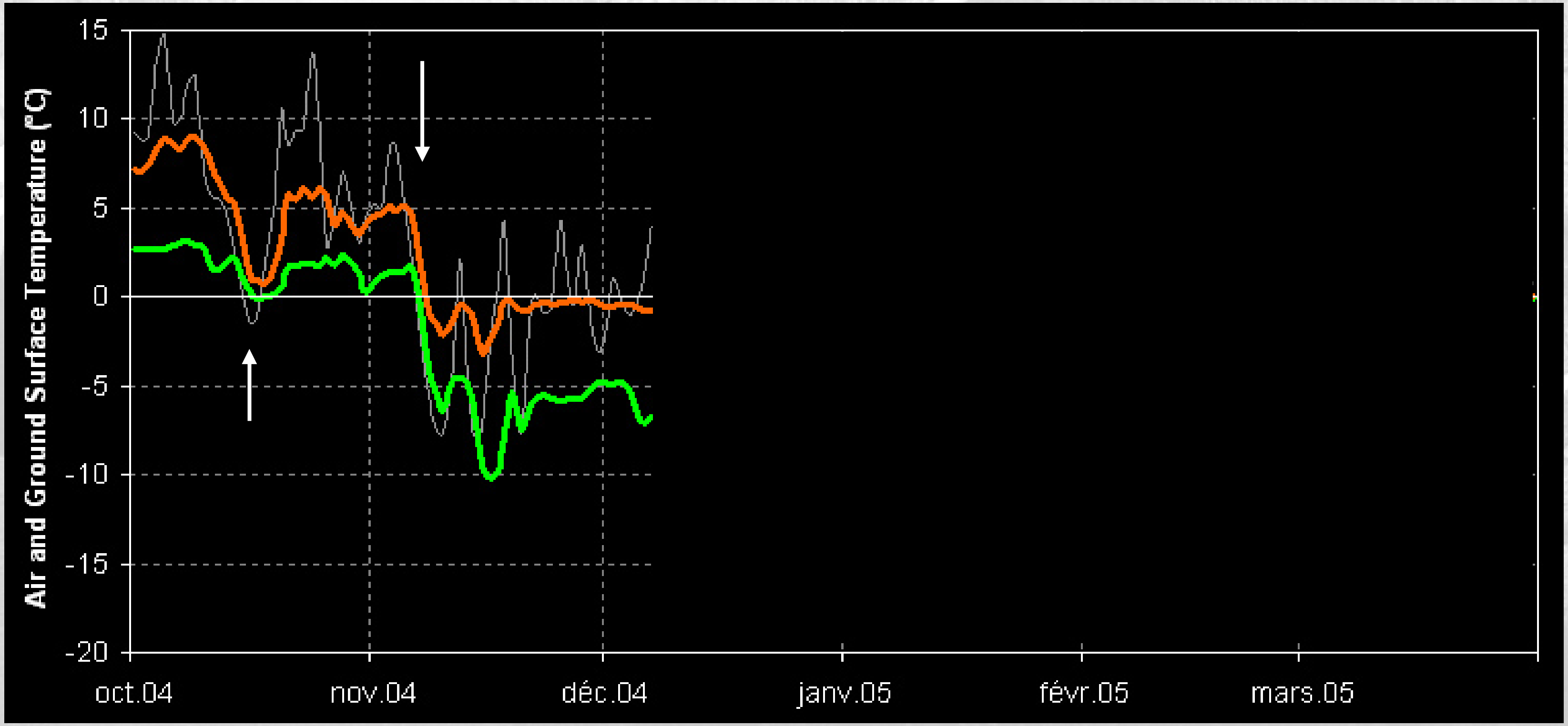
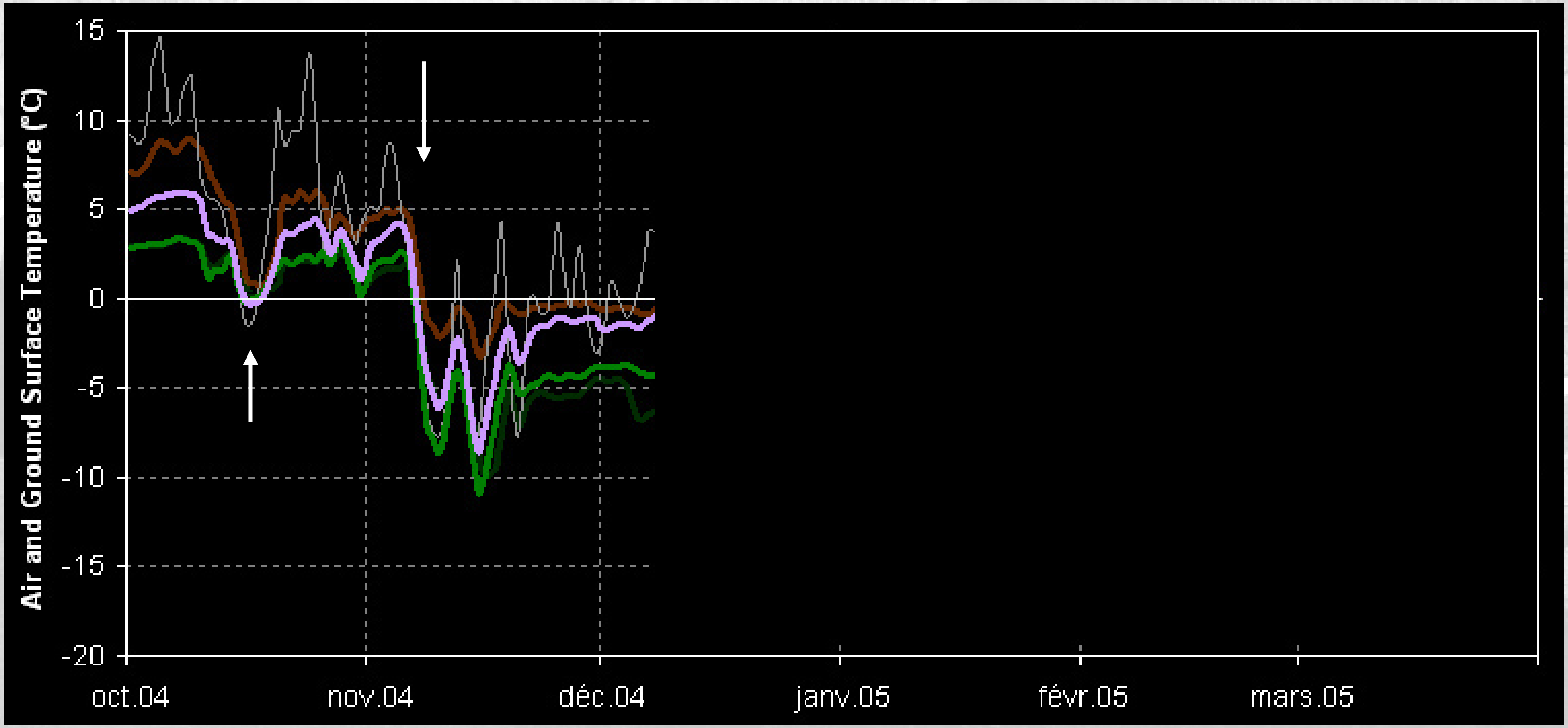


# AUTUMN AND EARLY WINTER (reversibility)


- **Rapid decrease in GST** also in the relict rock glacier !
- **Aspiration occurs when the external air temperature < ~ +5.5°C.**



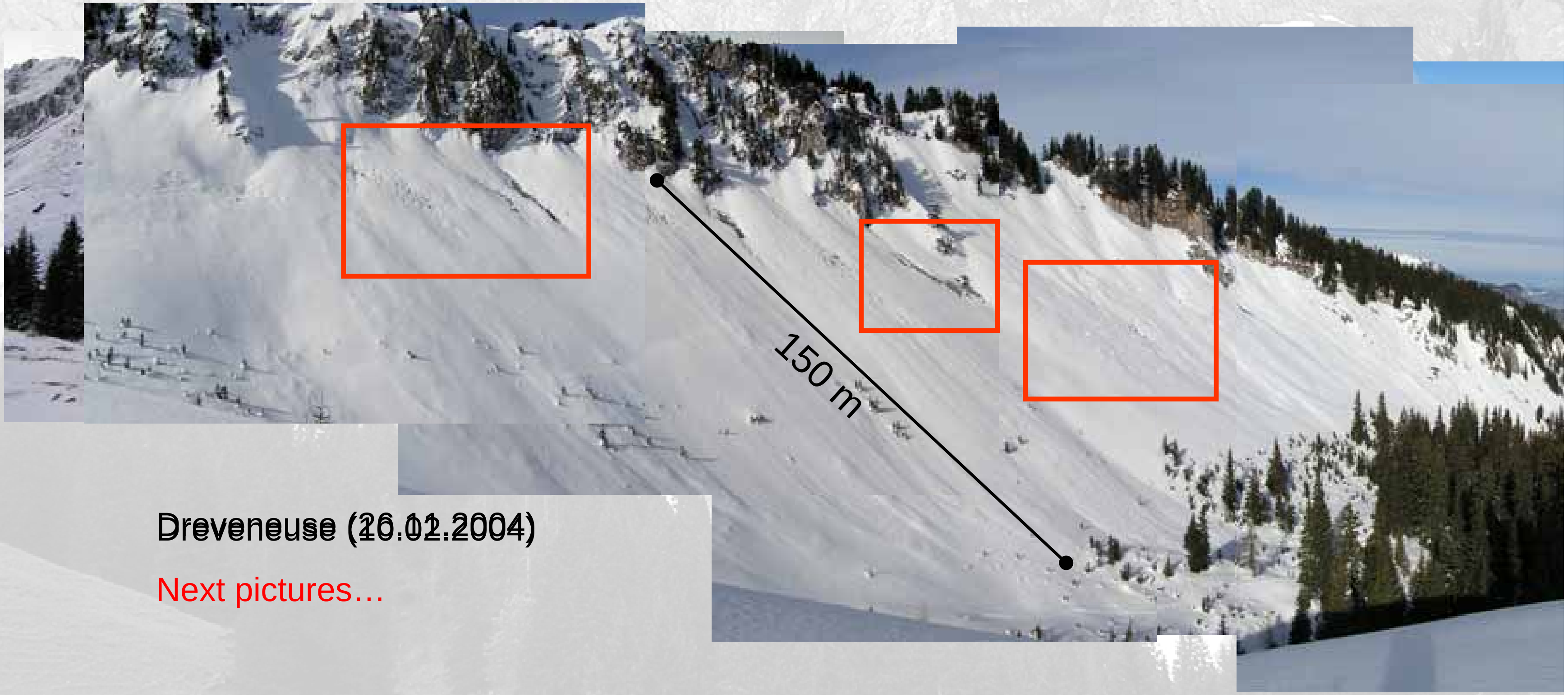
# AUTUMN AND EARLY WINTER (reversibility)



# WINTER (ascending air circulation regime)

What does happen when the snow cover becomes thicker and aspiration holes disappeared?

**Air circulation takes place trough the porous snow cover**, as attested by…



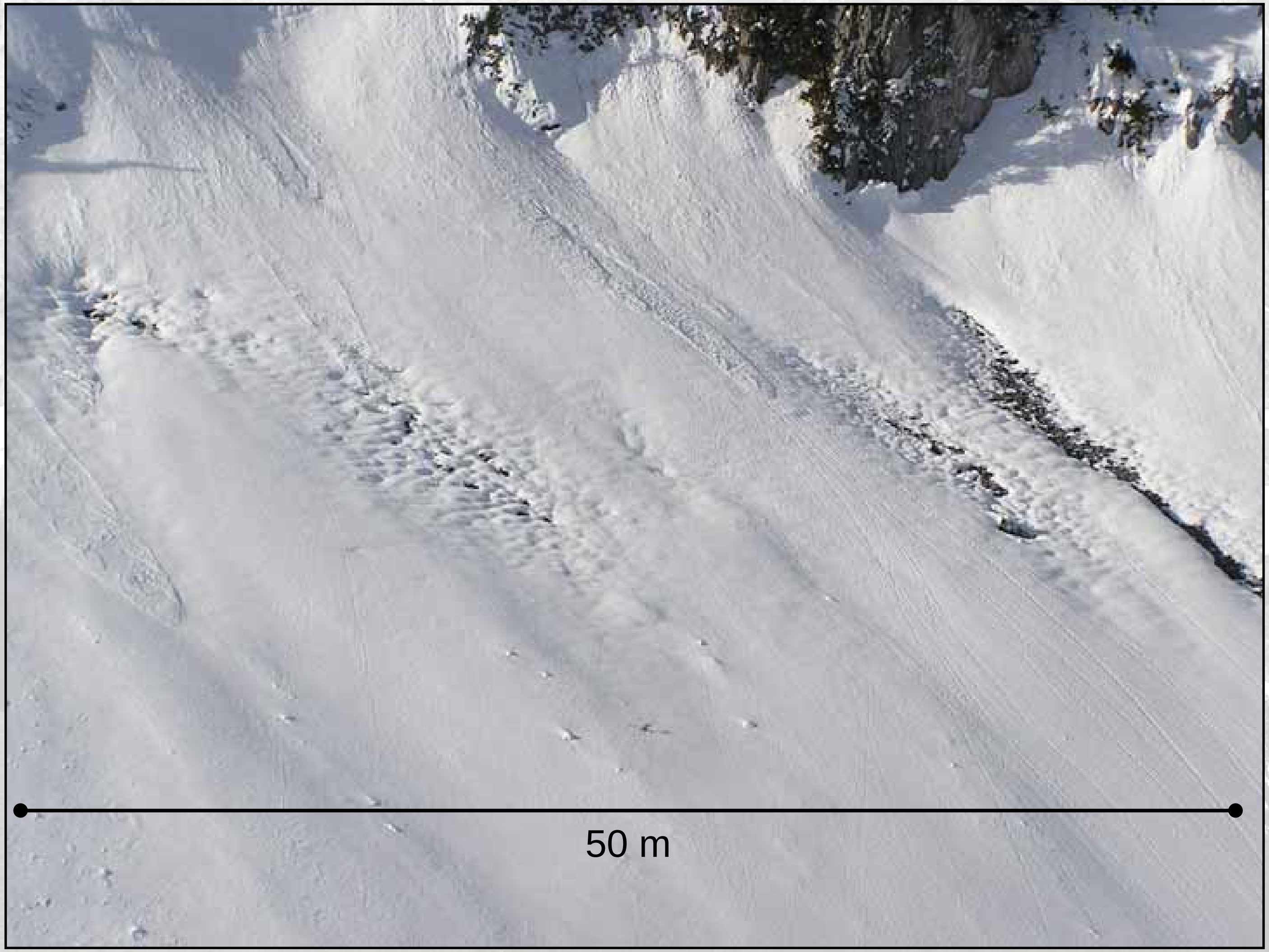

Dreveneuse (26.01.2004)

Dreveneuse (10.12.2004)

Next pictures…

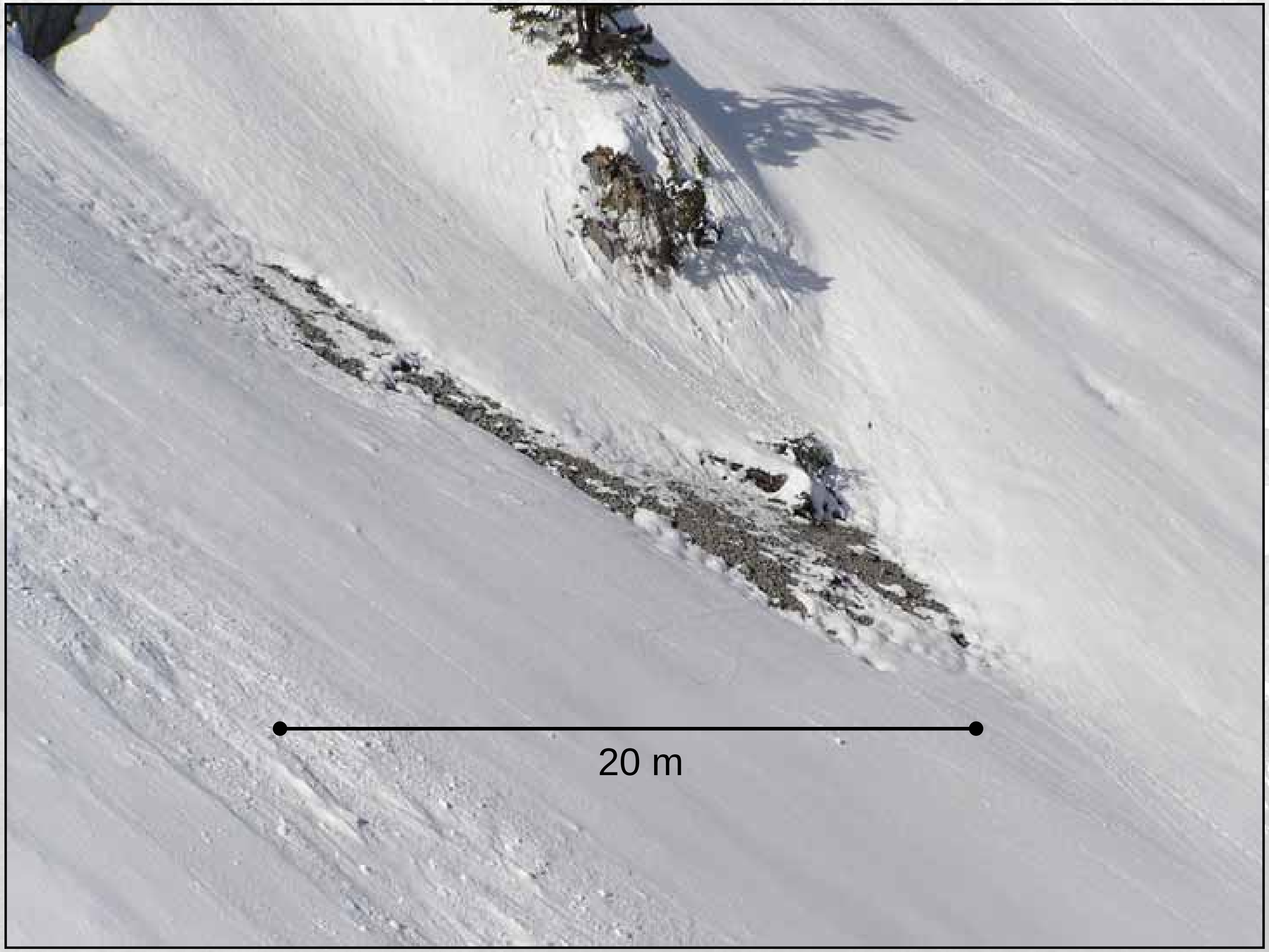
# WINTER (ascending air circulation regime)

… snowmelt windows (*diffused "warm" air outflow*) …



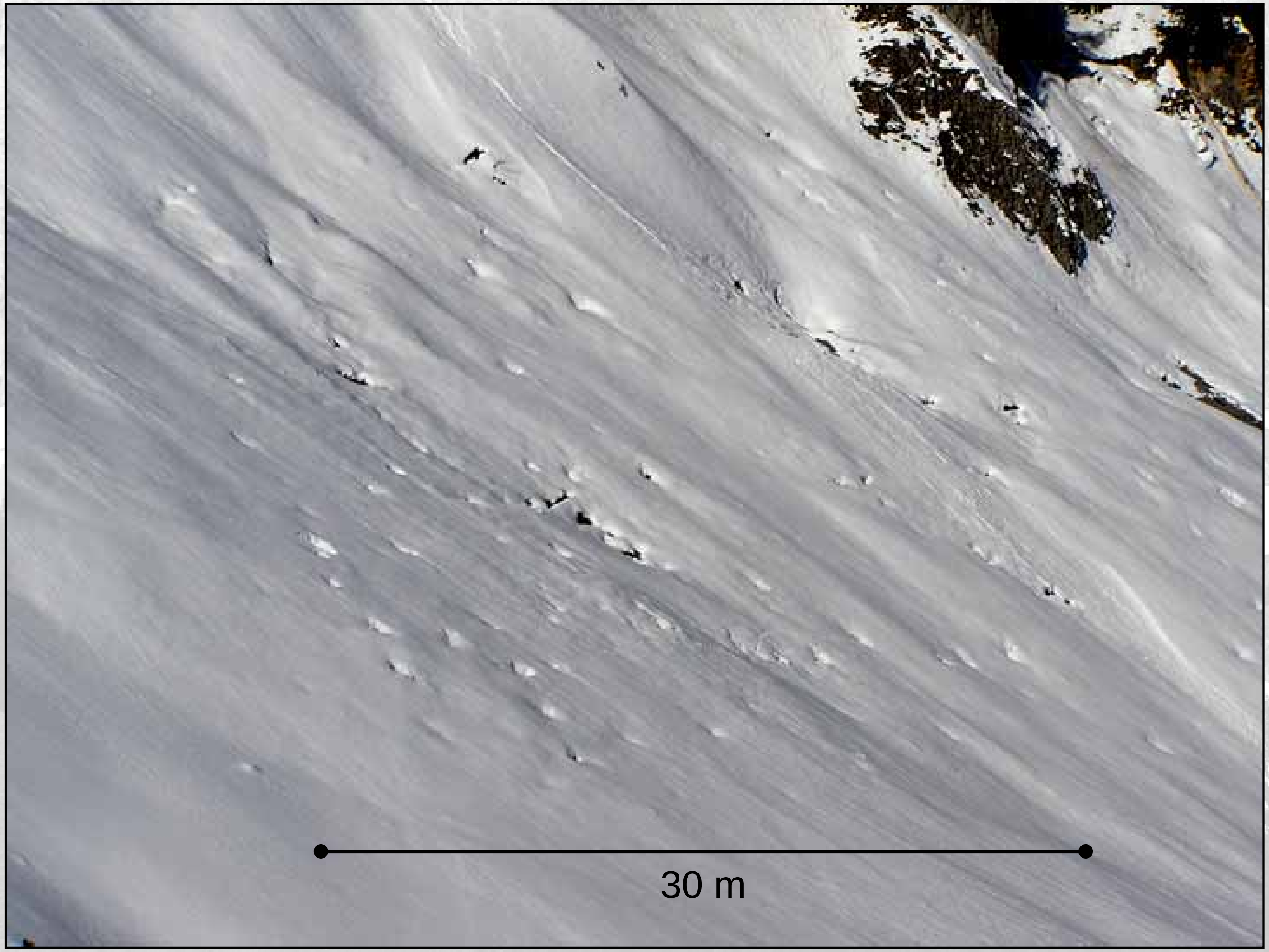
# WINTER (ascending air circulation regime)

… snowmelt windows (*diffused “warm” air outflow*) …



# WINTER (ascending air circulation regime)

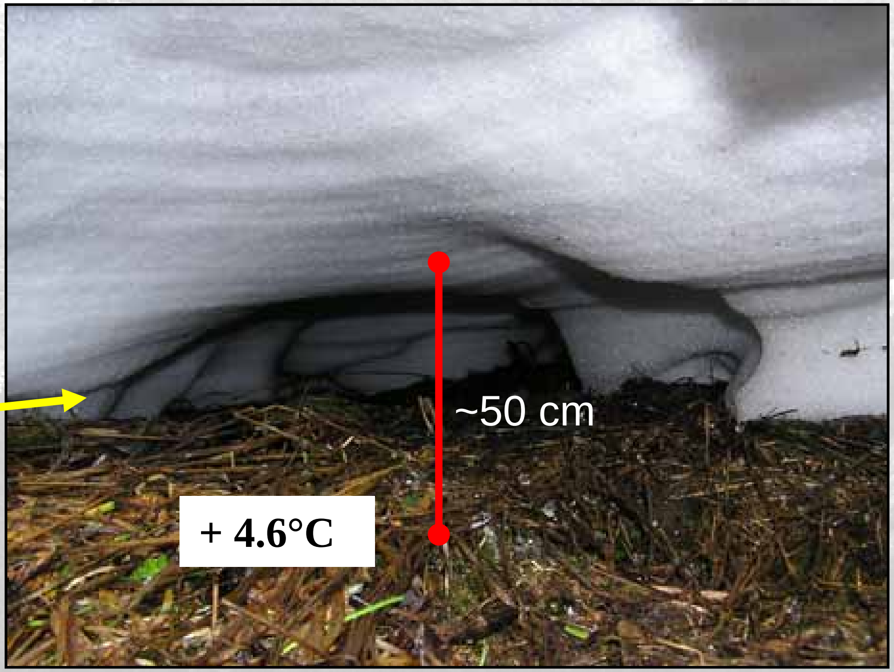
… funnels with hoarfrost (*concentrated "warm" air outflow*) …



# WINTER (ascending air circulation regime)


Vudèche (08.02.05)

… funnels with hoarfrost (*concentrated "warm" air outflow*) …

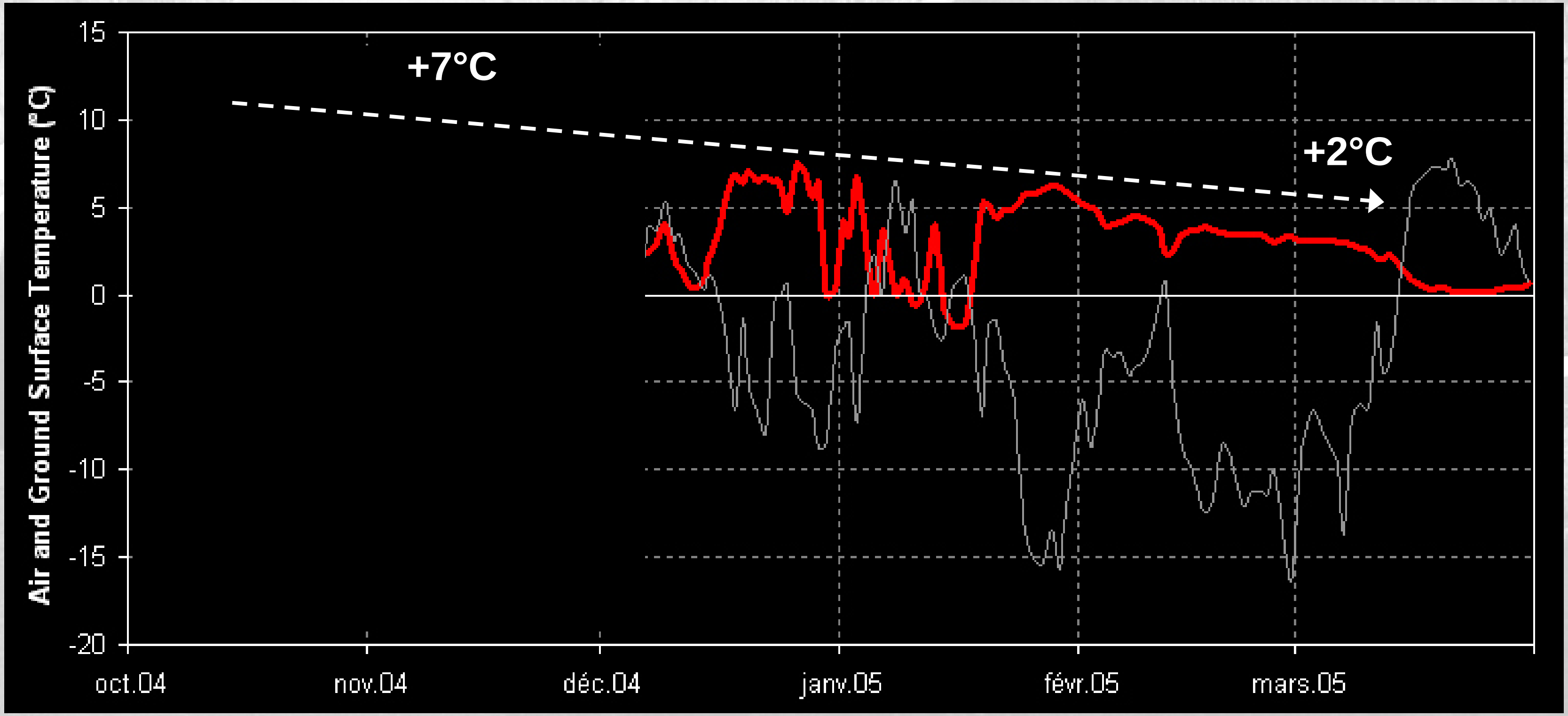


# WINTER (ascending air circulation regime)

Vudèche (08.02.05) (*J. Dorthe*)

# WINTER (ascending air circulation regime)

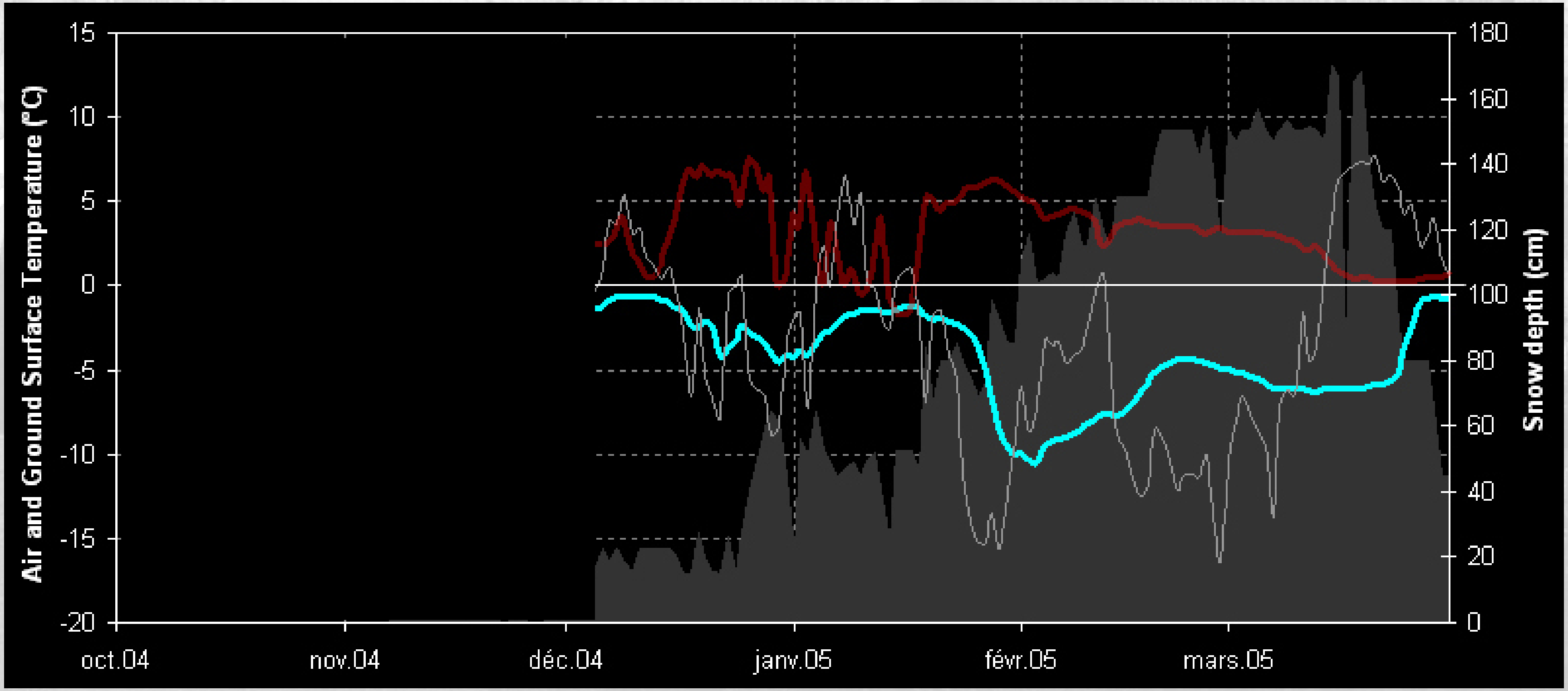
- **Expelling of warmer air** (snowmelt windows, funneling…)
- GST **gradually decrease**…
- …**Inverse** relationship with air temperature.
- **Episodic freezing**… *when outside temperature rises* !



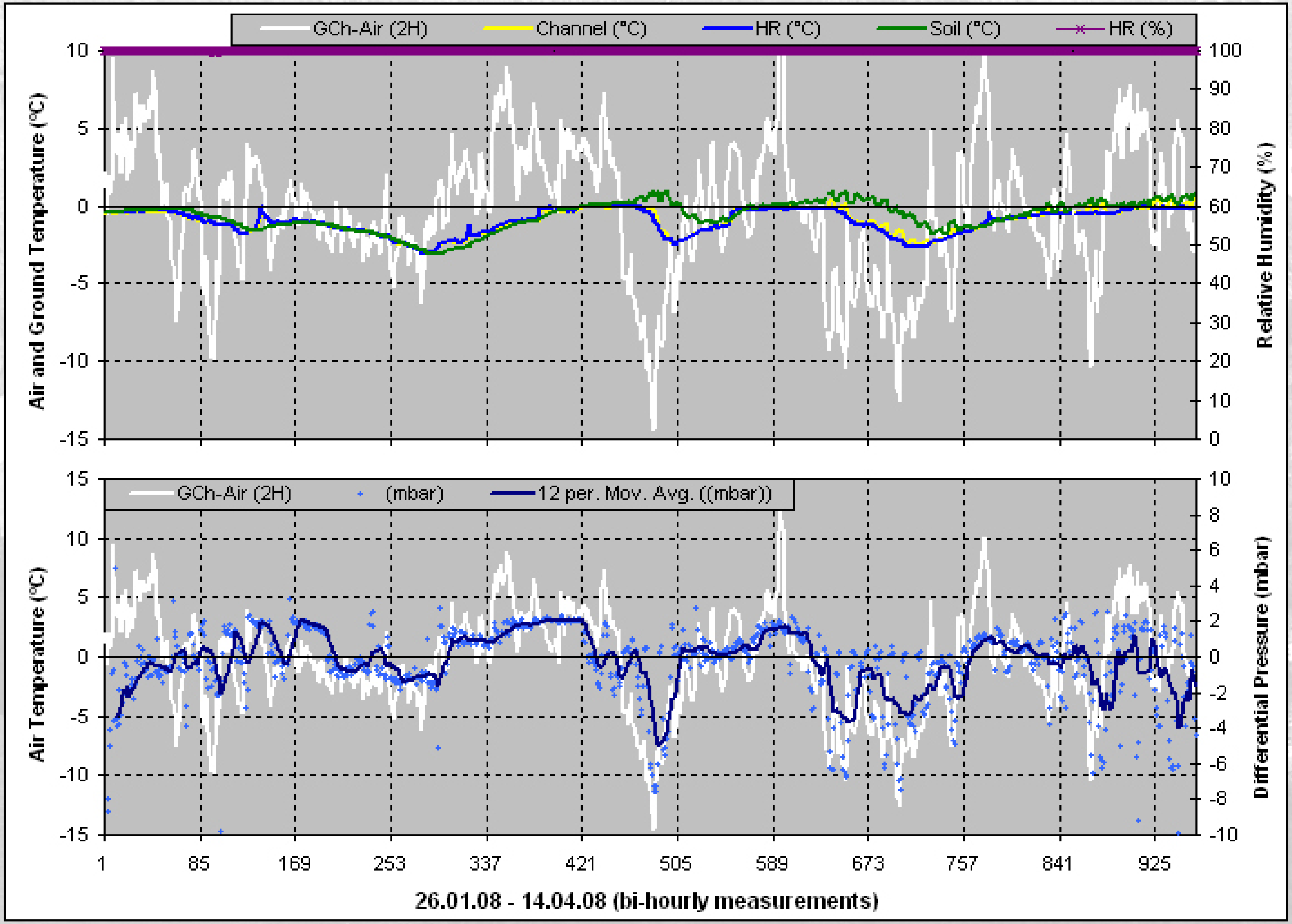
# WINTER (ascending air circulation regime)

…Due to the ascent of warmer air, **an aspiration of cold air takes place trough the porous snow cover**, as attested by…

- GST **below freezing point** during the whole winter…
- GST controlled by the evolution of the external air temperature with a time lag of a few days…



# WINTER (ascending air circulation regime)



# WINTER (ascending air circulation regime)

- GST **below freezing point** during the whole winter…
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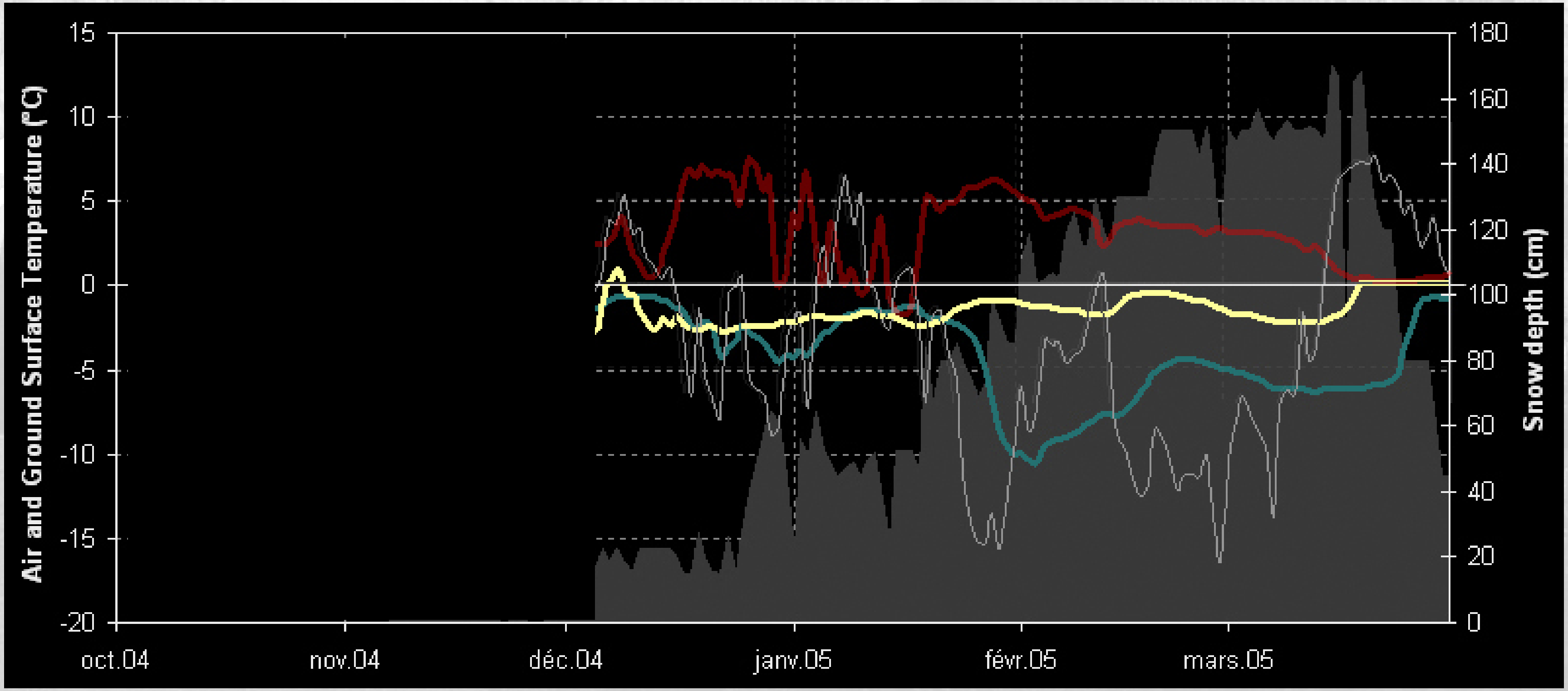

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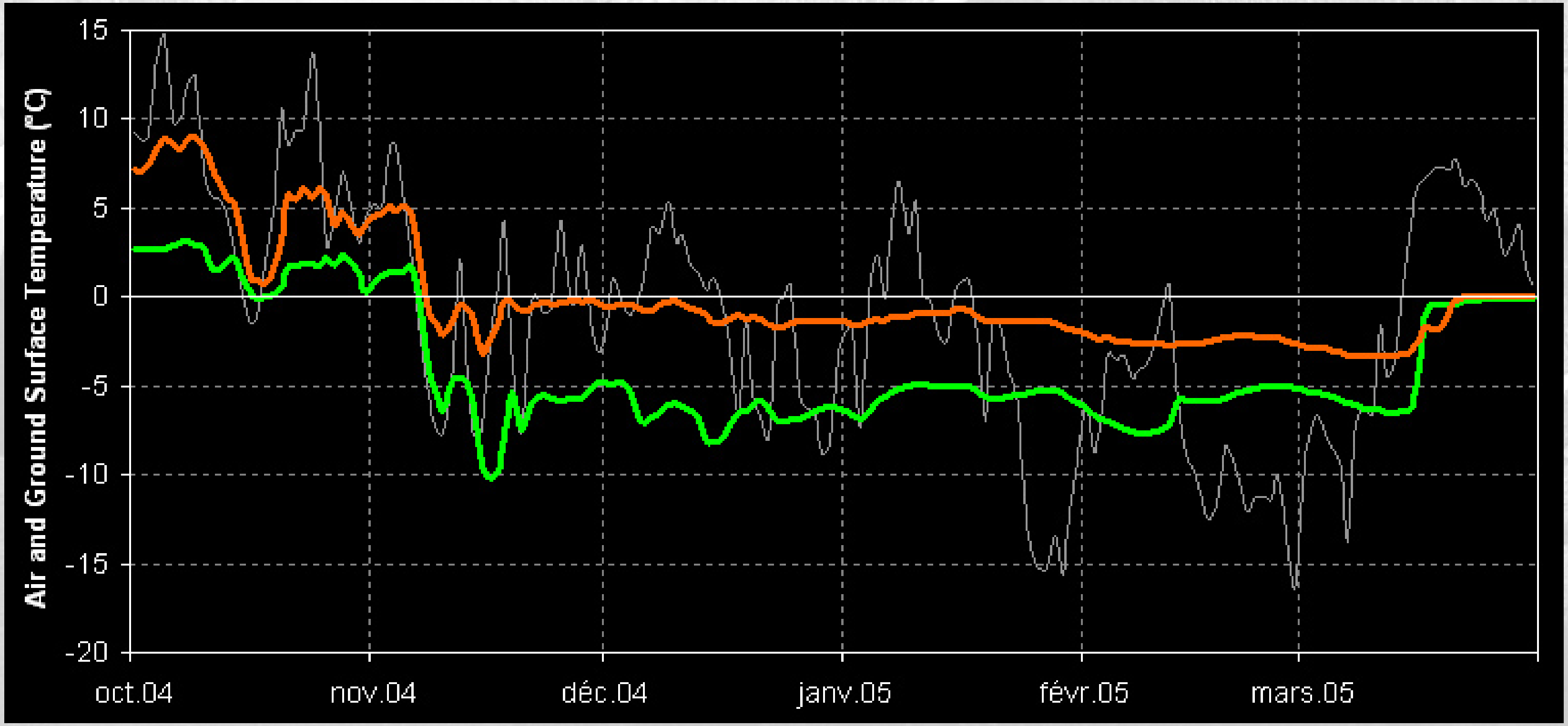

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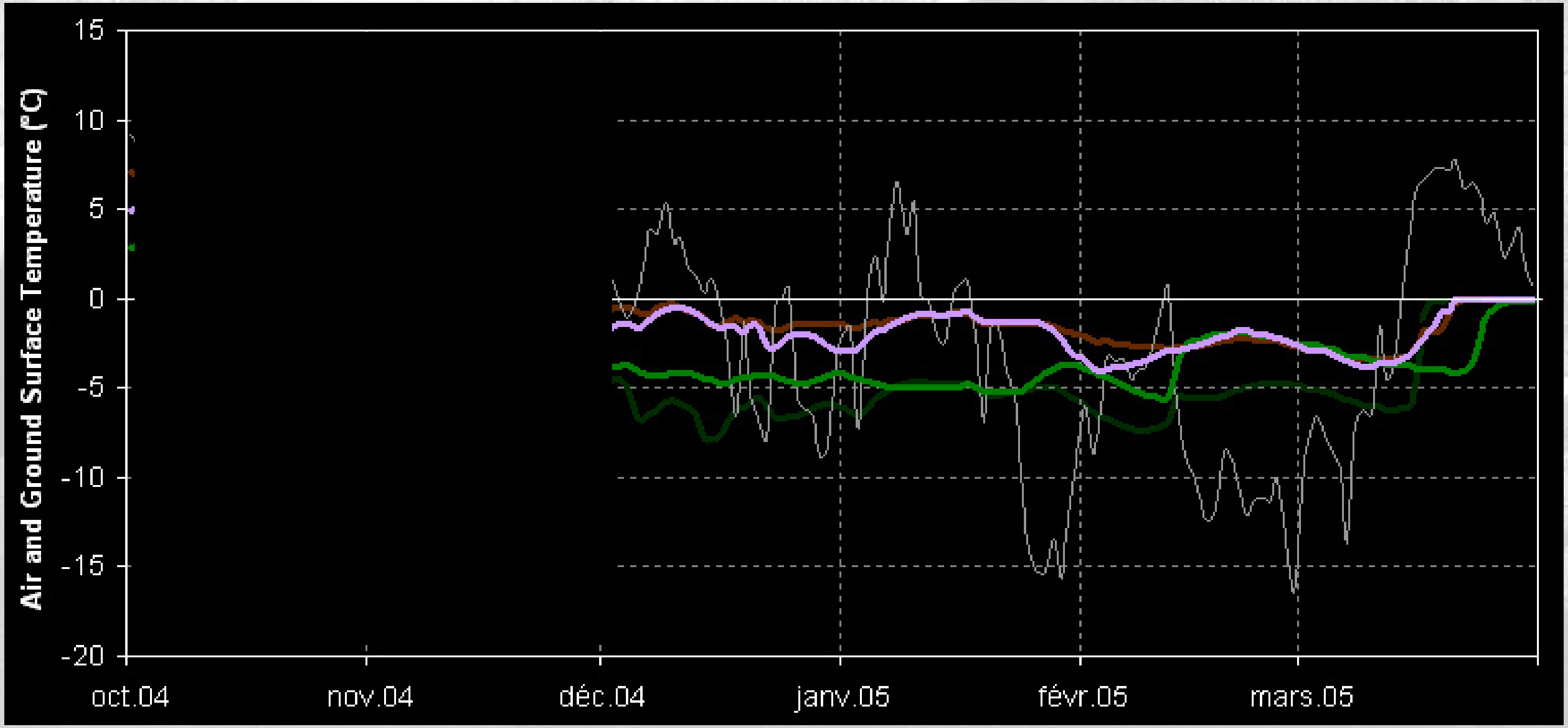
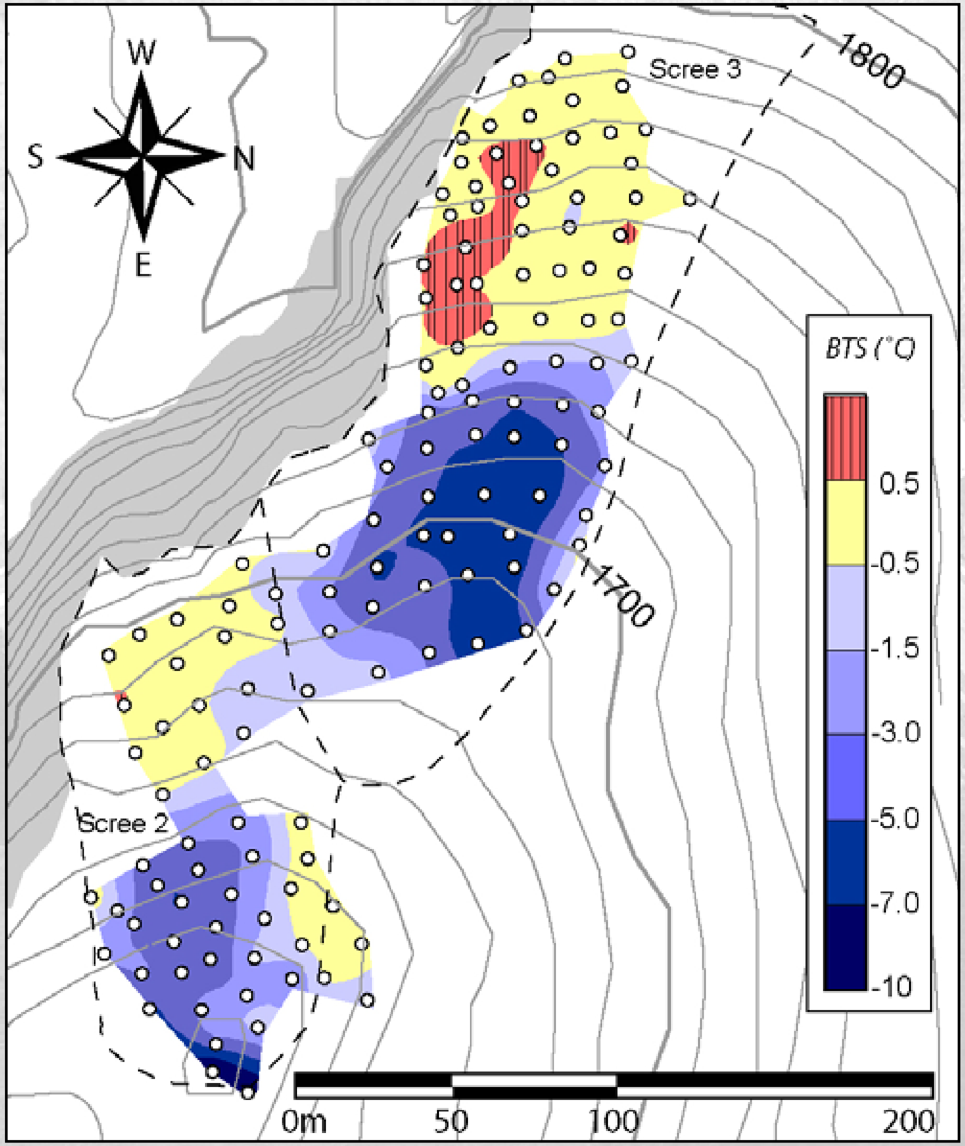


# WINTER (ascending air circulation regime)

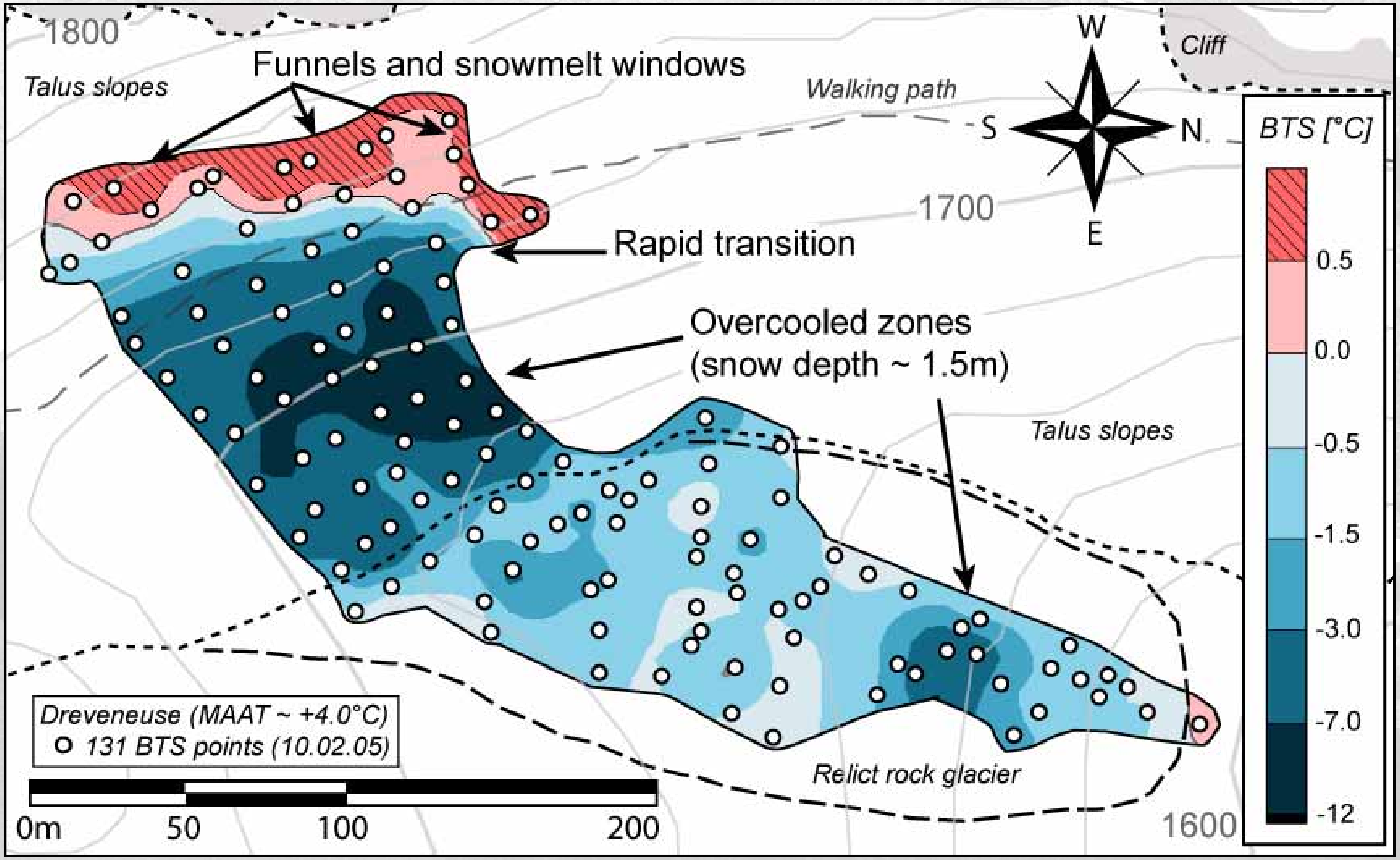



**⇒The winter ascending phase overcools the (middle) / lower part of the system.**

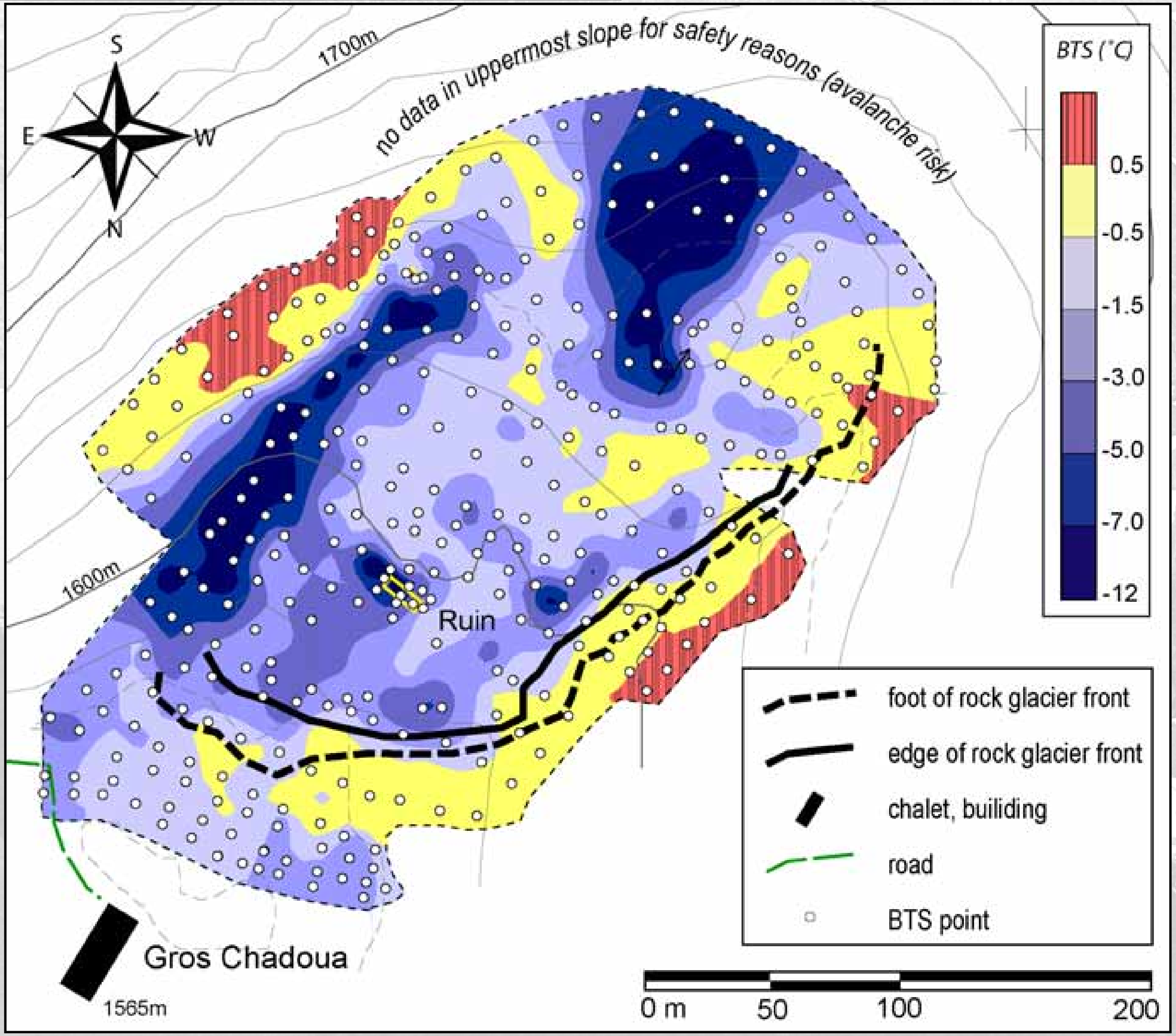
Vudèche (141 points, 08.02.05)

# WINTER (ascending air circulation regime)

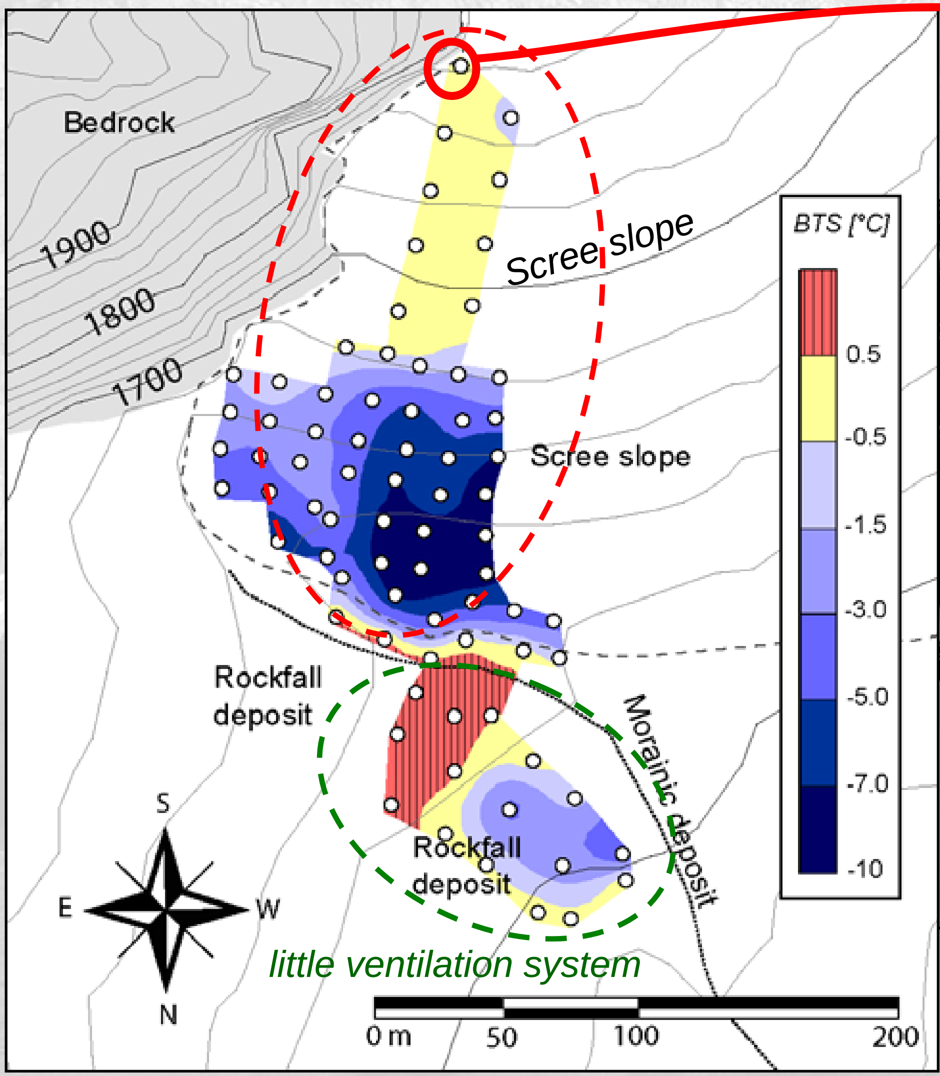
**⇒The winter ascending phase overcools the (middle) / lower part of the system.**



# WINTER (ascending air circulation regime)



# WINTER (ascending air circulation regime)

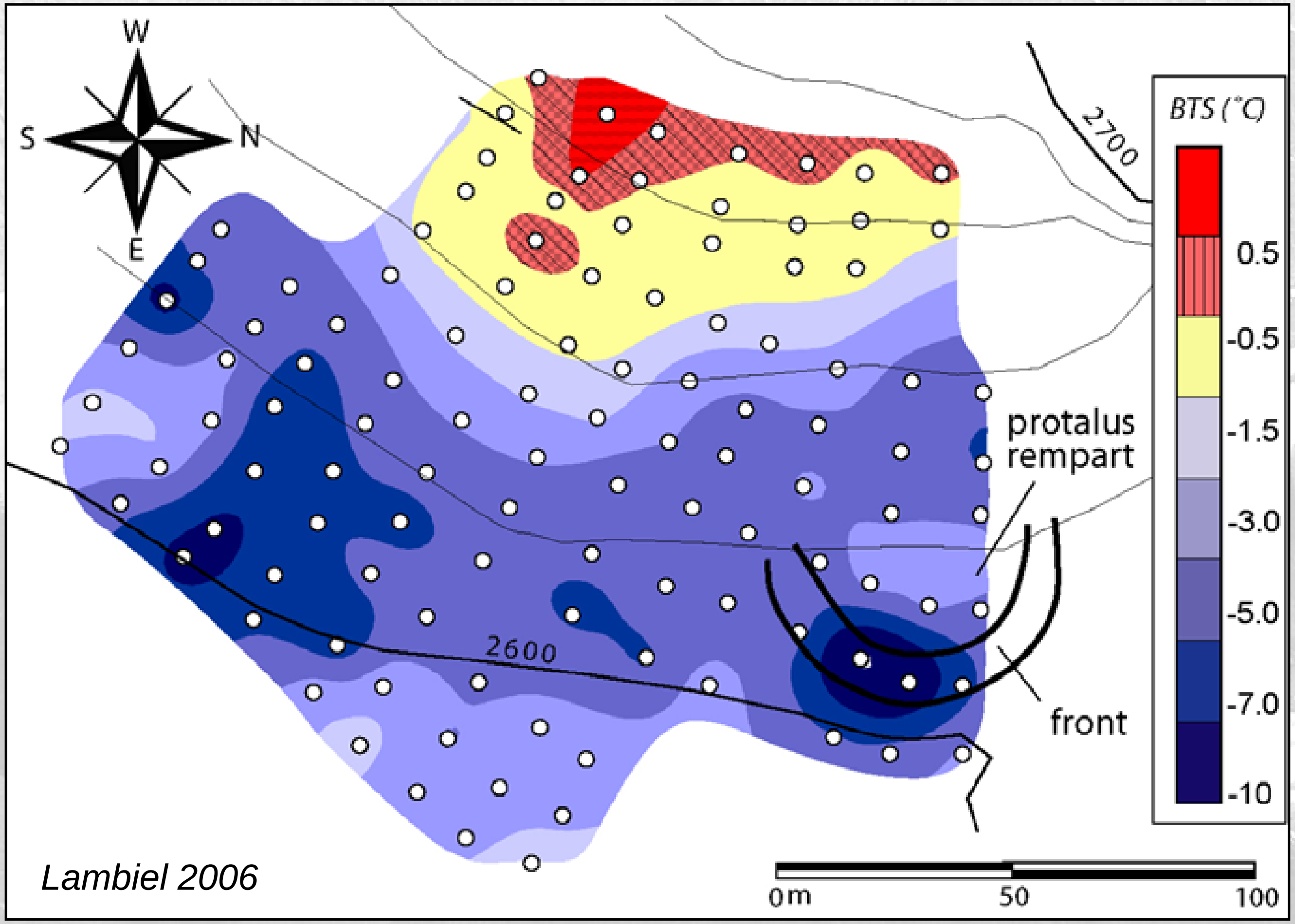



*La Pierreuse (77 points, 11.02.05)*


Several ventilation systems in the same area !

# WINTER (ascending air circulation regime)

…and also at higher elevation (in the permafrost belt) !

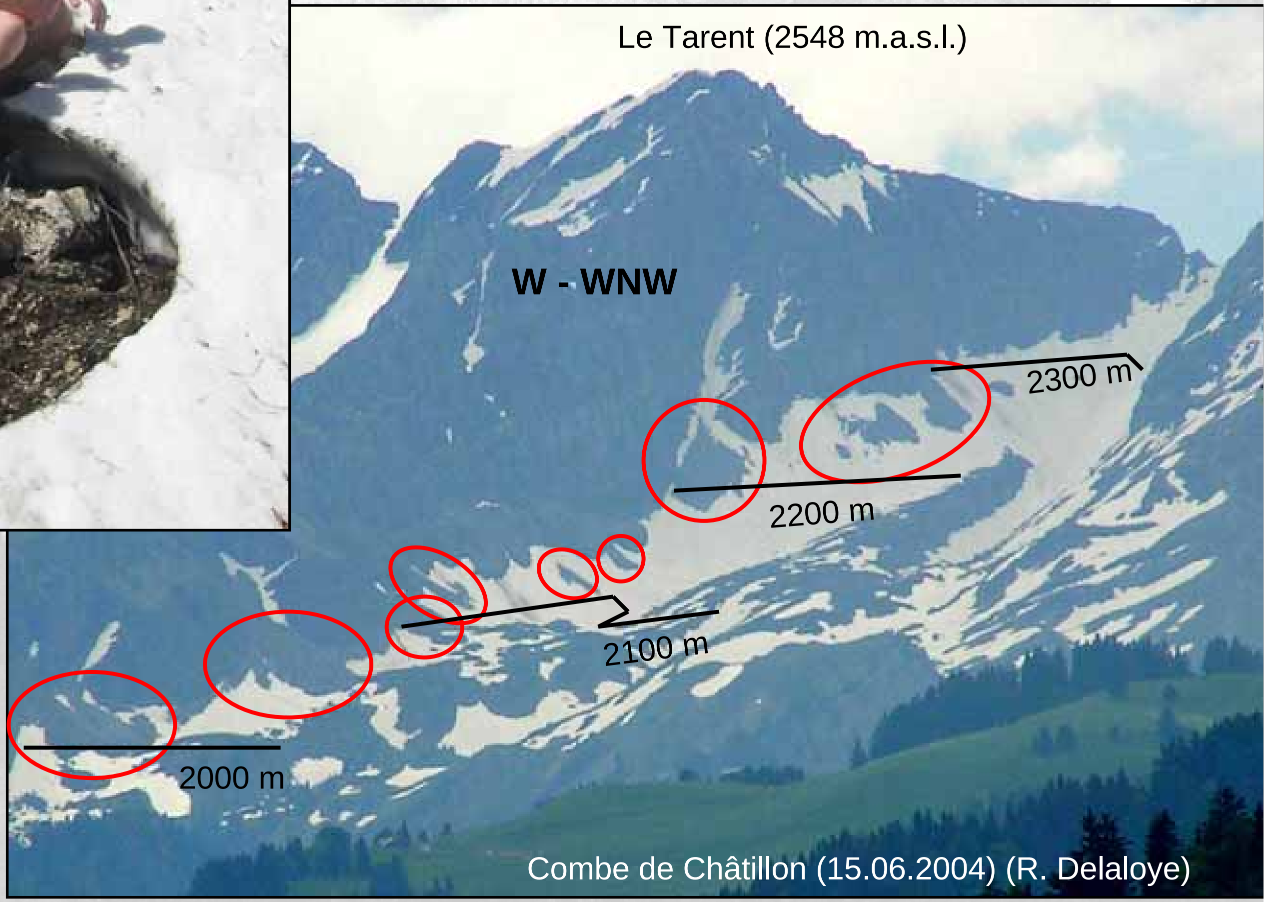



*Lambiel 2006*

# SNOWMELT PERIOD (ice formation)

Vudèche (26.05.05) (J. Dorthe)

Early snowmelt windows ?

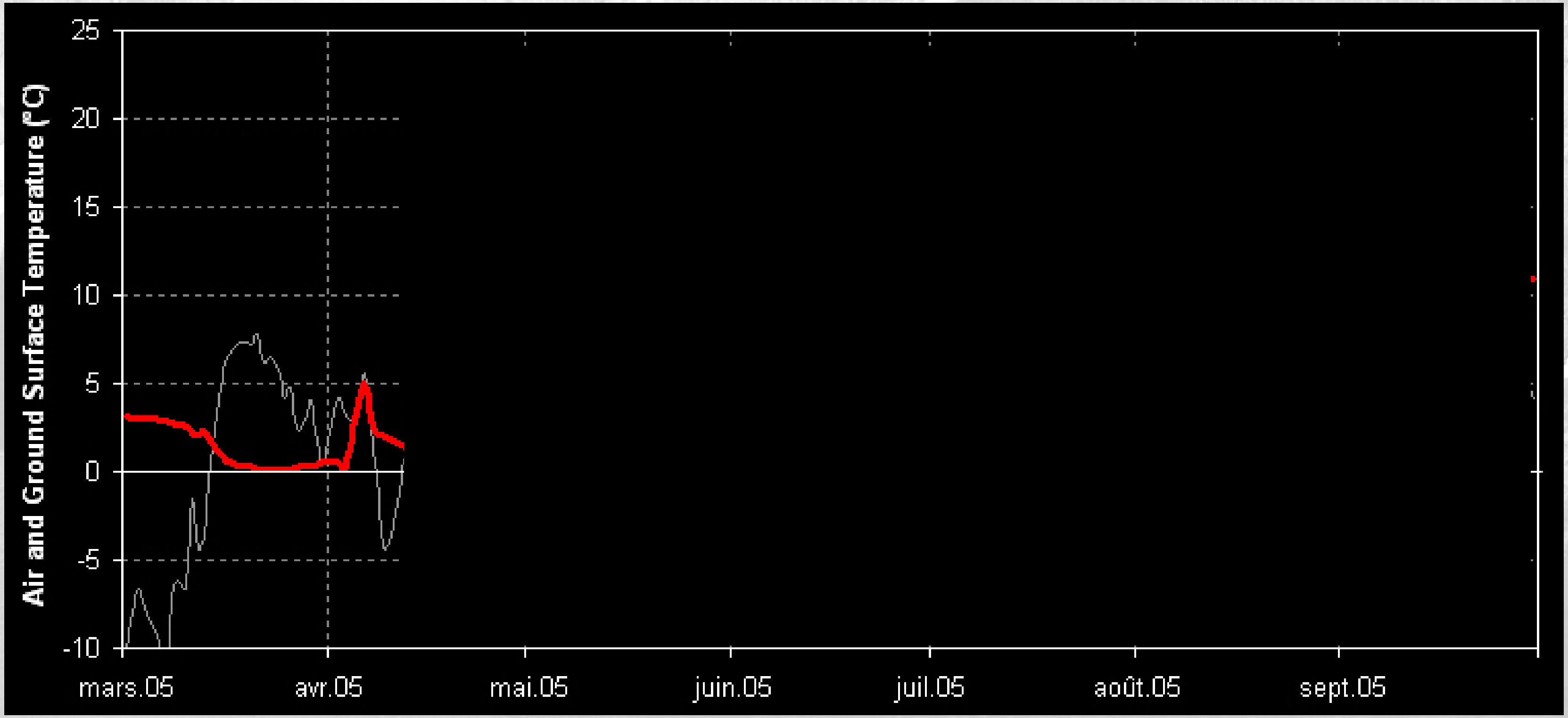



Combe de Châtillon (15.06.2004) (R. Delaloye)

# SNOWMELT PERIOD (ice formation)

**Zero curtain duration :**

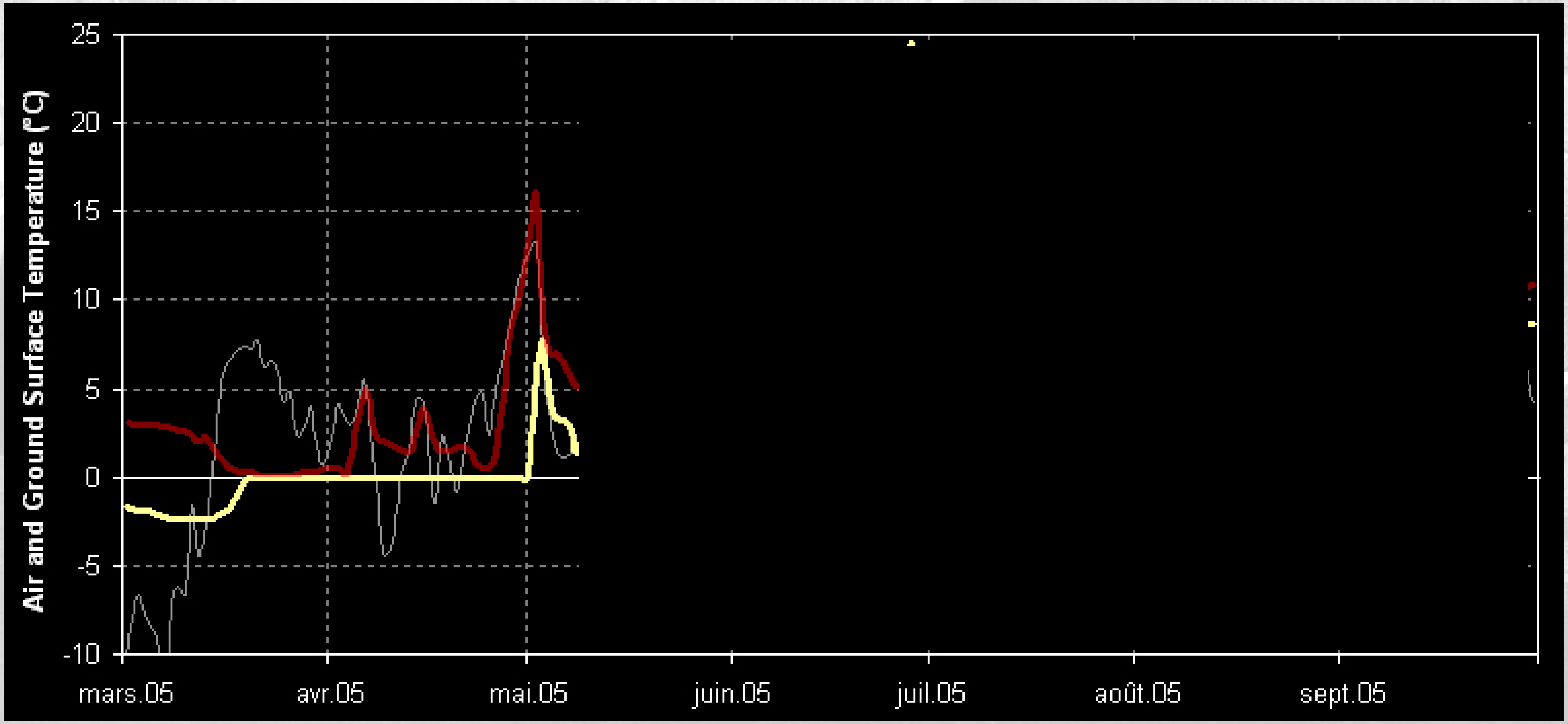
- Upper part : **few days**



# SNOWMELT PERIOD (ice formation)

**Zero curtain duration :**

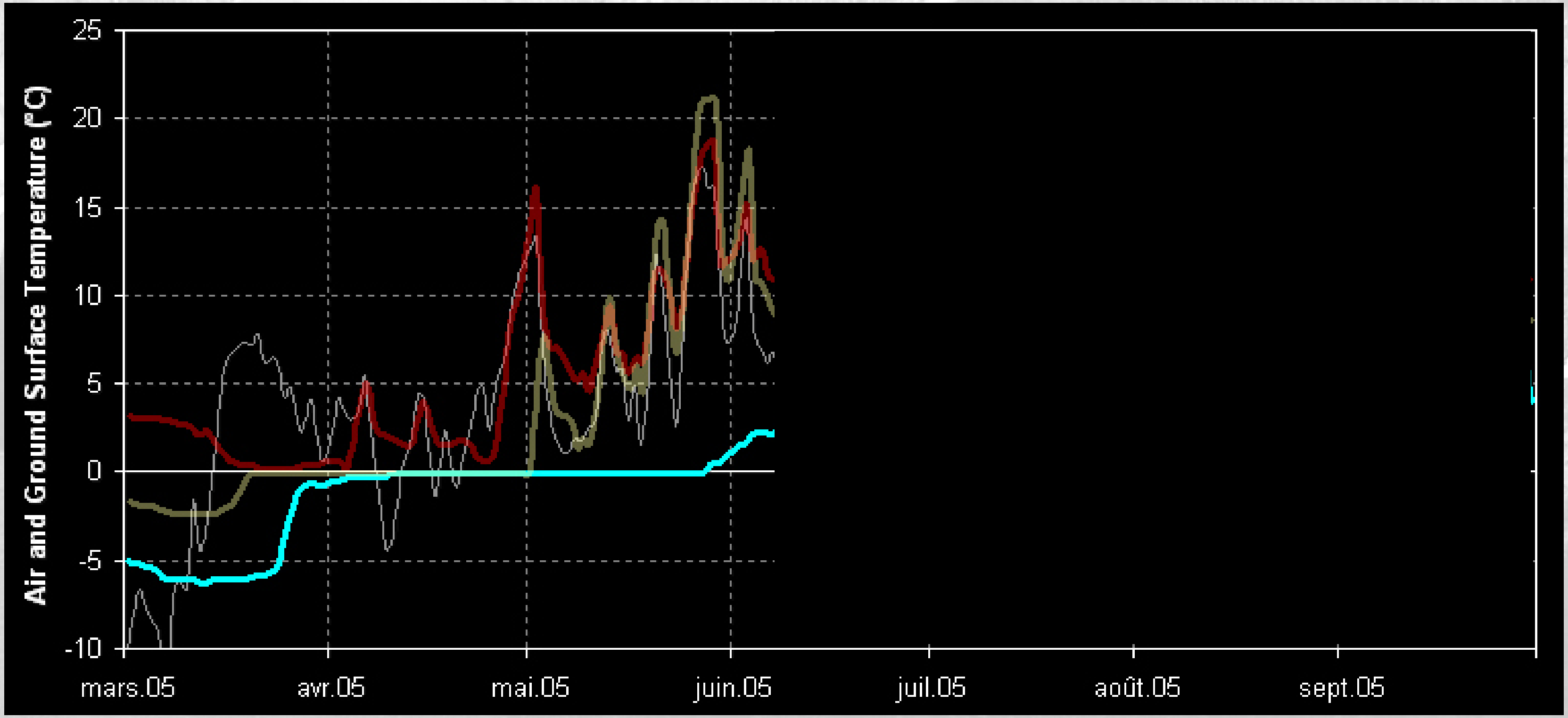
- Upper part : few days
- Middle part : **42 days** (March 20. – May 1.)



# SNOWMELT PERIOD (ice formation)

**Zero curtain duration :**

- Upper part : few days
- Middle part : 42 days (March 20. – May 1.)
- Lower part : **48 days** (April 10. – May 27.)



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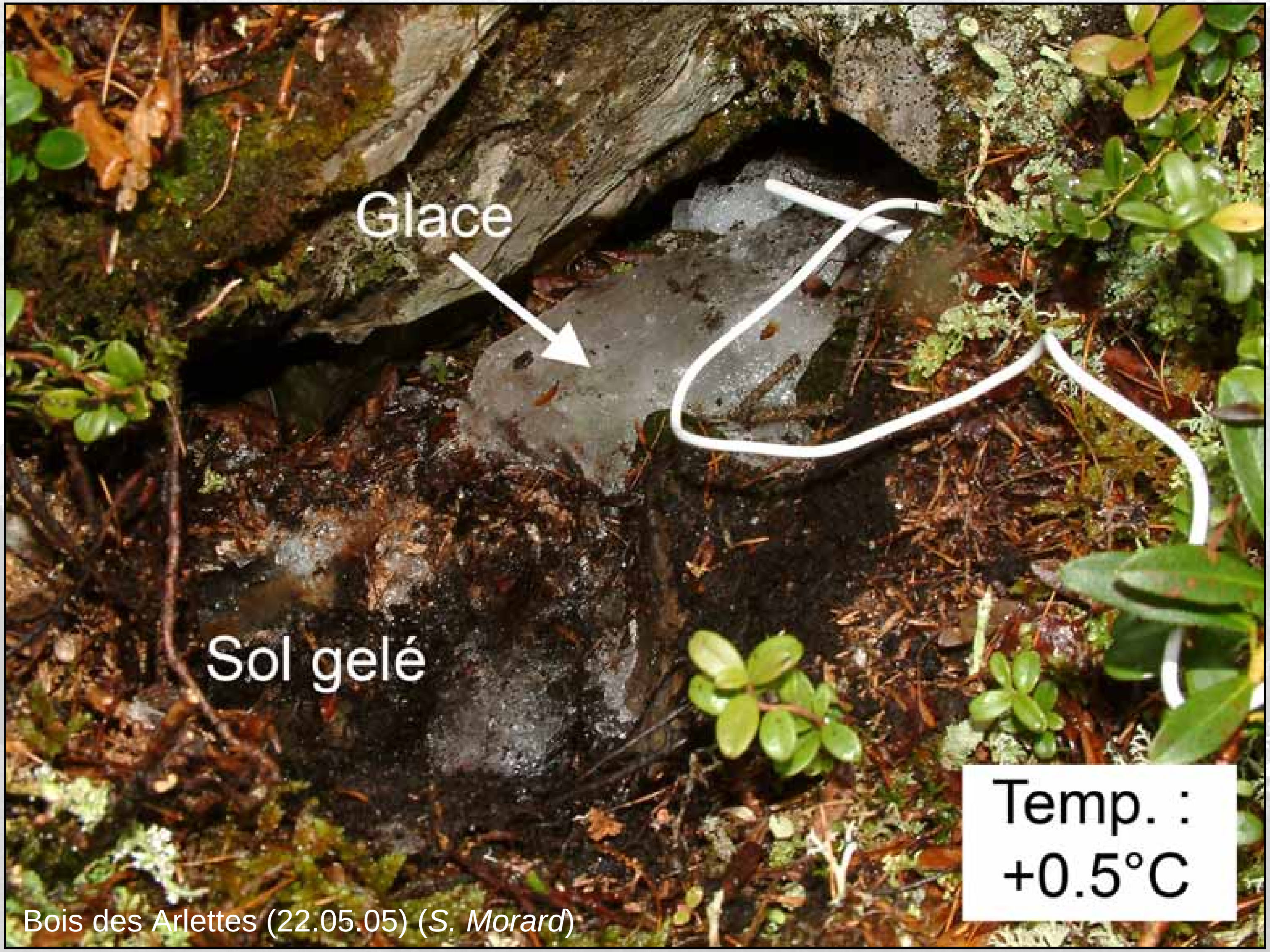
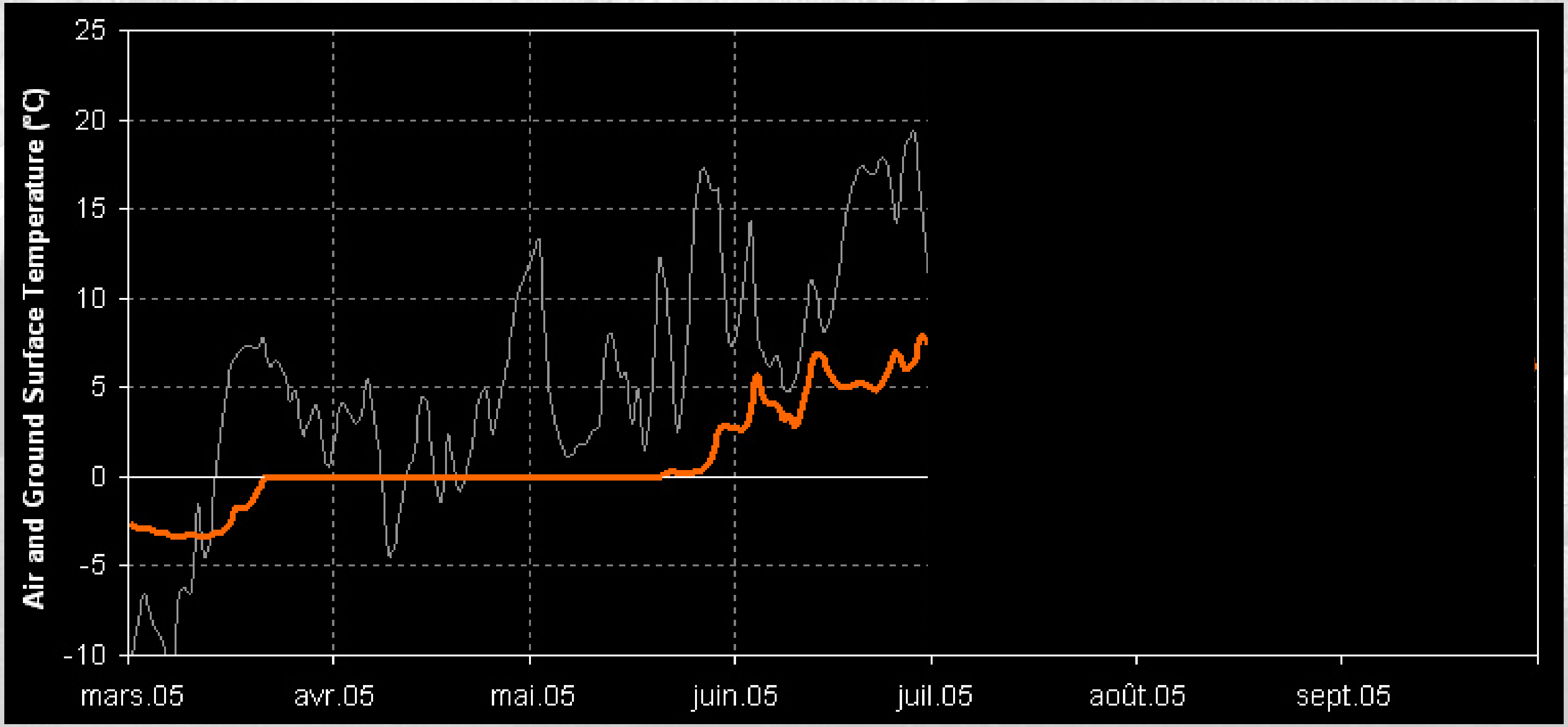



Bois des Arlettes (22.05.05) (*S. Morard*)

# SNOWMELT PERIOD (ice formation)

**Zero curtain duration :**

- Upper part : few days
- Middle part : 42 days (March 20. – May 1.)
- Lower part : 48 days (April 10. – May 27.)
- RRG ridge : **58 days** (March 23. – May 20.)

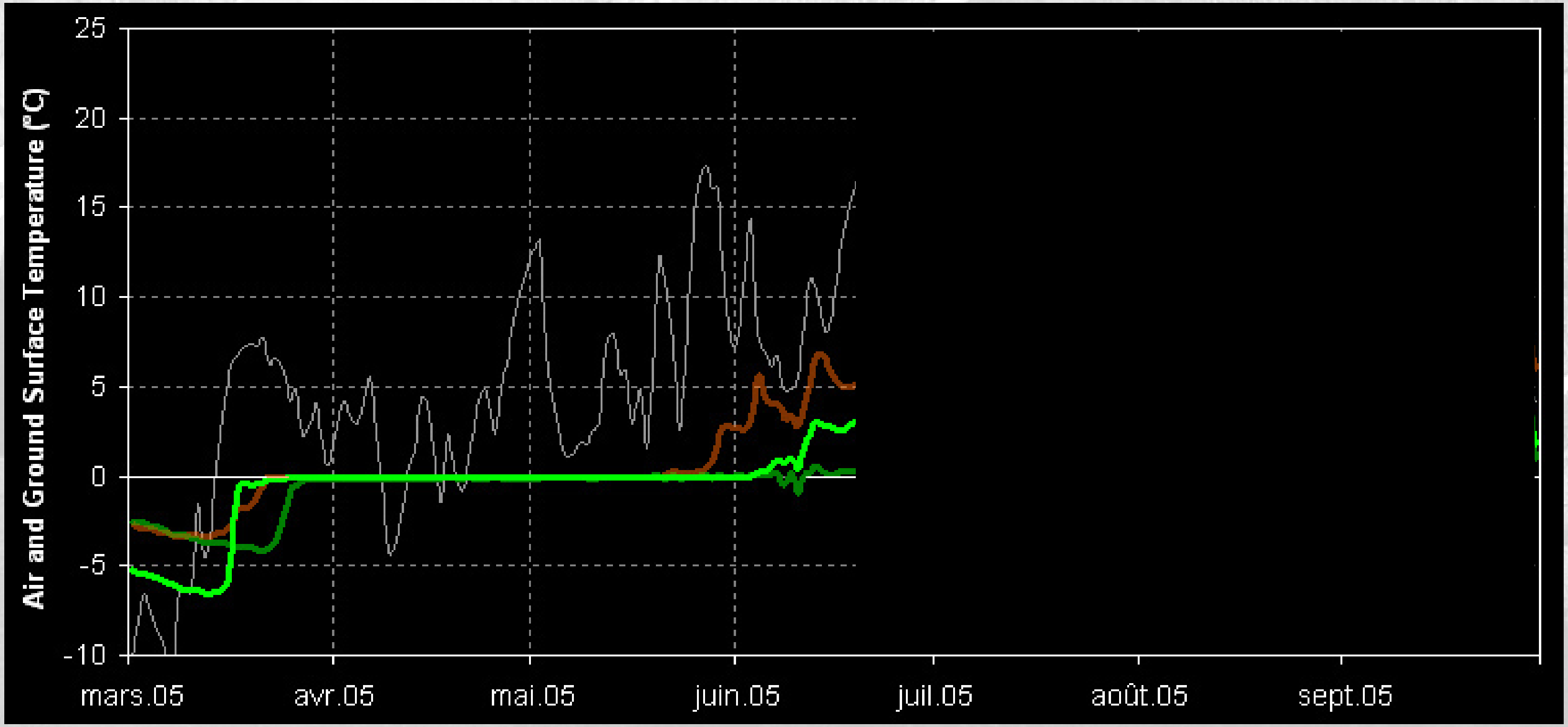


# SNOWMELT PERIOD (ice formation)

**Zero curtain duration :**

- Upper part : few days
- Middle part : 42 days (March 20. – May 1.)
- Lower part : 48 days (April 10. – May 27.)

- RRG ridge : 58 days (March 23. – May 20.)
- RRG furrow : **74 days** (March 22. – June 4.)
- RRG body : **74 days** (March 28. – June 10.)



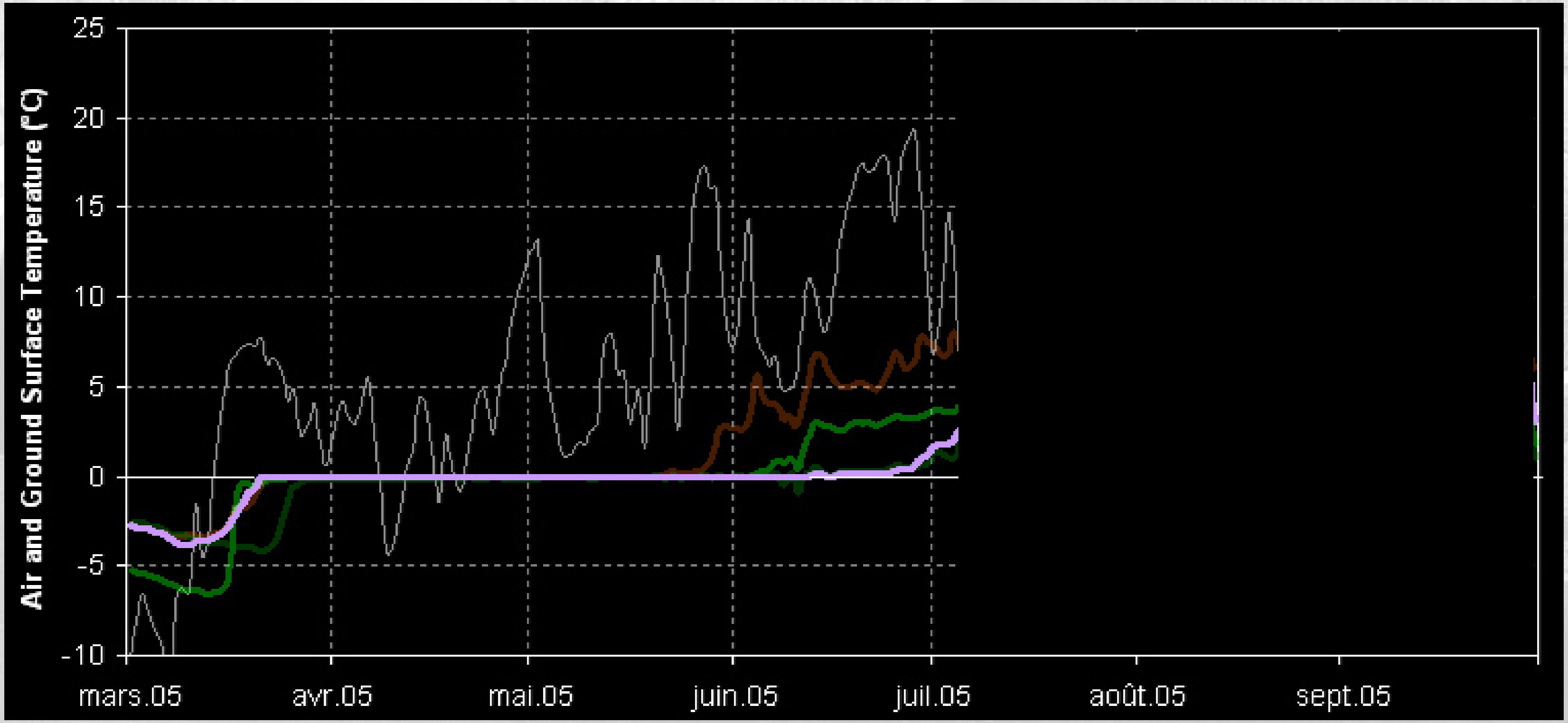
Upper part
Intermediate
Lower part
RRG Roots Furrow
RRG Roots Ridge
RRG Body
RRG Front

# SNOWMELT PERIOD (ice formation)

**Zero curtain duration :**

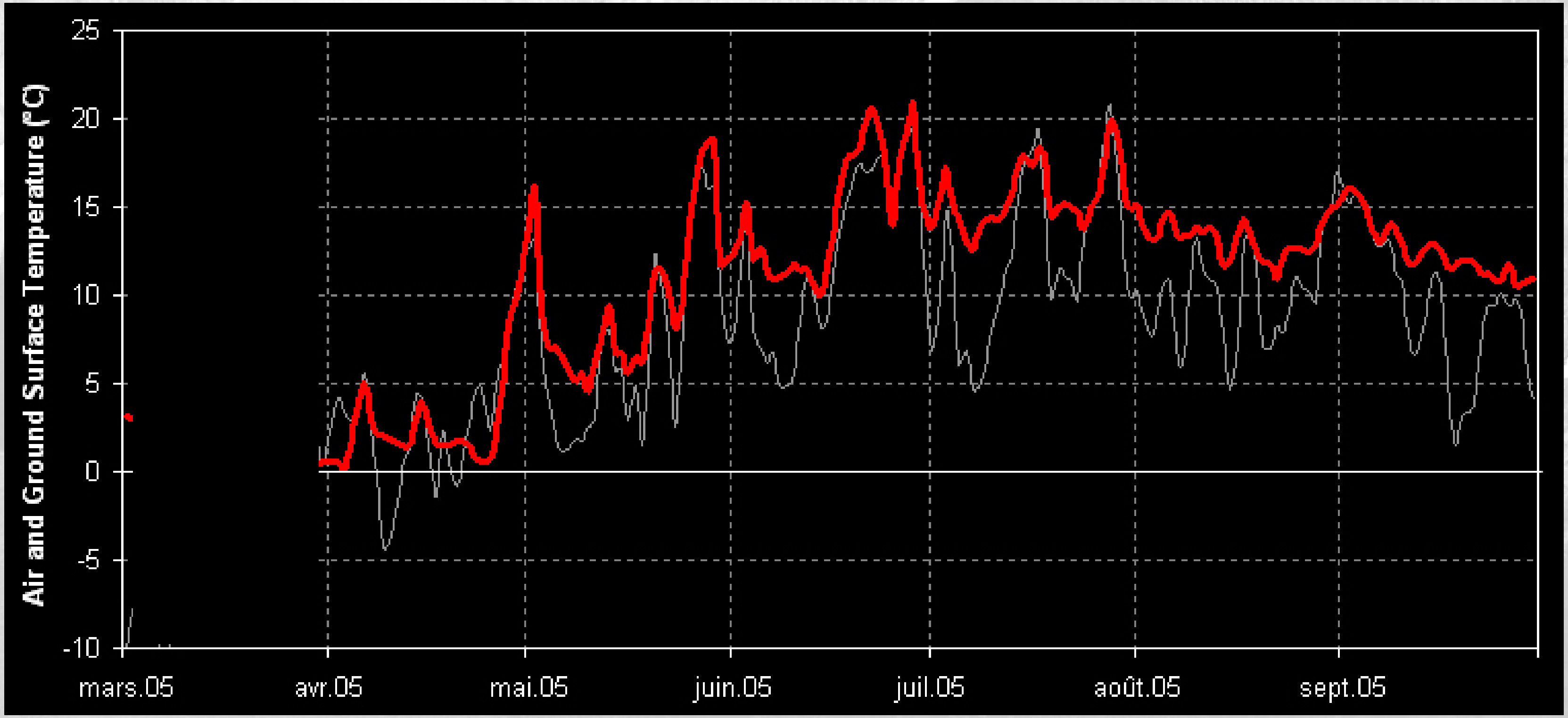
- Upper part : **few days**
- Middle part : 42 days (March 20. – May 1.)
- Lower part : 48 days (April 10. – May 27.)

- RRG ridge : 58 days (March 23. – May 20.)
- RRG furrow : 74 days (March 22. – June 4.)
- RRG body : 74 days (March 28. – June 10.)
- RRG front : **87 days** (March 21. – June 16.)



# SUMMER (gravity discharge of cold dense air)

- GST varies in close correspondence with the evolution of the external air temperature.



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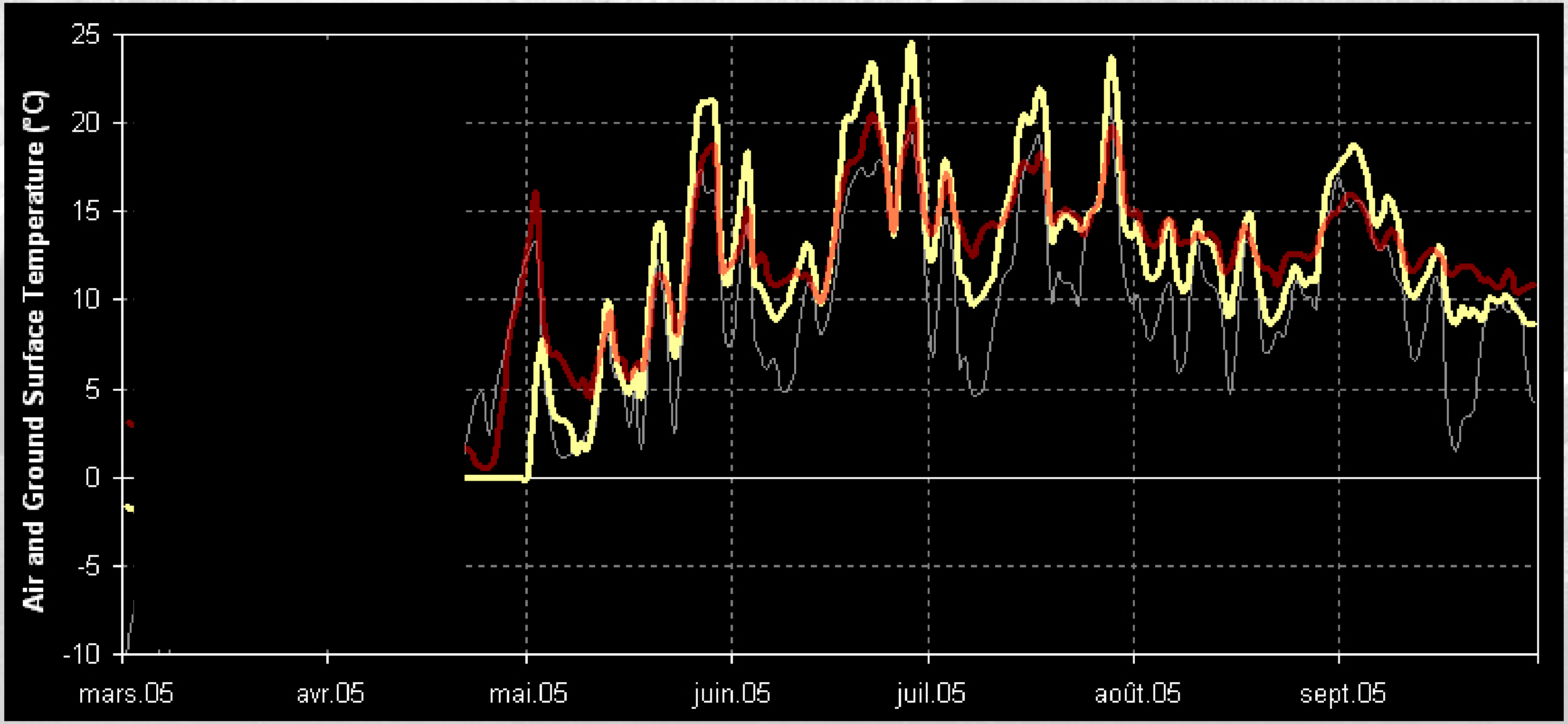
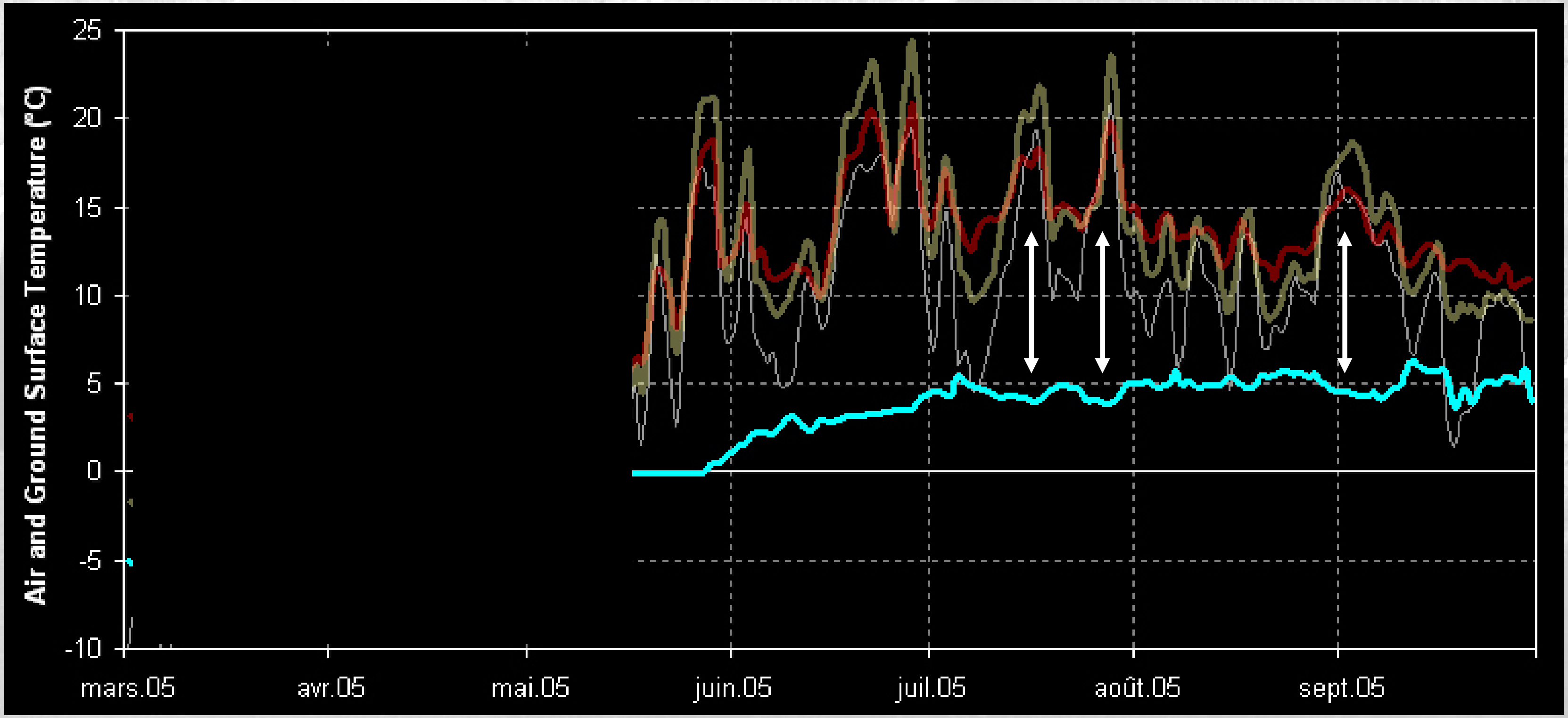


# SUMMER (gravity discharge of cold dense air)

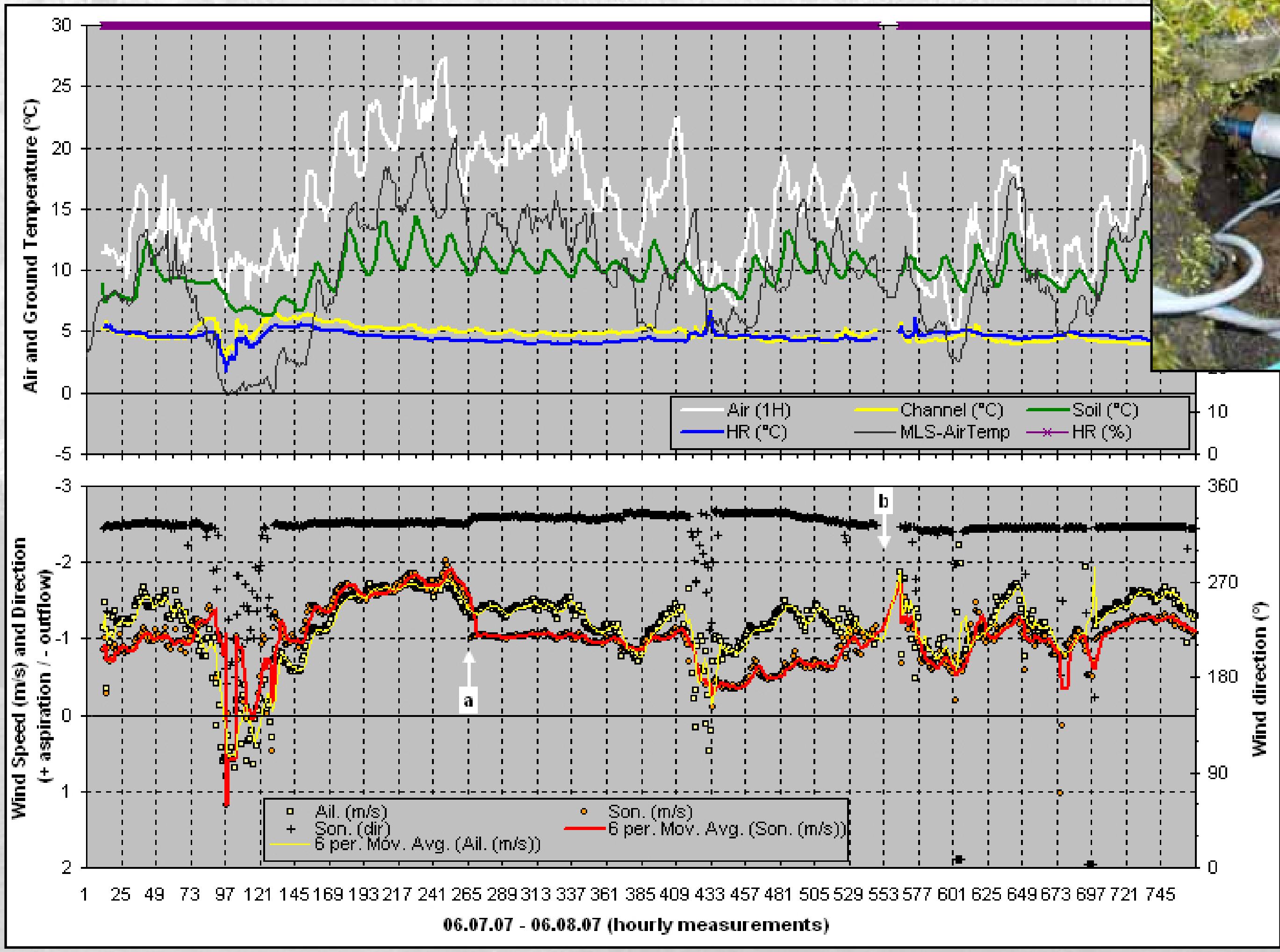
**Gravity discharge** of cold air :

- Stable and cold GST : **4.44°C +/- 0.89°C**.
- **Inverse** relationship with air temperature.
- Cold air outflow, azonal vegetation, ground ice, late-lying residual snow patches…



# SUMMER (gravity discharge of cold dense air)

**Airflows of cold air** (0.5° to 5°C) (*with outside temp. = 15-20°C*),




*Gros Chadoua*
*(S. Morard)*

# SUMMER (gravity discharge of cold dense air)

**Late lying of snow patch**,

**Ground ice**…

Bois des Arlettes (1750m., 29.06.04) (S. Morard)

Wandflue (1625m., 30.07.06!) (J. Dorthe)

# SUMMER (gravity discharge of cold dense air)

…beyond the lower part of scree slopes

…at the top of relict rock glacier ridges.

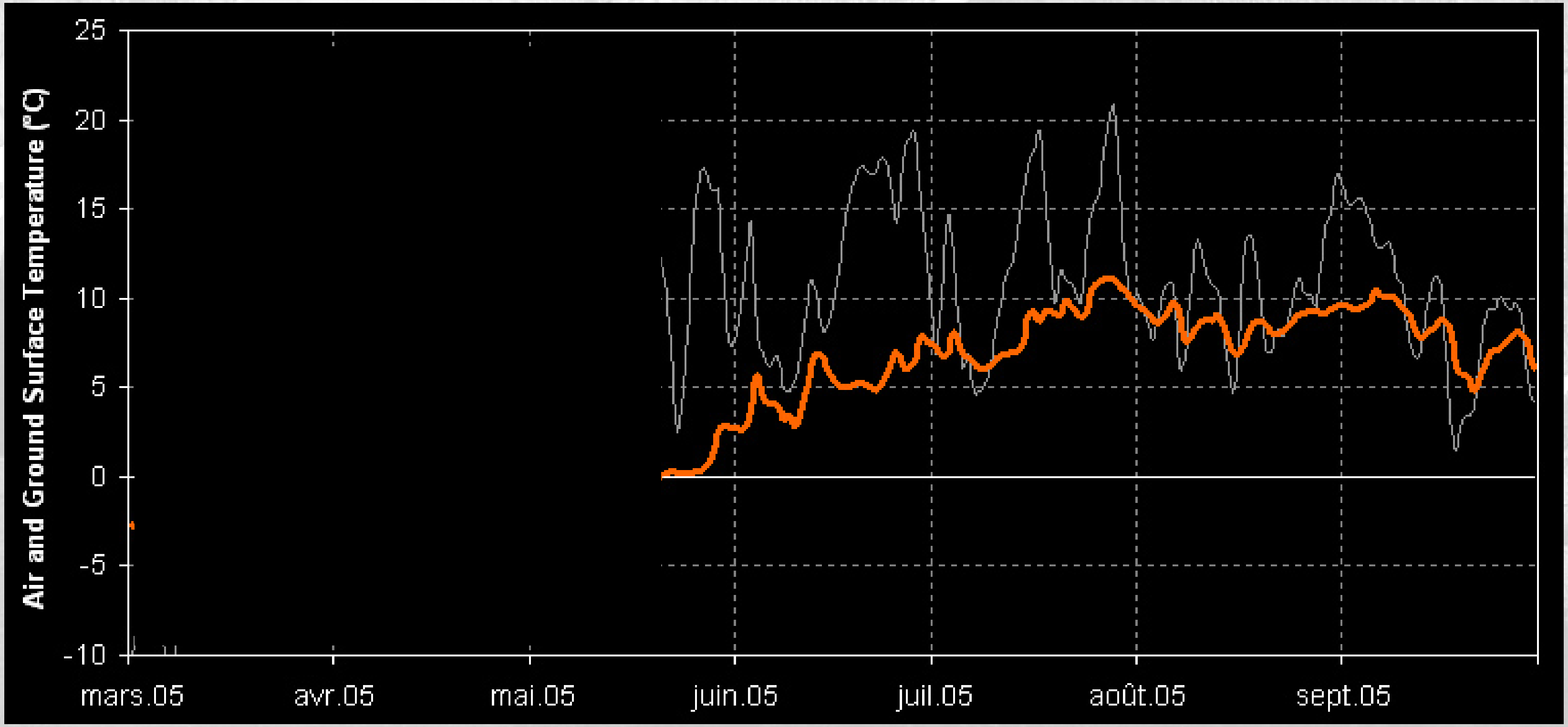
…located with **azonal vegetation areas** (dwarf trees, alpine species…)

*Bois des Arlettes (S. Morard)*

*Dreveneuse (R. Delaloye)*

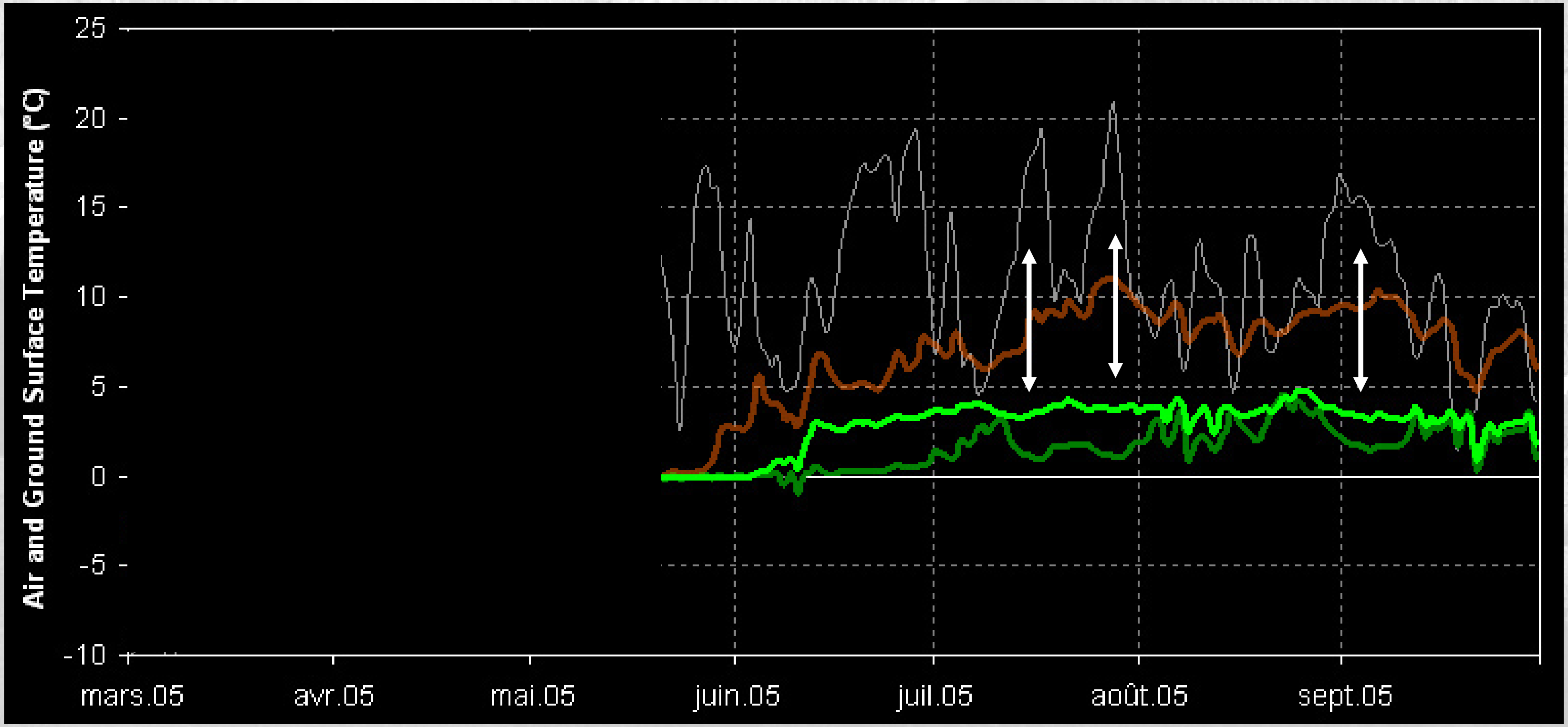
# SUMMER

- Smooth fluctuations directly **dependent** on the external air temperature.



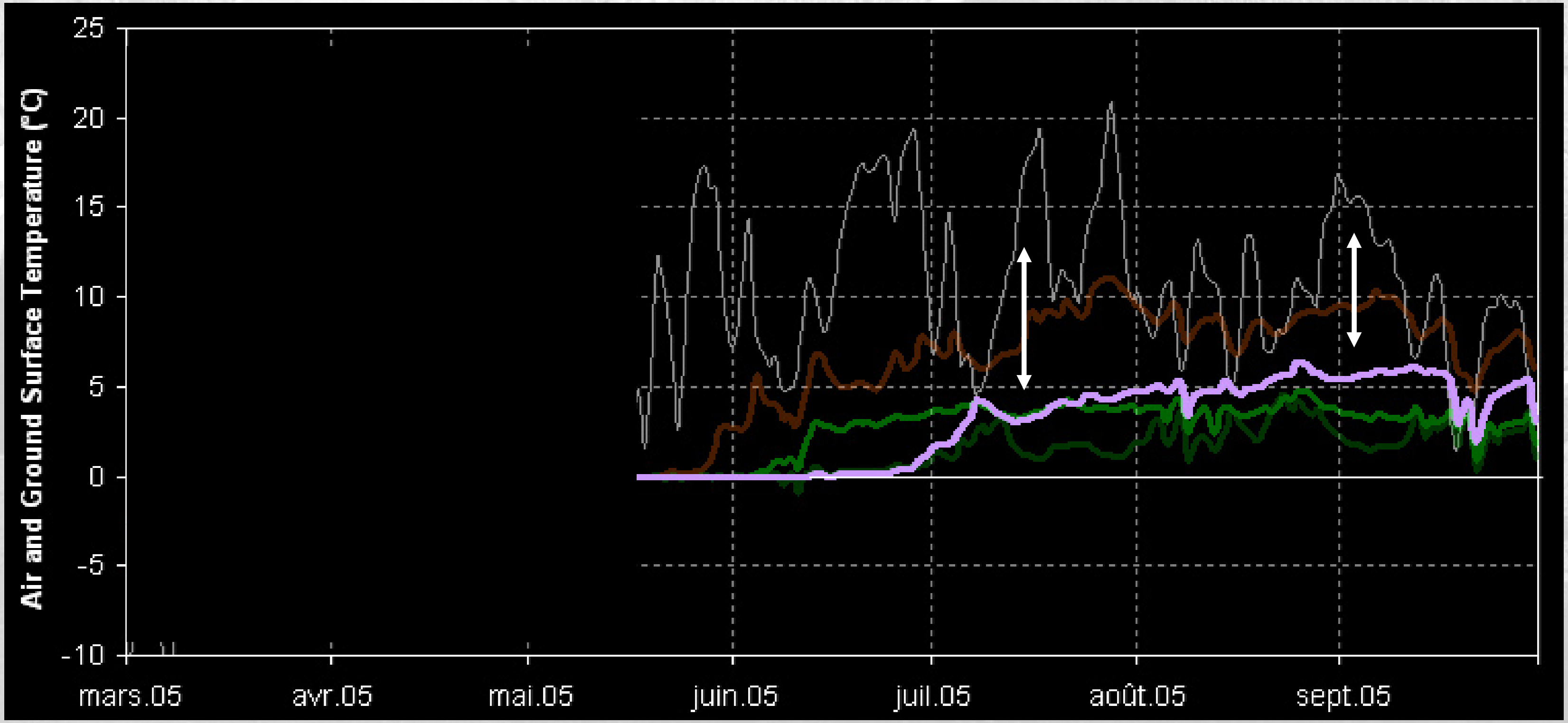
# SUMMER

- **Stable and cold GST** (1.5 - 3°C),…
- … with **inverse** relationship with air temperature.
- Azonal vegetation (with alpine species)



# SUMMER (gravity discharge of cold dense air)

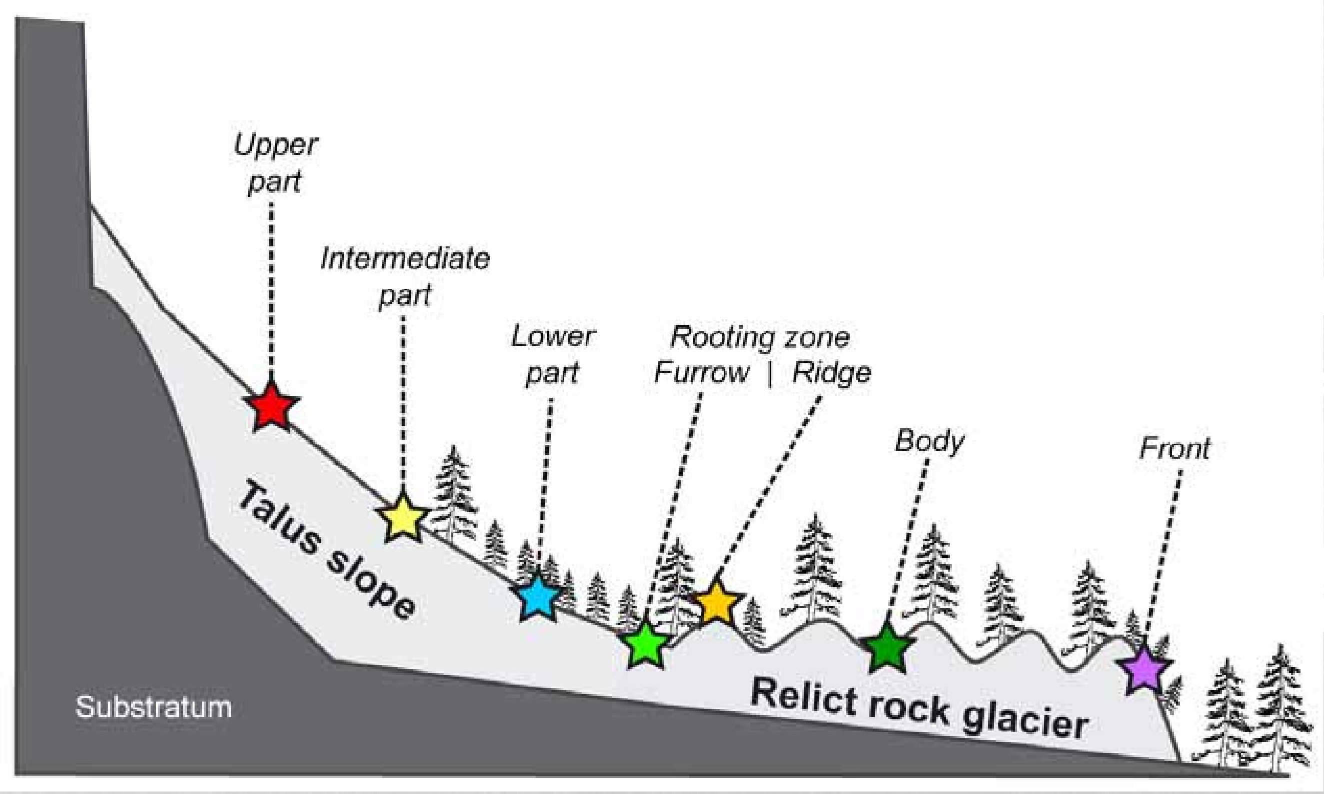
- **Stable and cold GST** (4 – 5°C),…
- … with **inverse** relationship with air temperature.
- Azonal vegetation (with alpine species)



# SUMMARY

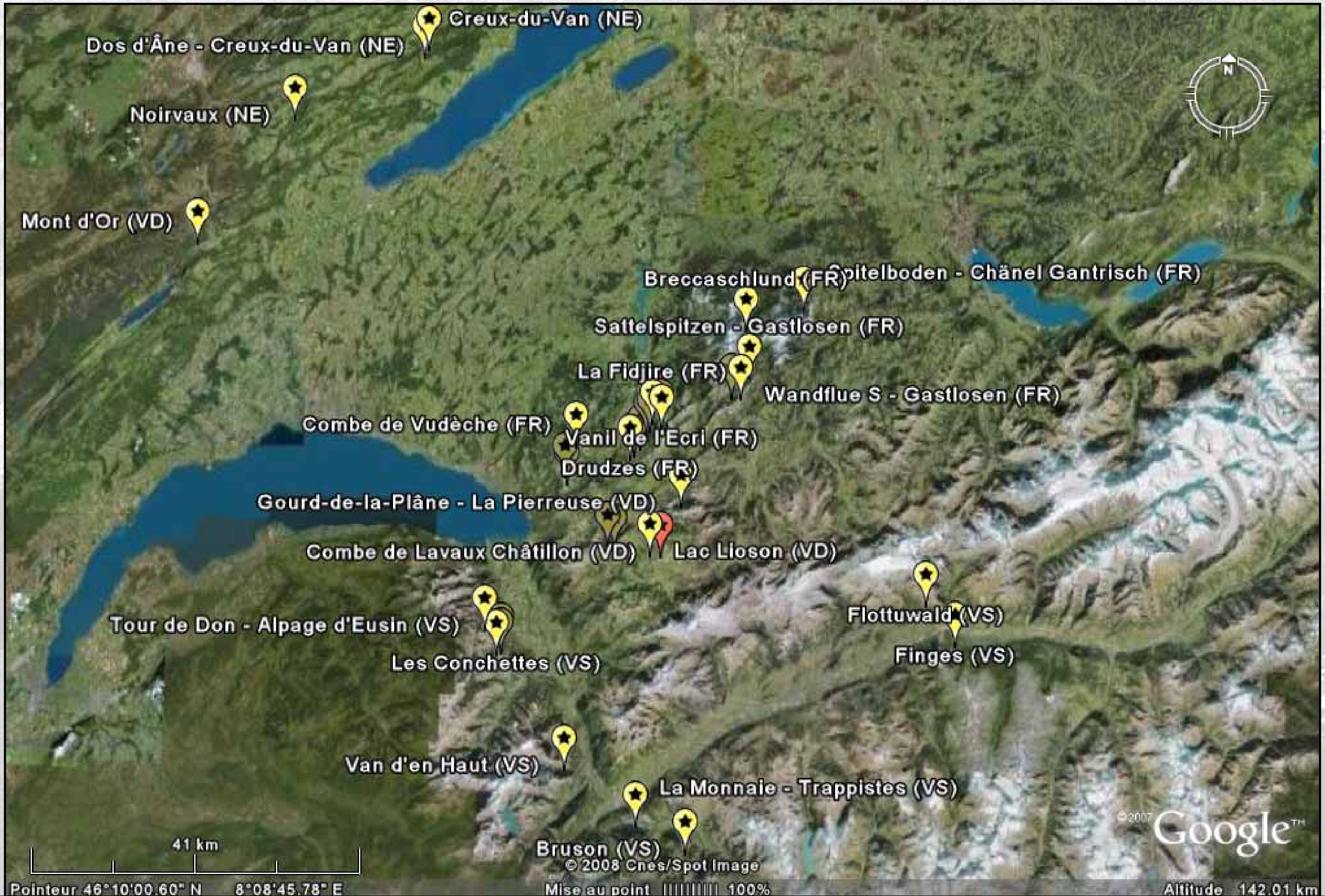
- An **heterogeneous** annual GST regime (*Delaloye 2004, Morard et al. 2008*)…

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **MAGST** | 7.94 | 5.54 | **- 0.01** | **- 0.92** | 2.54 | **- 0.85** | 0.68 | ***MAAT = 3.9°C*** |
| **ATA** | +4.04 | +1.64 | **- 3.91** | **- 4.82** | -1.36 | **- 4.75** | **- 3.22** | |



# OCCURRENCE AND FREQUENCY ?

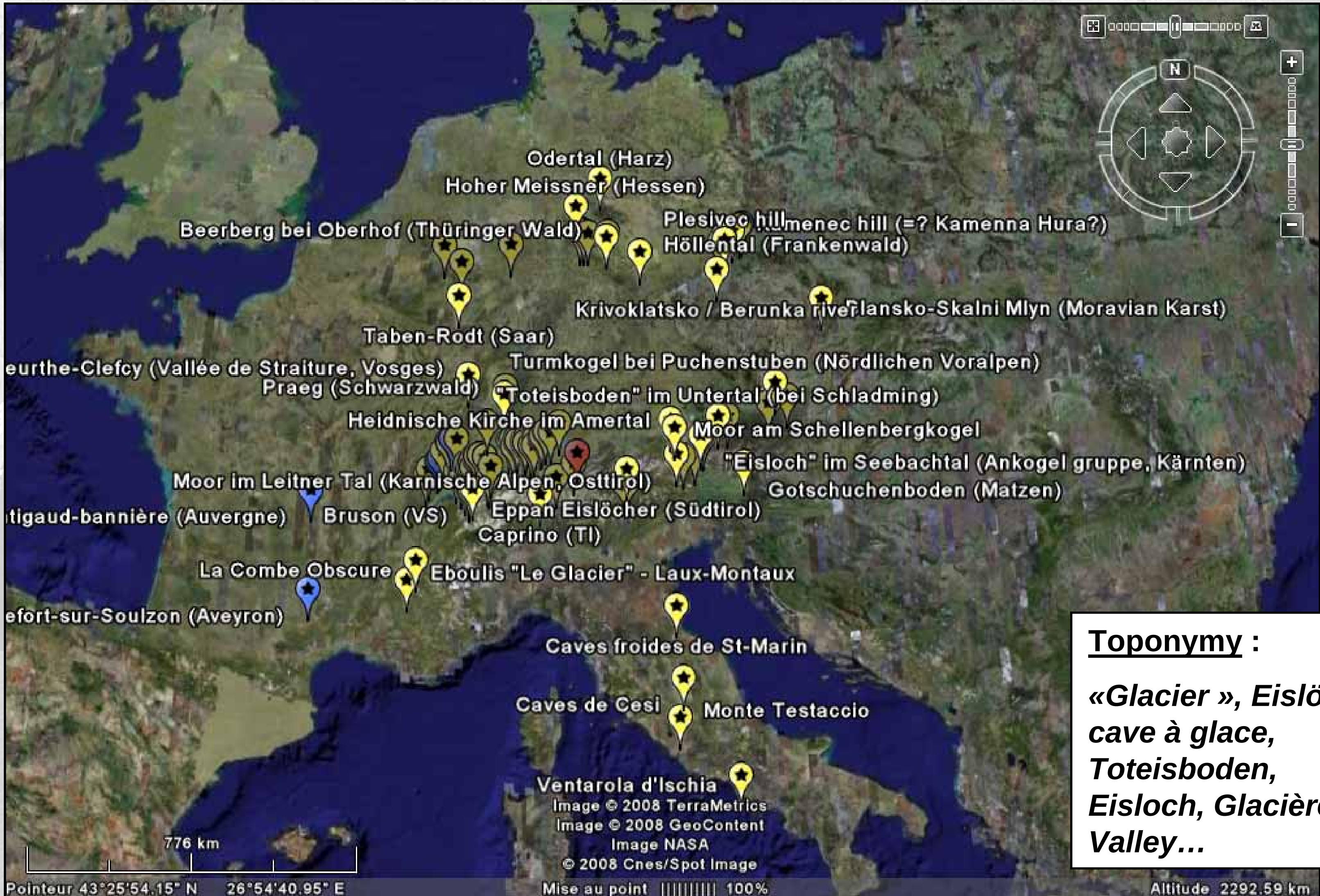
In western part of Switzerland…



# OCCURRENCE AND FREQUENCY ?

…In Europe (more than 100 sites detected)…

…and in the world (Japan, USA)…




**<u>Toponymy</u> :**

***«Glacier », Eislöcher, cave à glace, Toteisboden, Eisloch, Glacière, Ice Valley…***

# WHICH PROCESSES ?

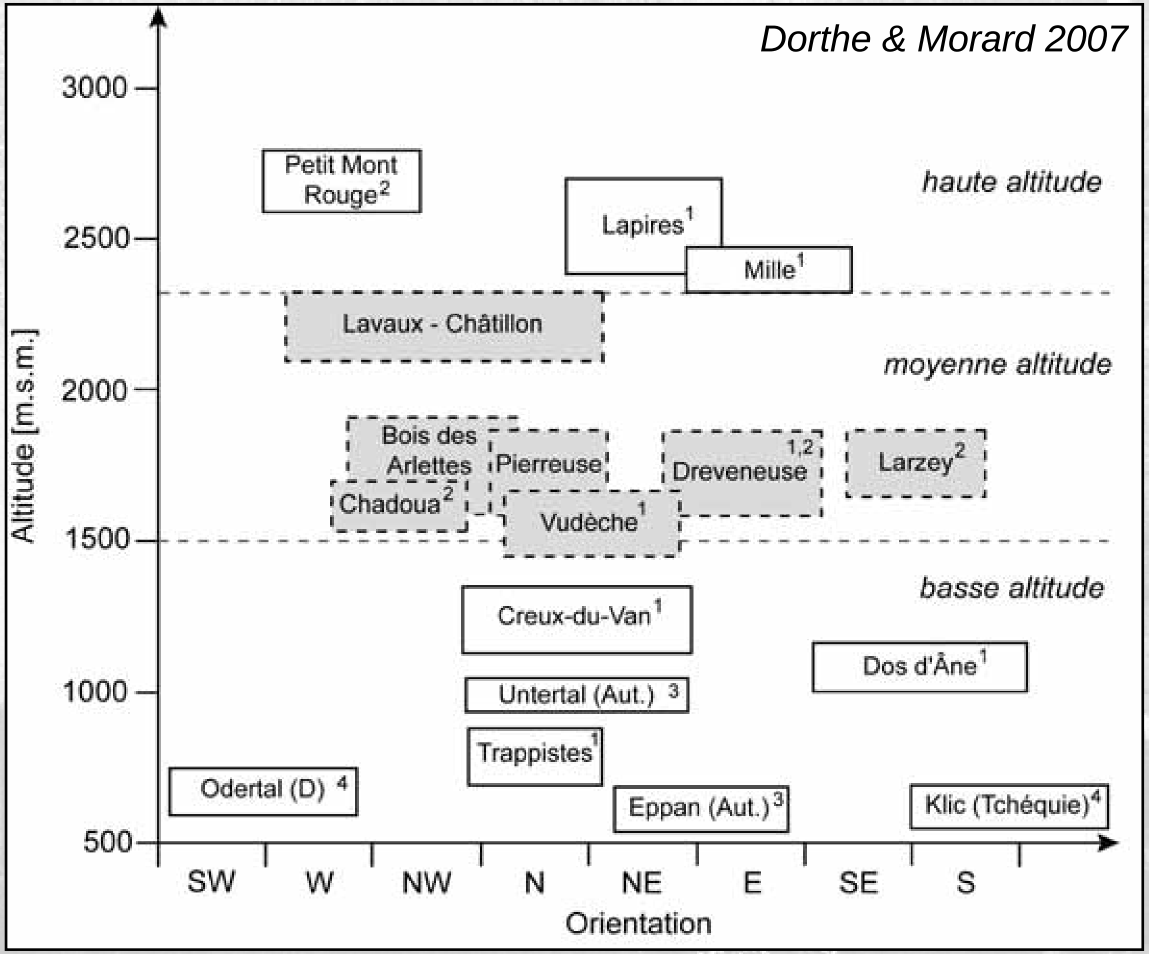
- **Thermal gradient** between the outside and inside (ground) air

⇒ Mid-latitude climate with seasons.

- Material : **every type of rocks** (limestone, granite…)

⇒ Efficient **porosity** needed.

- **Orientation** : all !



# WHICH PROCESSES ?

- **Thermal gradient** between the outside and inside (ground) air

⇒ Mid-latitude climate with seasons.

- Material : **every type of rocks** (limestone, granite…)

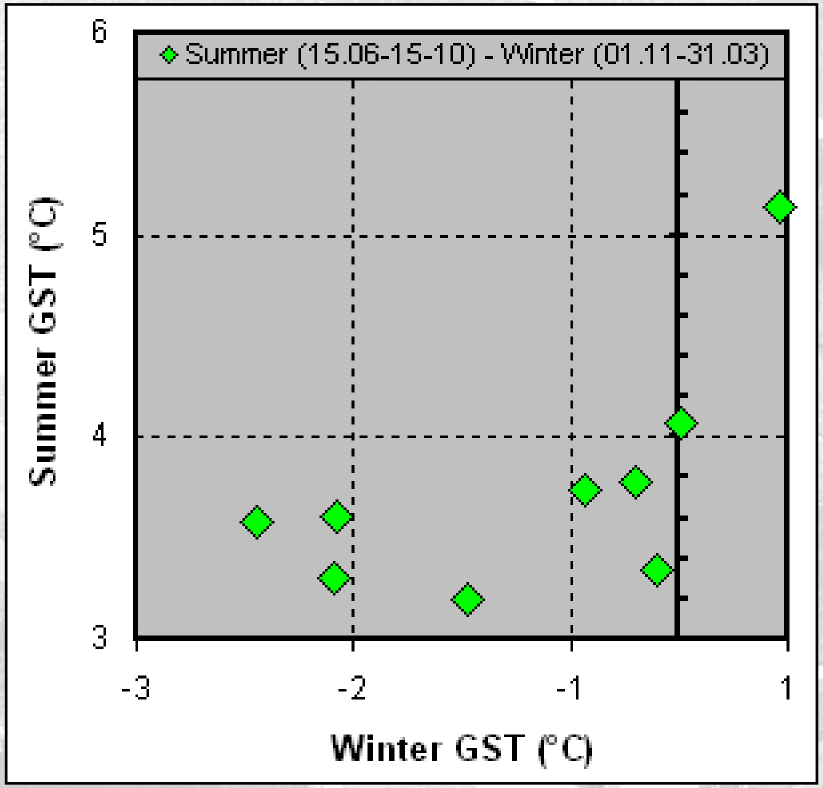
⇒ Efficient **porosity** needed.

- **Orientation** : all !

- **Winter external meteorological conditions**.

⇒ Main influence on ventilated system energy balance ?

- Others : vegetation, snow, evaporative cooling… ?




*Creux-du-Van (1998 – 2007)*

# IMPLICATIONS ON ECOSYSTEMS ?

- **Dwarfing** of trees (*Hexenwald*), phenological development (Descroix 2001),
- Occurrence of **alpine and boreal species** (*prizelago alpina, dryas octopetalia*…)
- Soils → ***ORAL PRESENTATION OF MICHELE FREPPAZ (coming next…)***

*Which is the oldest one?*

# IMPLICATIONS ON ECOSYSTEMS

- **Arctic / high alpine species** (spider, mite, beetle…) (*Gude & Molenda 2000, 2003*).

- DNA analysis → own genetic evolutionary way (**island like character** of this biotope) !

- **Relict fauna from ice age** (*Gude & Molenda 2003*)

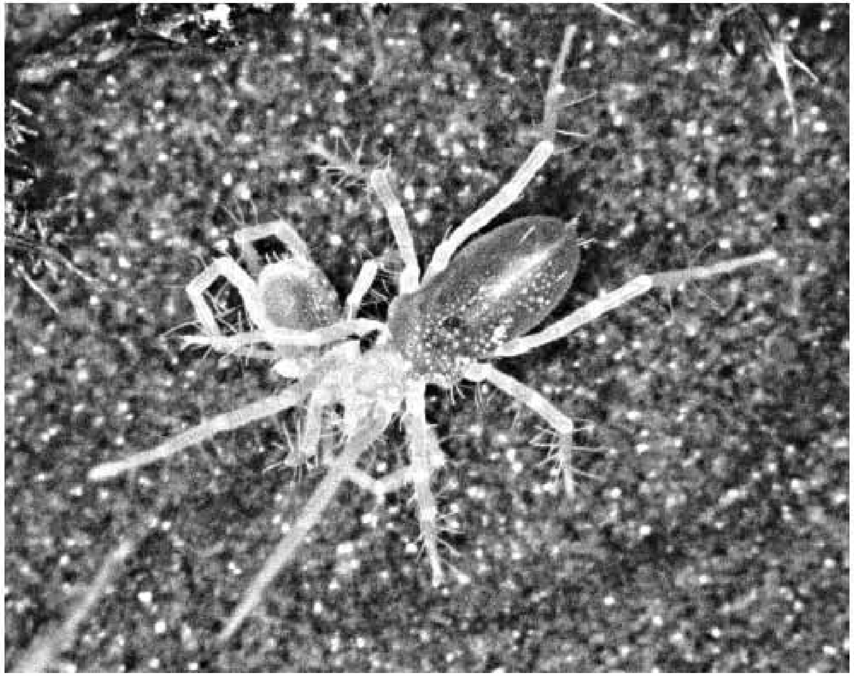


FIGURE 5. The cool tolerant predatory mite *Rhagidia gelida*, with hoarfrost on its dorsum, cannibalizing a member of its own species.

During the European Pleistocene glaciation there was a vast periglacial zone between the Alps and the northern continental ice sheet. This zone was subject to severe nival climate and permafrost with associated upper active layer cryogenic processes such as intensive frost weathering, solifluction, and growth of ice wedges. Similar conditions still prevail in the Arctic (Ives, 1974; Schrott, 1999). The predatory mite *R. gelida* frequently occurs in the Arctic and was also collected in Barrow, Alaska (Strandtmann, 1971), in high arctic tundra meadow on the Arctic Coastal Plain where surface temperatures reach +8–13°C during the summer (MacLean and Pitelka, 1971; Hinkel et al., 2001). The temperature regimes of the surface organic layer in the Klíč and Kamenná Hůra scree ice hollows are strikingly similar to those near Barrow, Alaska. In the Arctic the mite has only been collected in localities with permafrost (Fig. 7) and periglacial microclimate. Direct

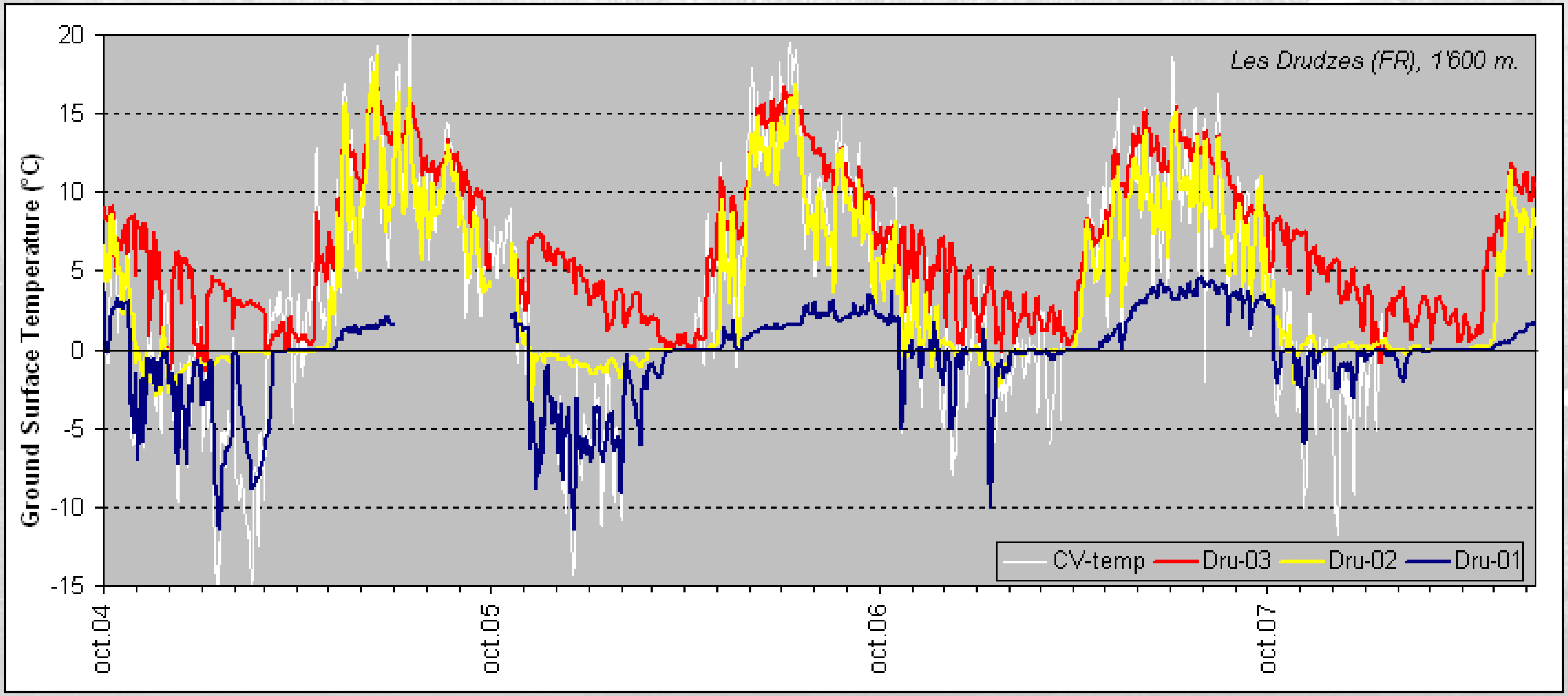
a glacial or, strictly speaking, periglacial (sensu Molenda, 1996) relict that has survived in the periglacial-like microclimate of the ice hollows, at least from the height of the last Pleistocene glaciation, when most of Europe was tundra (Matthews, 1979).

*Zacharda et al. 2005*

# IMPLICATIONS ON ECOSYSTEMS

• **Year-to-year relative thermal stability** is observed in summertime where cold air outflows occur.

⇒ Possible favorable long term abiotic conditions for azonal and less-competitive species ?



# AND AT DEPTH ? PERMAFROST ?

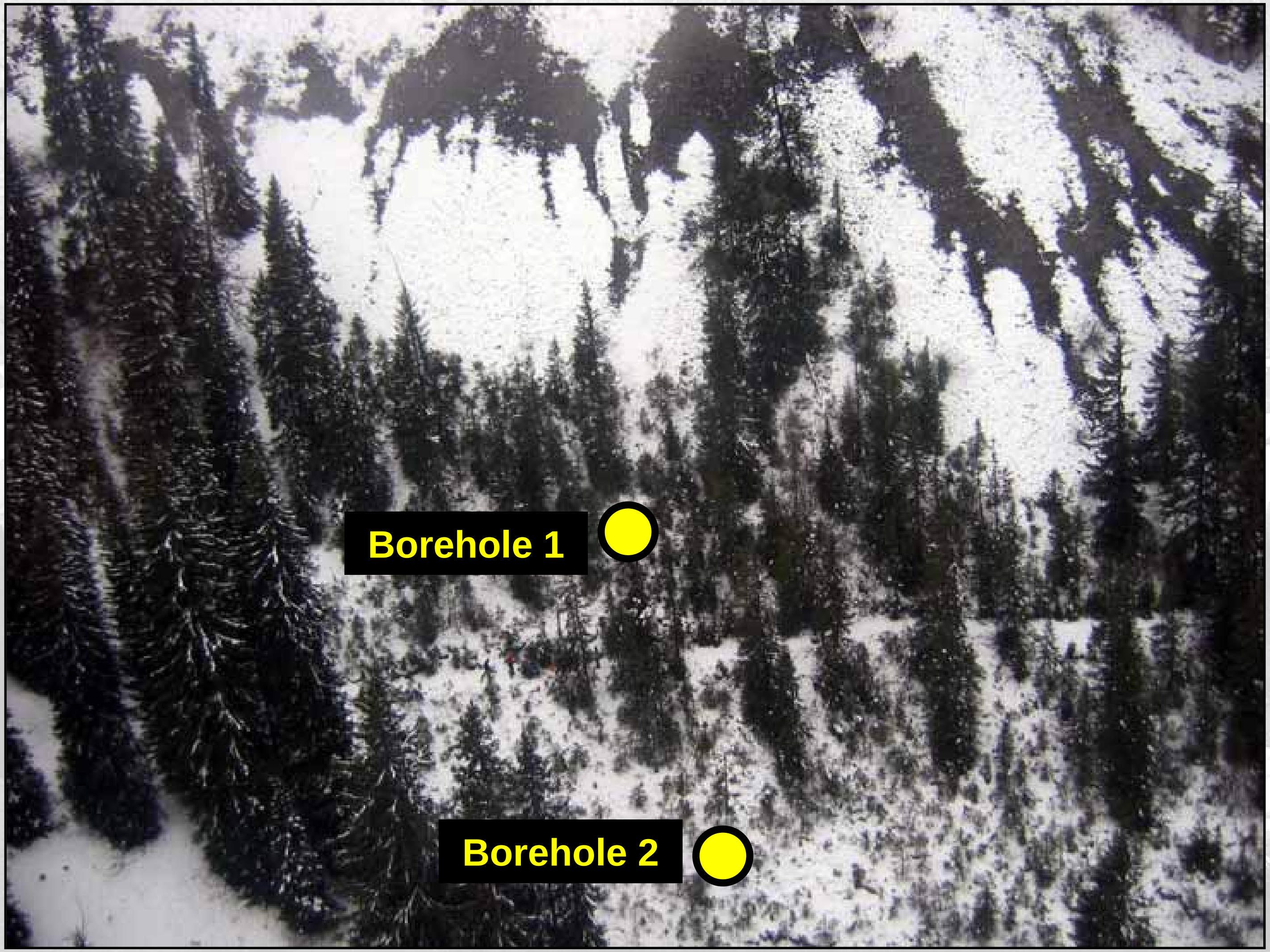
*At the ground surface…*

- **Frequent field observations and temperature measurements** (*with handy thermometer*).
- **Ground surface temperature recording** (*UTL*).
- **“BTS” mapping** (*to detect winter thermal anomalies*).
- Wind velocity, pressure, humidity…

*…and at depth*

- **Boreholes**.
- **Electrical resistivity measurements** (*to determine ground structure at depth, and eventually temperature change*).

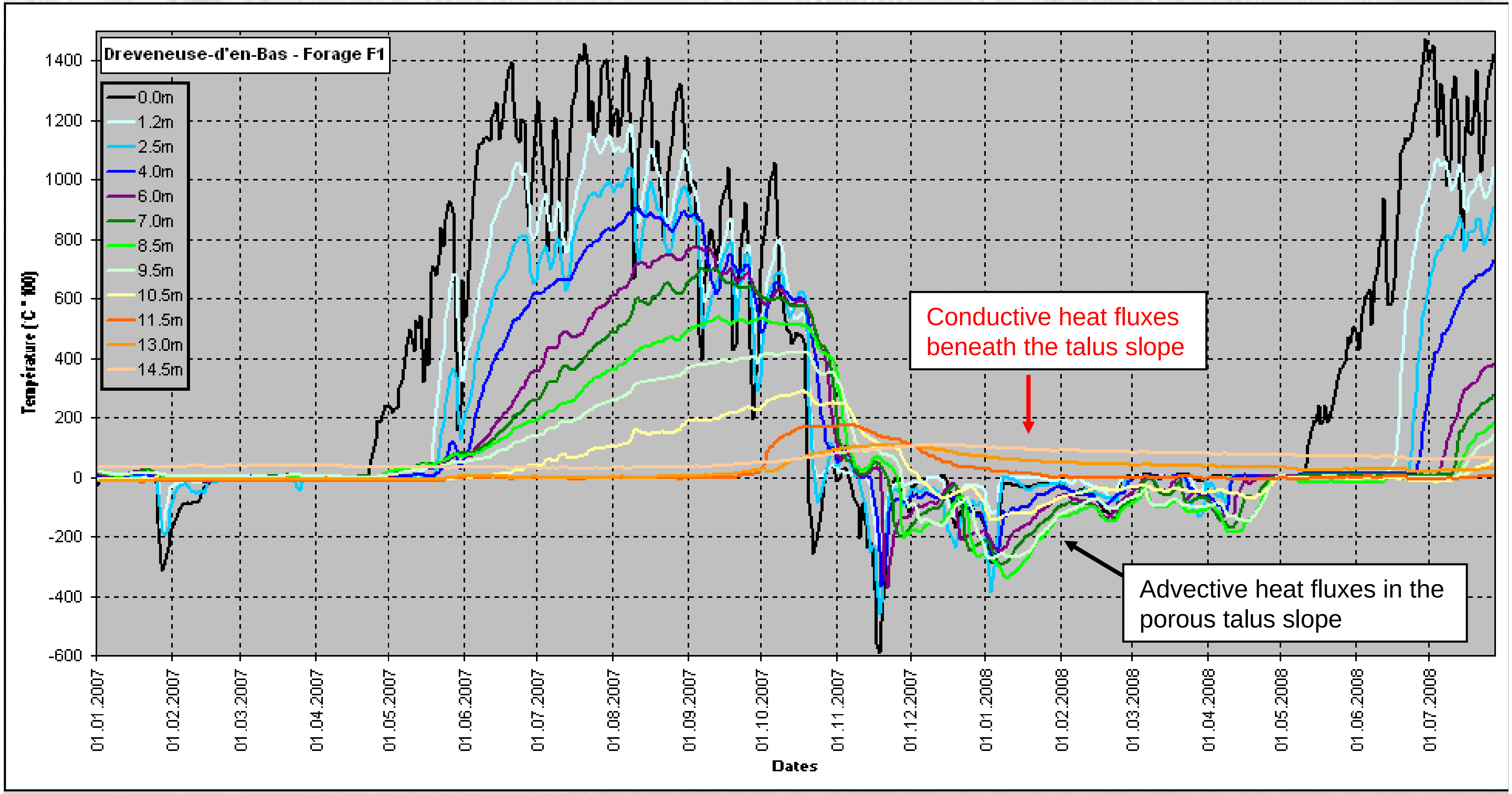
# AND AT DEPTH ? PERMAFROST ?



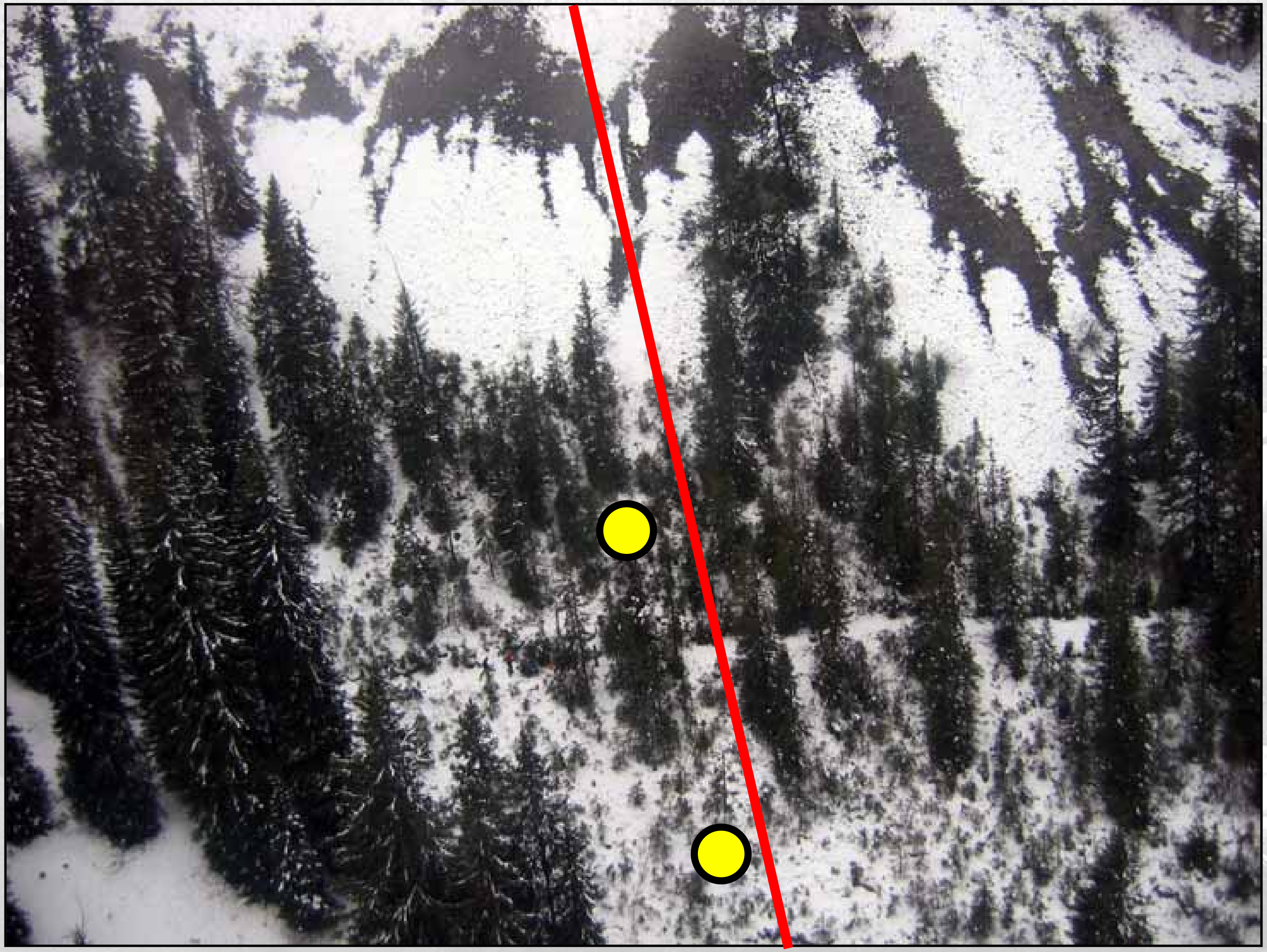

Dreveneuse *(C. Lambiel, 23.11.04)*

# AND AT DEPTH ? PERMAFROST ?

• A rapid winter cooling… **also at depth !**



# AND AT DEPTH ? PERMAFROST ?



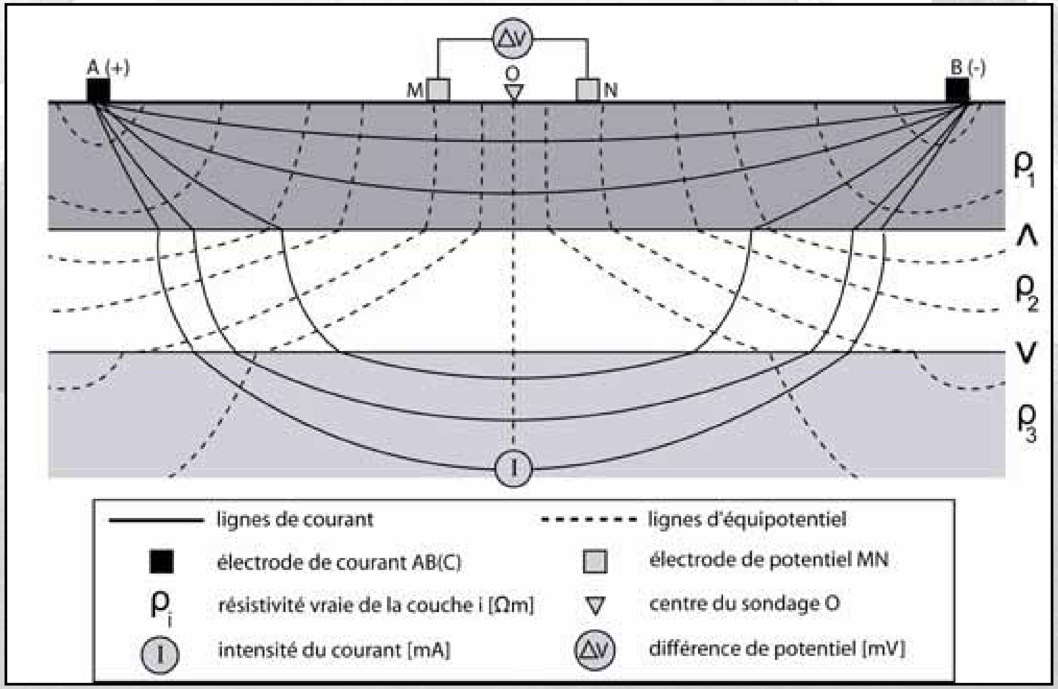
Dreveneuse *(C. Lambiel, 23.11.04)*

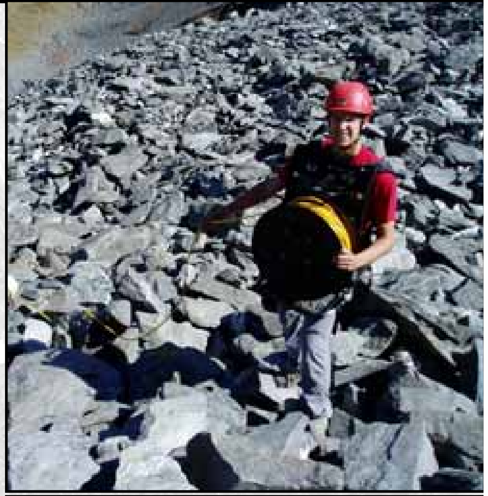
# AND AT DEPTH ? PERMAFROST ?

## Electrical Resistivity Tomography (ERT)

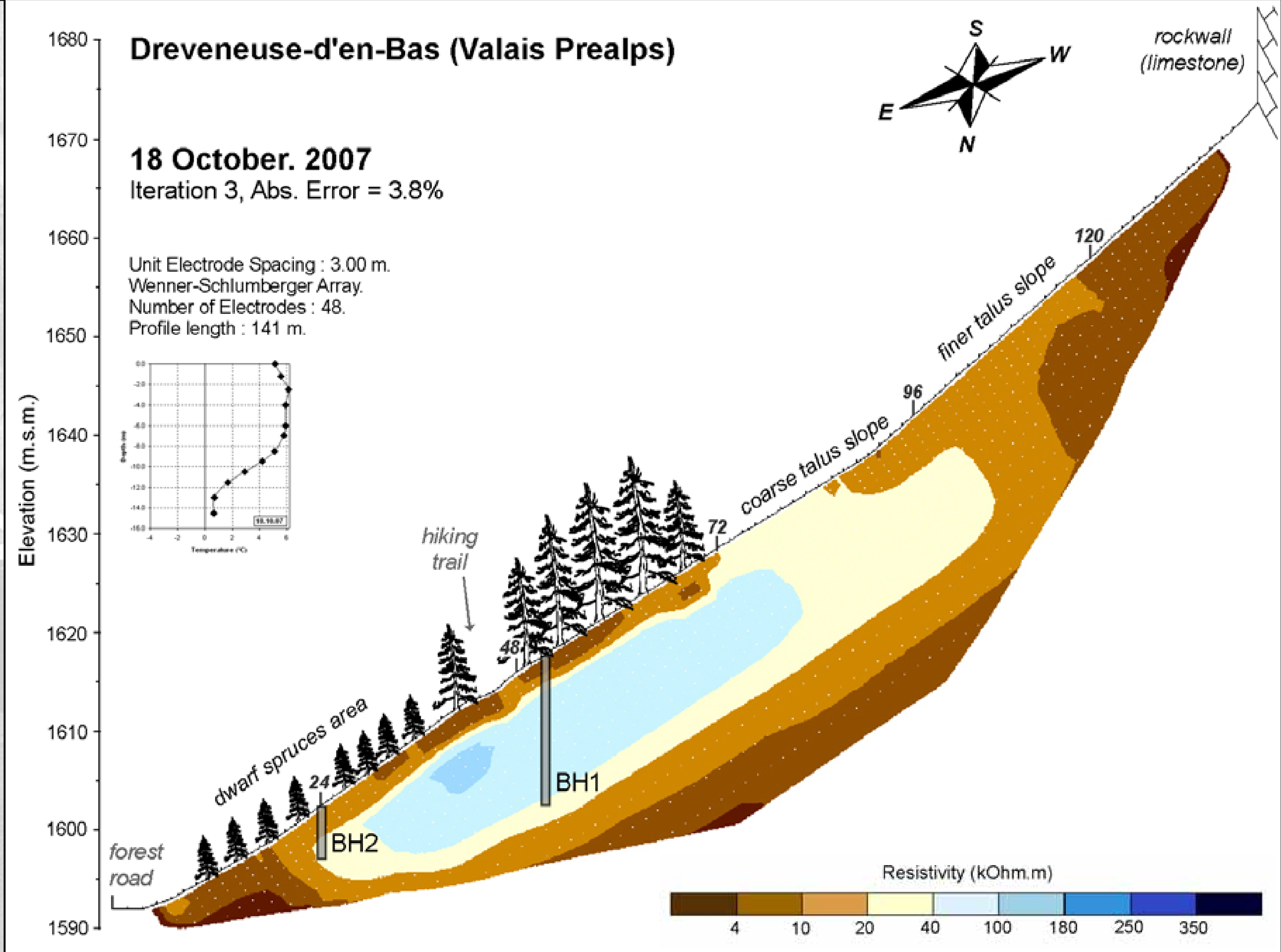
- Detecting ground electrical properties to construct a physical model of the ground.

- Resistivity depends on :
  - **Nature** of material
  - **Porosity** (air content)
  - **Water** content (very conductive)
  - **Ice** content (very resistive)
  - **Temperature**



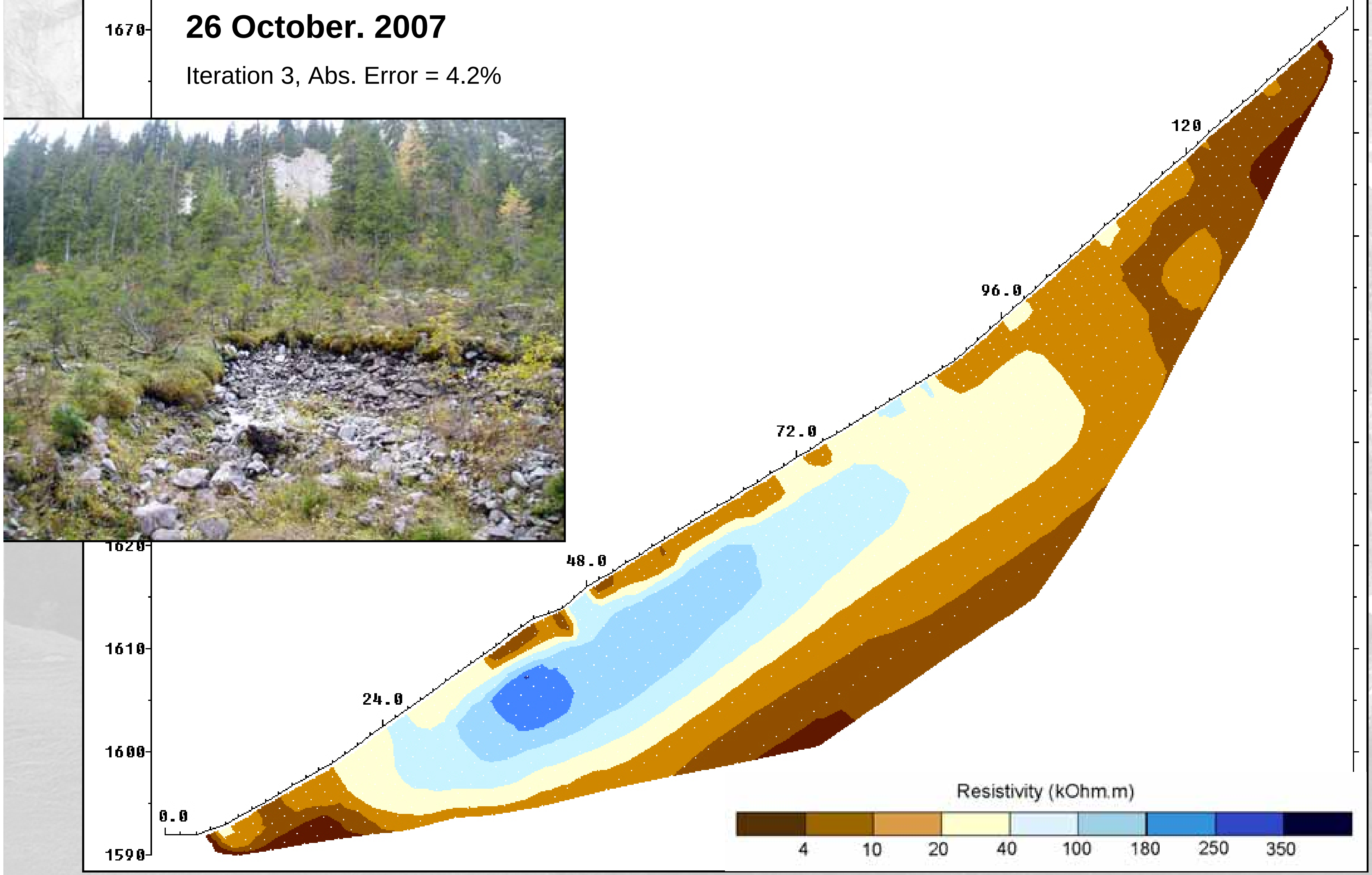



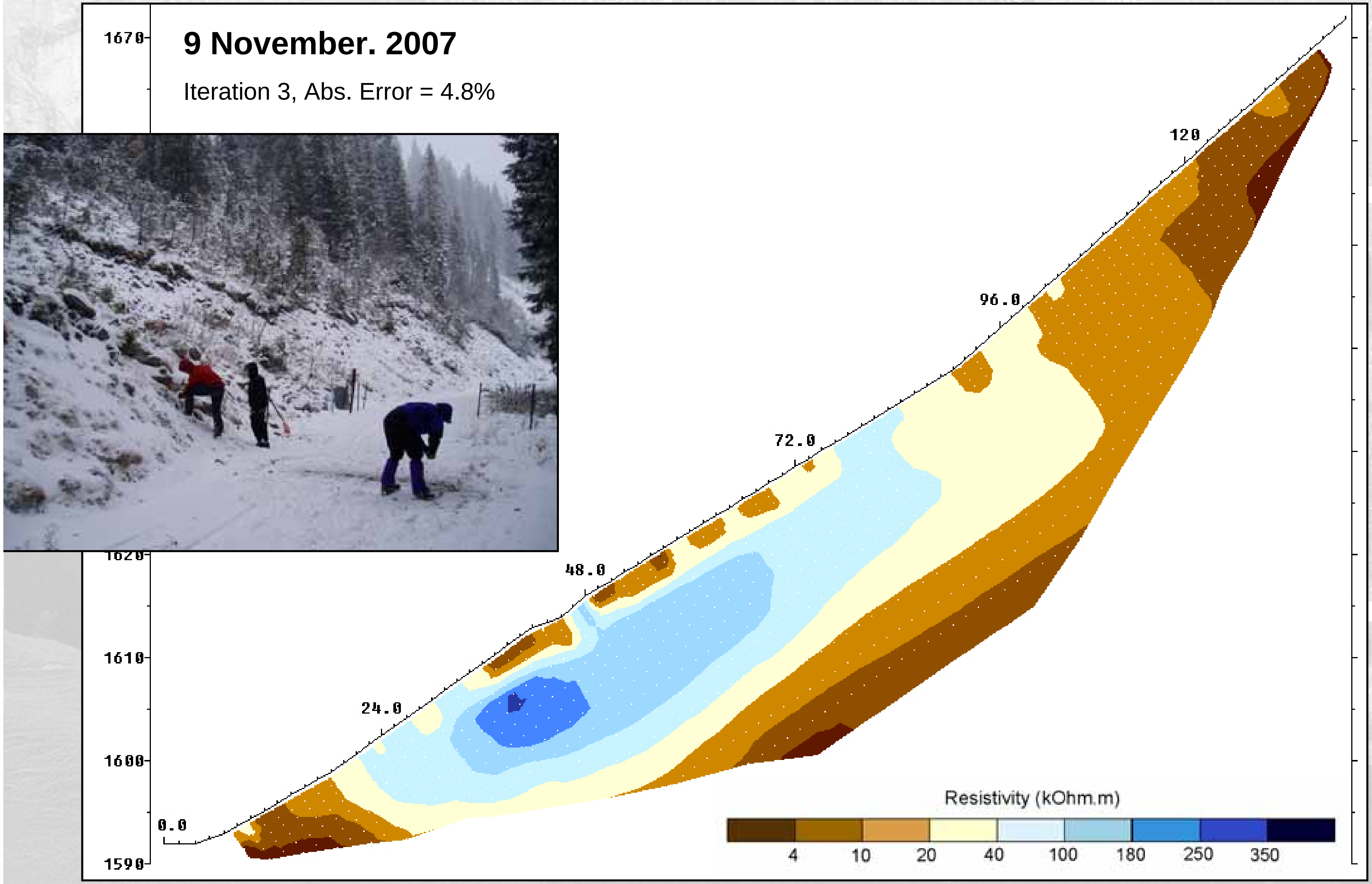

18. October 2007


Dreveneuse-d'en-Bas (Valais Prealps)
18 October. 2007
Iteration 3, Abs. Error = 3.8%
Unit Electrode Spacing : 3.00 m.
Wenner-Schlumberger Array.
Number of Electrodes : 48.
Profile length : 141 m.
Elevation (m.s.m.)
1680
1670
1660
1650
1640
1630
1620
1610
1600
1590
S
W
E
N
rockwall
(limestone)
finer talus slope
coarse talus slope
hiking
trail
dwarf spruces area
forest
road
120
96
72
48
24
BH1
BH2
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350

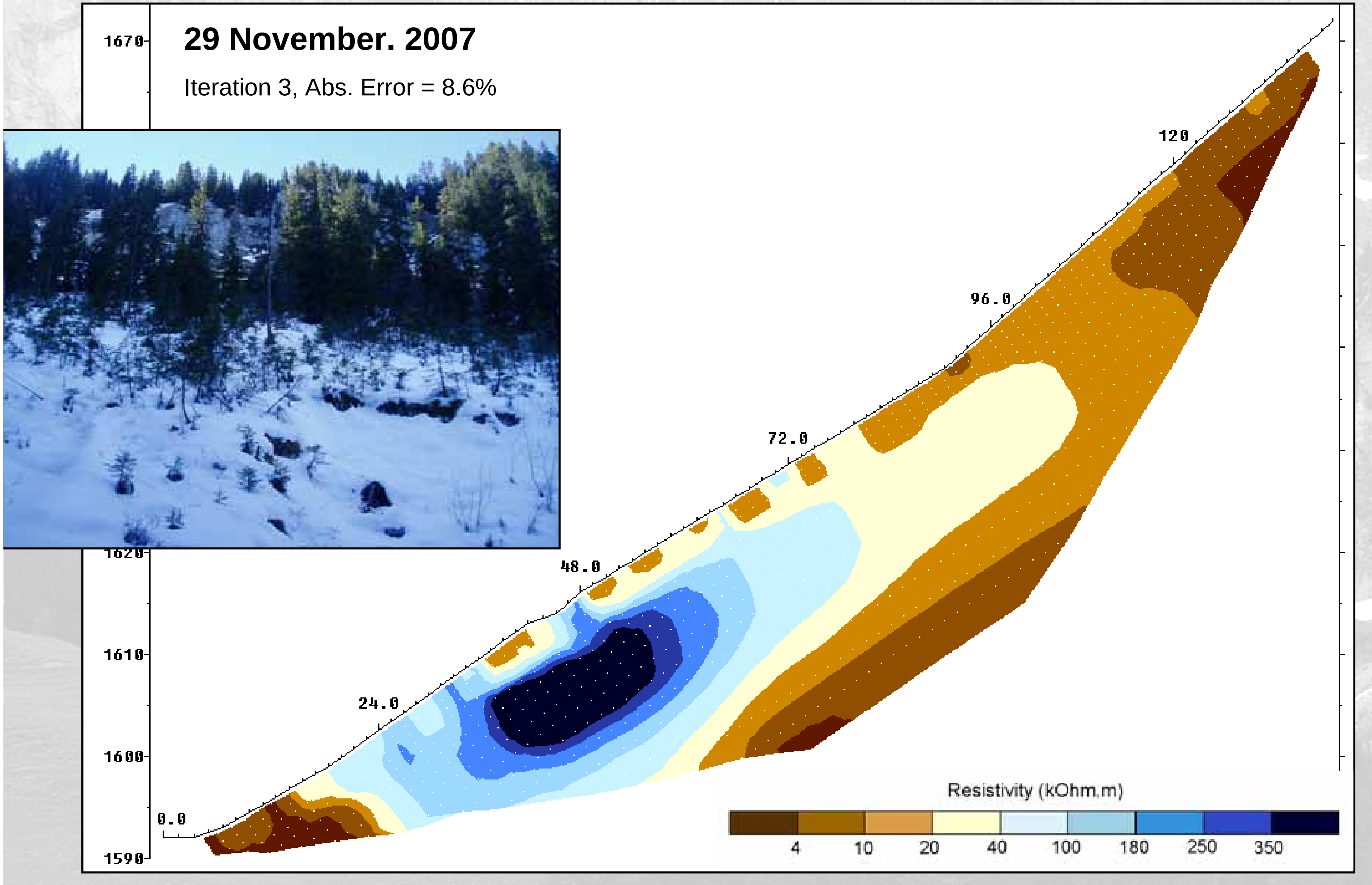
## 26 October. 2007

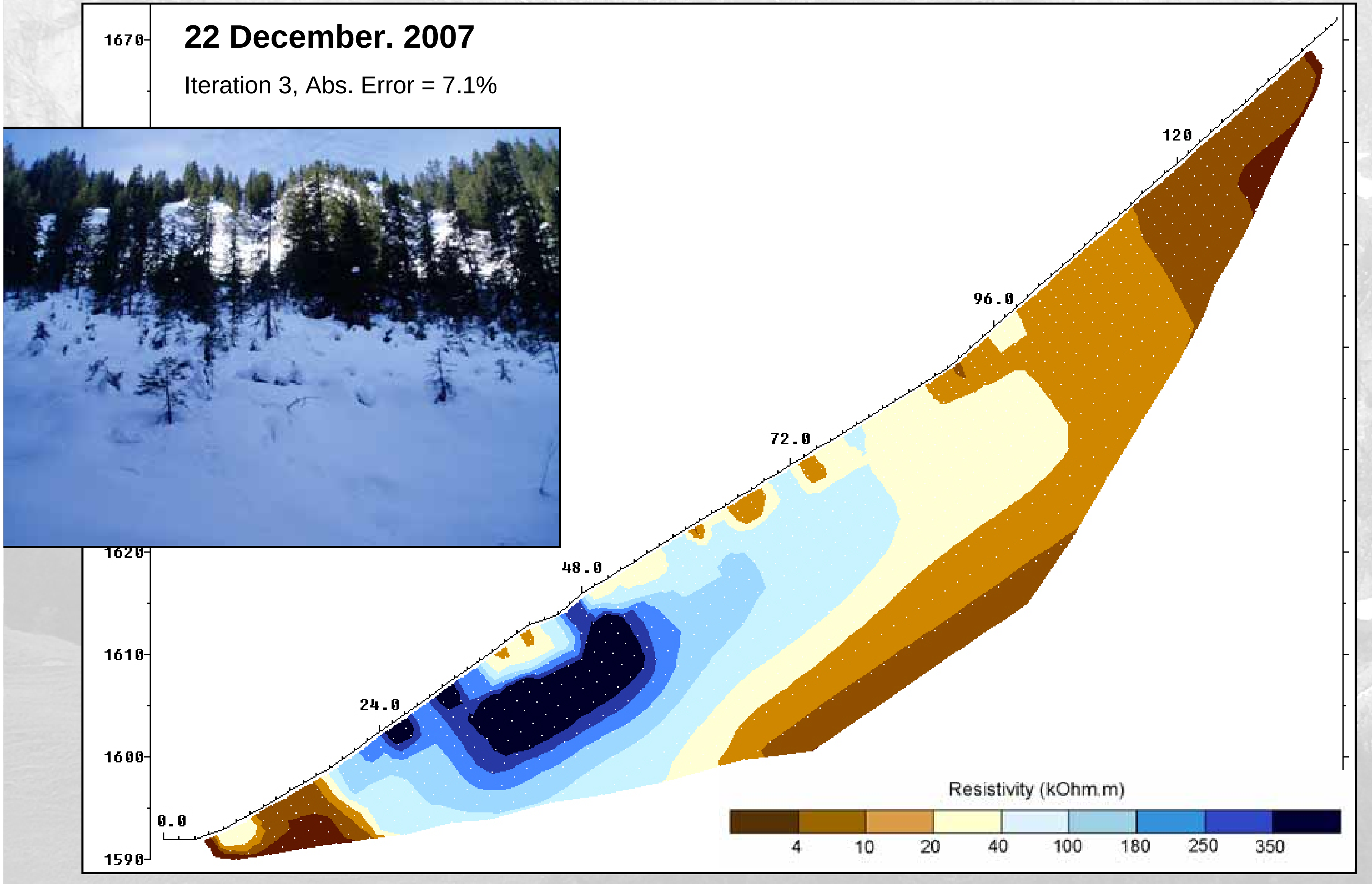
Iteration 3, Abs. Error = 4.2%

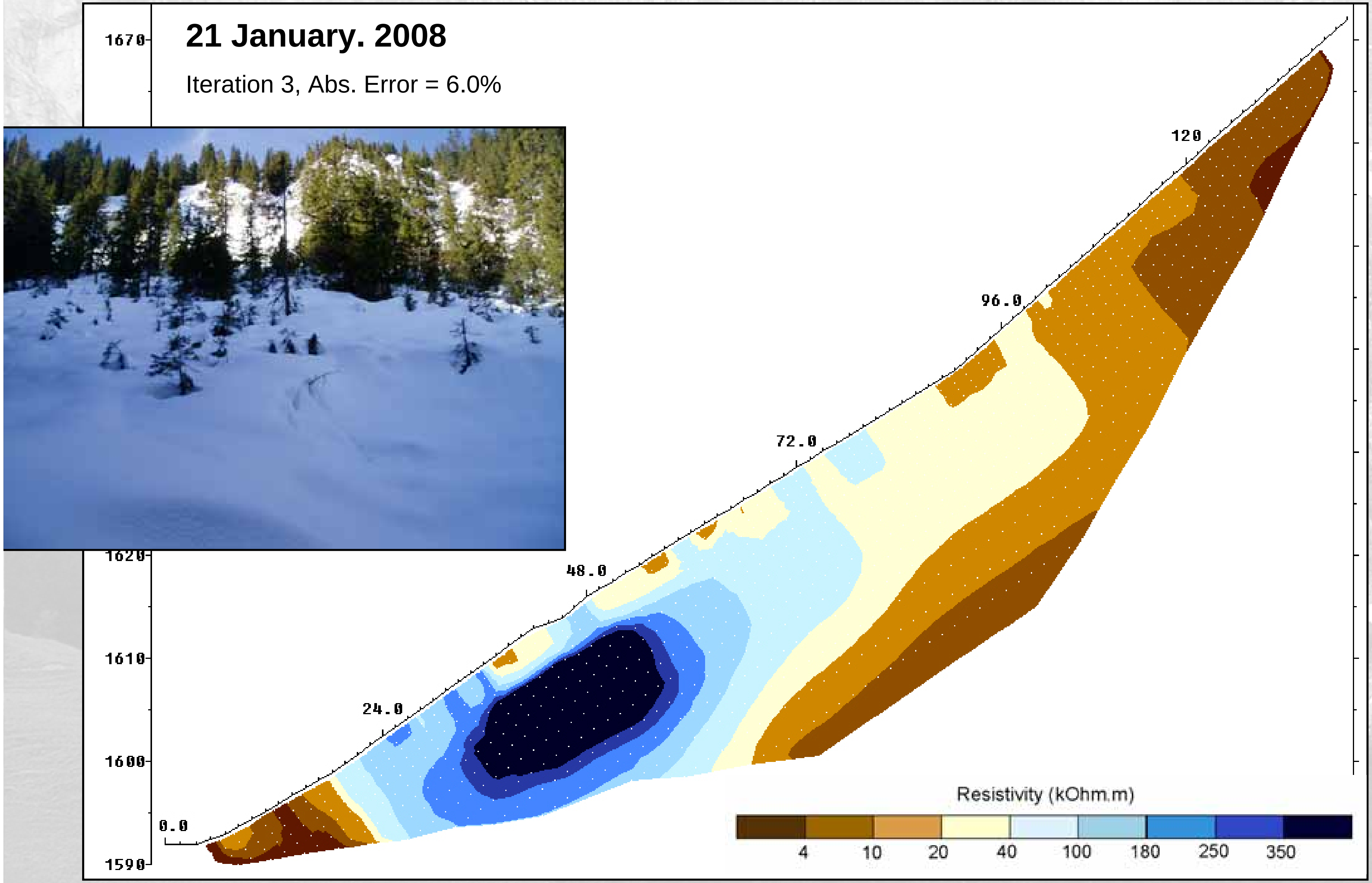


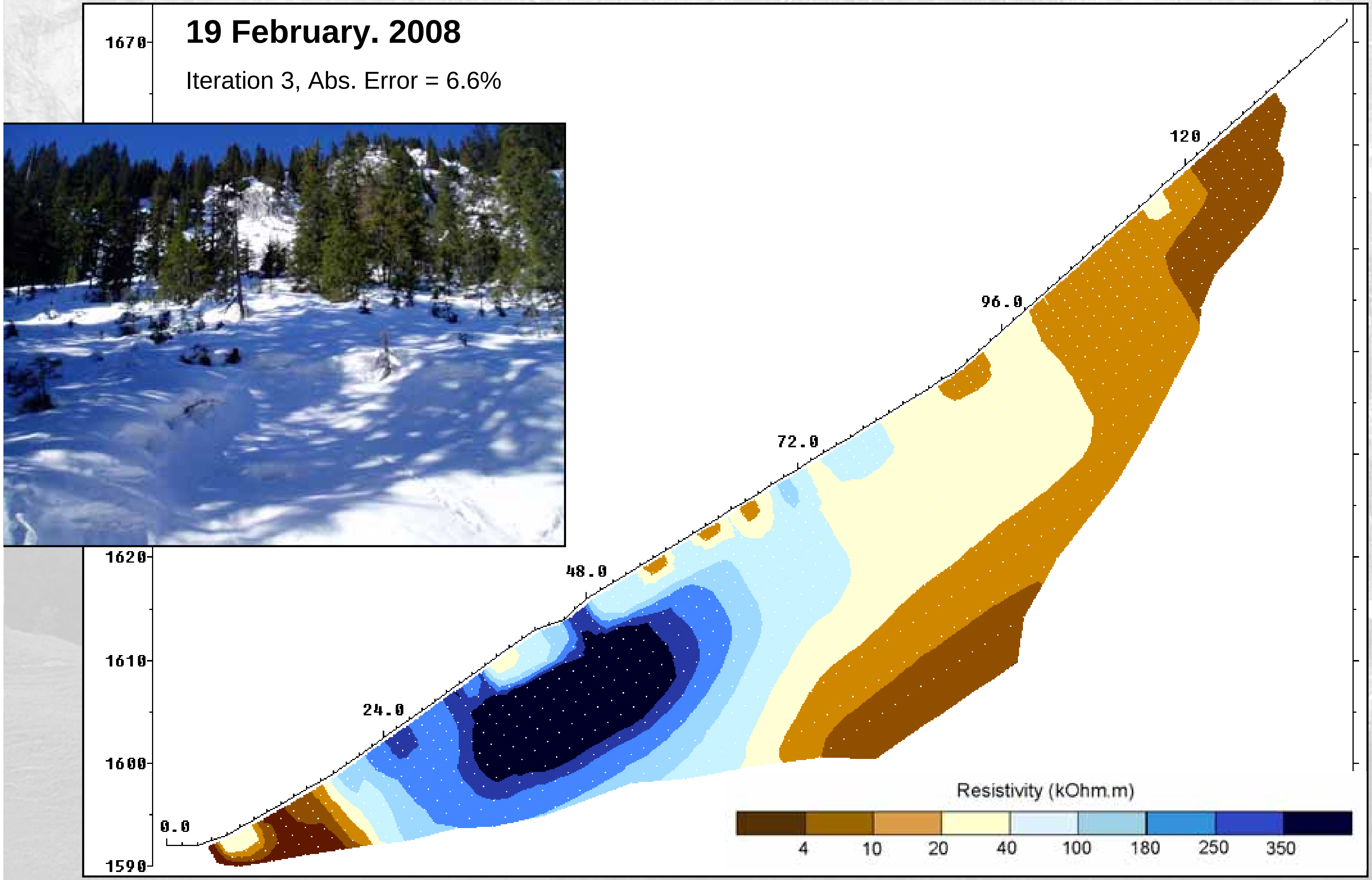


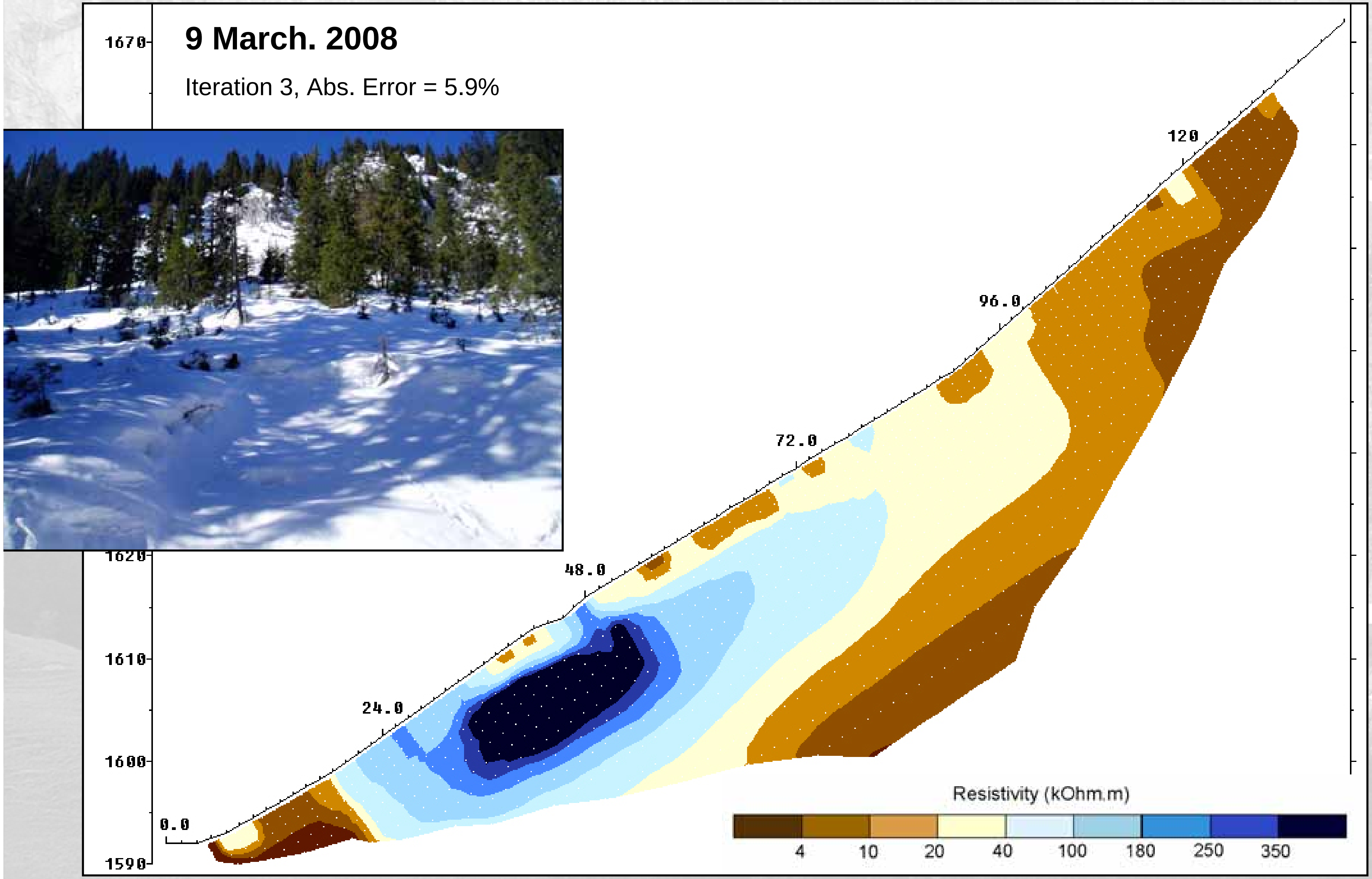
9 November. 2007
Iteration 3, Abs. Error = 4.8%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350

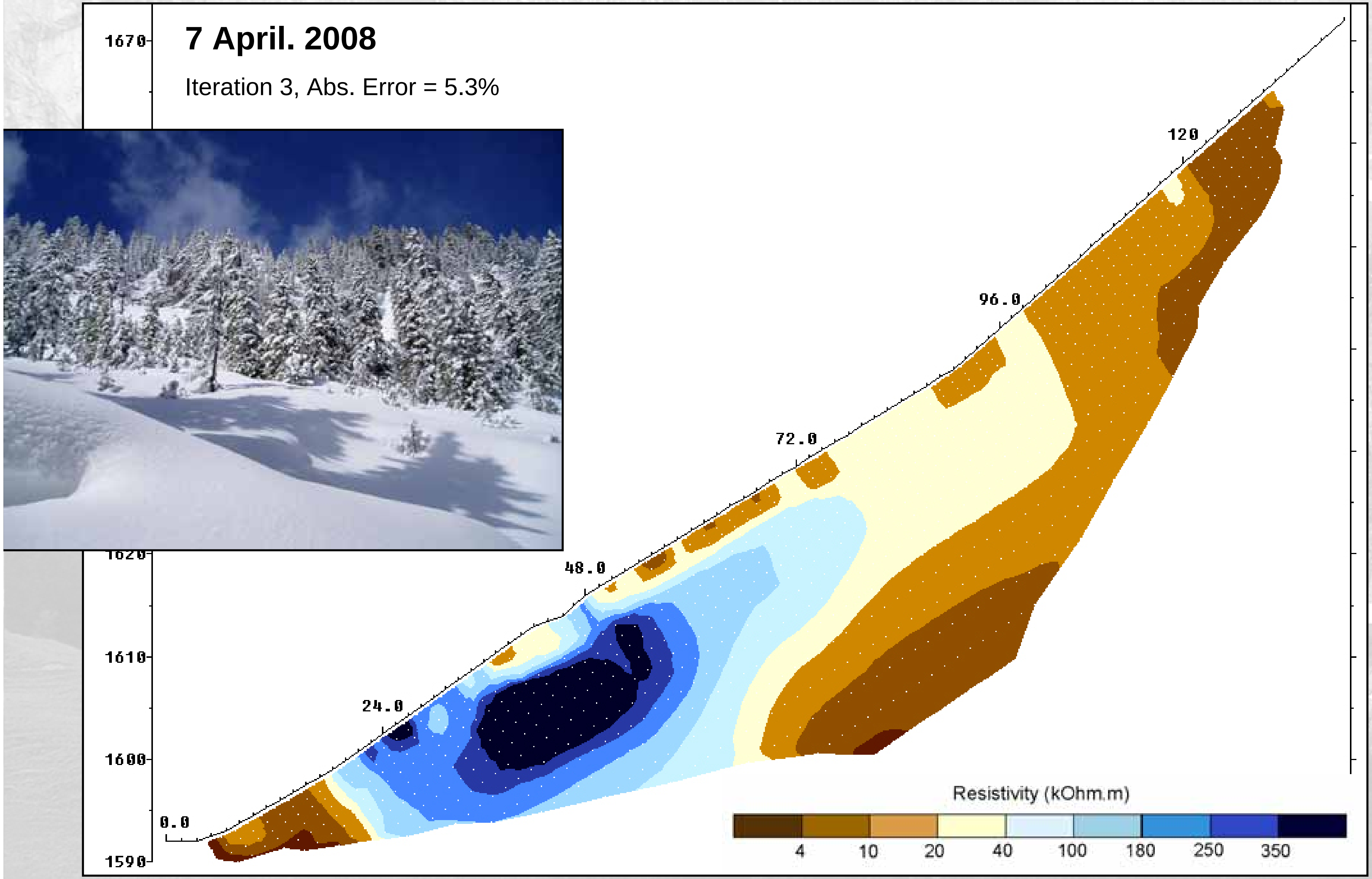

29 November. 2007
Iteration 3, Abs. Error = 8.6%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350

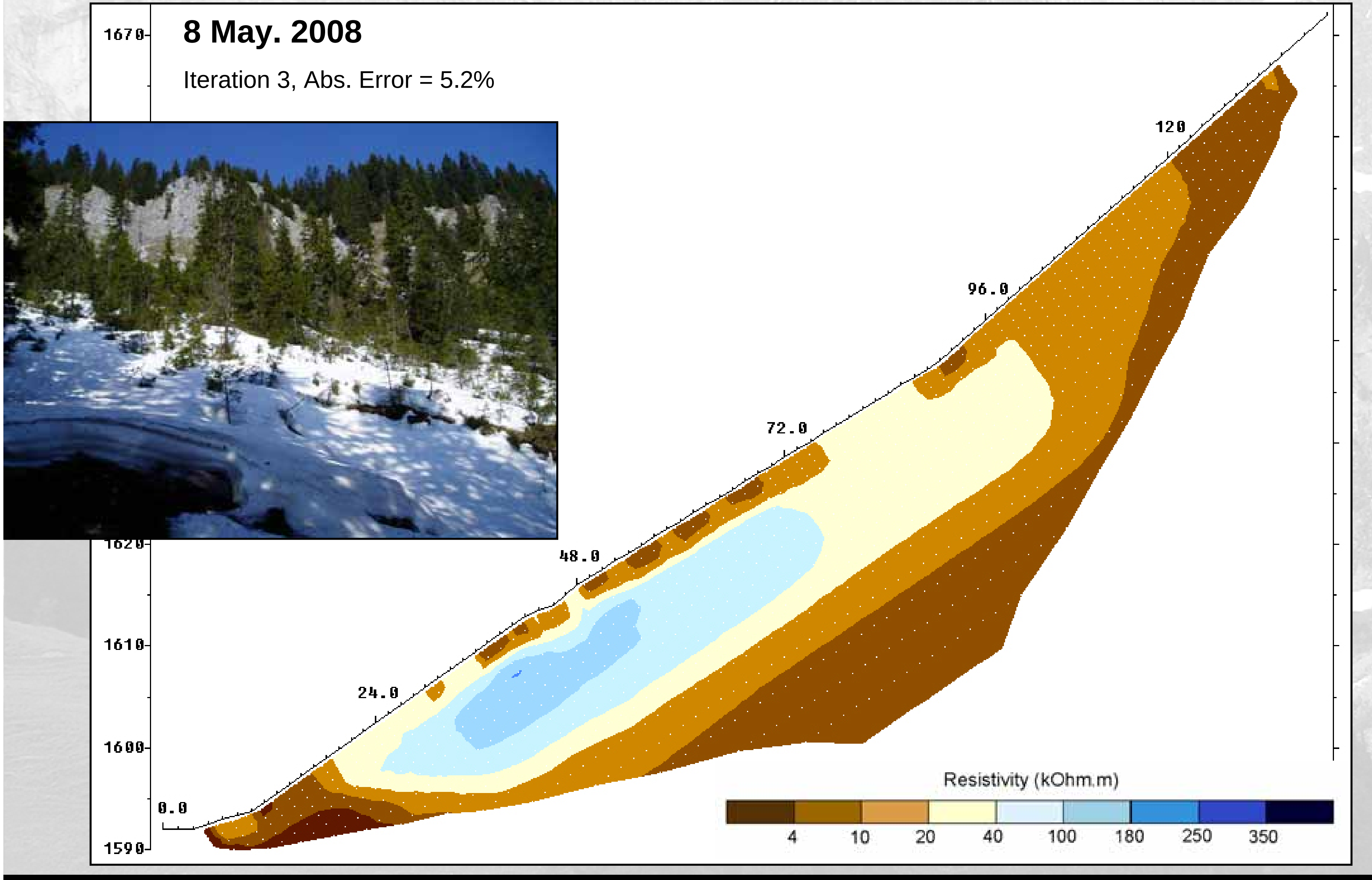

22 December. 2007
Iteration 3, Abs. Error = 7.1%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350


21 January. 2008
Iteration 3, Abs. Error = 6.0%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350


19 February. 2008
Iteration 3, Abs. Error = 6.6%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350

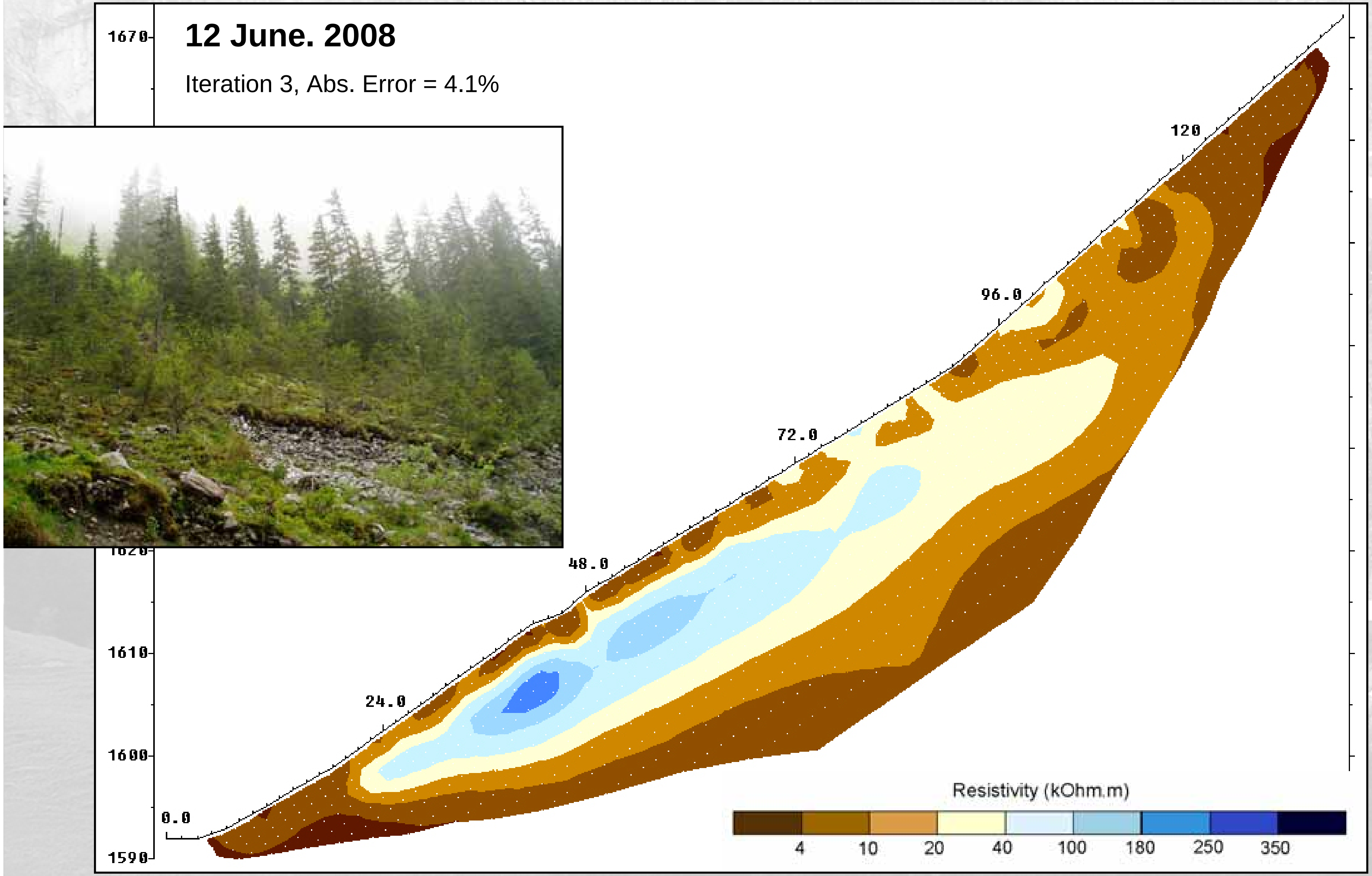

9 March. 2008
Iteration 3, Abs. Error = 5.9%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350

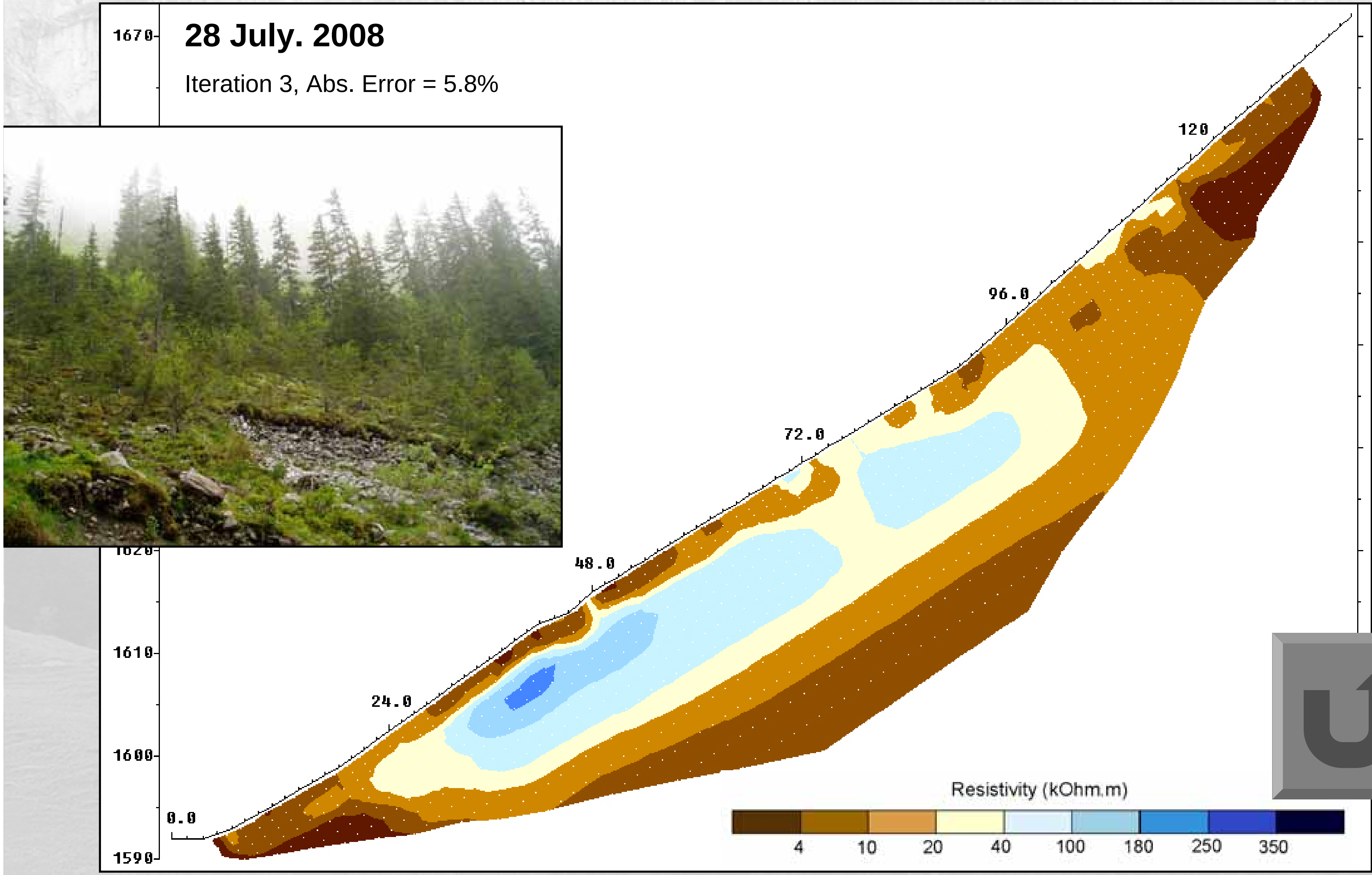

7 April. 2008
Iteration 3, Abs. Error = 5.3%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350


8 May. 2008
Iteration 3, Abs. Error = 5.2%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350

## 12 June. 2008

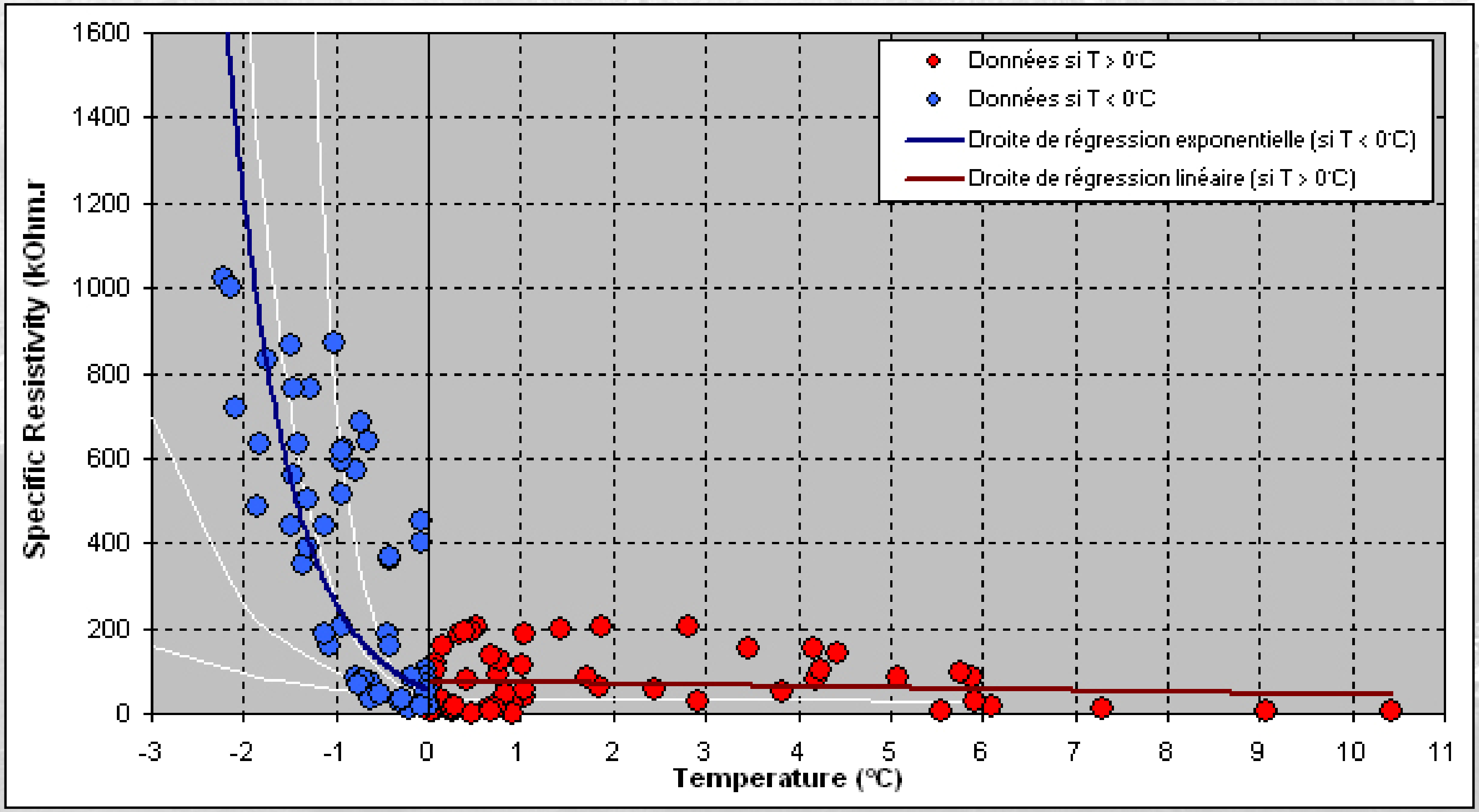
Iteration 3, Abs. Error = 4.1%




28 July. 2008
Iteration 3, Abs. Error = 5.8%
1670
1620
1610
1600
1590
0.0
24.0
48.0
72.0
96.0
120
Resistivity (kOhm.m)
4
10
20
40
100
180
250
350

# AND AT DEPTH ? PERMAFROST ?

- Electrical resistivity as a proxy for ground temperature evolution…



# CONCLUSIONS

- **Deep reversible** air circulation mechanism…
- A **very efficient** process for overcooling the ground surface and at depth…
- **Very common** (evidences)**…**
- Sometimes permafrost…
- Major role on **specific ecosystems**…
- But **very sensitive** environment!
- Future ?

# MANY THANKS FOR YOUR ATTENTION !

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**Webpage : http://www.unifr.ch/geosciences/geographie/delaloye**