UMR CNRS/INSU 6143

Warming impact on experimental permafrost: data from physical modelling using the CryoEx platform

INTERFROST kick-off meeting

Marianne FONT-ERTLEN

Paris - 19 Novembre 2014

Objectives

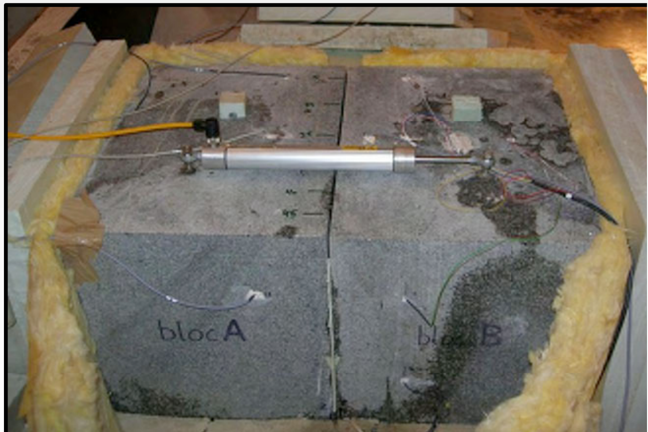
The objectives of CryoEx is to use **physical modelling**:

• to test the impact of **periglacial erosion processes** on experimental permafrost that undergoes **superficial freeze/thaw cycles** which lead to a thin active layer;

• to determine (i) the **physical parameters** that control erosion processes and degradation of experimental permafrost (ii) and the active layer **dynamics**.

Hillslopes,

Soils,



and rocks

Experimental set-up and procedure

Preliminary remarks

Interests of physical modelling:
- **time contraction** allowed by the shift of natural inactive phases,

- to extrapolate and to understand slow periglacial processes → **significant number** of freeze-thaw cycles → experiments over 2 years

- to determine the **influence of each parameter** on the landscape evolution.

Experimental models may be used to provide **physical test** to numerical models and give **insights** and new research **perspectives** to the processes investigated.

In CryoEx's cold rooms, modelling is only experimental, **not analog**.

We focused on **processes** and not on landscape reproductibility.

Experimental set-up and procedure

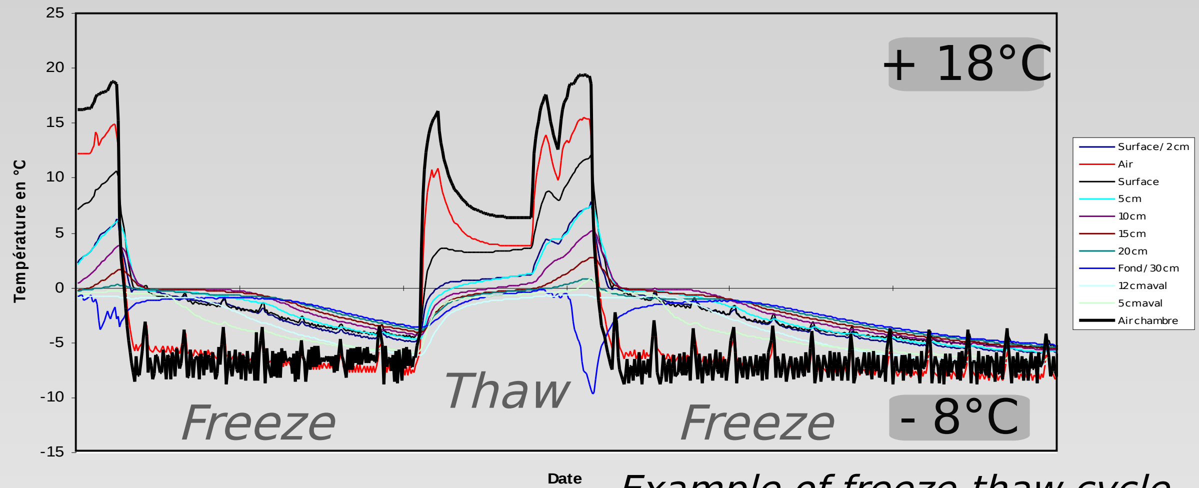
Experimental set-up and procedure

Thermal regime

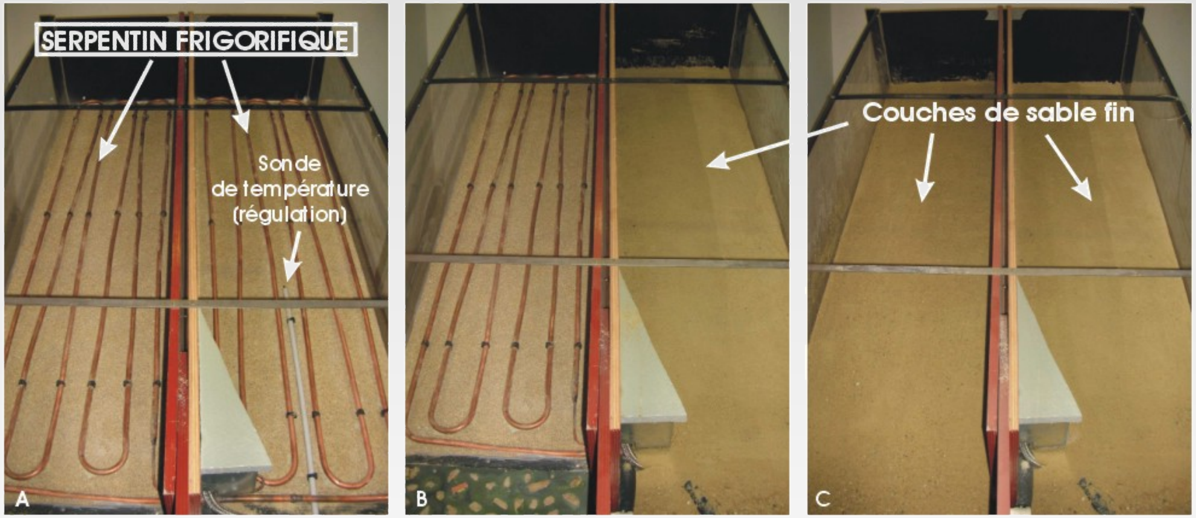
- Cold room: air temperature → -15 °C)

- Basal refrigerating system

- Infra-red emitter



Example of freeze-thaw cycle



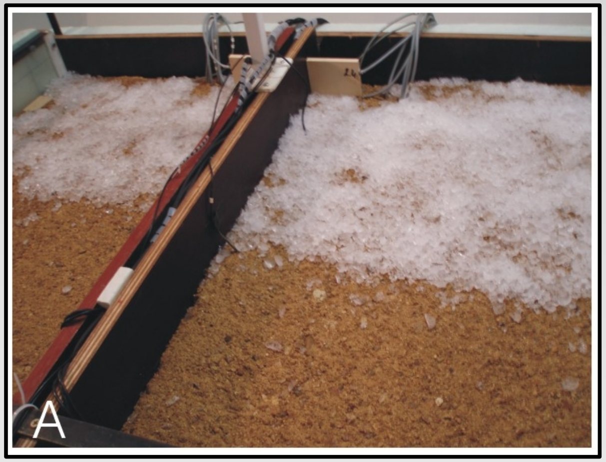
Cooling coil to maintain basal permafrost – Védie et al., 2011

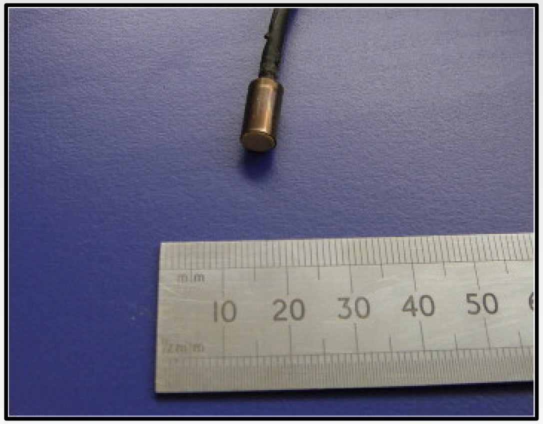
Infra-red emitters with reflectors on fast ground warming experiments – Hurault, 2011

Experimental set-up and procedure

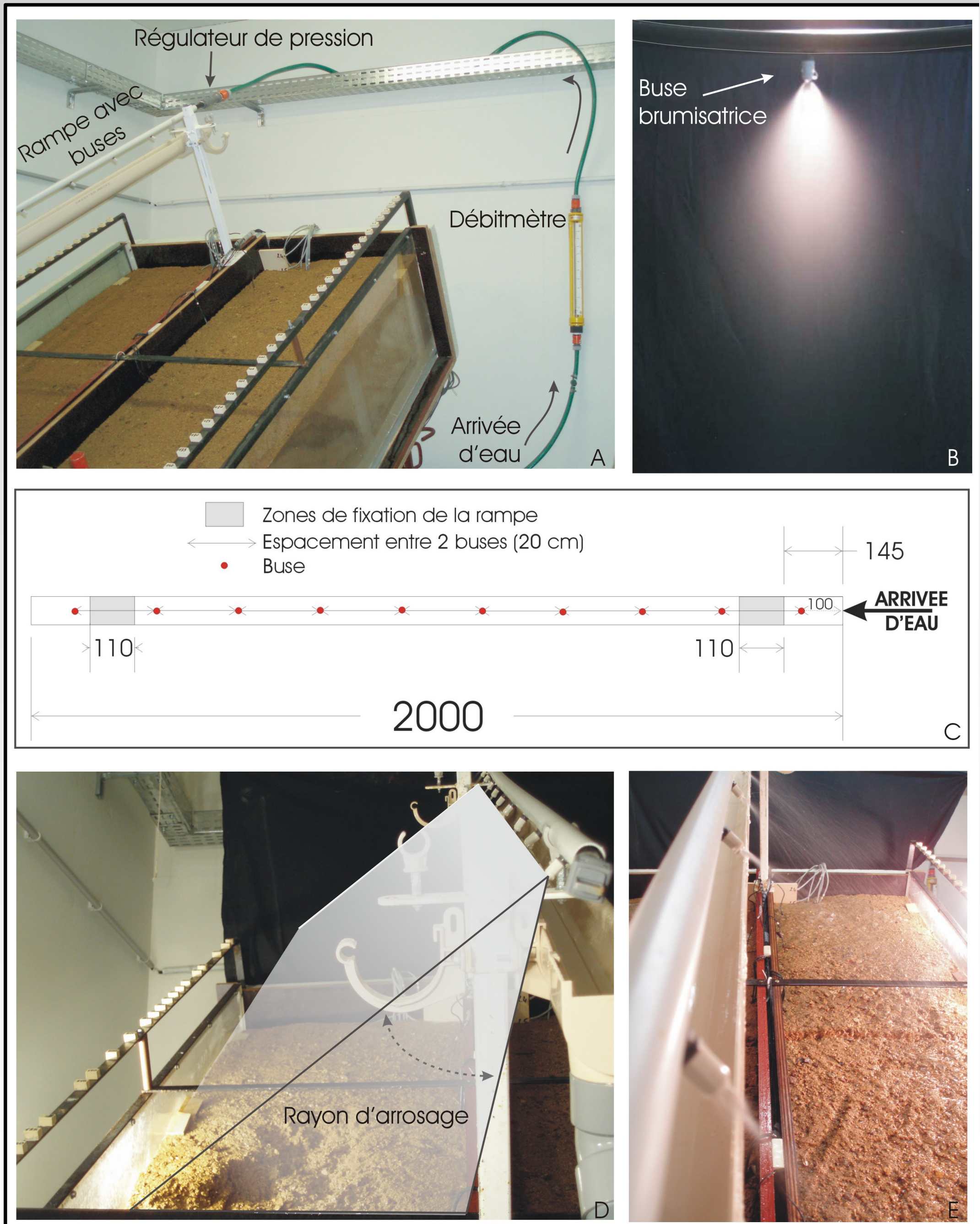
Hydrological regime

Snowmelt - Védie, 2008





Pore water pressure transducer – Harris et al., 2008

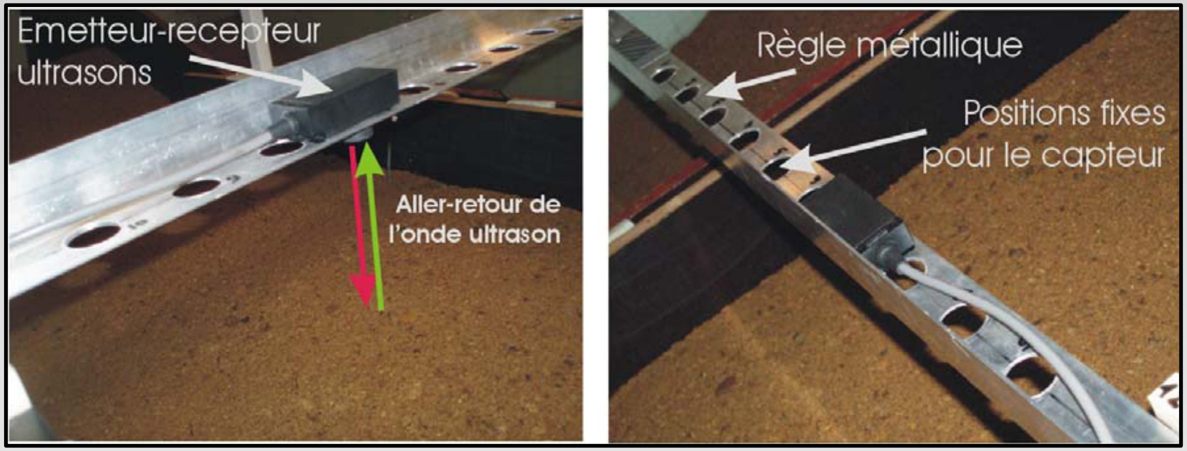


Rainfall apparatus - Védie et al., 2011

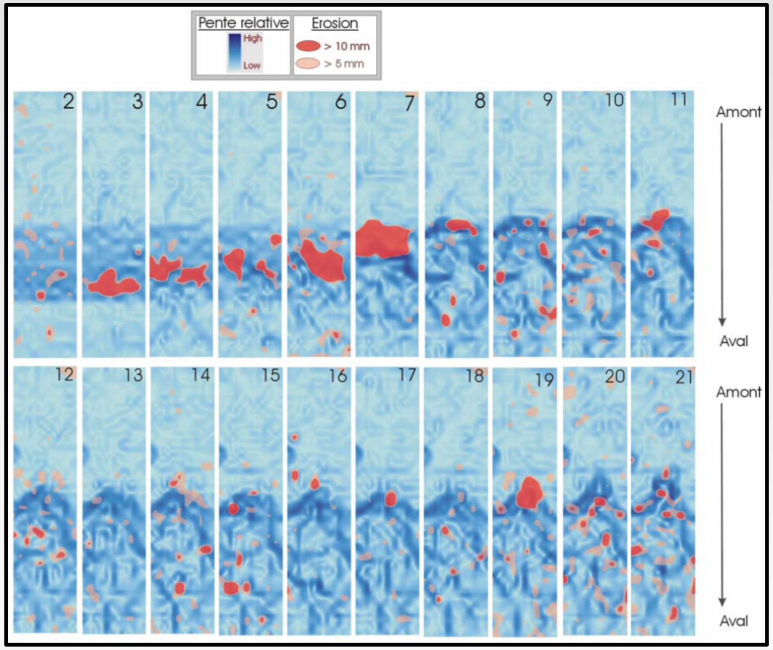
Experimental set-up and procedure

Data acquisition

Data acquisition of frost heave and downslope displacements in the active layer



Ultrasonic sensor used to measure model topography – Font et al., 2006; Védie et al., 2011



Slope and incision maps of experimental hillslope – Védie et al., 2011

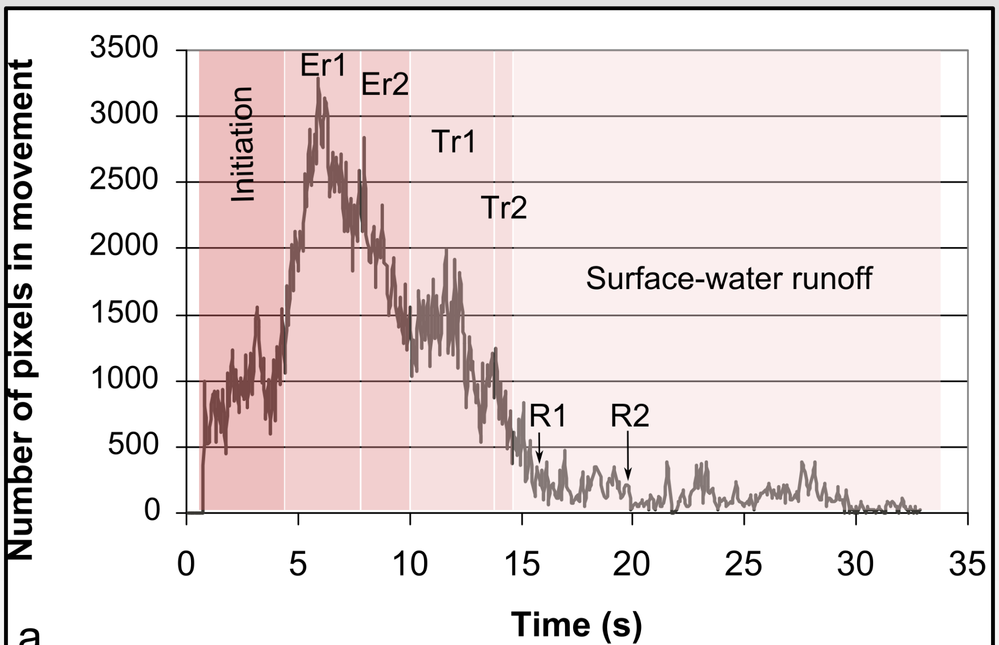
Soil surface motion measurements – Harris, 2007

Experimental set-up and procedure

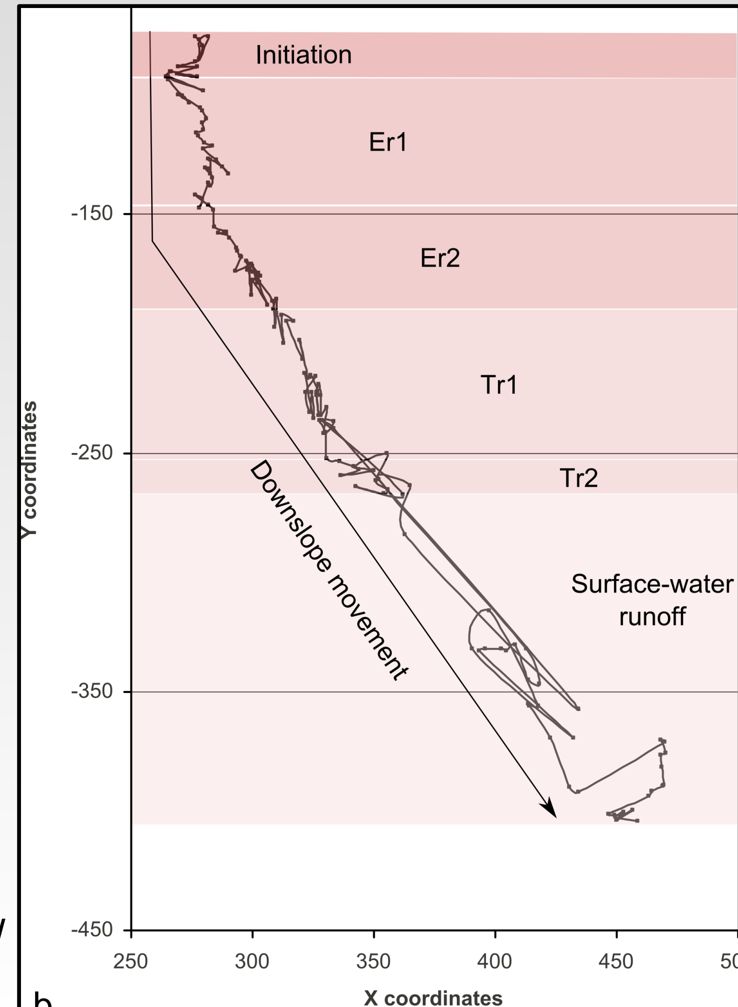
Data acquisition

Photo & video acquisition
Debris flow kinematics

Photo and video systems location – Védie, 2008



Surface size evolution during experimental debris flow – Font et al., 2011



Downslope movement of the experimental debris flow gravity center – Font et al., 2011

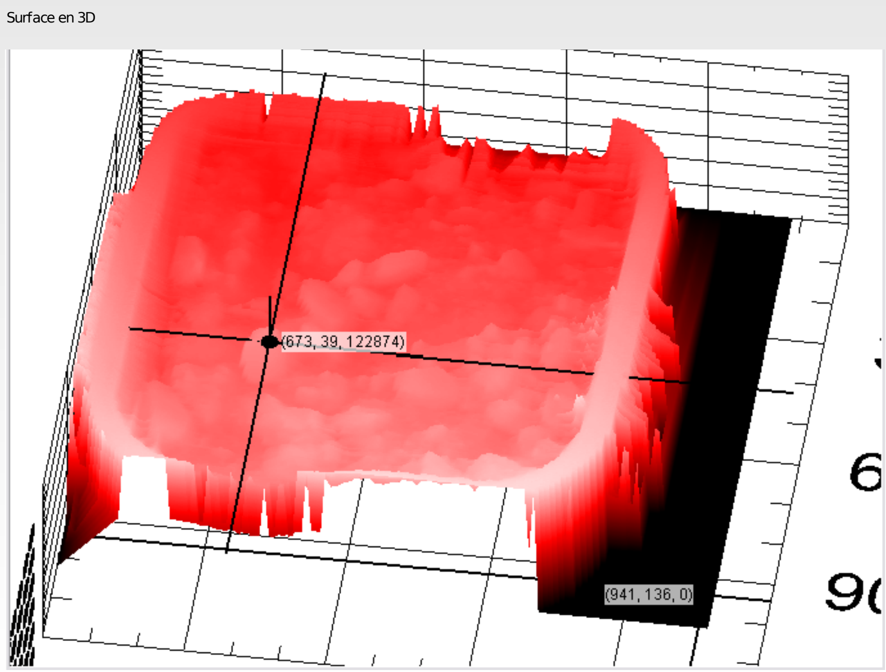
Experimental set-up and procedure

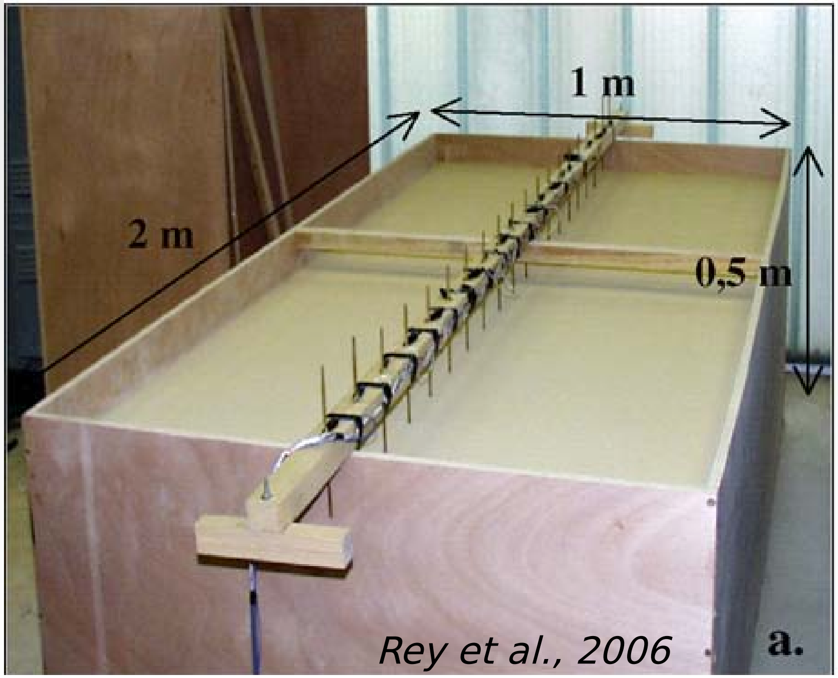
Data acquisition

Under development

High resolution DEM, using high-frequency close-range photogrammetry → growth and settlement of ice lenses, thickness and volume of the active layer, over successive freeze-thaw cycles.

Adequate resistivimeter for **ER tomography** → to localise the top of the permafrost and to interpolate water content, over successive freeze-thaw cycles.



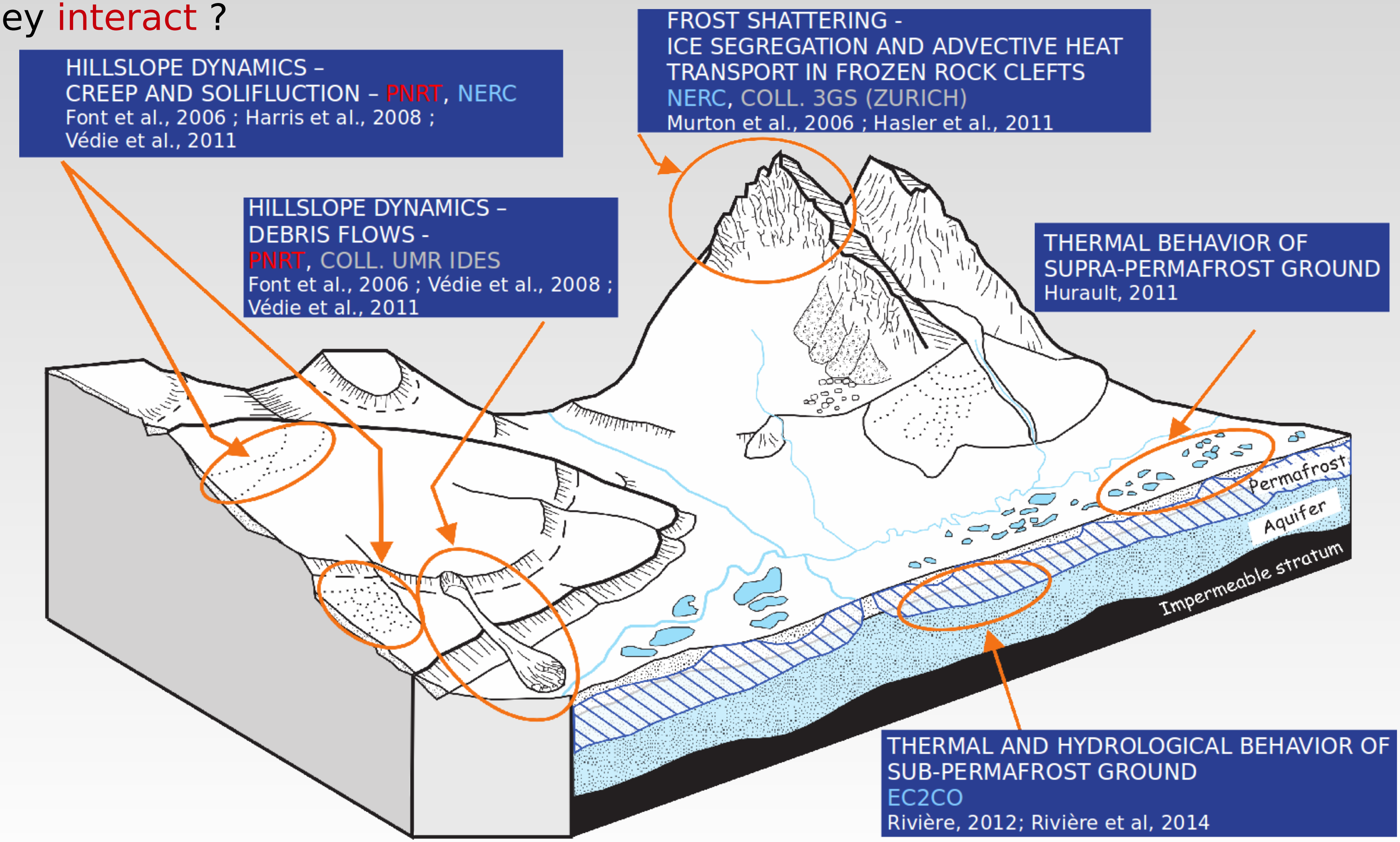


Rey et al., 2006

Impact of climate change on permafrost degradation

- How does it change thermal and mechanical behaviours of rocks and soils ?

- Which are the periglacial processes involved, how/when do they start, how do they interact ?



Periglacial processes experimented with CryoEx, associated research programmes and main publications

Results

Key parameters

Active layer thickness

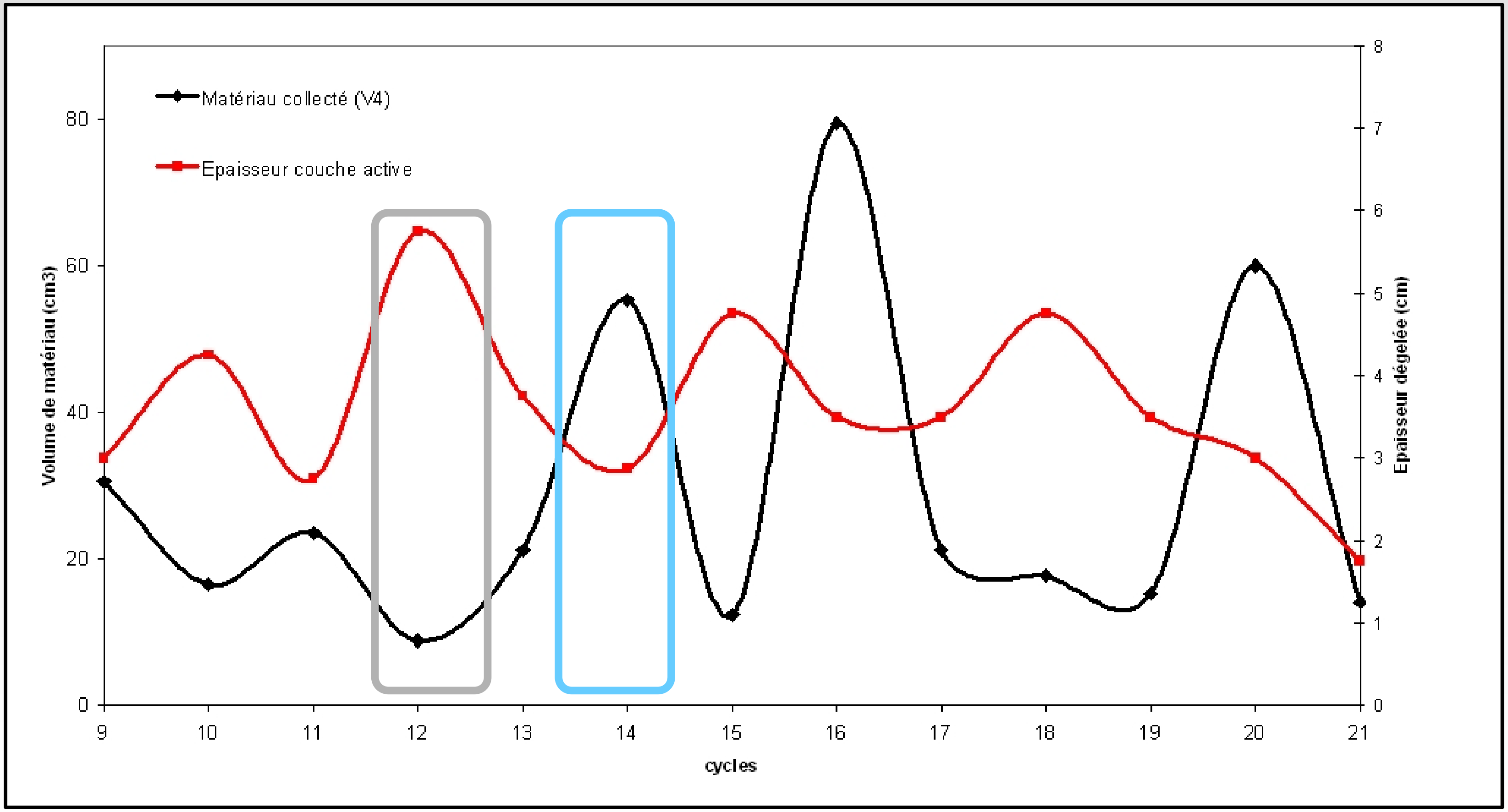
EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms **36,** 395–407 (2011)

Published online 23 July 2010 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.2054

Physical modelling of rainfall- and snowmelt-induced erosion of stony slope underlain by permafrost

E. Vedie, J.-L. Lagarde and M. Font*
Laboratoire M2C, Université de Caen-Basse Normandie, Caen, France

- A thin active layer is associated with high erosion rates due to the high frequency of small-sized slides and flows

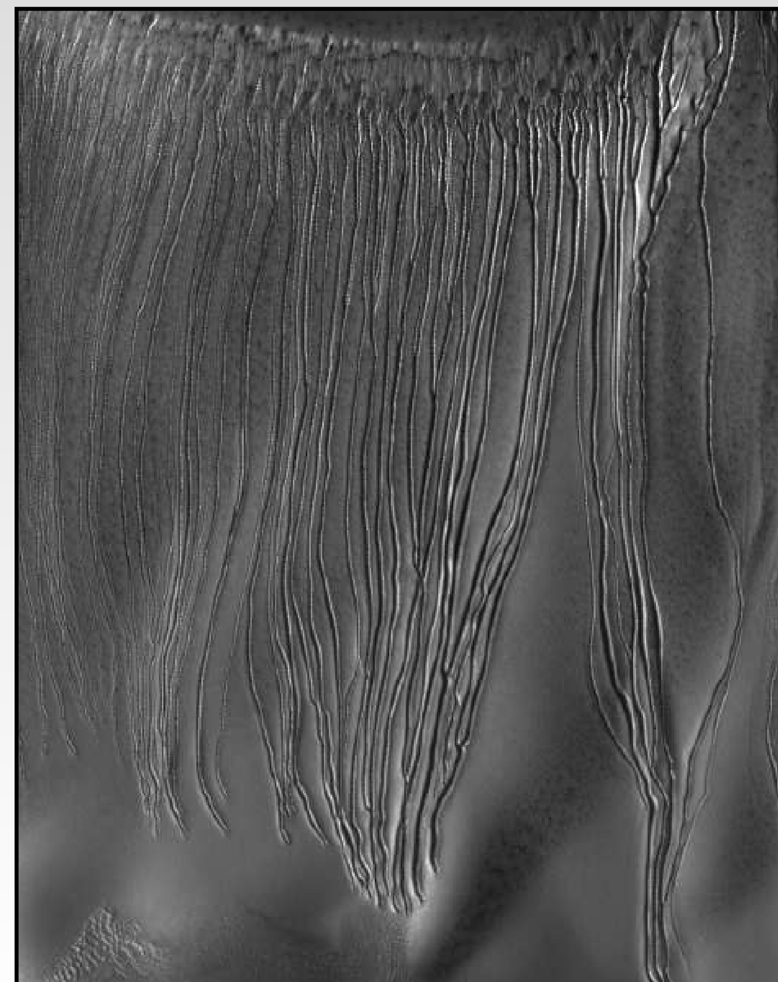


Results

Key parameters

Active layer thickness

- A thin active layer is associated with high erosion rates due to the high frequency of small-sized slides and flows **even on Mars !**



Martian gullies (NASA/JPL/University of Arizona)

Results

Key parameters

Earth Surface Processes and Landforms
Earth Surf. Process. Landforms (in press)
Published online in Wiley InterScience
(www.interscience.wiley.com) **DOI:** 10.1002/esp.1371

Physical modelling of fault scarp degradation under freeze–thaw cycles

M. Font,* J.-L. Lagarde, D. Amorese, J.-P. Coutard, A. Dubois, G. Guillemet, J.-C. Ozouf and E. Vedie
UMR CNRS 6143 'M2C', Morphodynamique Continentale et Côtière, 2–4 rue des Tilleuls, 14 032 Caen, France

Active layer texture

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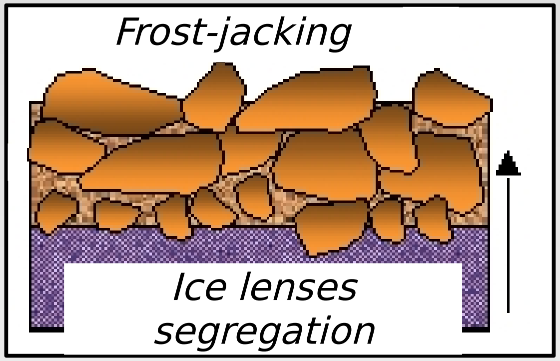
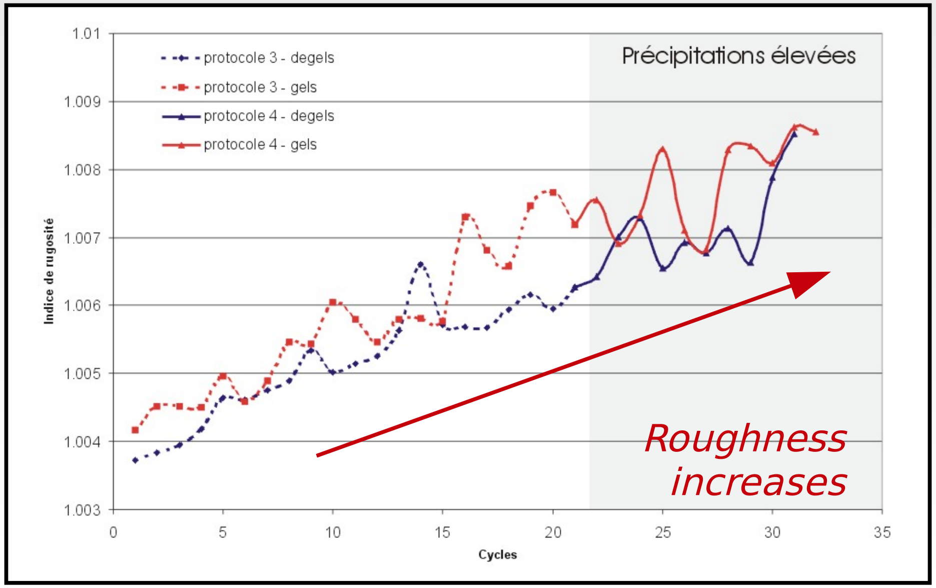
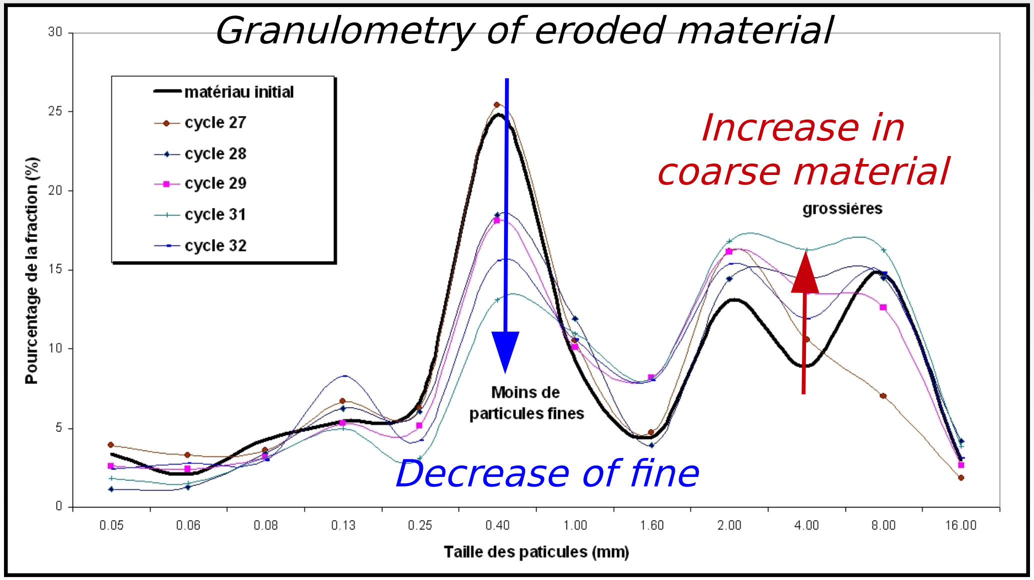
- Frost-jacking and superficial runoff contribute to grain-size redistribution into the active layer and to the constitution of a fine-particle soil layer → triggering of catastrophic events







Results

Key parameters

Local slope gradients

Earth Surface Processes and Landforms
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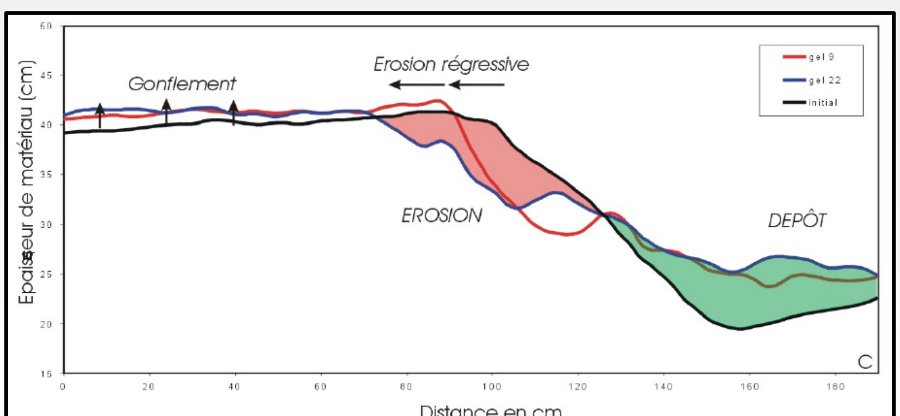
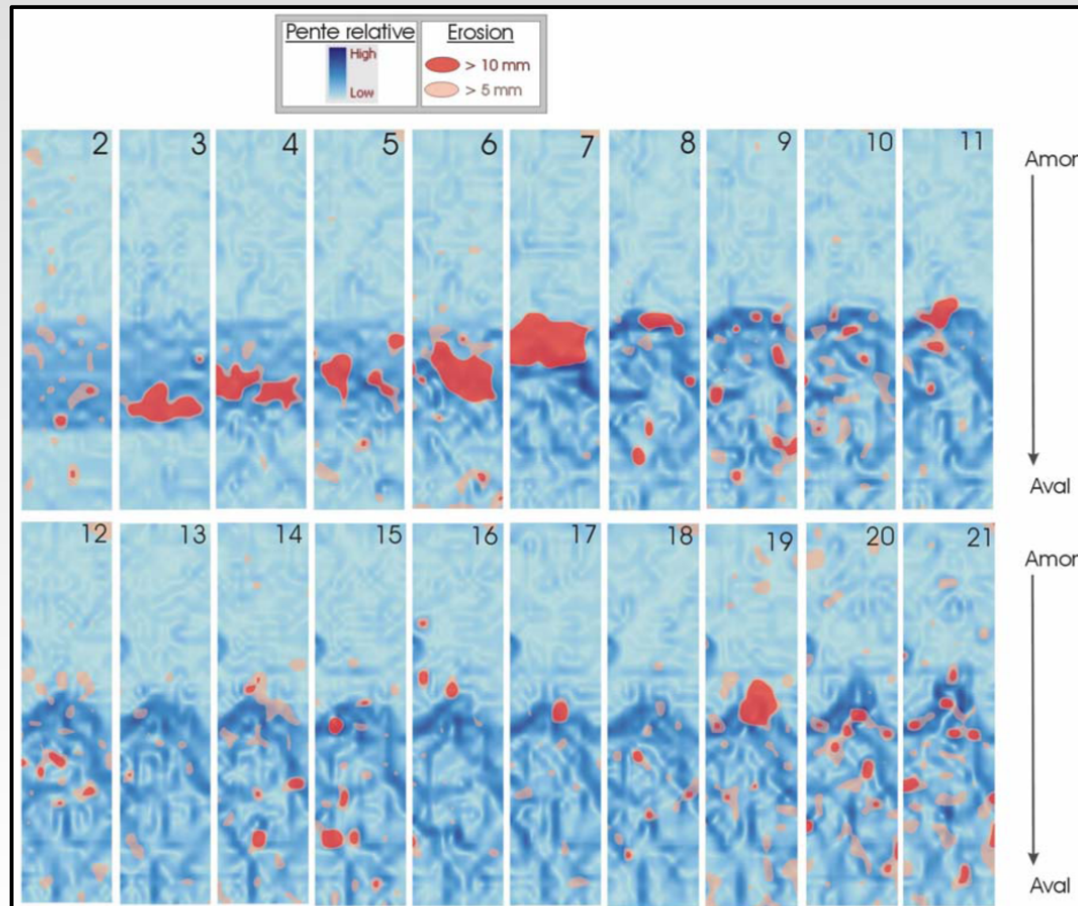
- The steepest part of the soil surface is smoothed by regressive erosion
- Formation of a curvilinear crest line
- Erosion localized within narrow dip zones = triggering of small scale debris and mud flows



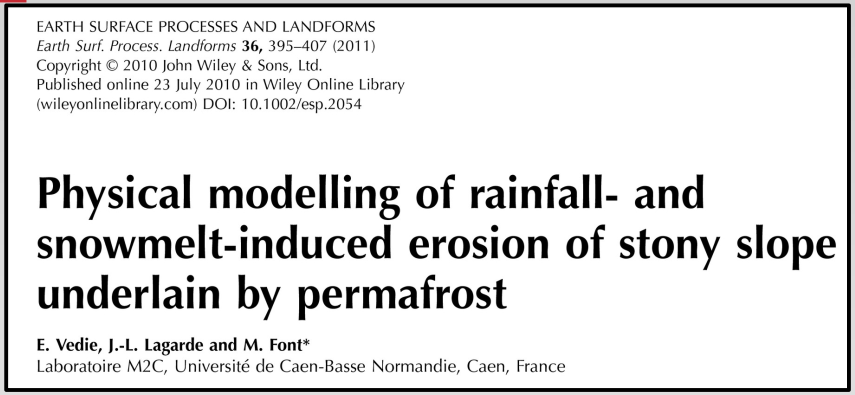


Results

Results

Key parameters

Water supply



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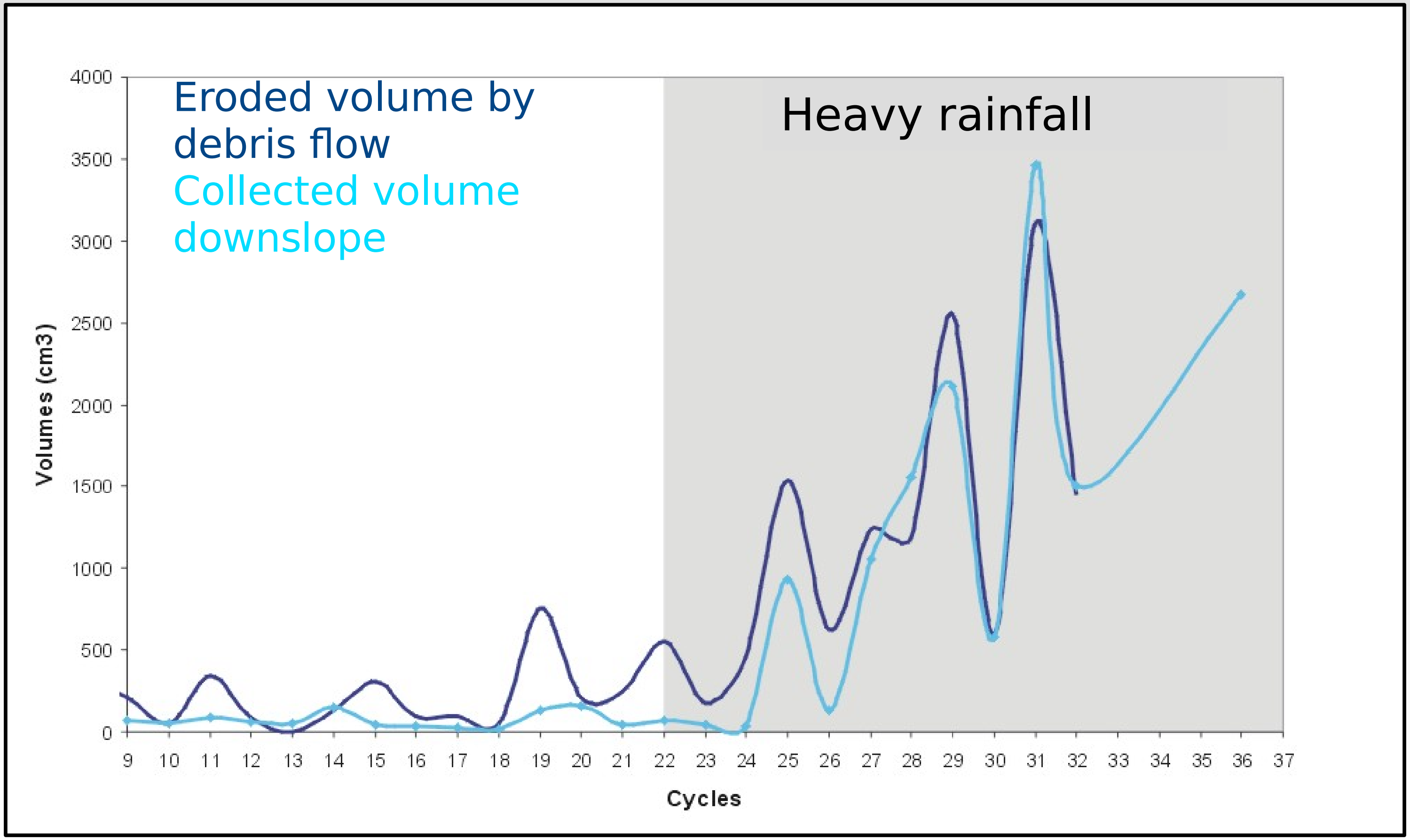
- When heavy rainfall was applied, rapid mass wasting became prominent → important slope degradation and development of marked scars



Results

Key parameters

Water supply

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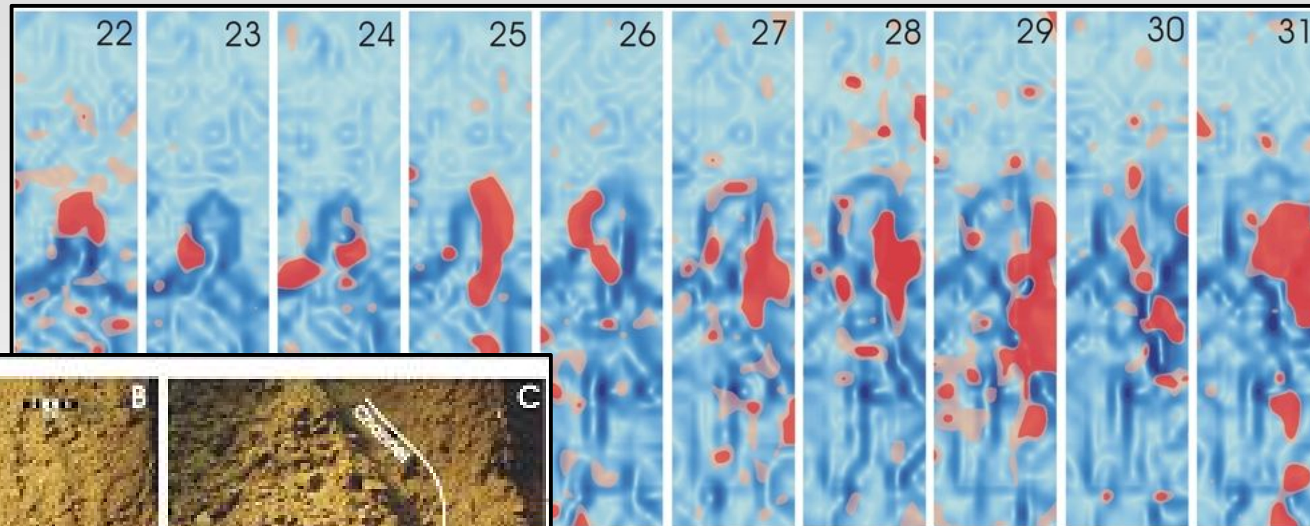
- When heavy rainfall was applied, rapid mass wasting became prominent→ important slope degradation with development of marked scars, large eroded zone which are the source area and a deep channel



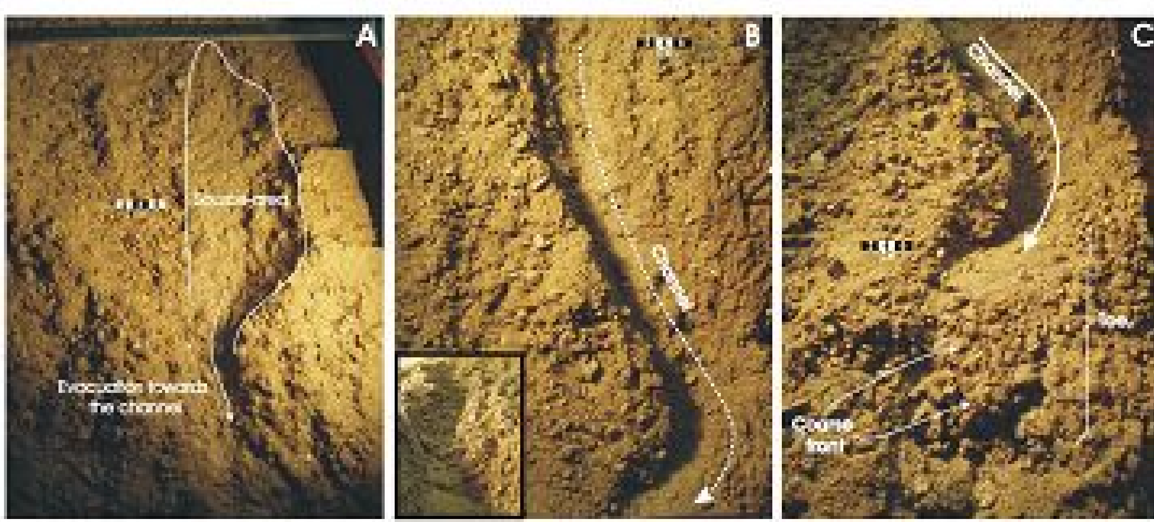
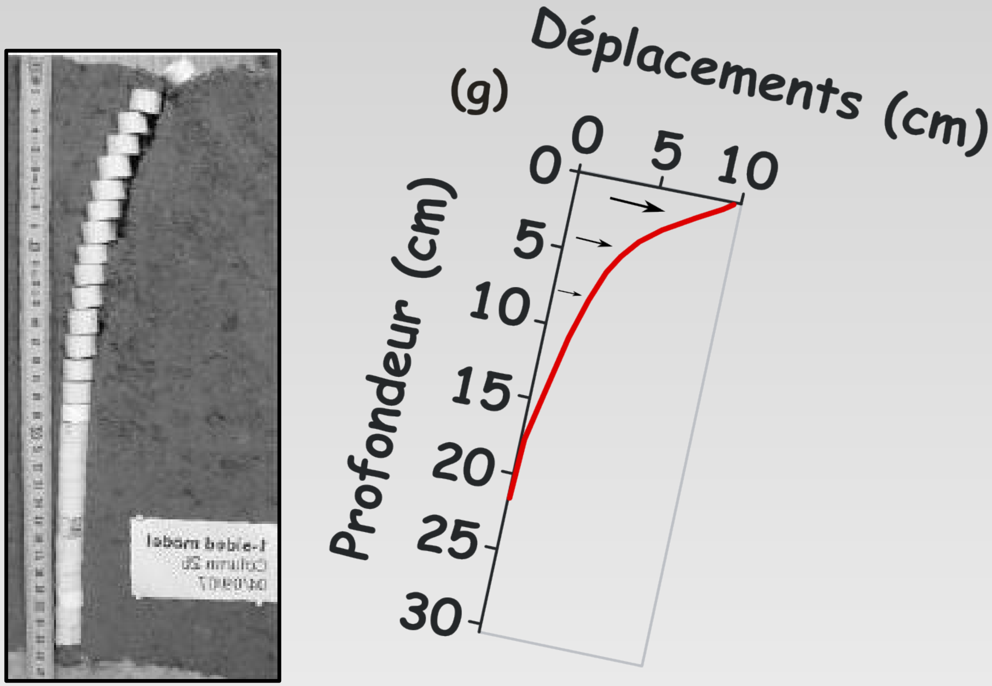


Fig. 9 SOURCE-AREA CHANNEL DEPOSIT TOE

Results

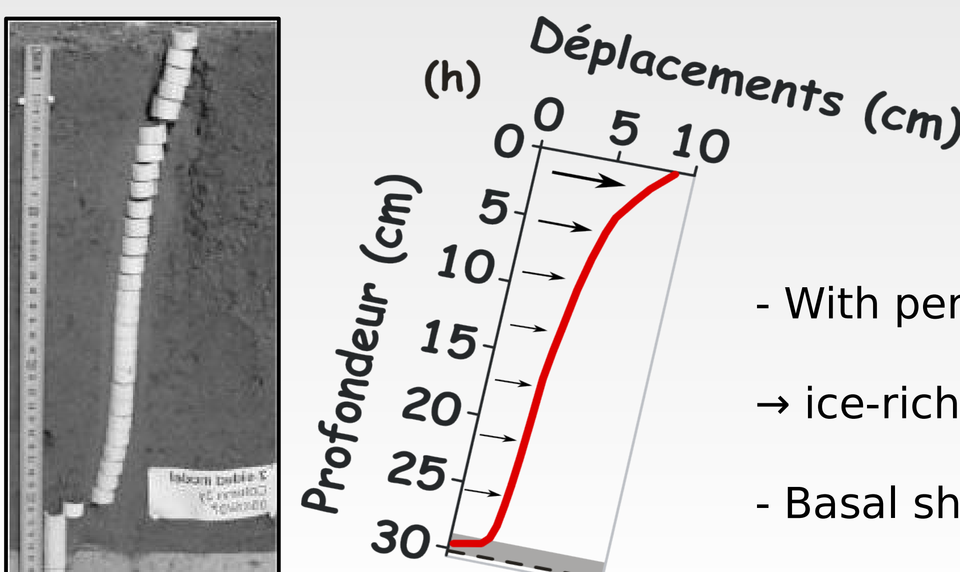
Processes characterisation

Solifluction



- Without permafrost - *One-sided freeze*

Harris et al., 2008



- With permafrost - *Two-sided freeze*

→ ice-rich basal active layer zone

- Basal shear zone → solifluction increases

Results

Processes characterisation **Advective heat transport in ice-filled clefts**

Impact of climate warming on frozen bedrock = warming by heat conduction do not explain the rockfall activity

Fracturated rocks → preferential percolation paths → advective heat transport in ice-filled clefts

What are the effect of advection on cleft ice and temperature around the cleft ?

HASLER ET AL. 2011: ADVECTIVE HEAT TRANSPORT IN FROZEN ROCK CLEFTS

Paper published in PERMAFROST AND PERIGLACIAL PROCESSES

Advective Heat Transport in Frozen Rock Clefts – Conceptual Model, Laboratory Experiments and Numerical Simulation

Andreas Hasler[1], Stephan Gruber[1], Marianne Font[2], and Anthony Dubois[2]

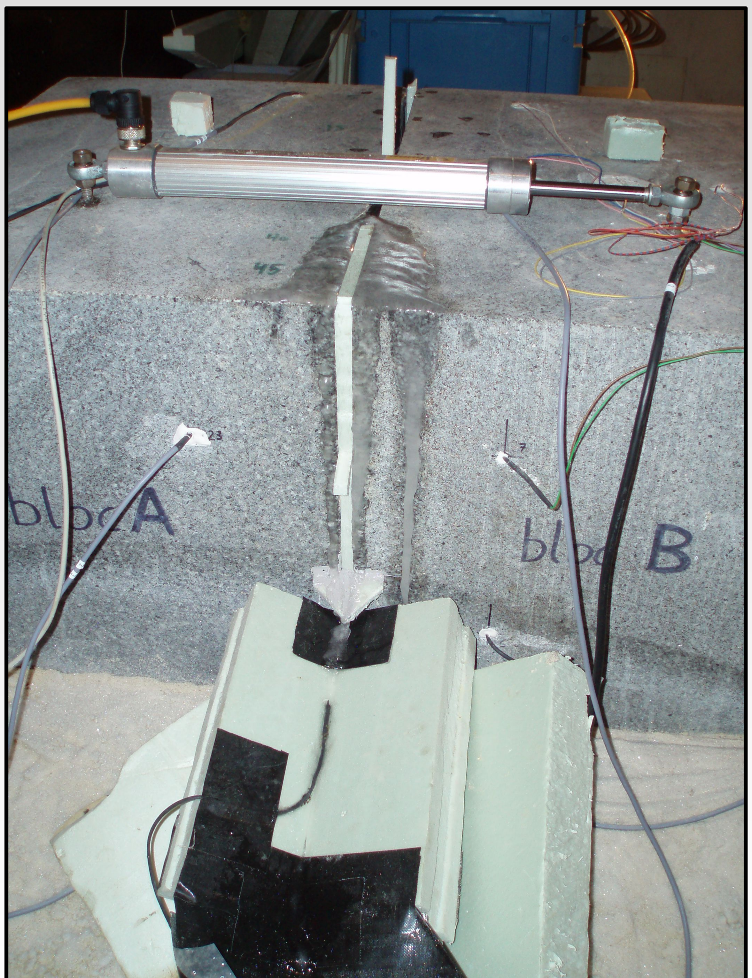
[1] Glaciology, Geomorphodynamics and Geochronology, Department of Geography, University of Zurich, Switzerland.

[2] Laboratoire M2C, UMR CNRS/INSU 6143, Université de Caen-Basse Normandie, France.

Detachment surface of a rockfall, Matterhorn, 2003 – Gruber and Haeberli, 2007

Results

Processes characterisation **Advective heat transport in ice-filled clefts**



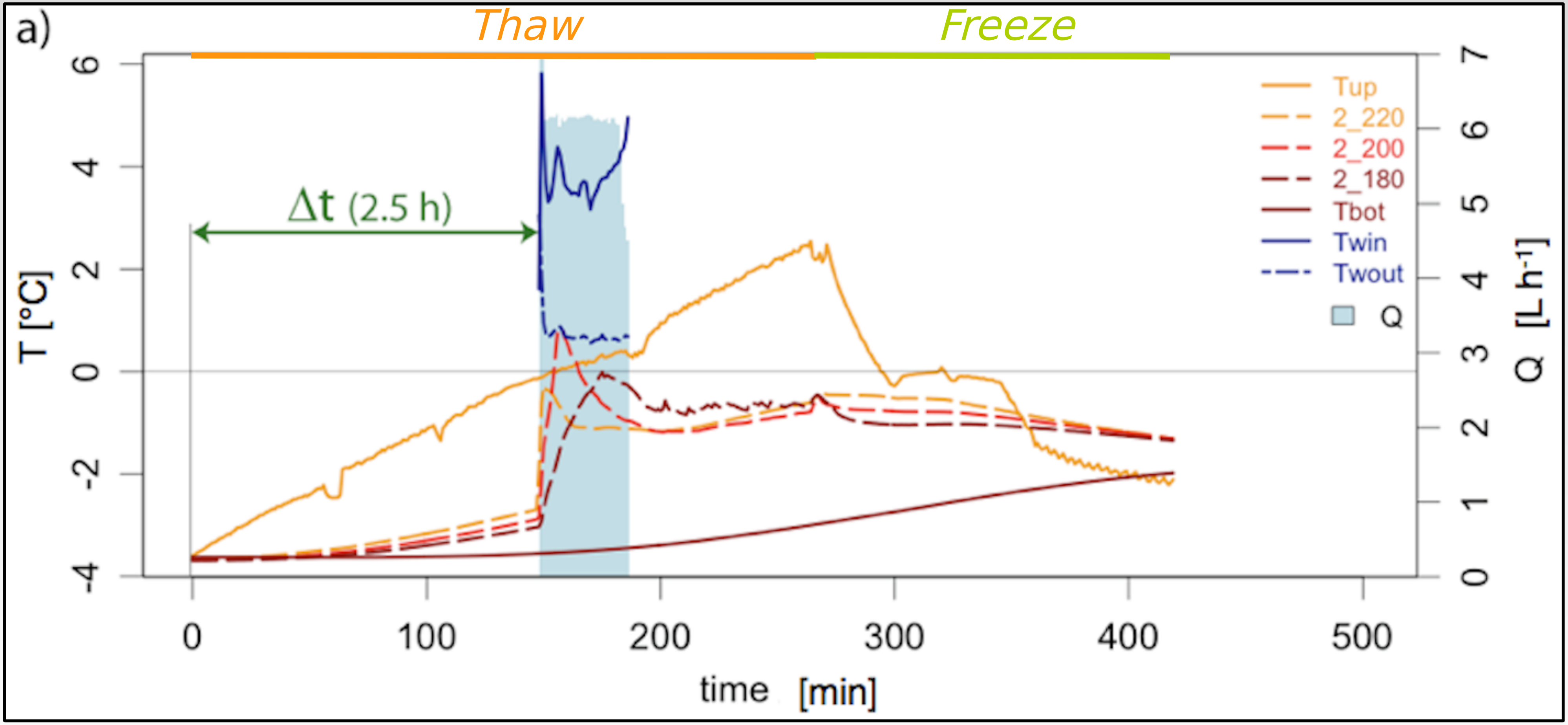
Zoom on the ice-filled 8 mm cleft

Two granite blocks (0.36x0.36x0.5 m) form a cleft ~ 8 mm wide

Results

Processes characterisation Advective heat transport in ice-filled clefts

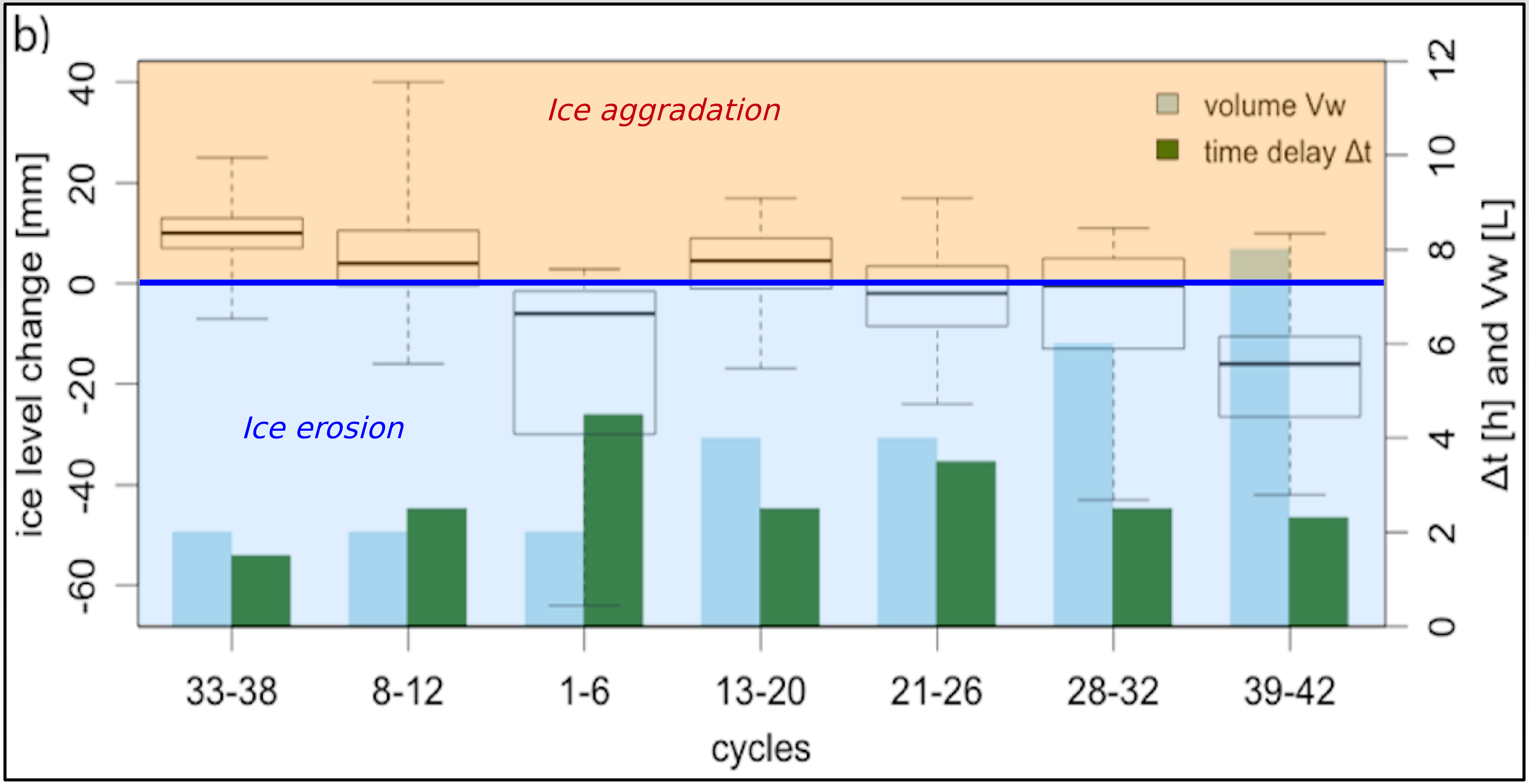
- Water flowing along the ice surface during the thaw



Results

Processes characterisation **Advective heat transport in ice-filled clefts**

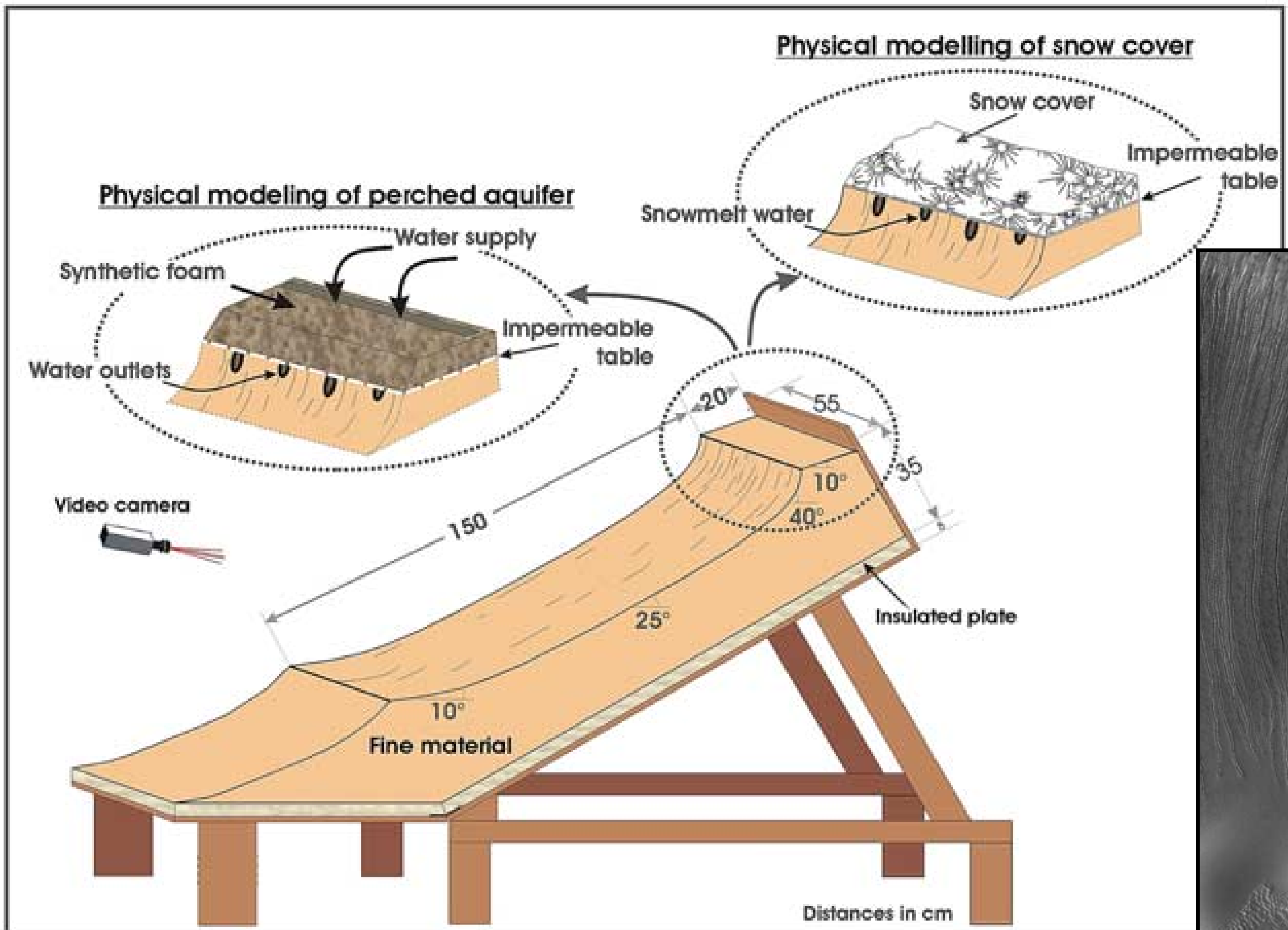
- At the beginning of the thaw, the main processes is ice **aggradation**
- Ice aggradation releases latent heat → local warming of the rock → later ice erosion
- The equilibrium between aggradation and erosion may be very sensitive to small changes in timing and magnitude of melt water supply



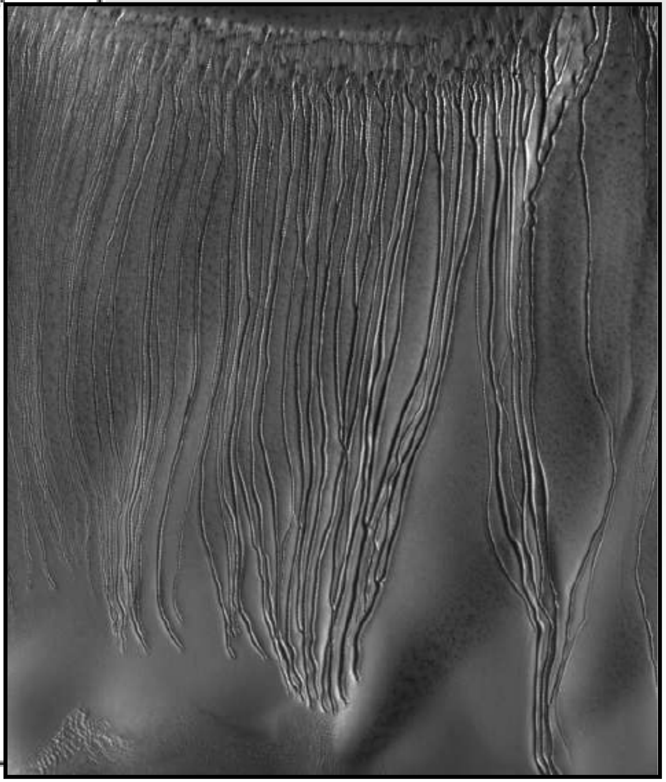
Results

Processes characterisation **Martian gullies**

Objective: Use of physical modelling
→ to test the erosion processes that can give rise to long and narrow channels,
→ to determine their triggering conditions (it is not an analog).



Védie et al., 2008

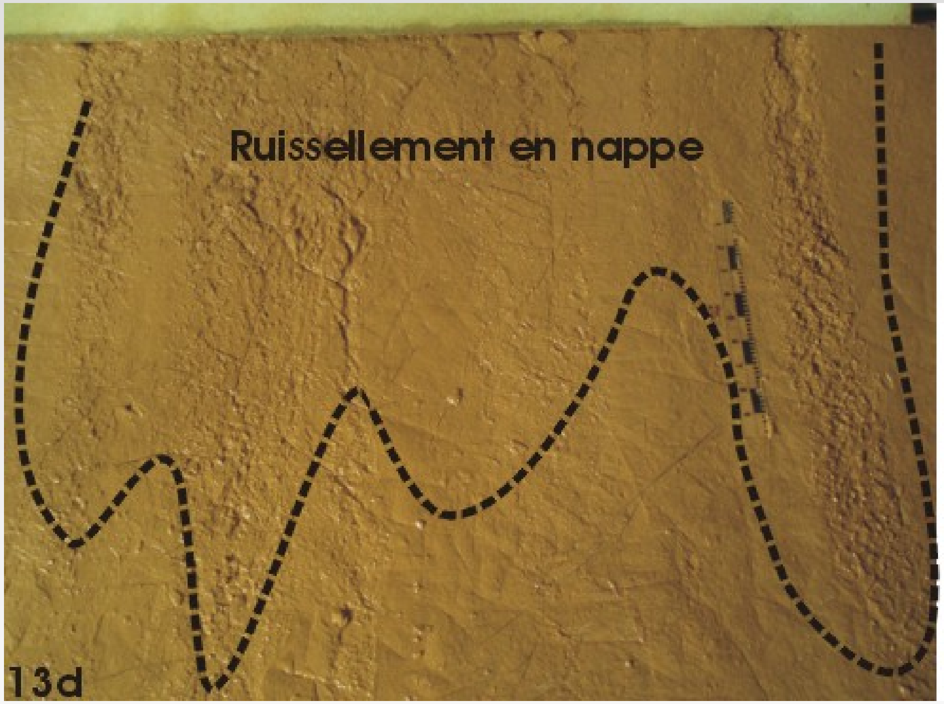


Results

Processes characterisation **Martian gullies**

Preliminary data (more than 50 experiments) shows the 3 following points:

1- Periglacial conditions and the **presence of a permafrost near the surface** are needed to favour the developpement of long and narrow debris flows.



Thick active layer (>10 mm)
Weak incision

Thin active layer (~1 mm)
Single water pulse &
linear, narrow gullies

Results

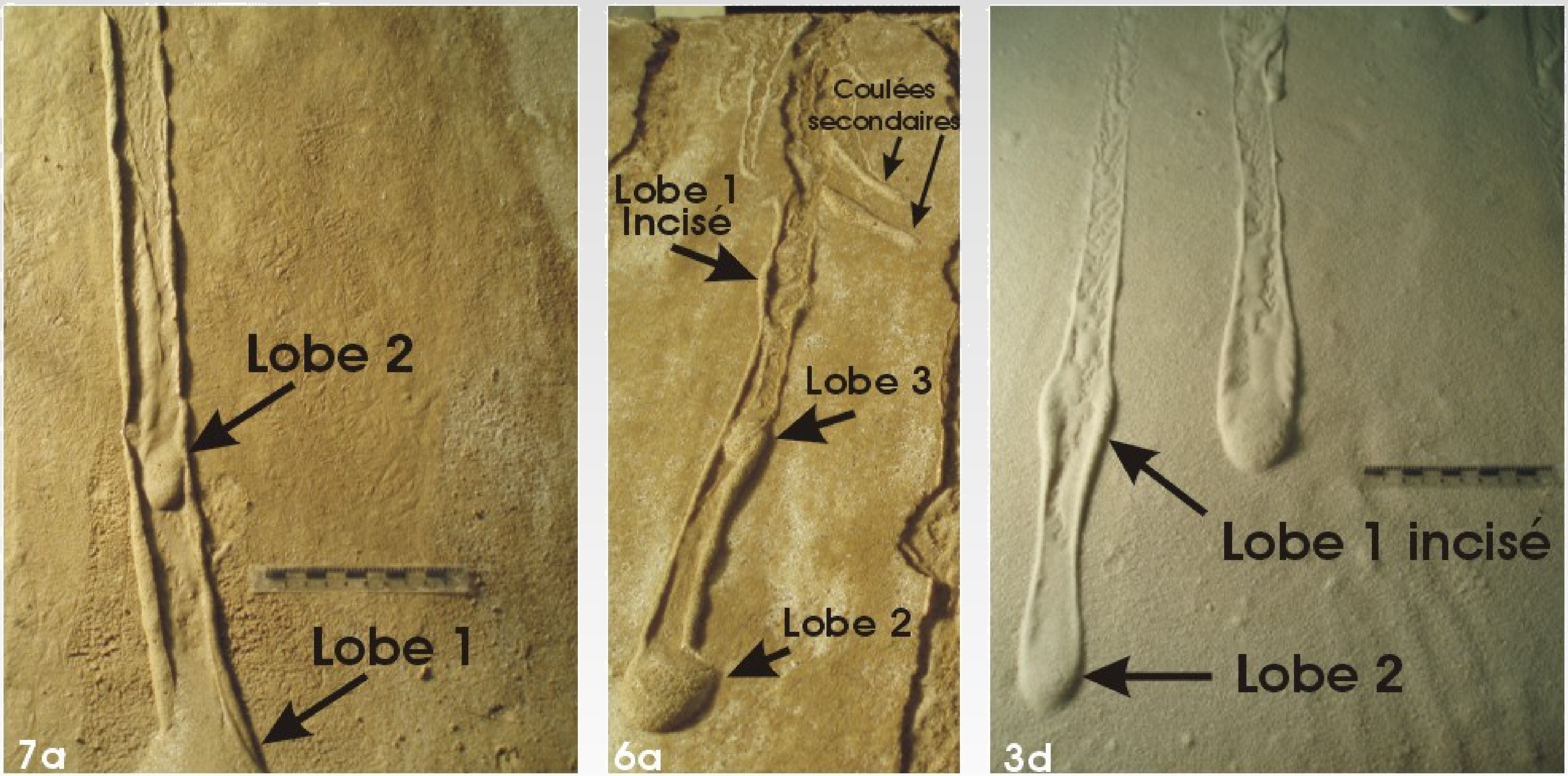
Results

Processes characterisation

Martian gullies

Preliminary data (more than 50 experiments) shows the 3 following points:

2- Water supply must be a **single pulse** for each gully. Multi-pulses lead to digited gullies.

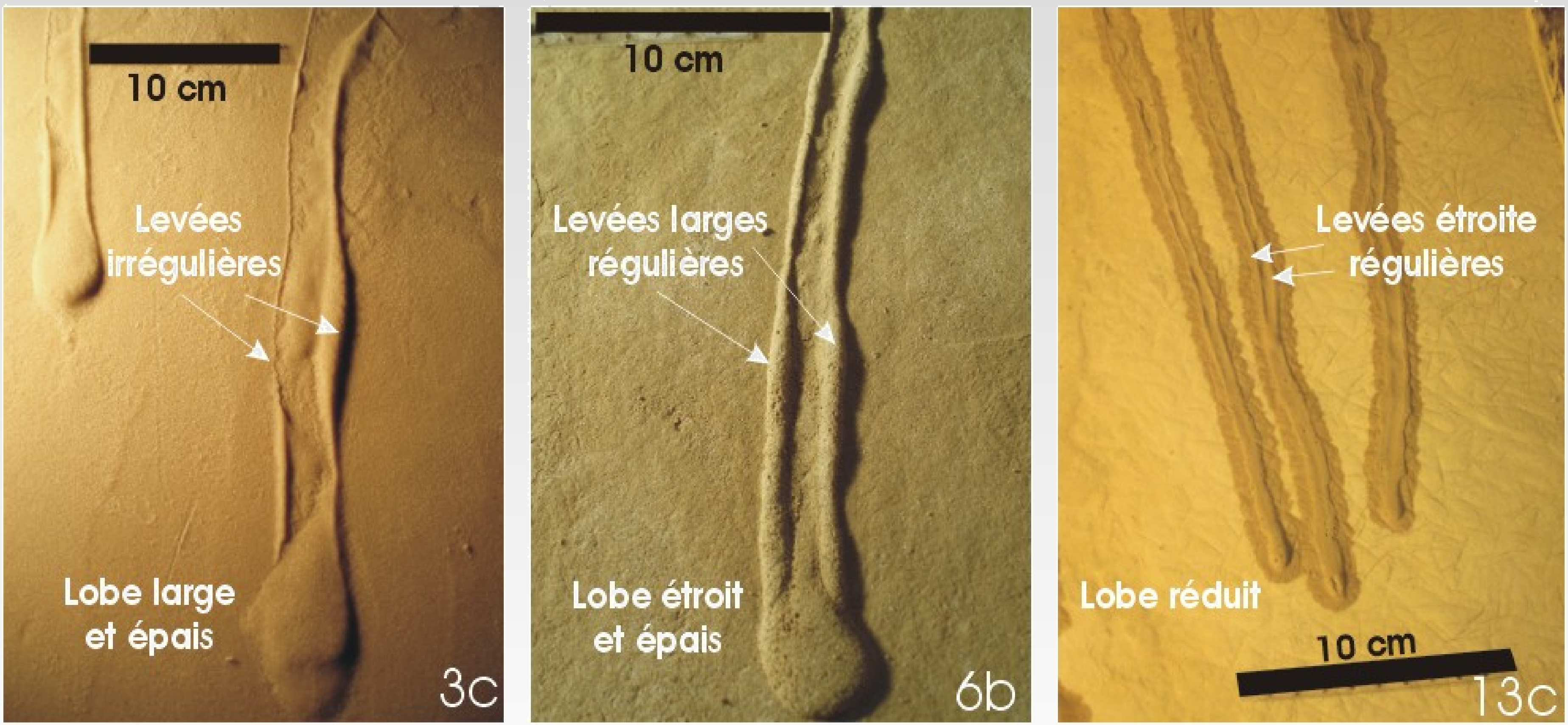


Results

Processes characterisation **Martian gullies**

Preliminary data (more than 50 experiments) shows the 3 following points:

3- Linearity and narrowness of the gullies are obtained with the **finest material** used.



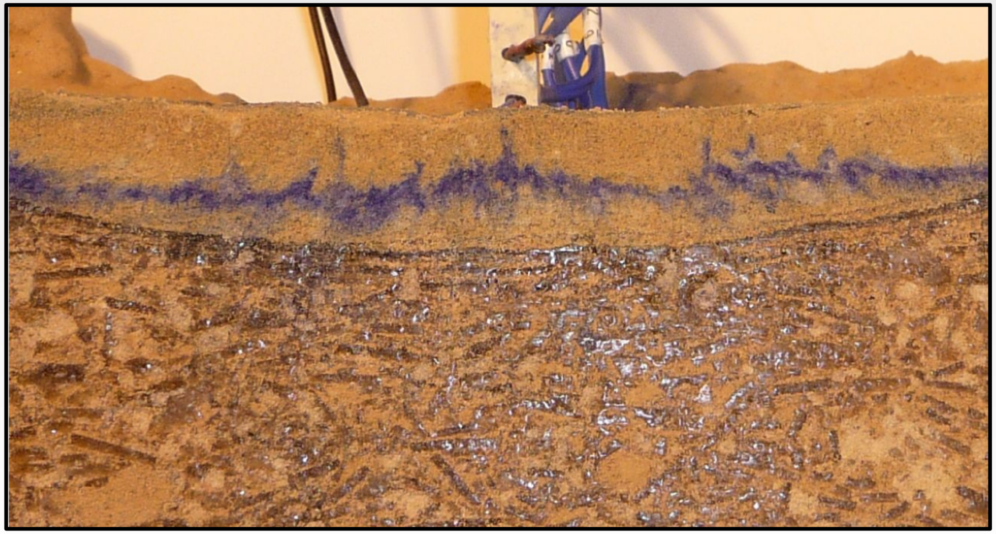
Comparative morphologies (channels, levées and lobes) for the 3 granulometries (3c: sand; 6b: mixture and 13c: silt)

Results

Processes characterisation permafrost

Warming impact on experimental permafrost

Three experimental permafrosts
Hurault, 2011



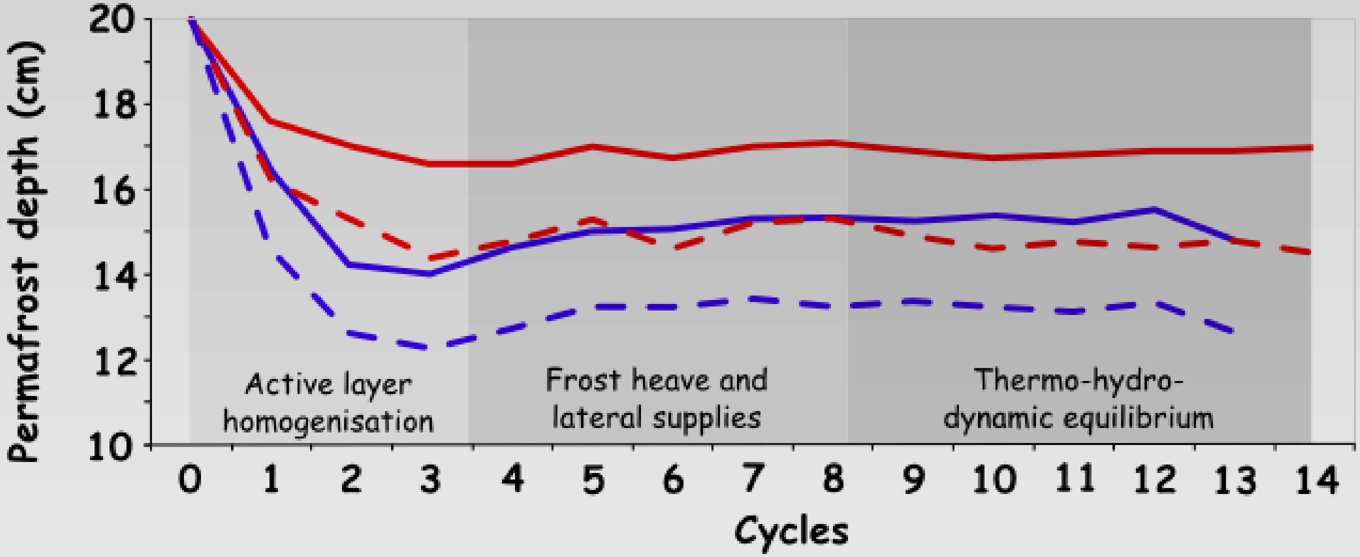
Segregated ice at the top of the permafrost

Massive ice lens within a permafrost

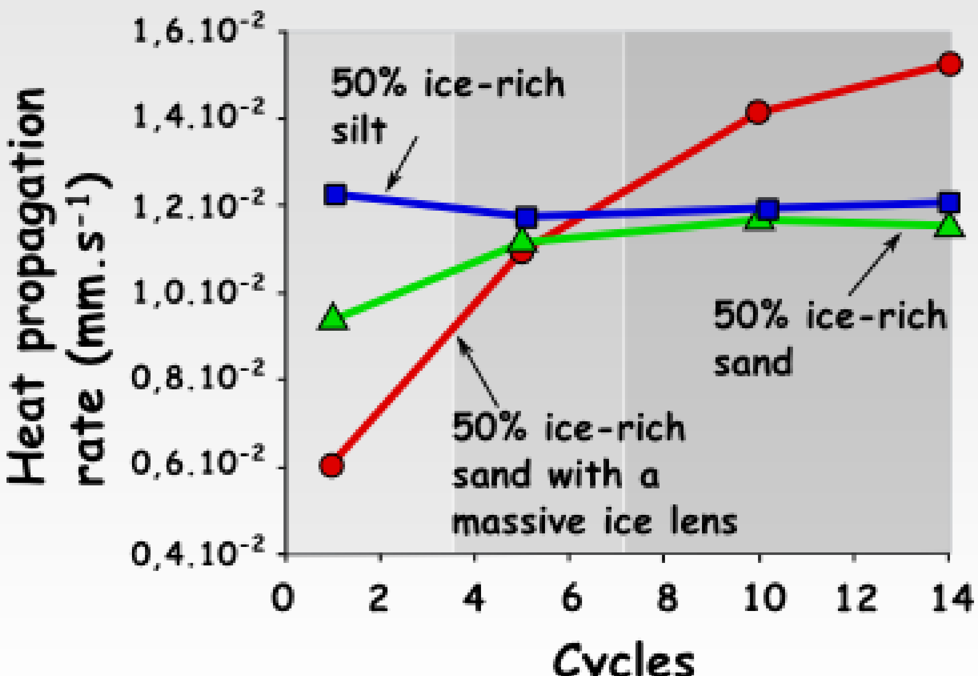
Results

Processes characterisation

Warming impact on experimental permafrost



Thaw settlement (full lines) and top of the permafrost depth evolutions (dashed lines) of a 80 % ice-rich silty sediment (in red) and of a 80 % ice-rich sandy sediment with an ice lens 4 cm depth from the surface (in blue)
Amended from Hurault, 2011

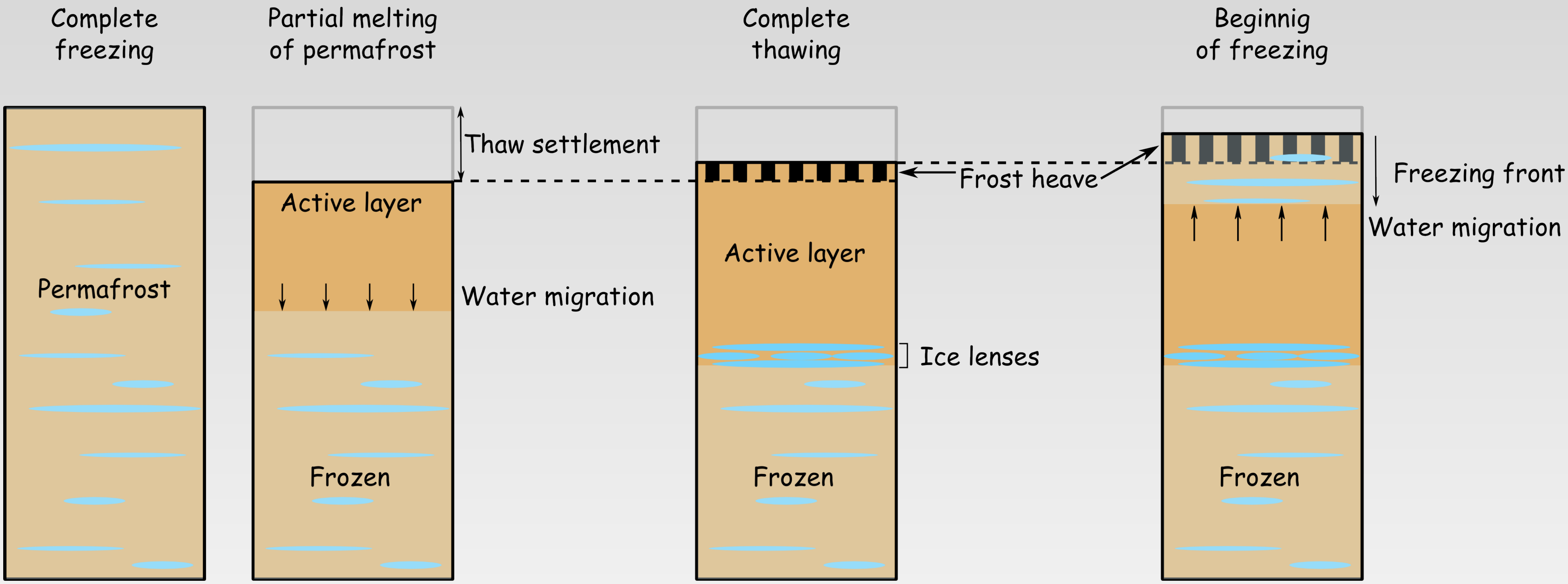


Heat propagation rate (0°C isotherm) measured on three experimental permafrost with different ice content, and granulometry.
The grayscale is the same as the figure above.
Amended from Hurault, 2011

Research perspectives

WIEPER - Warming Impact on Experimental PERmafrost: data from physical modelling using the CryoEx platform

Scientific challenge 1- Understanding of thermal and hydrological behaviour of experimental permafrost



1- What is the impact of thermal regime on water and ice spatial distribution?

2- How to constrain more accurately frost-heave?
→ close-range photogrammetry → high resolution DEM
→ ER tomography (ERT) → 3D images of moisture and ice contents

Scientific challenge 2- Characterization of warming impact on experimental permafrost, including microbial activity and greenhouse gases emissions

Conclusion

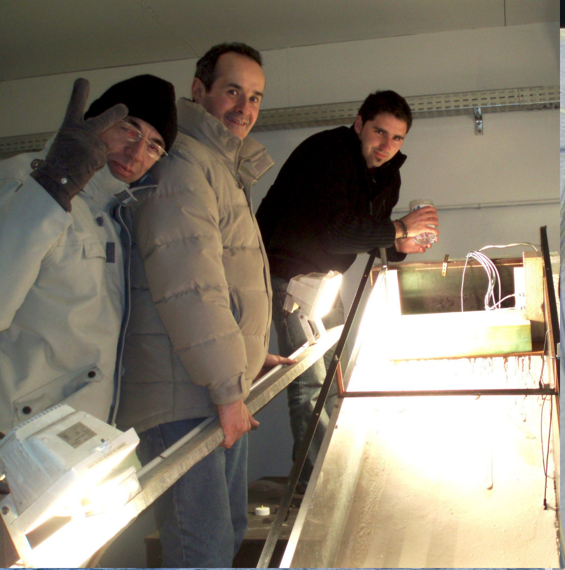
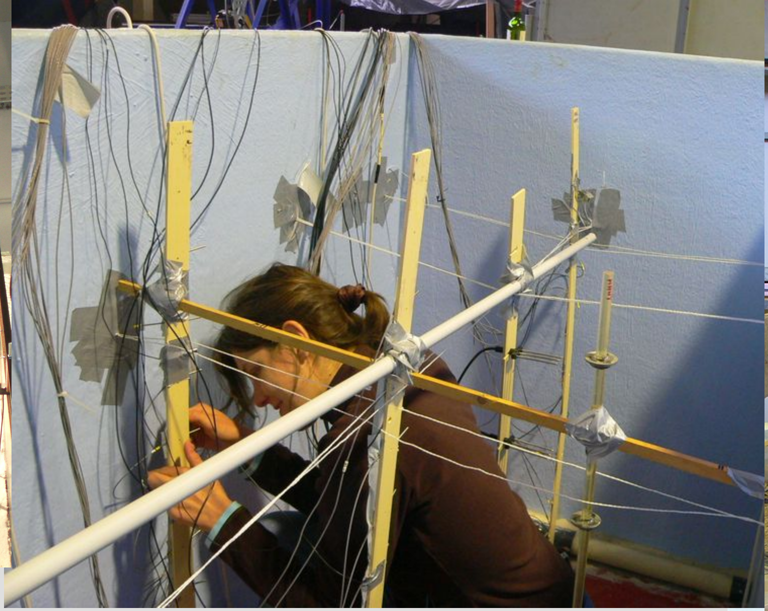
Periglacial processes are difficult to analyse *in situ*.

Physical modelling is a useful tool to visualize, analyse in real-time and better understand periglacial weathering processes and their interactions.

CryoEx platform allows particular scale of analysis that originally supplies field measurements (from several decimetres to a few decameters permafrost) and theoretical and numerical studies on a pluri-granular scale.

Physical modelling is a relevant source of reliable parametrisations to feed on numerical models.

These insights will be used to provide forecast of permafrost thawing and environmental and societal risk studies.

Thank you !



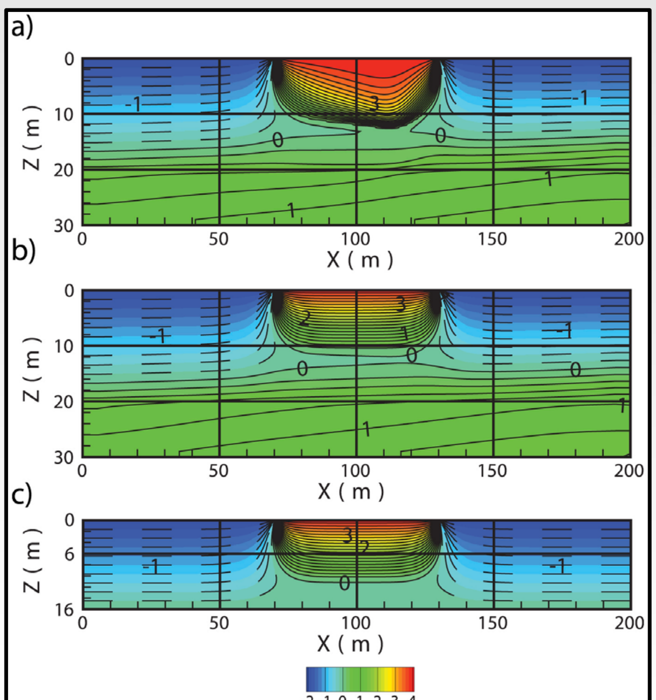


Research perspectives

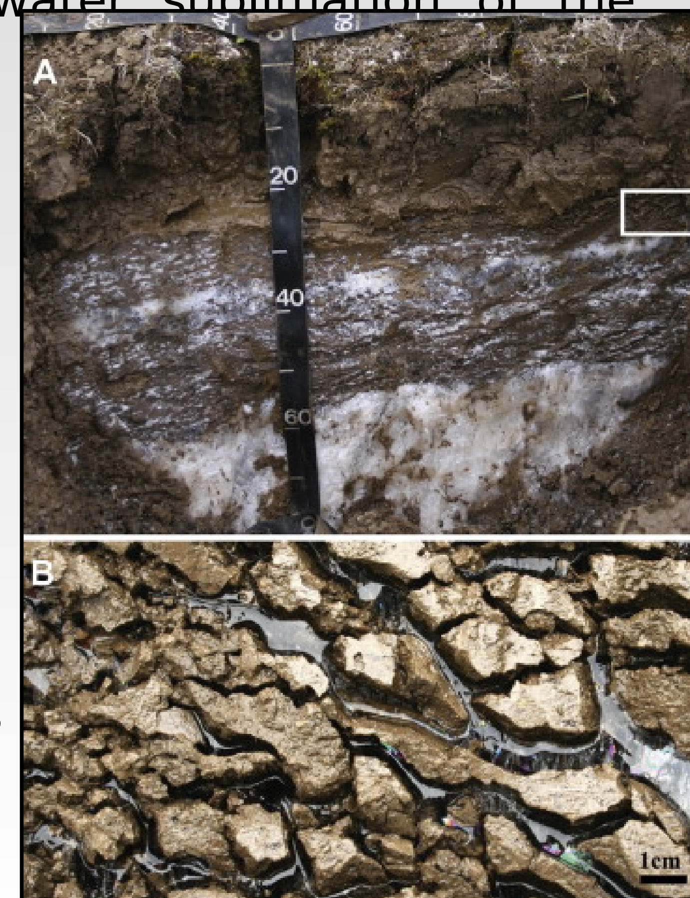
Short term

Understanding of the thermal and hydrological processes that drive permafrost evolution – Physical models improvement

- radiation impact on heat transfert
- heat transfert mecanism interaction in frozen ground: conduction, advection
- water exchanges quantification (cryosuction, water sublimation of the ground surface, segregated ice)
- numerical simulation studies



Permafrost and lake talik simulation by Arctic Hydrology (ARCHY) Model – Rowland et al., 2011



High Arctic soil with permafrost at 25 cm depth, (B) ice lenses in permafrost from the rectangle marked in (A). Timling and Taylor, 2012

Research perspectives

Long term

Impact of the continental permafrost degradation on the distribution of CH_4 and CO_2 in the atmosphere and the oceans

- study of microbial activity in experimental frozen ground
- the result will be faced with *in situ* measurement of the microbial diversity
- study of the local-scale feedback effect of heat released by microbes that could lead to rapid permafrost thaw

Methane emission measurements on Greenland permafrost. Photographer: Charlotte Sigsgaard

Sampling in the glacier mouth – Svalbard - June 2008

Results

Processes characterisation

Debris flow kinematics

- The video recording of the debris flow is sequenced to jpeg images
→ Binary images of successive subtracted images
→ four main phases in debris flow propagation

APPLYING IMAGE PROCESSING TECHNIQUES FOR THE CHARACTERIZATION OF DEBRIS FLOW KINEMATICS

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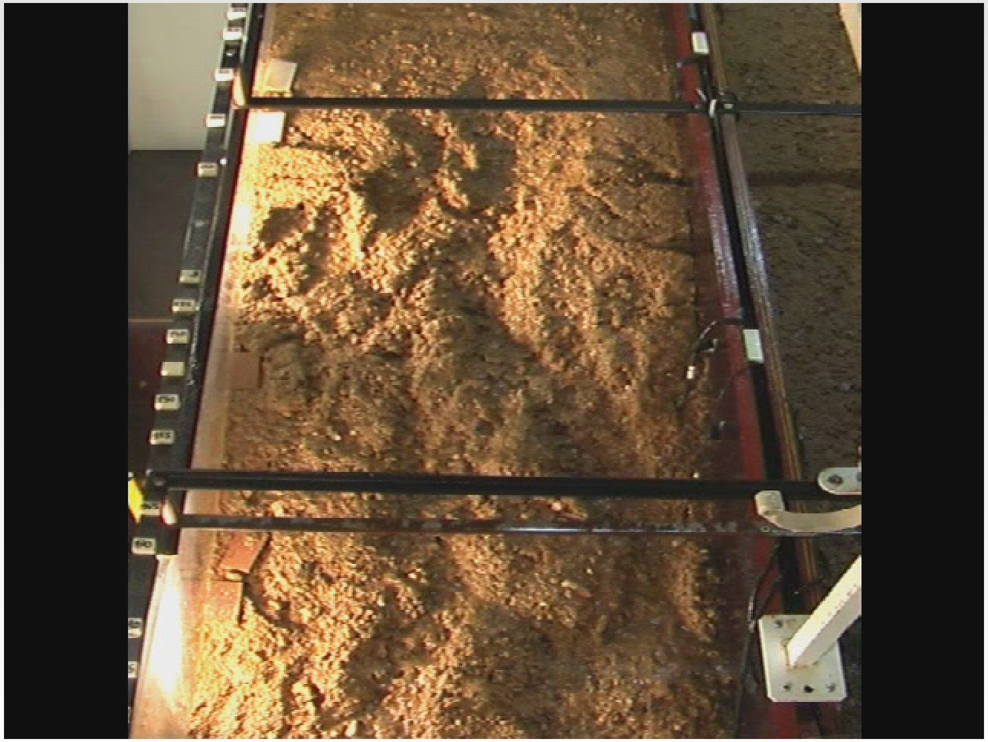
[2] CETE NP/Département RDT, 151 rue de Paris, Saint Quentin, F-02100, France



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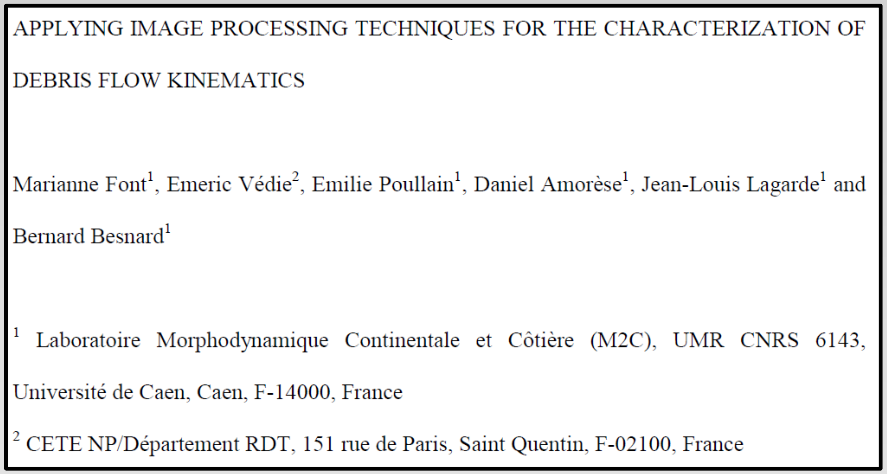
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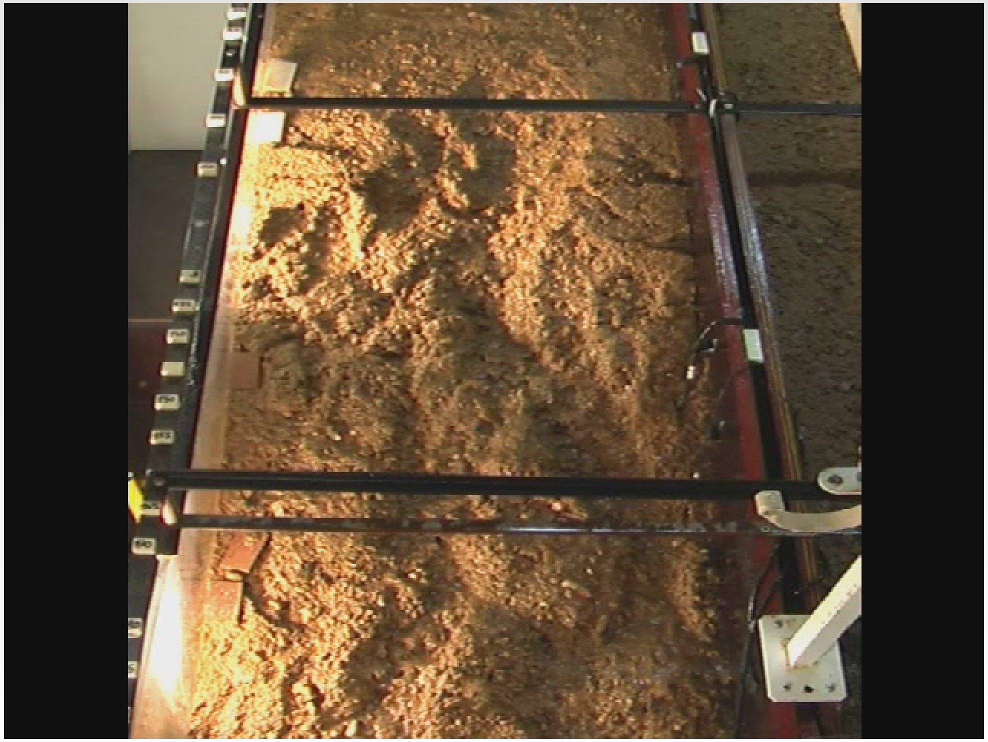

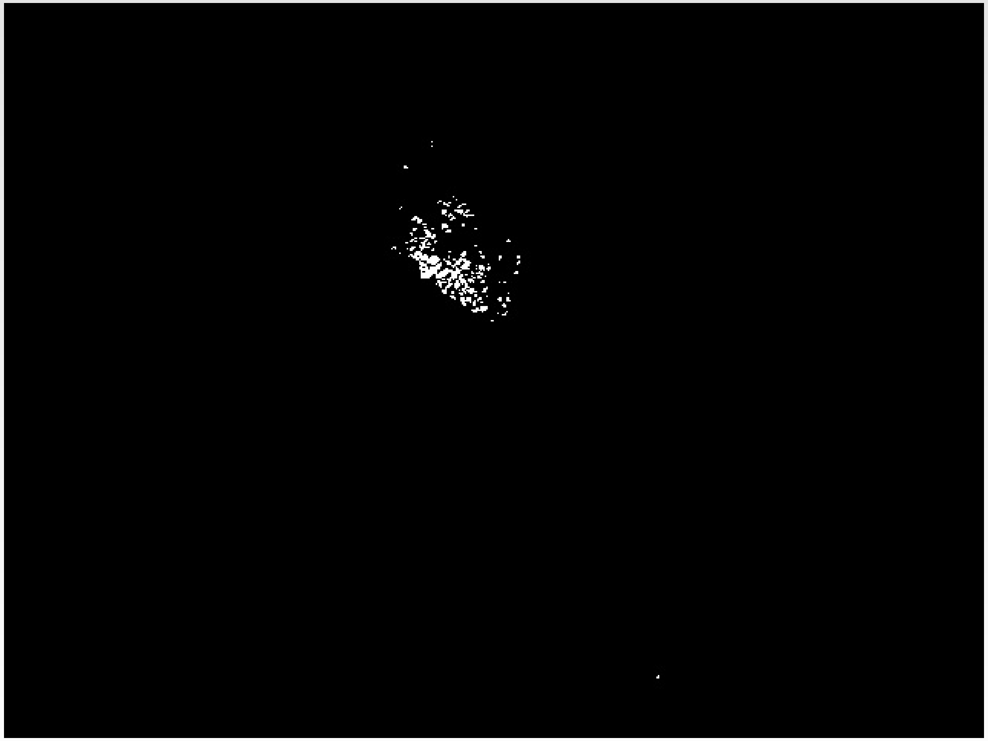

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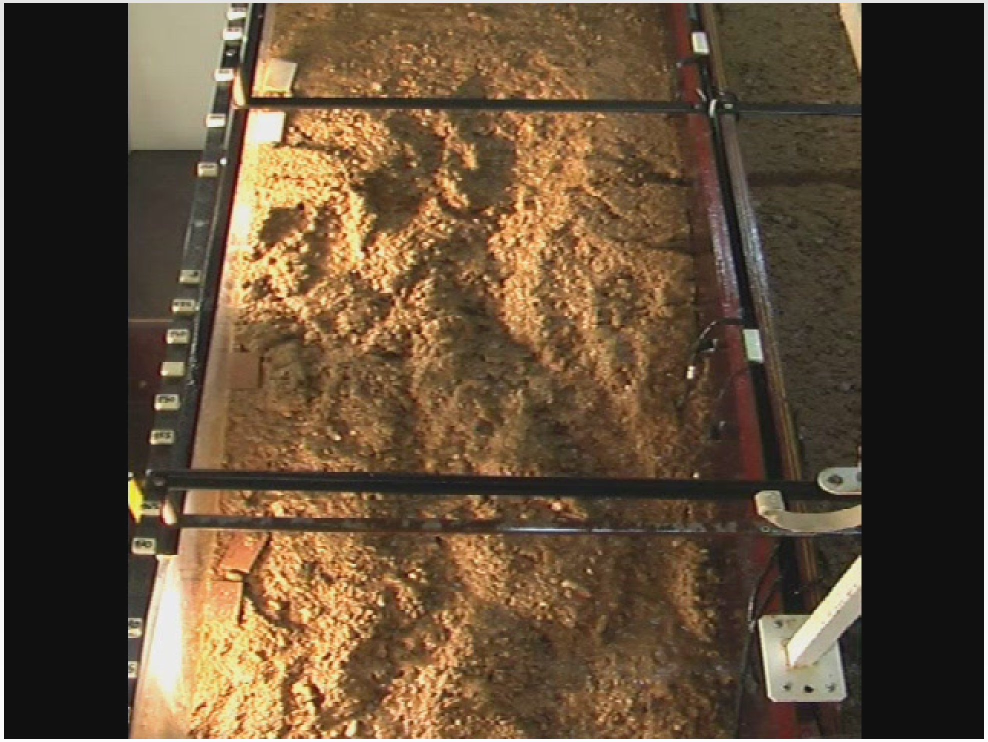

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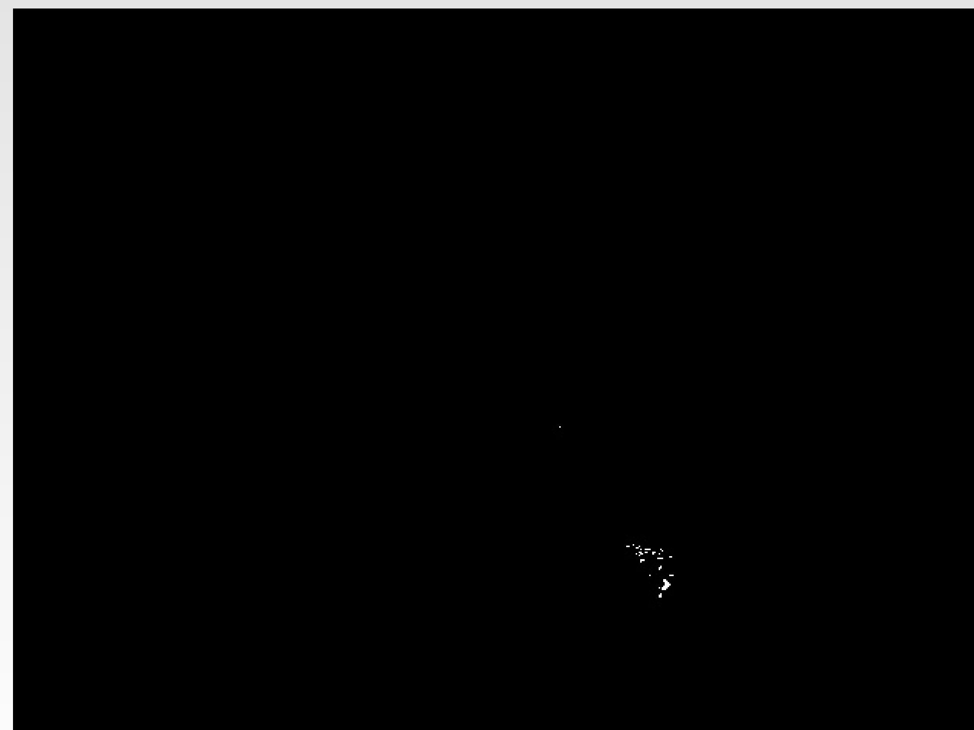

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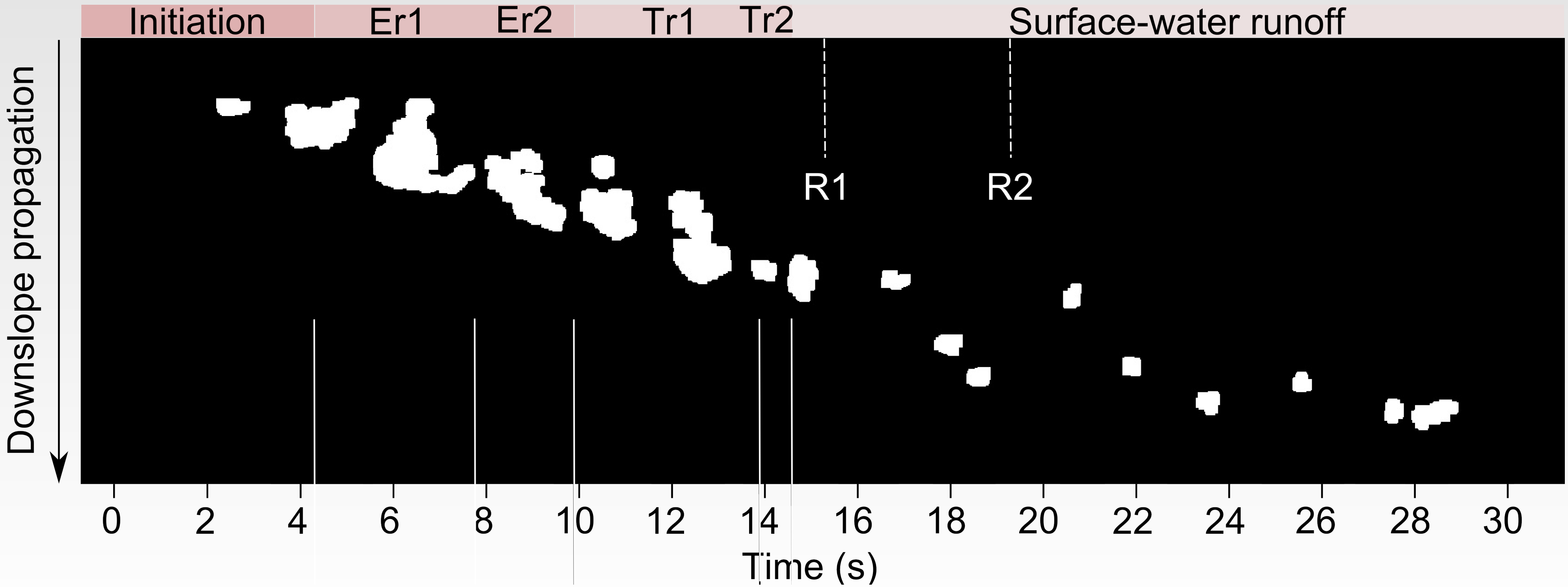
Processes characterisation **Debris flow kinematics**

a/ bouldery front showing a slow speed of the mass movement and lateral spreading;
b/ slow channelized flow of coarse suspended particles;
c/ debris flow surge runs with a bouldery front of rolling coarser elements and a thinner finer particles flow;
d/ residual water surface runoff.



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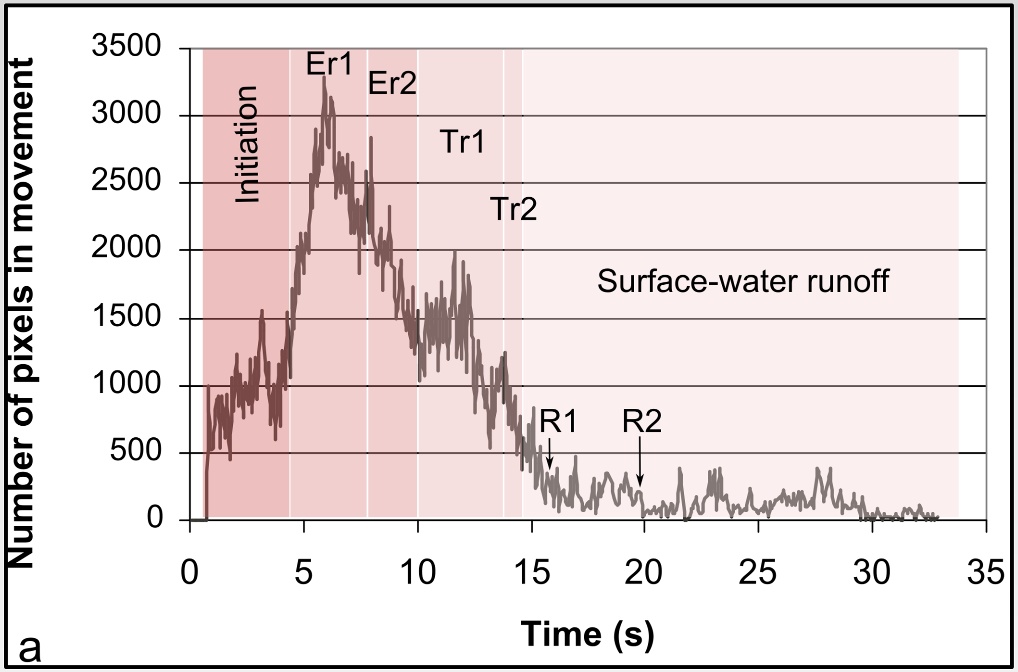
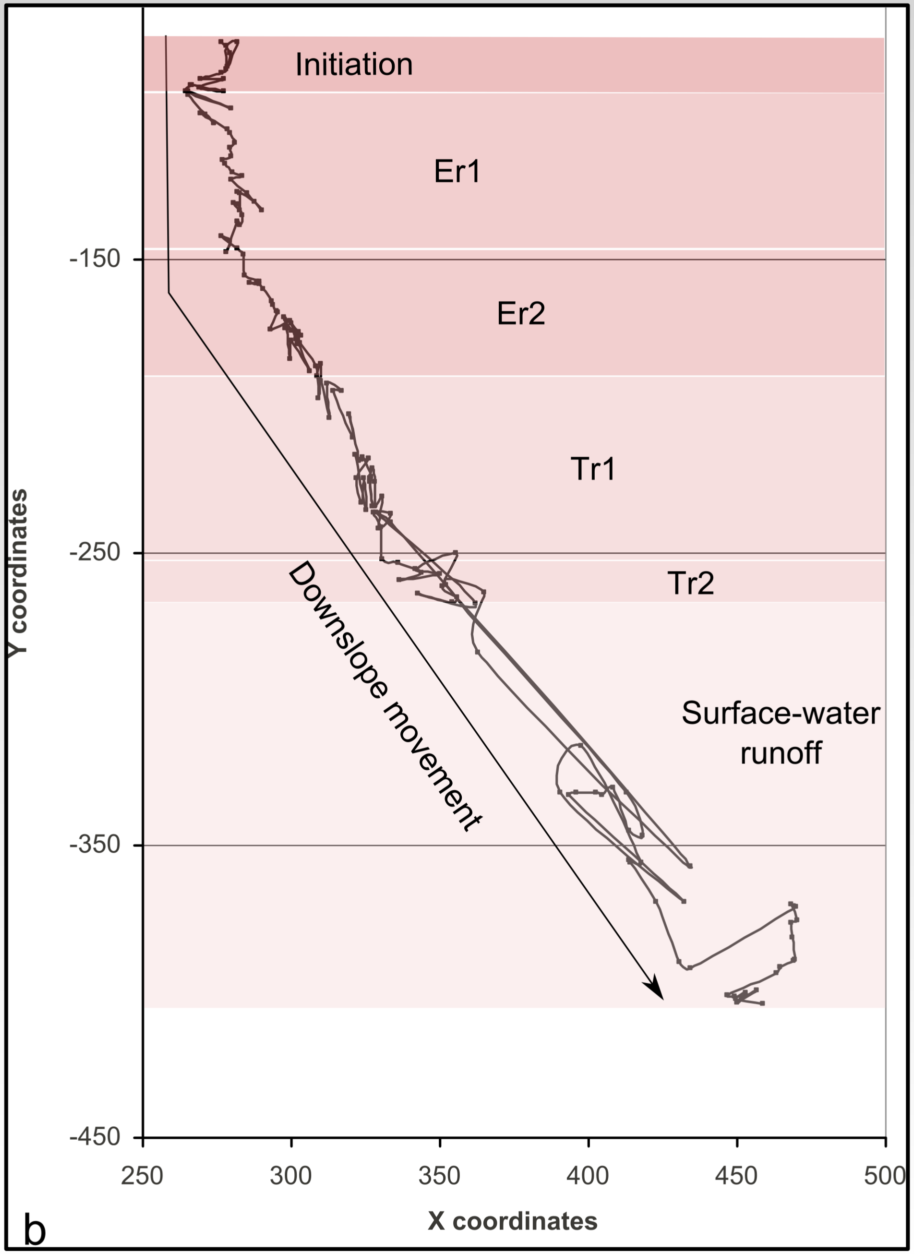


Surface size evolution during experimental debris flow – Font et al., 2011



Downslope movement of the experimental debris flow gravity center – Font et al., 2011, 2014