Workshop ARPA Piemonte – 7 febbraio 2018, Torino

Attività di studio e monitoraggio del'ambiente periglaciale e del permafrost nelle Alpi piemontesi

# La criosfera sotterranea delle alpi orientali, strumento paleoclimatico e di monitoraggio del cambiamento climatico


Renato R. Colucci

Department of Earth System Sciences and Environmental Technologies

ISMAR-CNR Trieste (Italy)

Commissione Grotte E. Boegan (SAG-CAI, Trieste)


# The periglacial environment – **Ice Caves**

## Ice Caves

### What is an ice cave?

Alpine ice caves are natural caves formed in bedrock, containing perennial accumulations of water in its solid phase

(*Perşoiu and Onac, 2012*)

Because one of their main characteristics is to have ground ice older than 2 years, many authors are prone to consider ice caves as *sporadic permafrost phenomena*

(*e.g. Holmlund et al., 2005; French, 2007; Kern et al., 2011)*

# The periglacial environment – **Ice Caves**

## Ice Caves

As part of the cryosphere, such ice masses are linked to the climate, but they do also exist in different kinds of environments, often at an altitude with an outside mean annual air temperature (MAAT) well above 0 °C

(e.g. Holmlund et al., 2005; Obleitner and Spötl,2011)

→ The accumulation of cold air into a cave during the winter seems to represent the main reason for the development and preservation of cold conditions leading to a progressive accumulation of ice

(Ford and Williams, 1989; Luetscher and Jeannin, 2004).

# The periglacial environment – **Ice Caves**

## Ice Caves

Ice forms through different mechanisms like recrystallization of snow, refreezing of percolating water, or with much less contribution, sublimation and deposition of cave-air vapor

(Luetscher and Jeannin, 2004).

# The periglacial environment – **Ice Caves**

## Ice Caves

Depending on their morphology, ice caves generally are described taking in account the relationships between ice formation and cave-air dynamics

classification

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# The periglacial environment – **Ice Caves**

## Ice Caves

### Static (SIC) and Dynamic (DIC)

**SIC** → quite simple air circulation system, where cold air is trapped owing to its higher density within a single entrance cave

(Thury, 1861; Luetscher and Jeannin, 2004)

**DIC** → are related to the so-called **chimney effect (Balch effect)**, in which multiple entrances at different elevations produce a more complicated air flow system that forces air convection and is strictly dependent on seasonal effects (Thury, 1861; Balch, 1900)

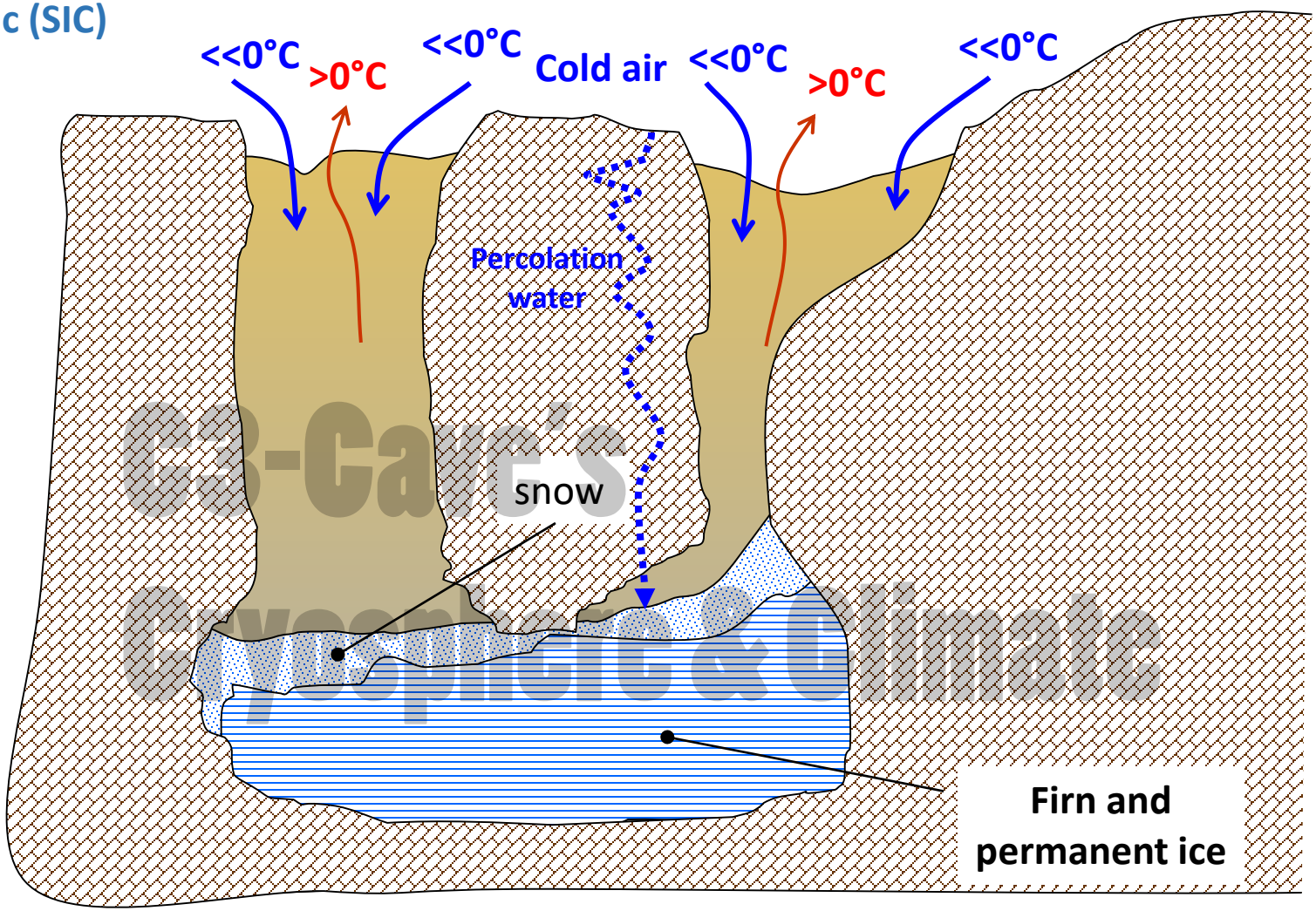
(Thury, 1861; Balch, 1900)

# The periglacial environment – **Ice Caves**

WINTER

## Ice Caves

### Static (SIC)

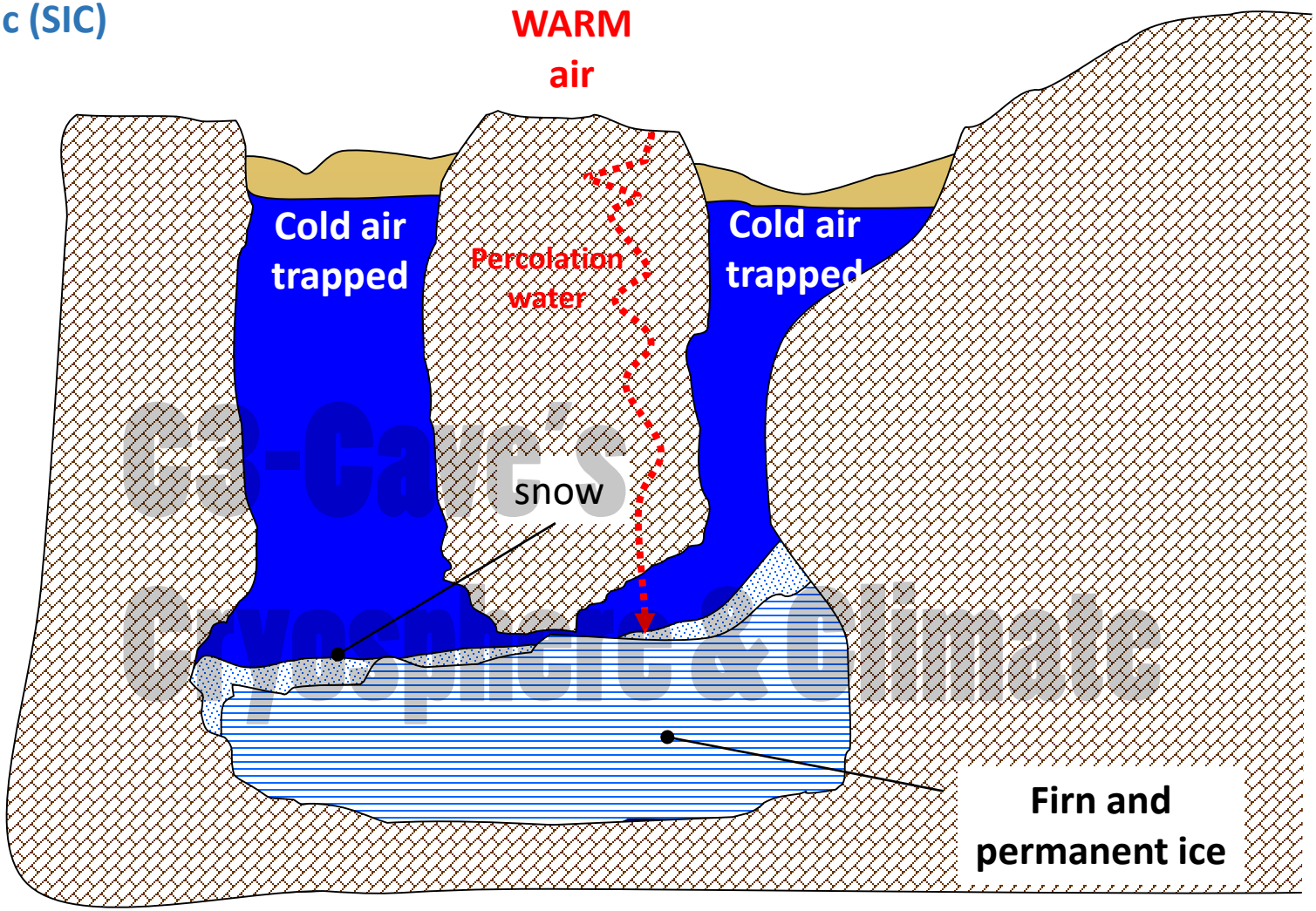


# The periglacial environment – **Ice Caves**

**SUMMER**

## Ice Caves

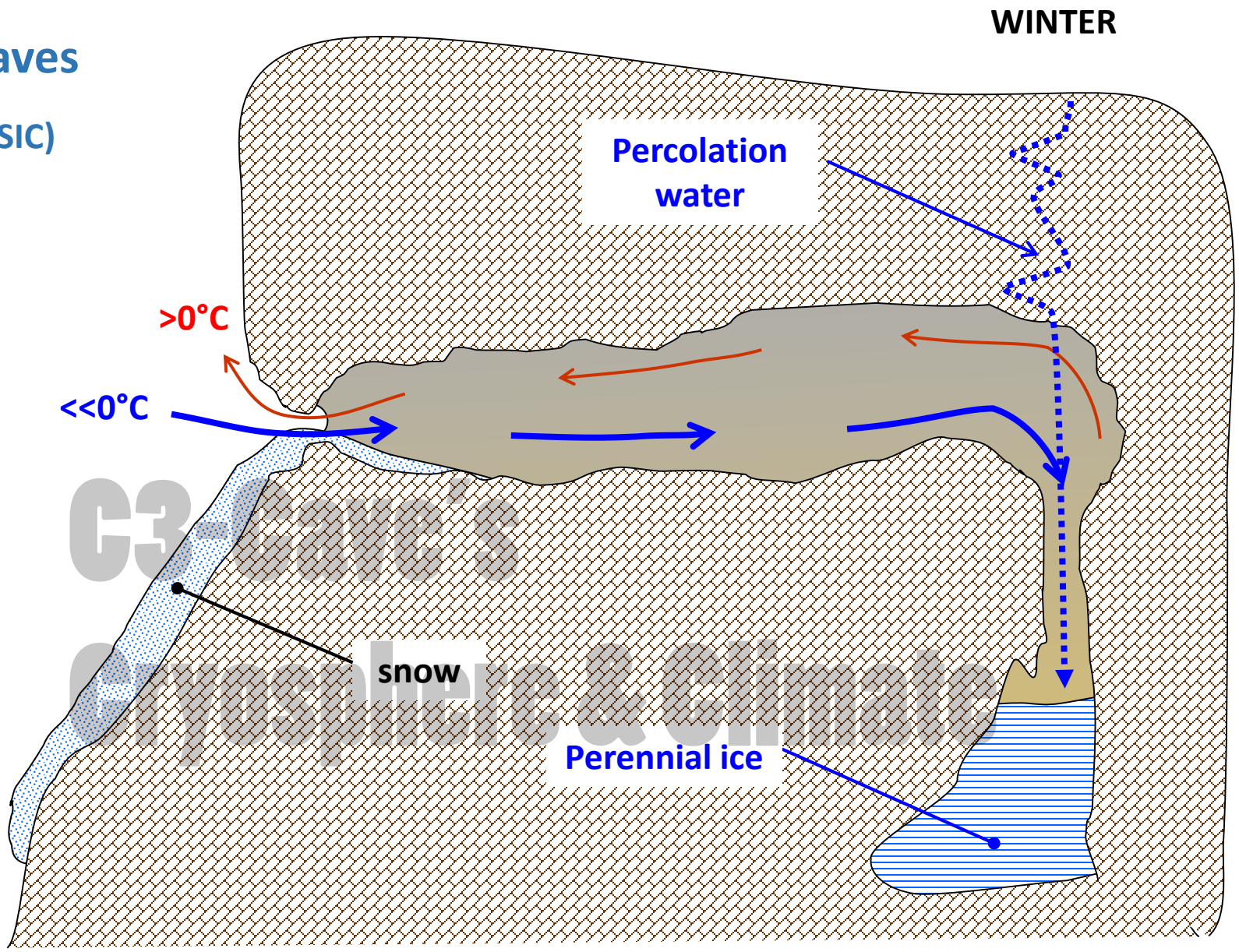
### Static (SIC)



# The periglacial environment – **Ice Caves**

## Ice Caves

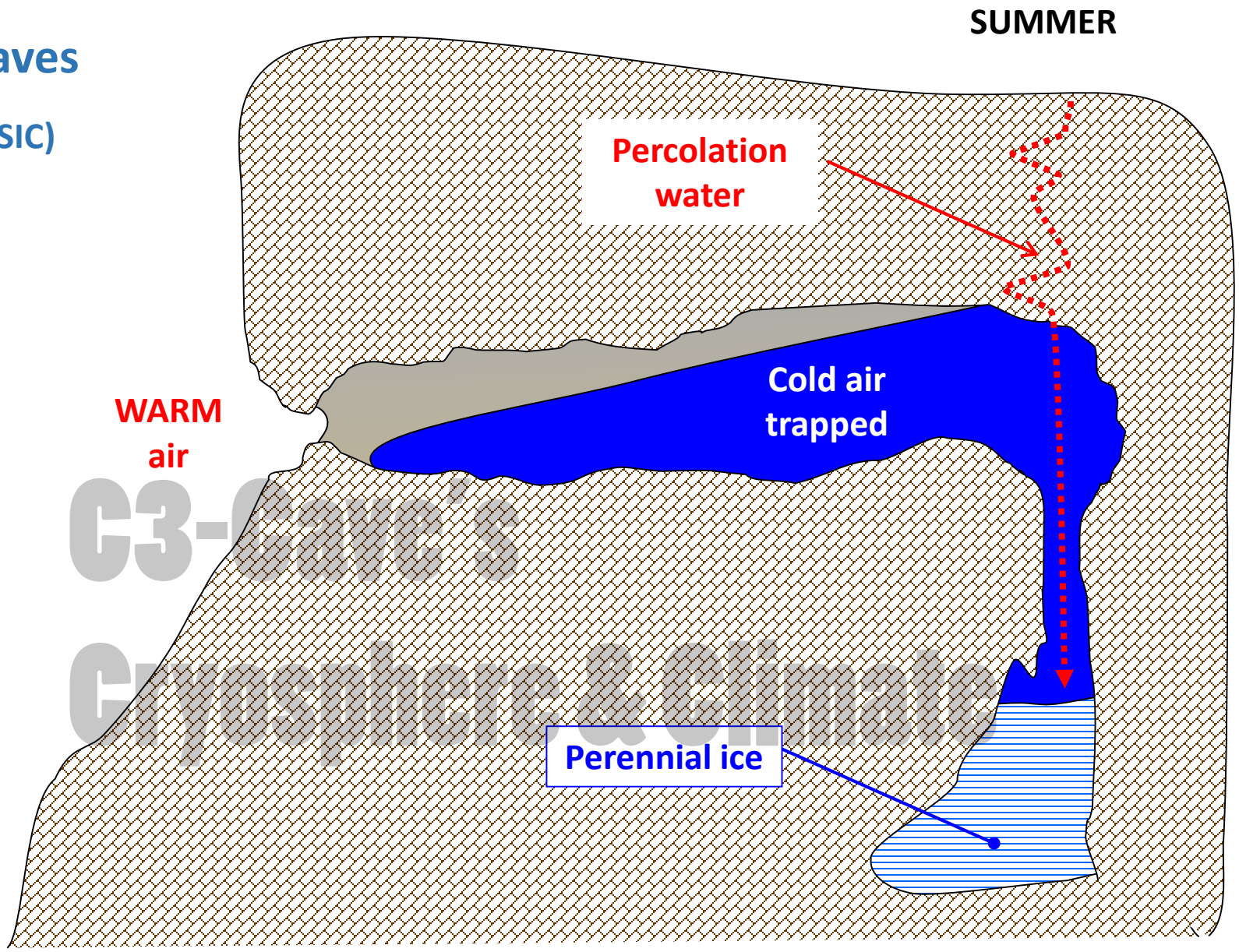
### Static (SIC)



# The periglacial environment – **Ice Caves**

## Ice Caves

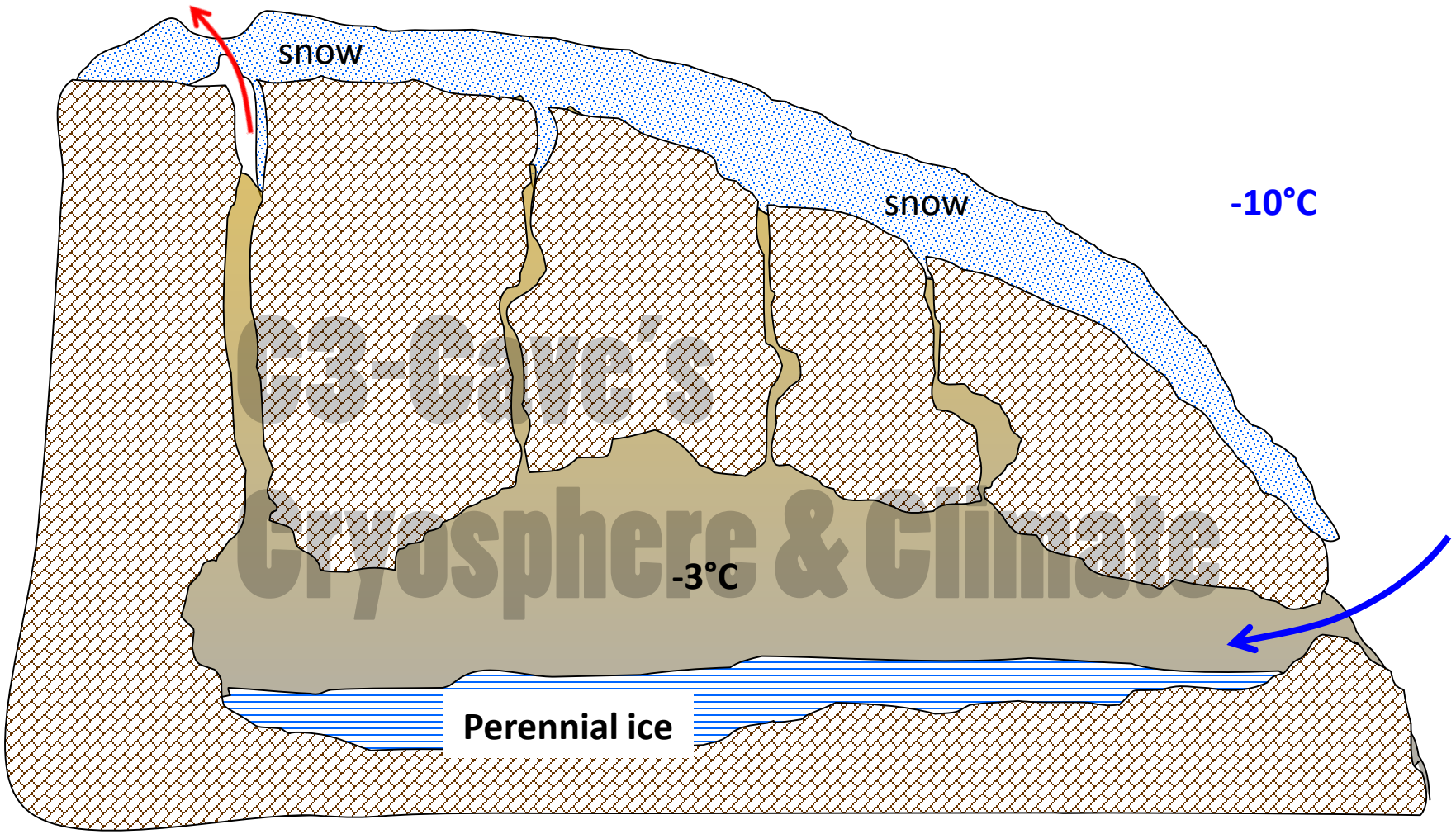
### Static (SIC)



# The periglacial environment – **Ice Caves**

## Ice Caves

### Dynamic (DIC)

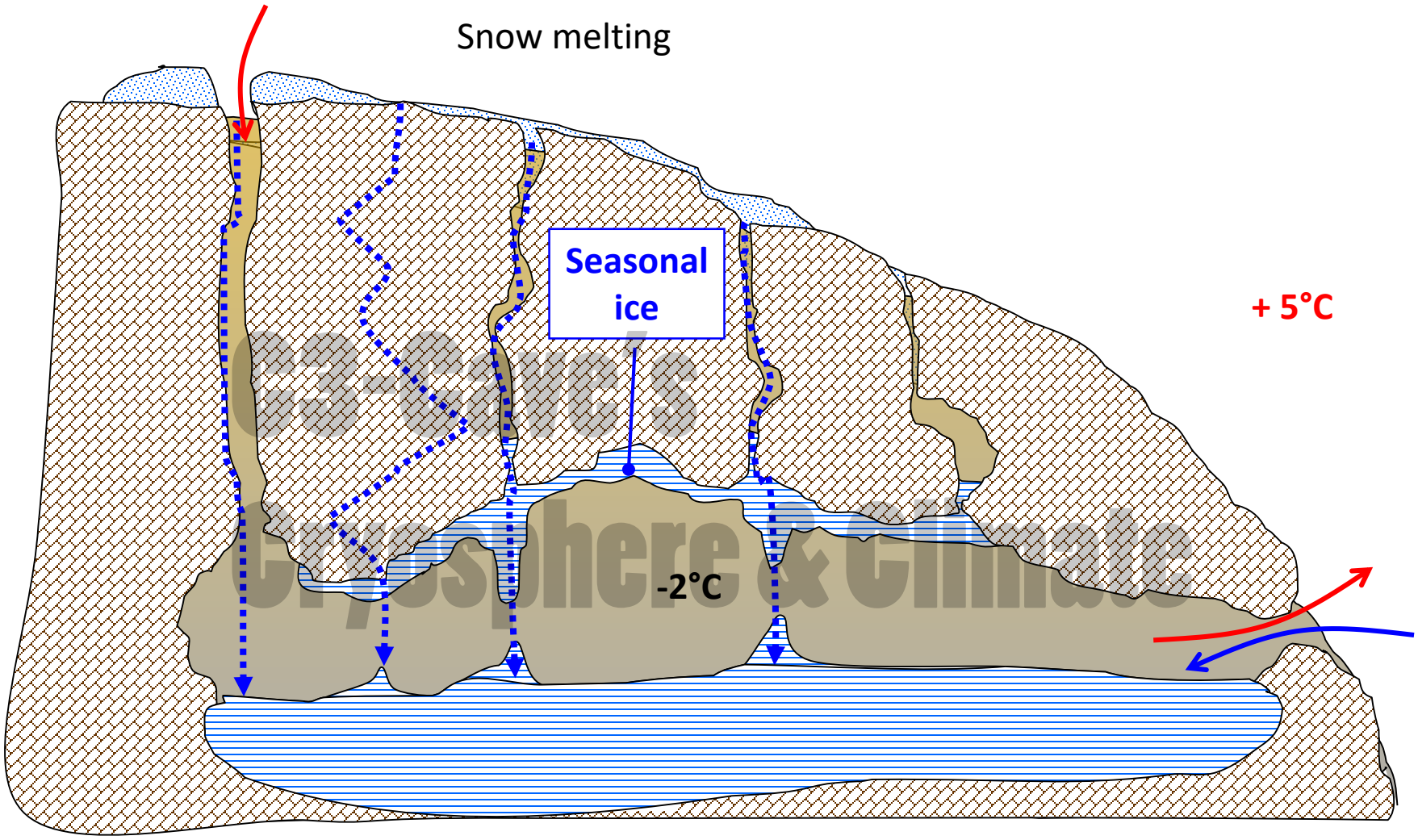


# The periglacial environment – **Ice Caves**

SPRING

## Ice Caves

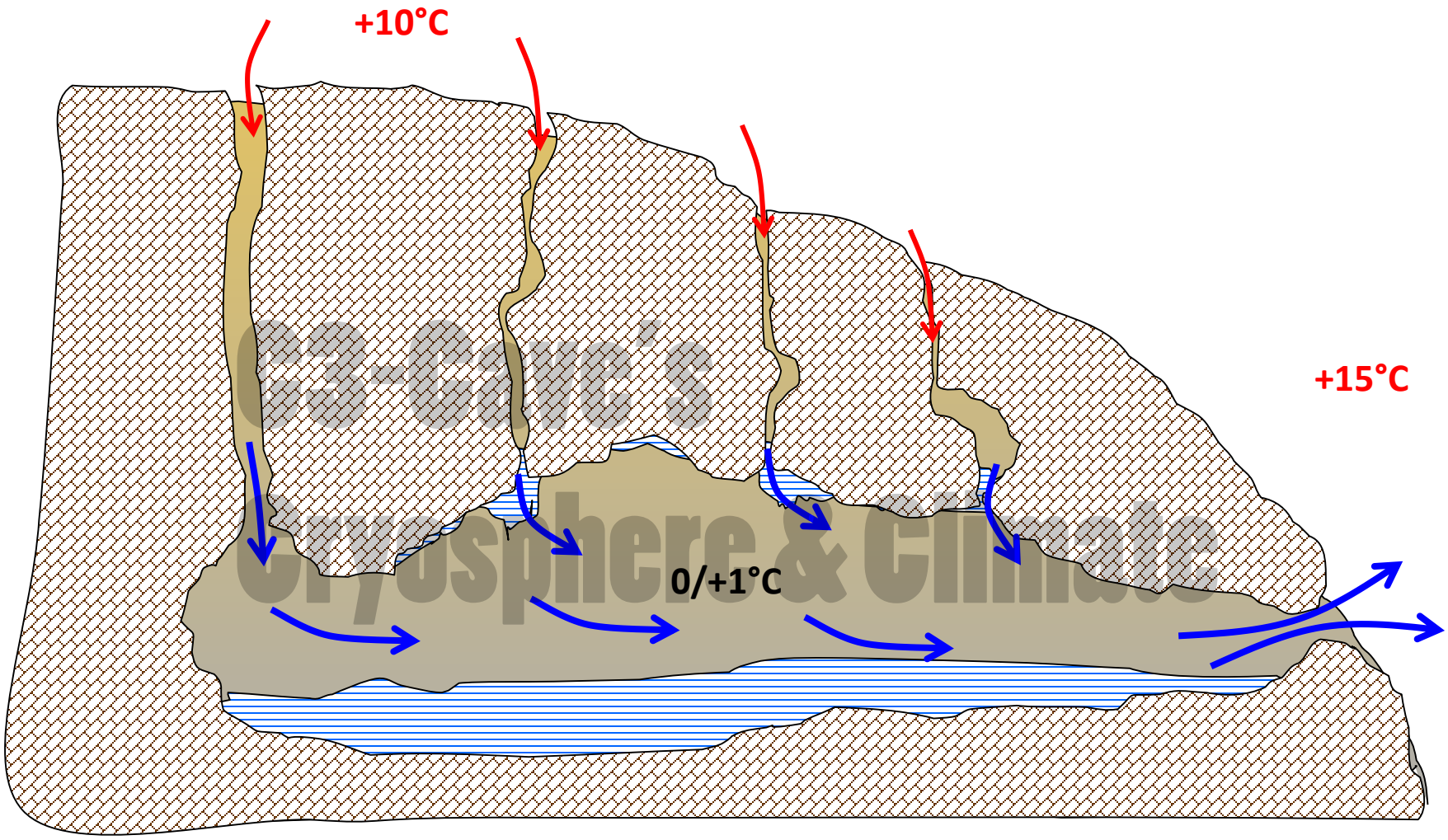
### Dynamic (DIC)



# The periglacial environment – **Ice Caves**

## Ice Caves

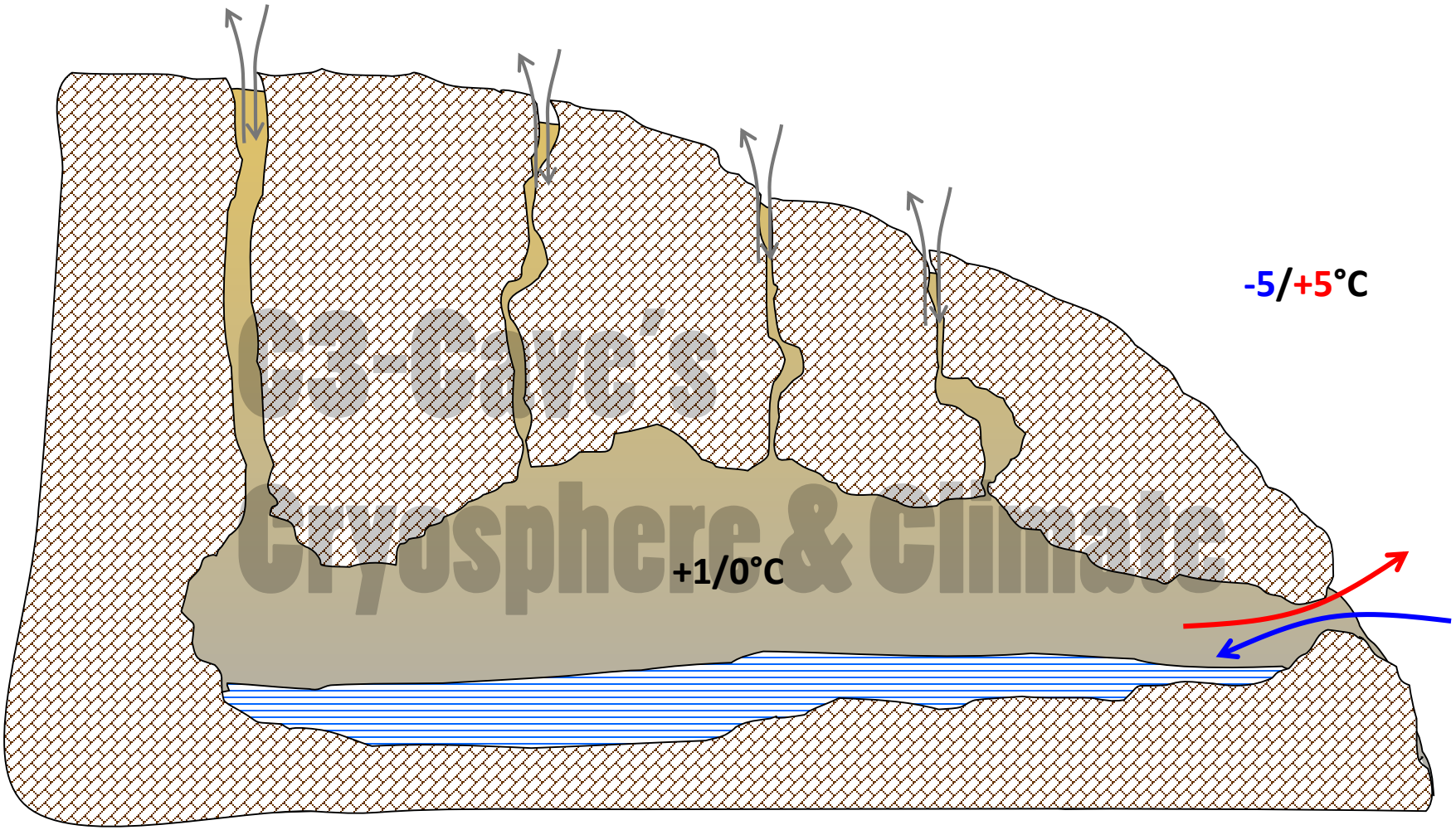
### Dynamic (DIC)



# The periglacial environment – **Ice Caves**

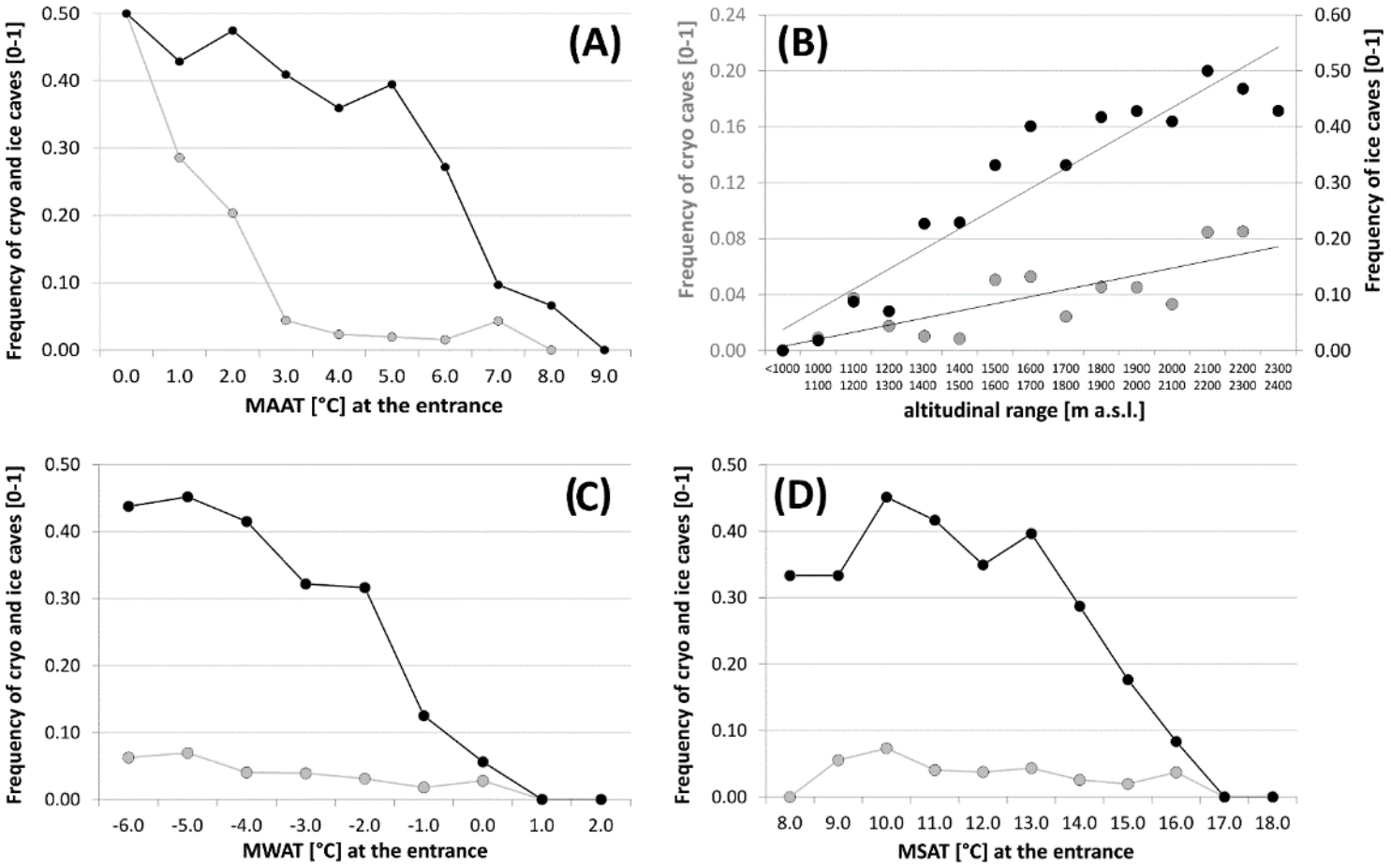
## Ice Caves

### Dynamic (DIC)



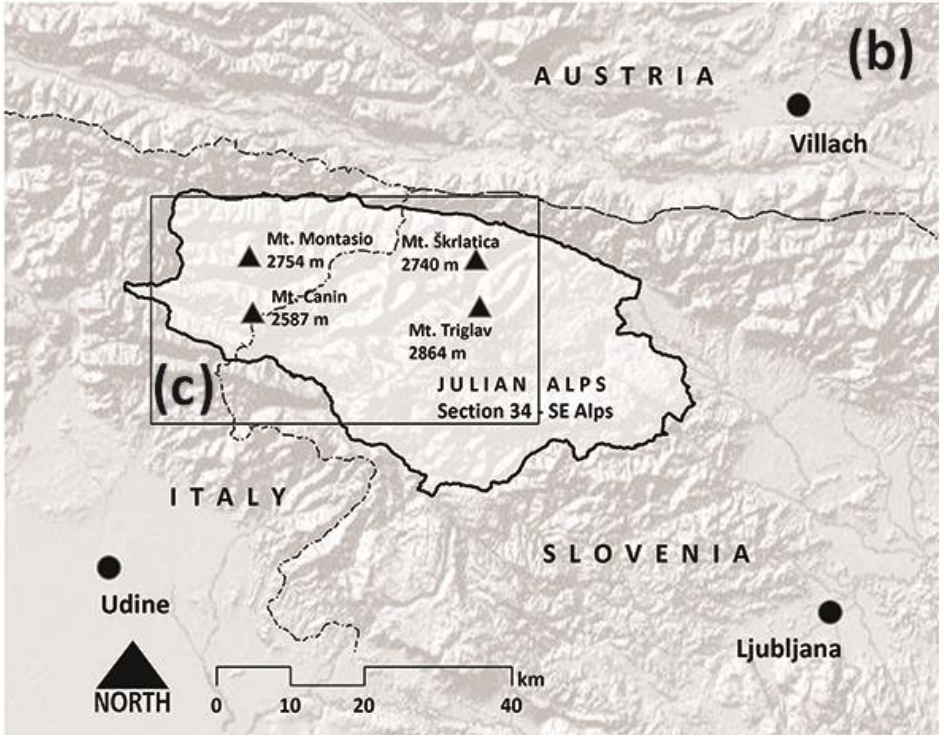
# The periglacial environment – **Ice Caves**

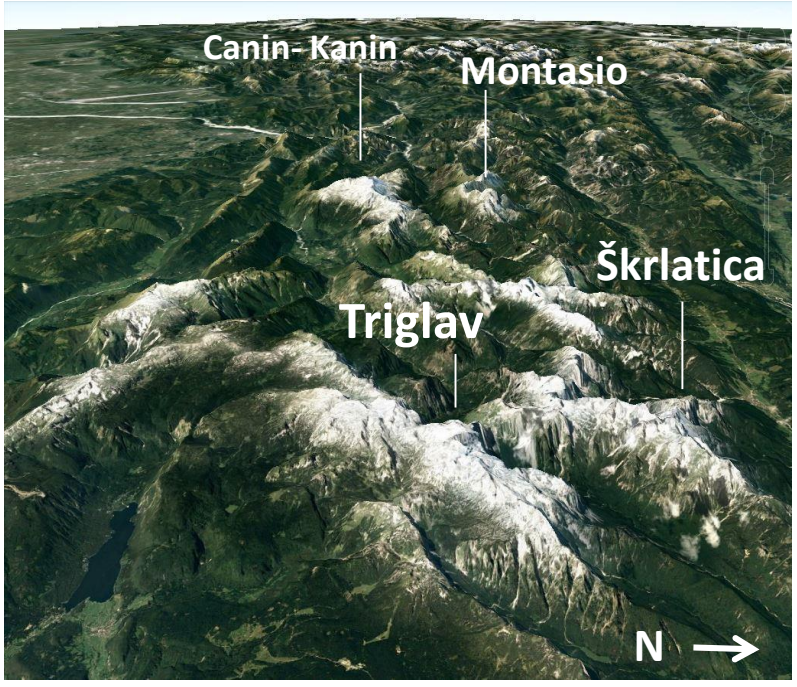
**Cryo cave climatology** → (A) mainly concentrated where MAAT < 5°C ; MAAT < 2°C for ice caves
(B) P increase with altitude (R=0.96 (cryo) & 0.97 (ice))
(C) not present where MWAT>0°C; significant increase MWAT<-2°C
(D) MSAT not significant → abrupt decrease with MSAT > 13°C




*(Colucci et al., 2016 - Geomorphology)*

# The Canin massif – **Julian Alps**

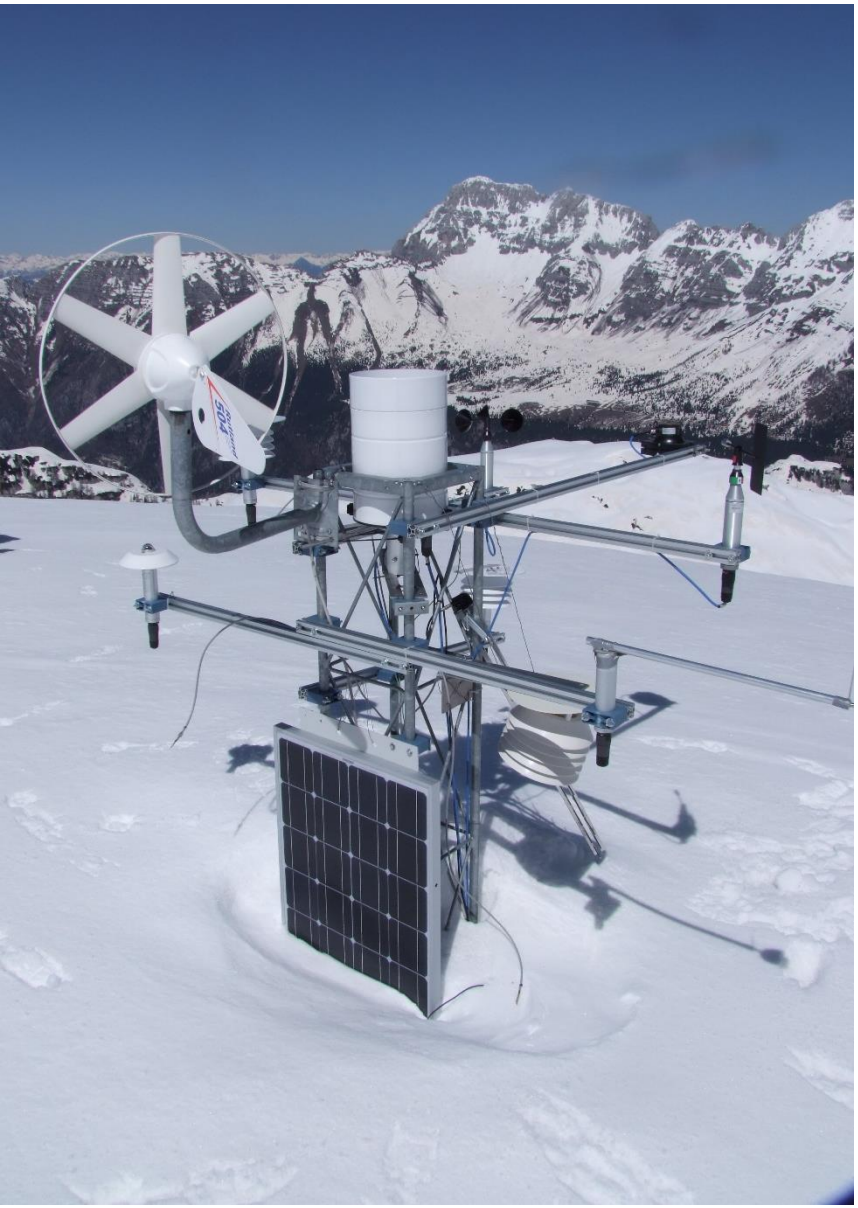

The Julian Alps
1853 km$^2$
west to east across the Ita–Slo border

Carbonate massifs

Highest elevations
- Mt.Triglav slo (2864m)
- Mount Montasio ita (2754 m)
- Mount Škrlatica slo (2740 m)

PARCO NATURALE PREALPI GIULIE

Unione Meteorologica del Friuli Venezia Giulia ONLUS



*Canin AWS - late April 2013*

Automatic weather station (AWS) Canin (since 2012)
2203 m asl - h 9 m
Air temperature
Relative humidity
Precipitation (liquid)
Snow height
Wind speed and direction
Soil temperature (7 depths)
Solar radiation (total and reflected)

*Canin AWS - late April 2014*

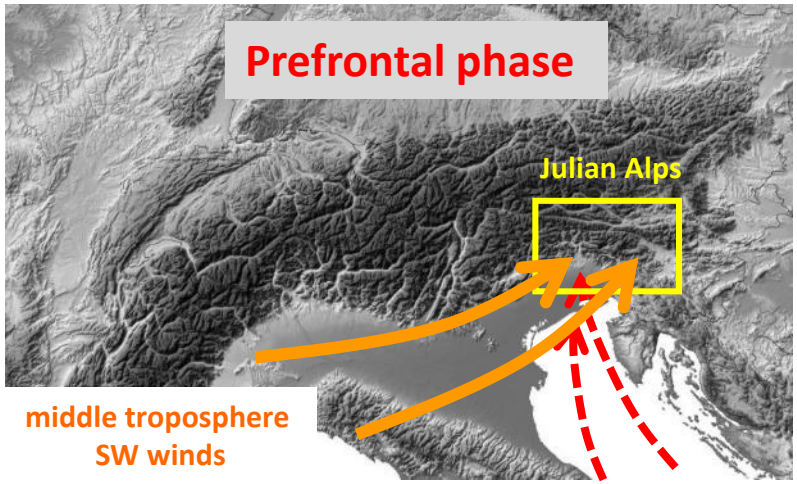
# Study area and climatology

*Ceschia et al., 1991*

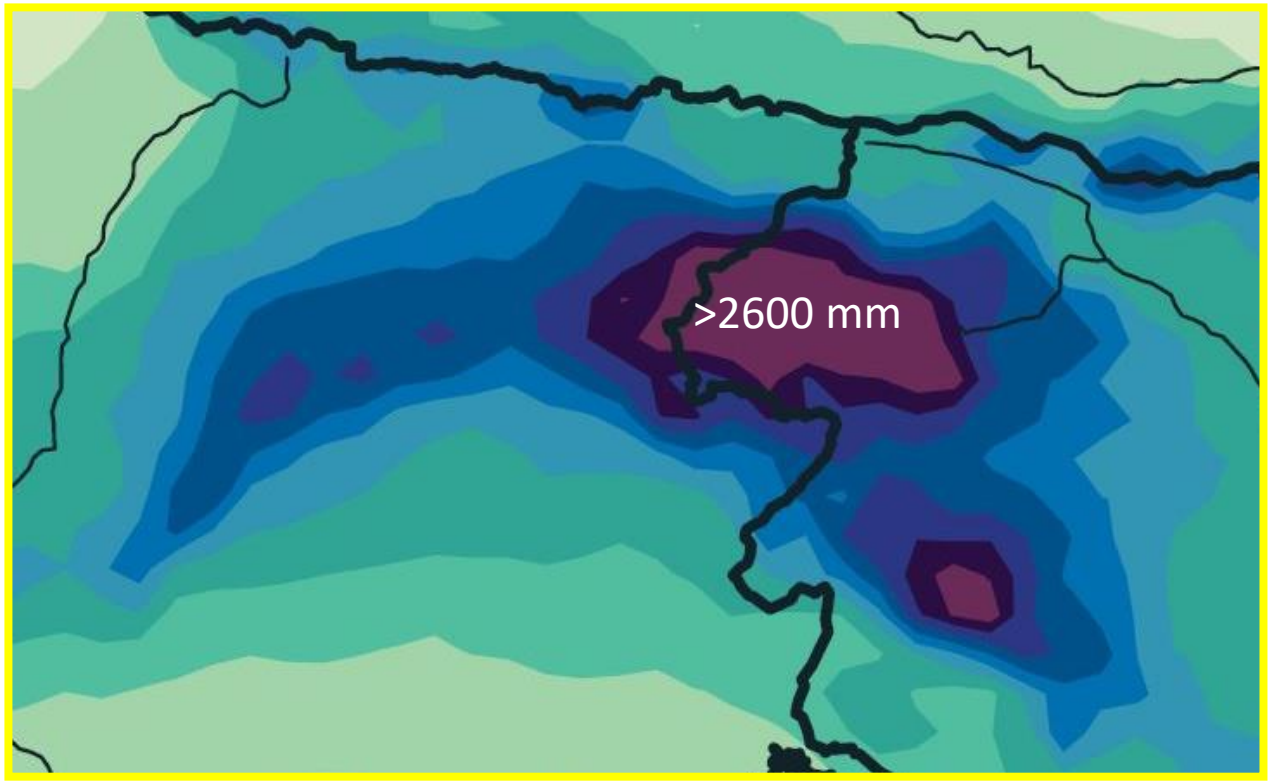
Synoptic generally prevails

Spring and early summer convection is predominant

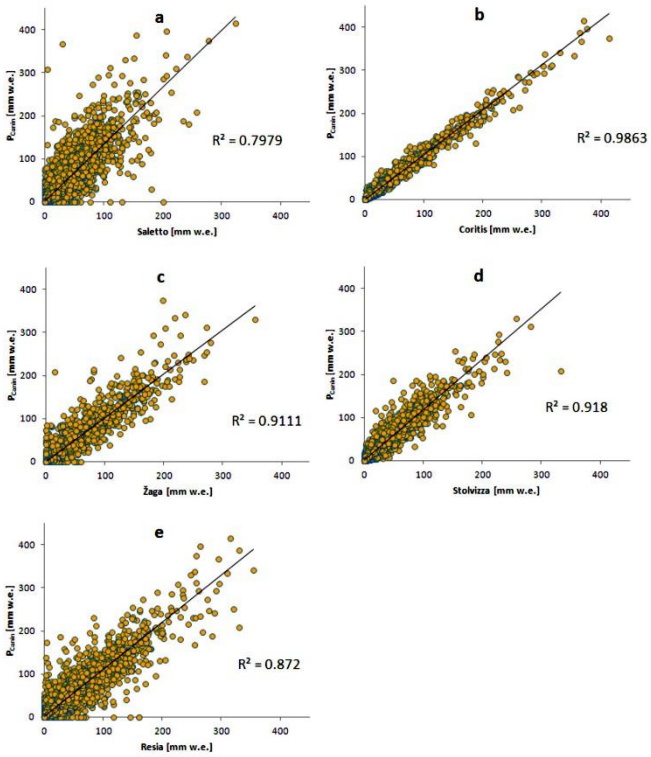
* **Cw (1800 m) = 7.2 m (winter snow accumulation)**

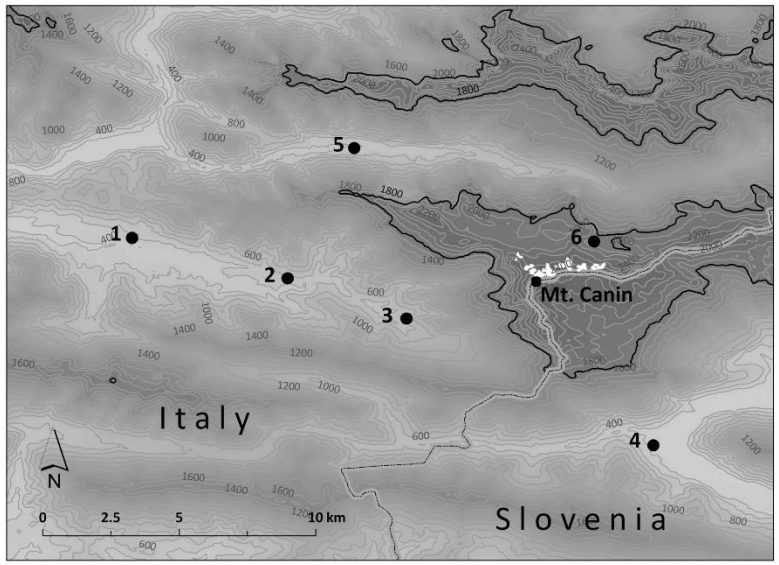


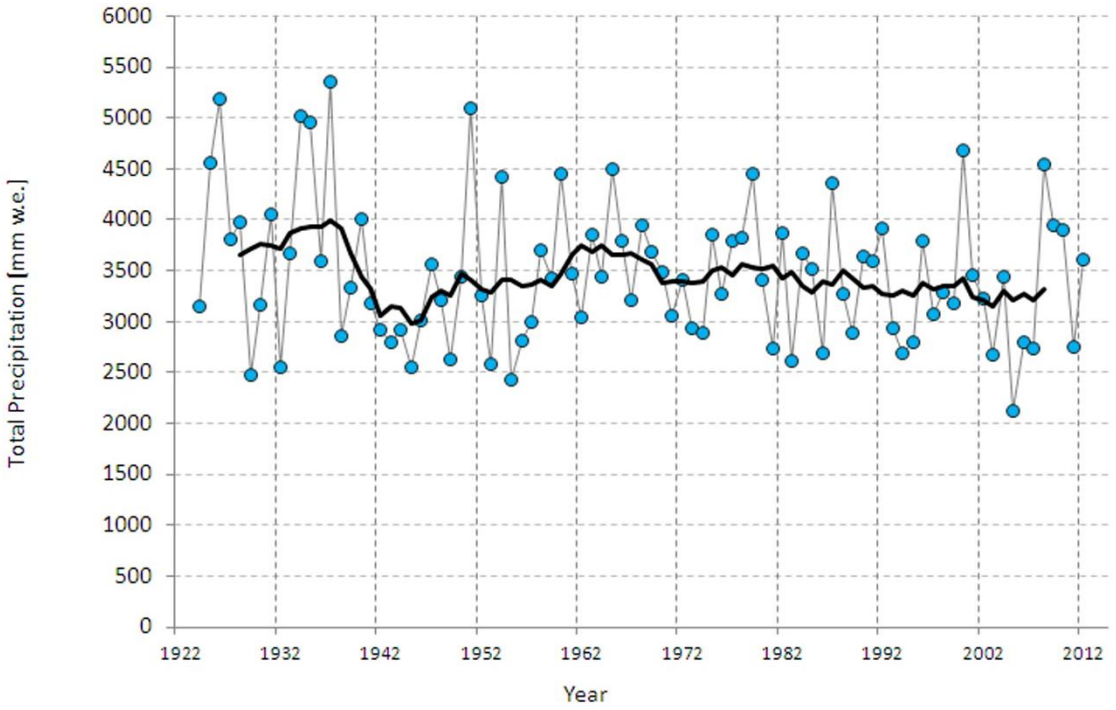

*Vrhovec et al., 2004*




*Isotta et al., 2013*



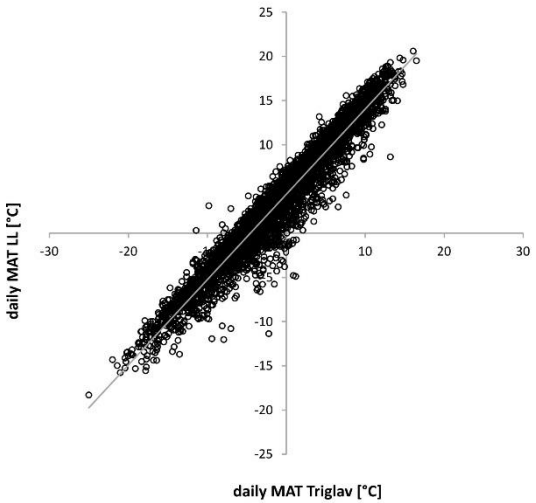




Precipitation reconstruction 1924-2012

Based on 5 valley weather station around Mt. Canin

*Colucci & Guglielmin, (2015) Int. Journal Clim.*

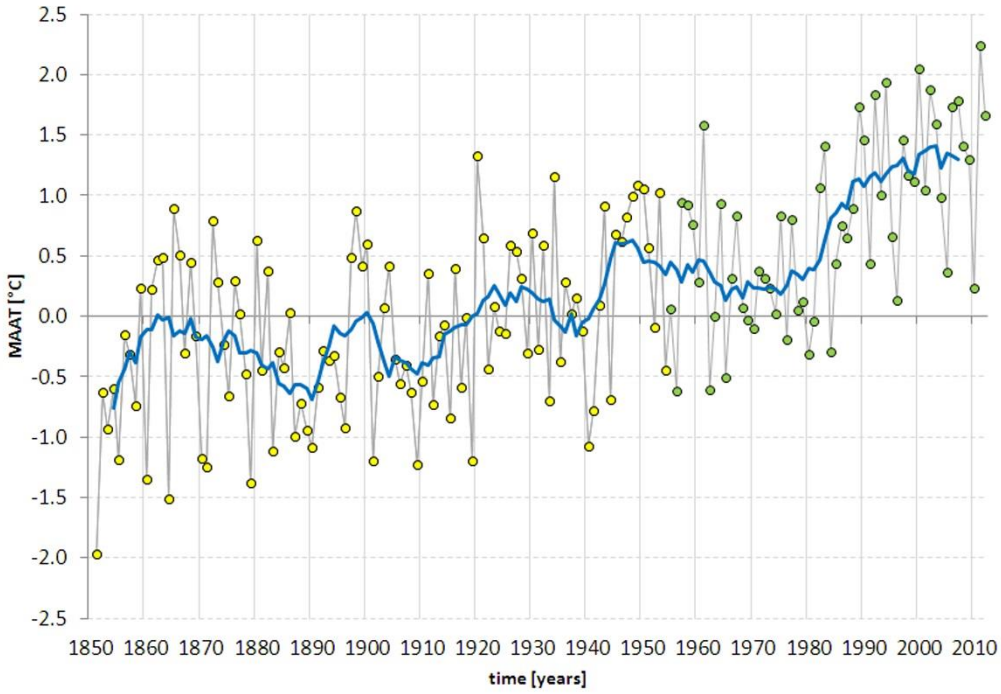


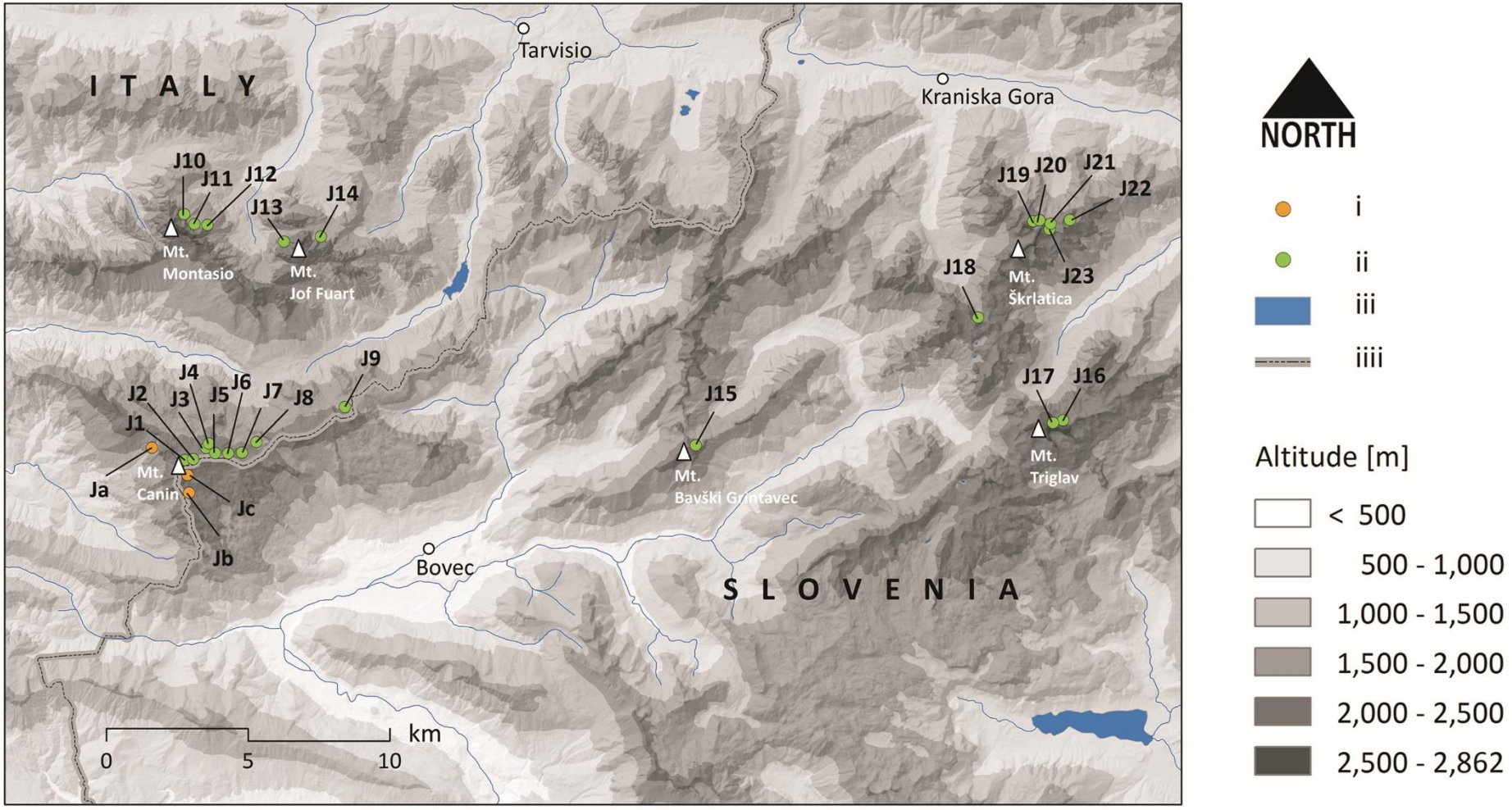


B → temperature reconstruction at the elevation of 2200 m 1851-2012

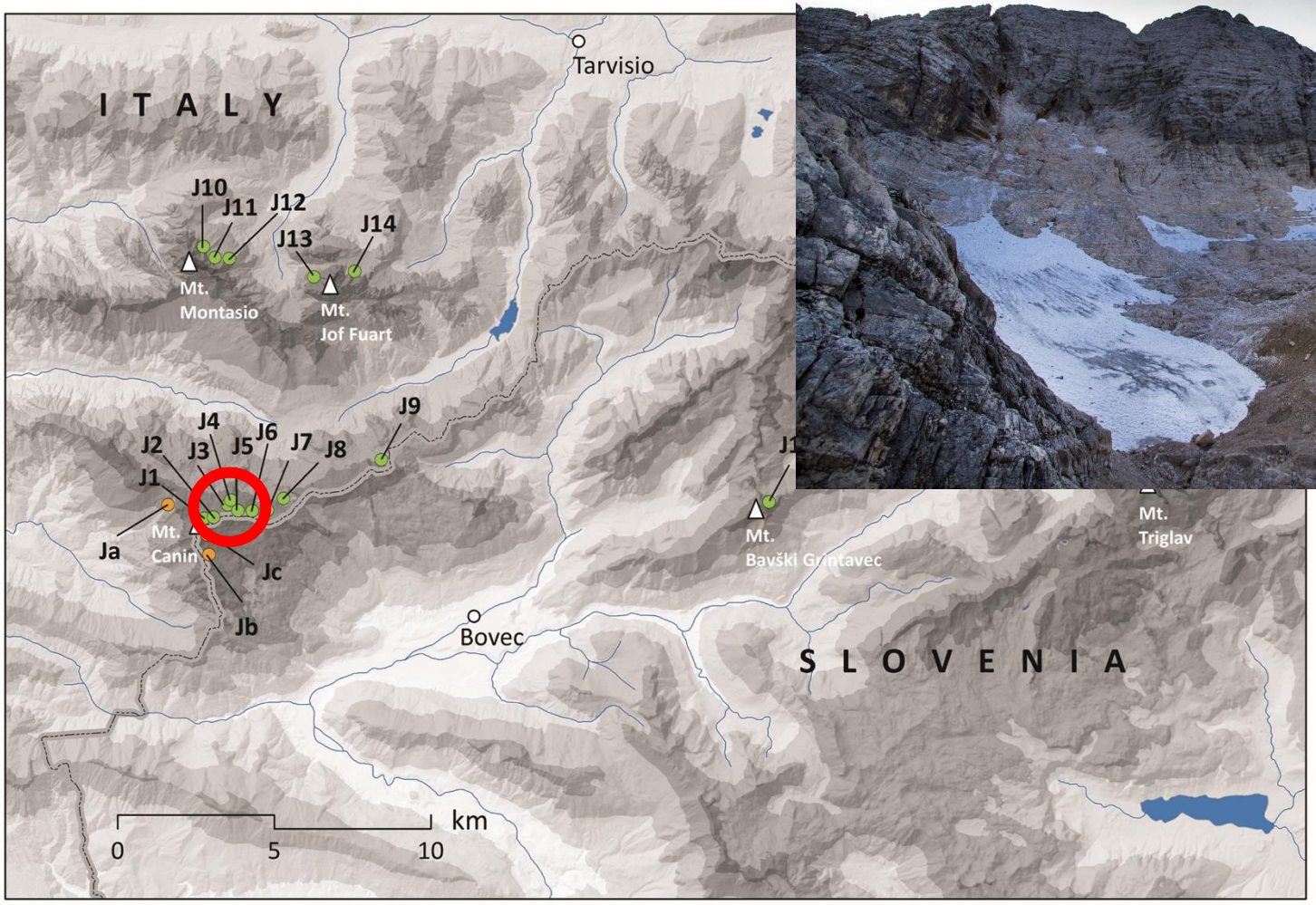
Based on 2 mountain station
(f) Villacher Alpe (2120 m) – Austria
(e) Triglav (2514 m) – Slovenia

*Colucci & Guglielmin, (2015) Int. Journal Clim.*





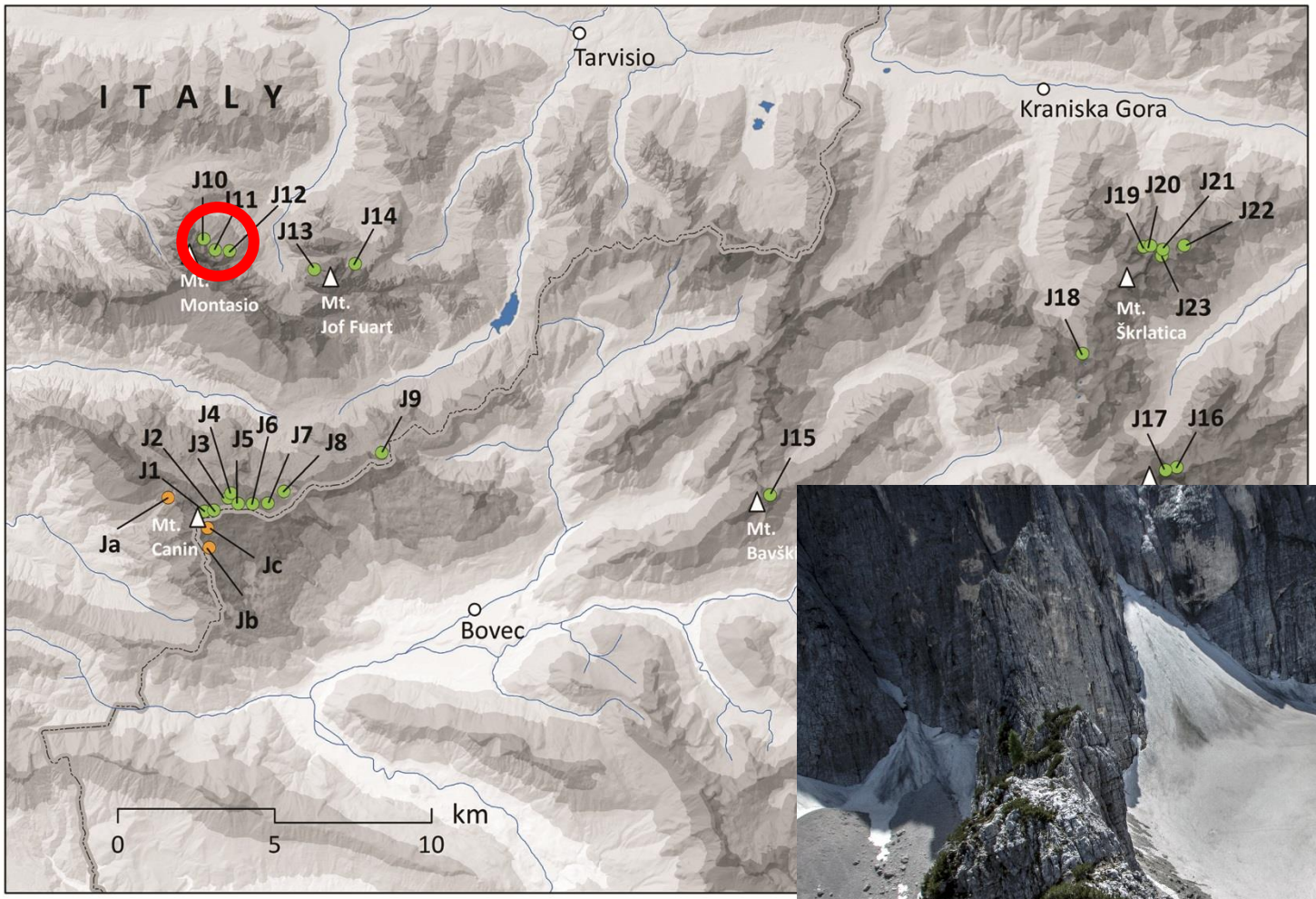

*Colucci (2016). Geomorphic influence on small glacier response to post Little Ice Age climate warming: Julian Alps, Europe. Earth Surface Processes and Landforms*


Altitude [m]

- < 500
- 500 - 1,000
- 1,000 - 1,500
- 1,500 - 2,000
- 2,000 - 2,500
- 2,500 - 2,862

*Colucci (2016). Geomorphic influence on small glacier response to post Little Ice Age climate warming: Julian Alps, Europe. Earth Surface Processes and Landforms*





NORTH

i

ii

iii

iiii

*Colucci (2016). Geomorphic influence on small glacier respo*
*Earth Surface Processes and Landforms*

# Glacial evolution in the Julian Alps since the Little Ice Age

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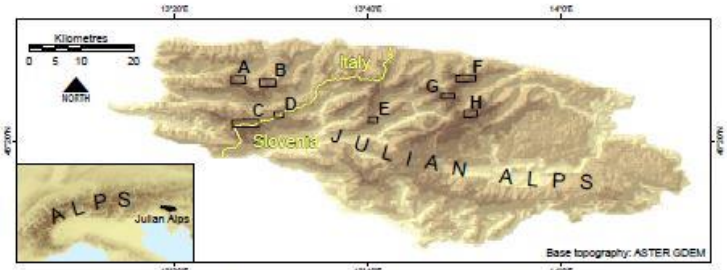
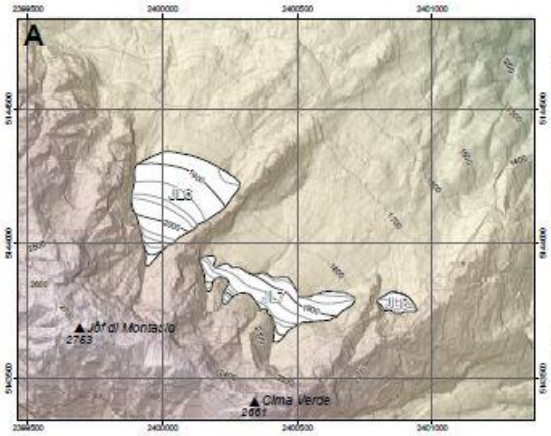
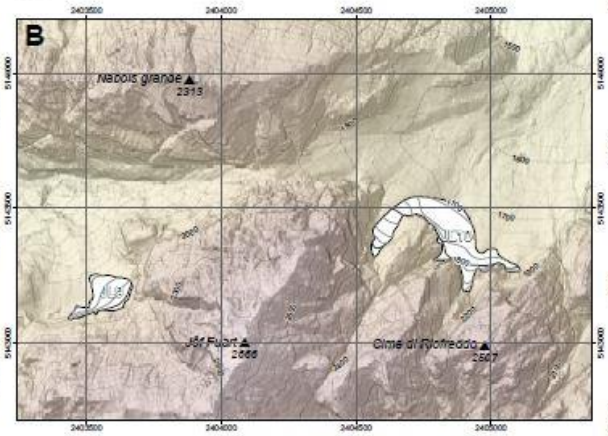
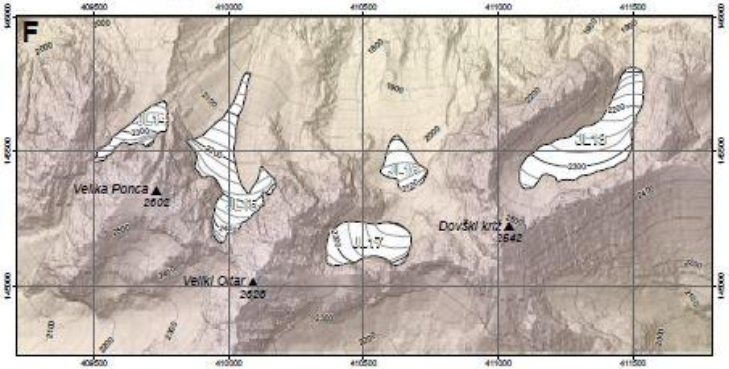


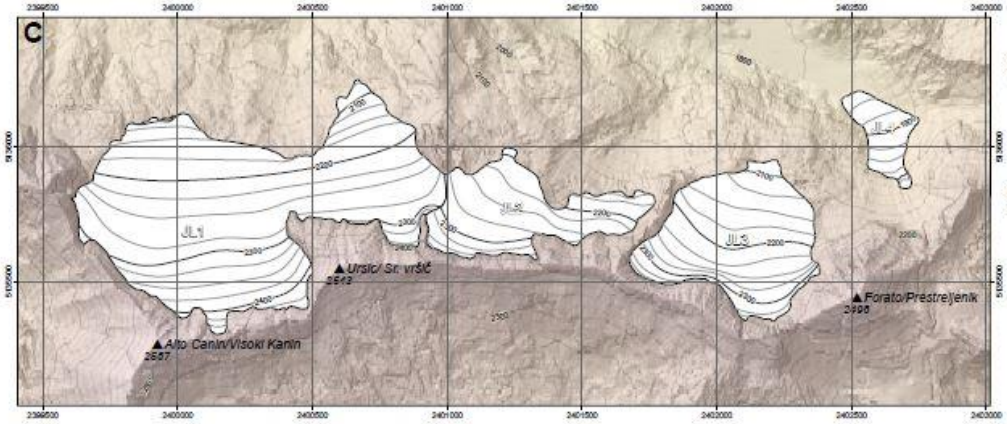



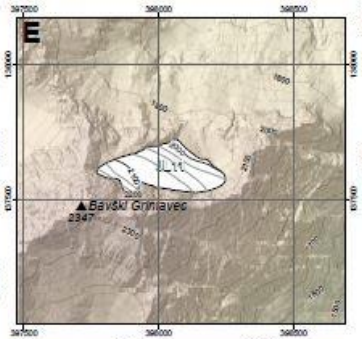

Metres
0 250 500 1.000 1.500

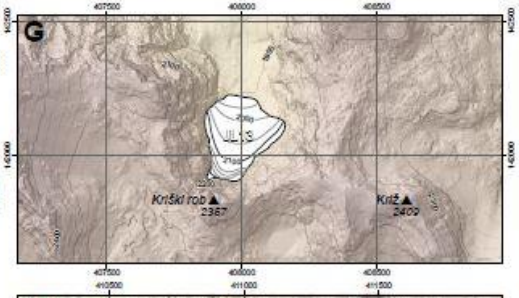
Scale 1:6.000

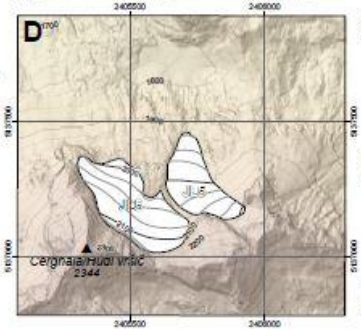
NORTH

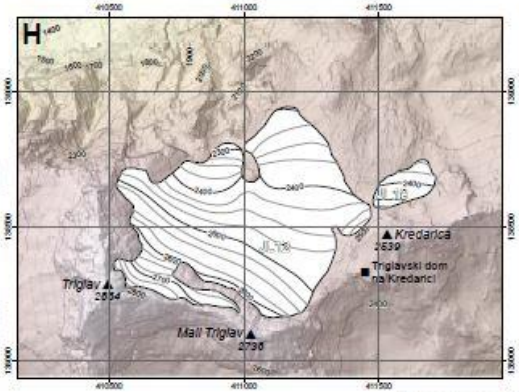
Coordinate system of maps A, B, C, D: Monte Mario Italy 2;
Projection: Transverse Mercator; Datum: Monte Mario
Coordinate system of maps E, F, G, H: D96 Slovenia;
Projection: Transverse Mercator; Datum: Slovenia Geodetic Datum 1996




**Legend**

Glacier extent in the Little Ice Age

Base topography of maps A, B, C, D: LiDAR data Italy 2006, Civil Defence of Friuli Venezia Giulia

Base topography of maps E, F, G, H: LiDAR data Slovenia 2014-2015, Geodetic Institute of Slovenia

**Area of glaciers in the Little Ice Age and loss of glacier volume since the Little Ice Age**

| ID | Name | Area [km²] | Volume [km³ 10⁻³] | ID | Name | Area [km²] | Volume [km³ 10⁻³] |
|---|---|---|---|---|---|---|---|
| JL1 | Canin | 0.678 | 27.9 | JL11 | Bavški Grintavec | 0.058 | 1.9 |
| JL2 | Ursic | 0.180 | 2.7 | JL12 | Zeleni sneg - Triglav | 0.442 | 13.8 |
| JL3 | Prestreljenik | 0.259 | 4.9 | JL13 | Kmica | 0.063 | 1.7 |
| JL4 | Prevala | 0.051 | 0.5 | JL14 | Ponca North | 0.022 | 0.4 |
| JL5 | Cergnala | 0.125 | 2.0 | JL15 | Ponca East | 0.068 | 1.2 |
| JL6 | Montasio West | 0.100 | 2.9 | JL16 | Low Oltar | 0.020 | 0.2 |
| JL7 | Montasio East | 0.063 | 1.3 | JL17 | High Oltar | 0.042 | 0.8 |
| JL8 | Montasio Minor | 0.008 | 0.1 | JL18 | Dovški križ | 0.083 | 1.9 |
| JL9 | Studence | 0.020 | 0.3 | JL19 | Kredarica | 0.025 | 0.4 |
| JL10 | Carnizza - Riofreddo | 0.061 | 1.0 | | | | |

# Glacial evolution in the Julian Alps since the Little Ice Age

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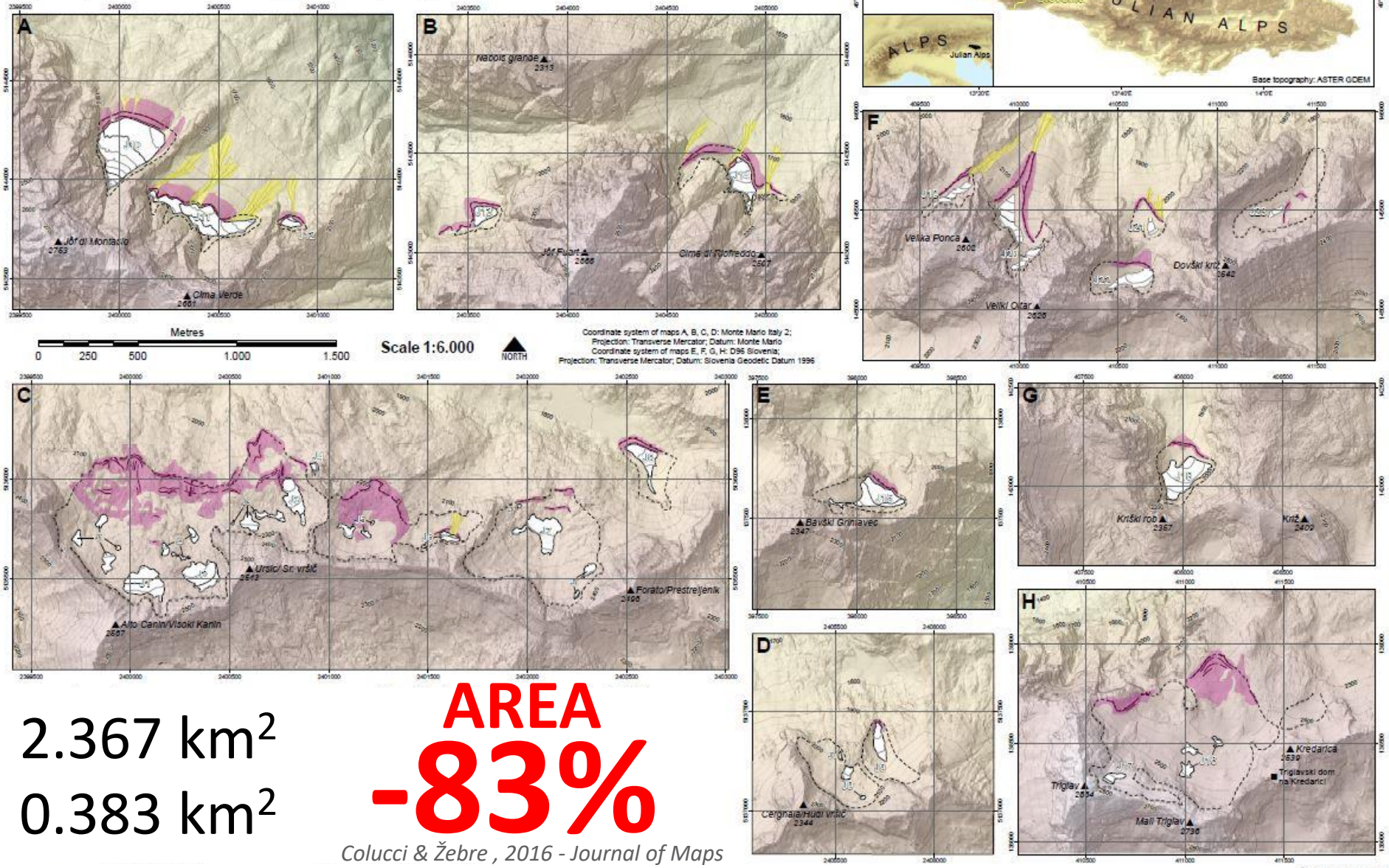


2.367 km²

0.383 km²

**AREA**

**-83%**

*Colucci & Žebre , 2016 - Journal of Maps*

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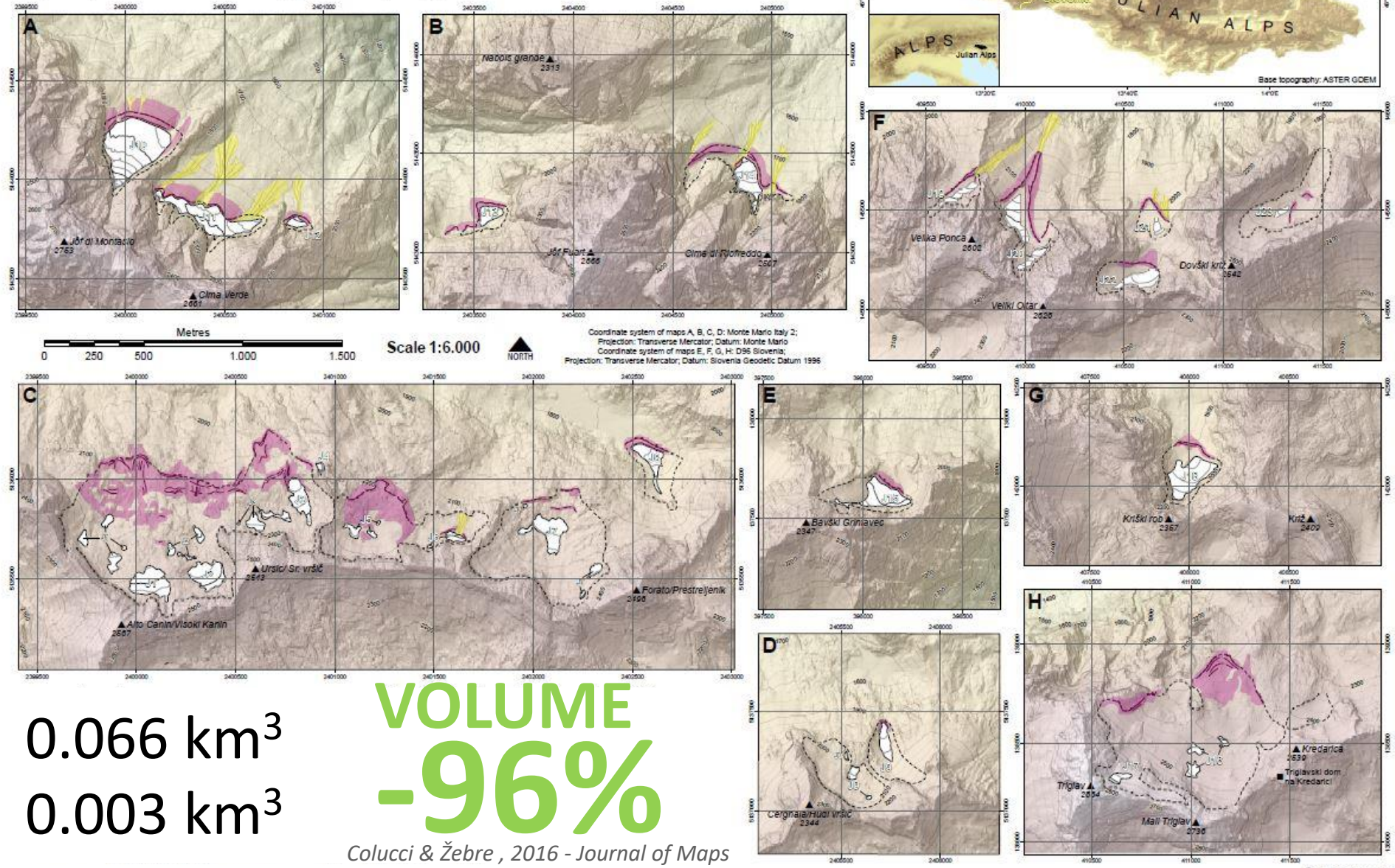



0.066 km$^3$

0.003 km$^3$

VOLUME

**-96%**

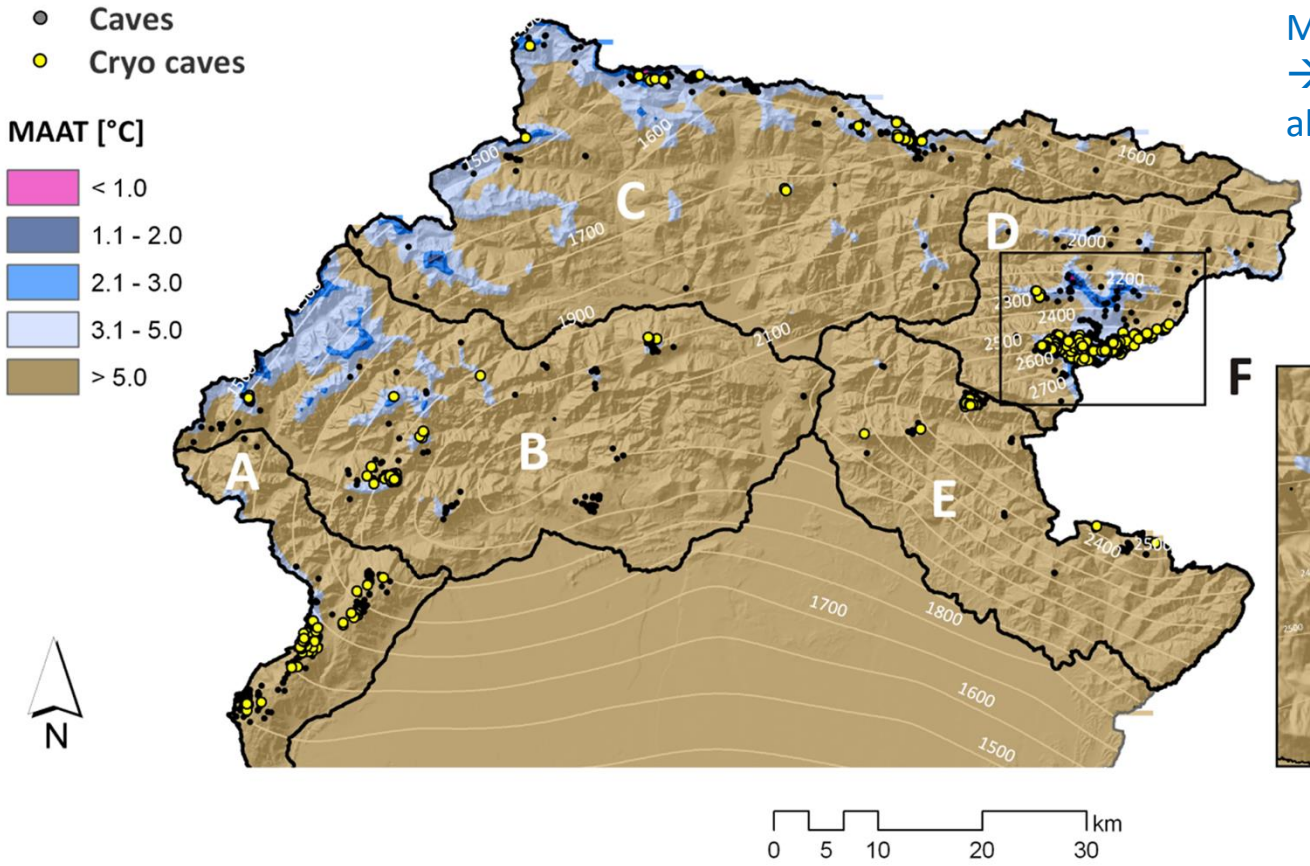
*Colucci & Žebre , 2016 - Journal of Maps*

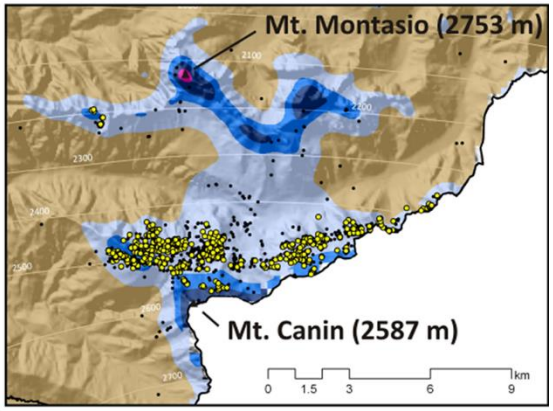
# The Canin massif – **Julian Alps**

**Cryo caves distribution** → 3068 caves > 1000 m asl
1111 CRYO caves of which 123 (11%) ICE caves
mainly between 1500-2200 m
mean el. 1838 m, median el. 1888 m

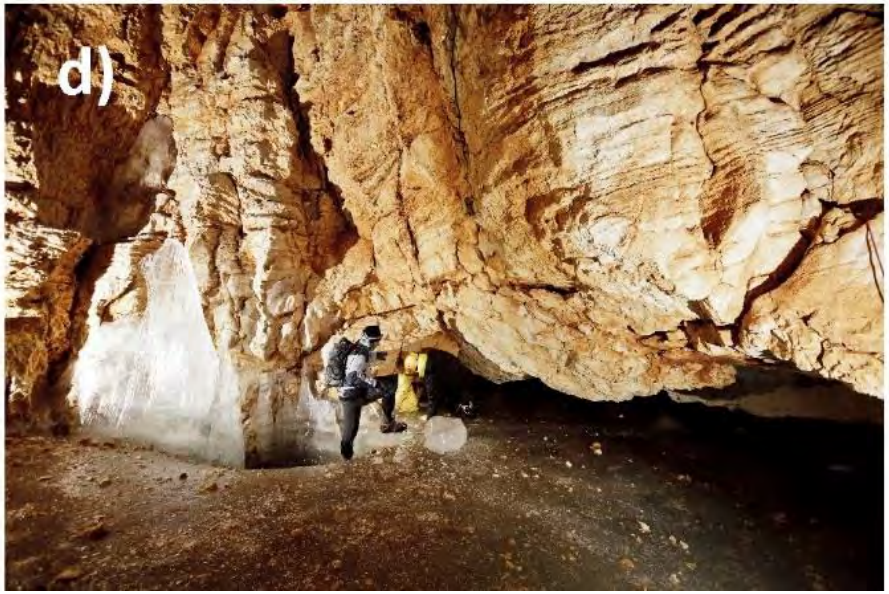
**Canin massif**
Highest cryo cave percentage
- 751 cryo caves
- 79 ice caves

Median elevation 1928 m asl
→ 991 cryo caves considering also the Slovenian side of Canin



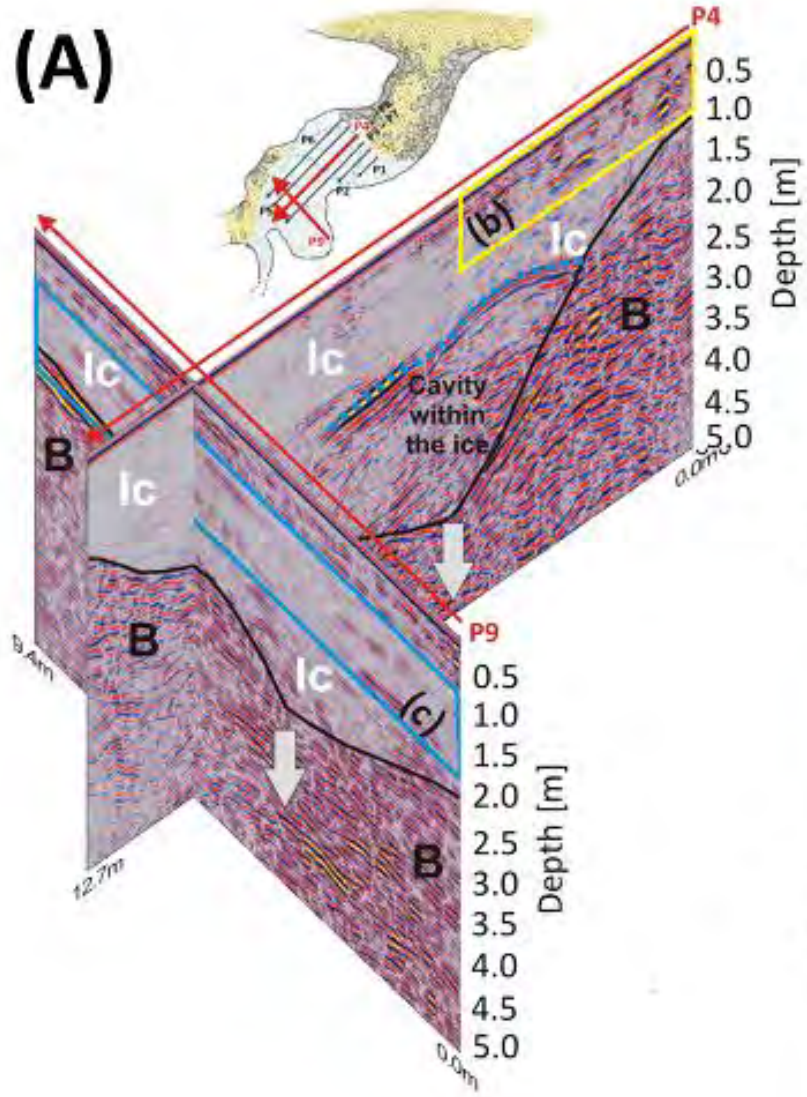



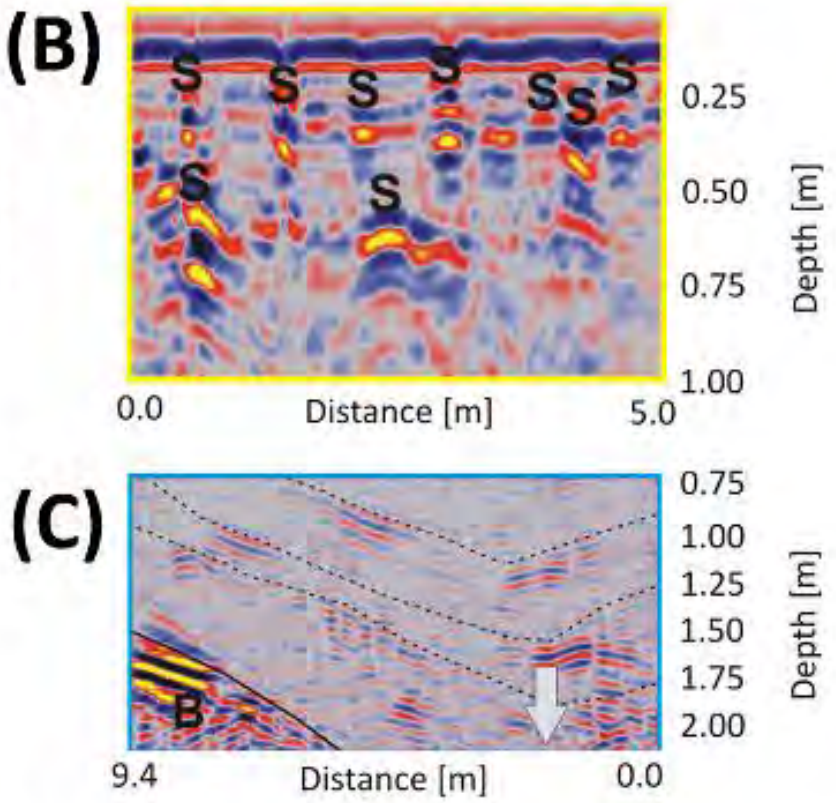


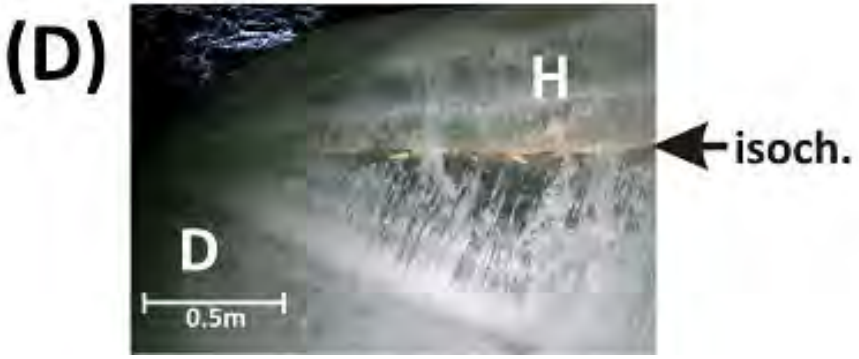




*Colucci et al., submitted*

# LEUPA Ice Cave

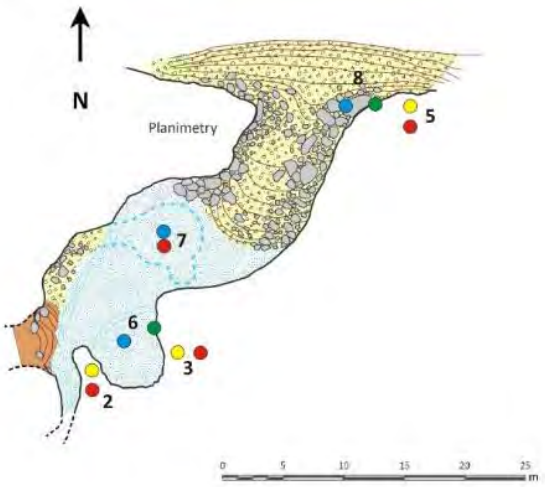


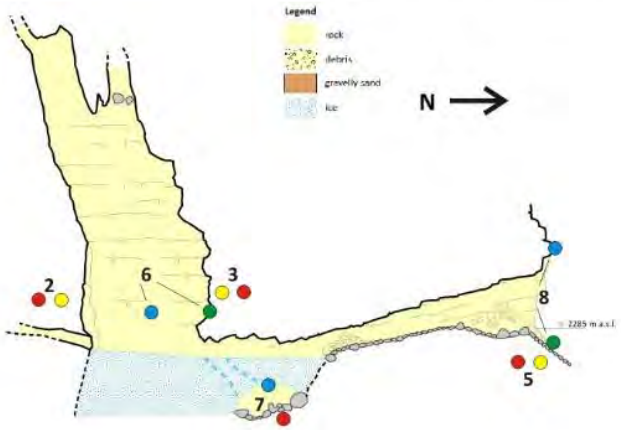




*Colucci et al., 2016 - Geomorphology*

# LEUPA Ice Cave



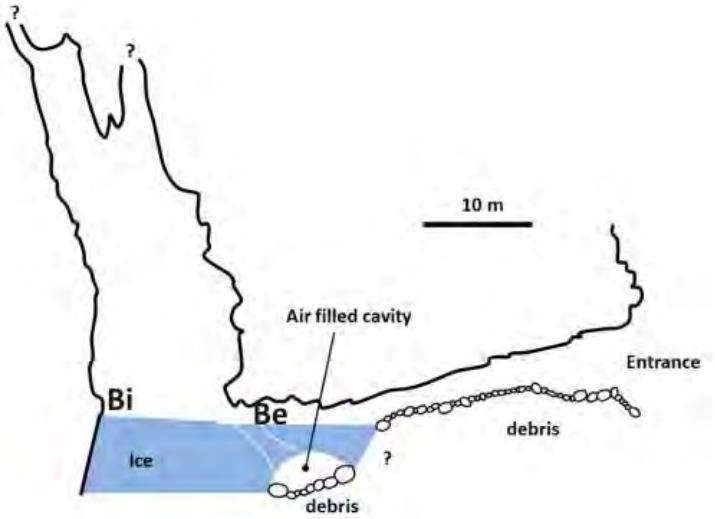




**Microclimatology**

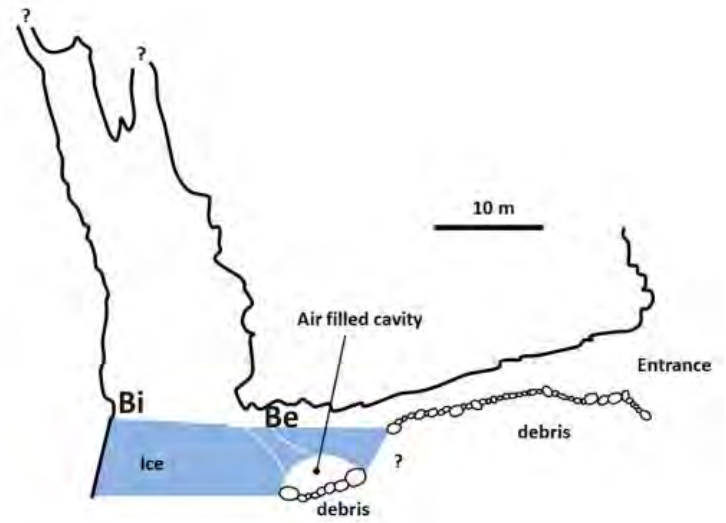
- 14 temperature monitoring sites since summer 2011 → Tinytag® dataloggers (rock, ice, air)
- MAAT = -1.4°C
- Rock in Permafrost (always <0°C ; t >2 years)

*Colucci et al., submitted*

# LEUPA Ice Cave
# Mass balance

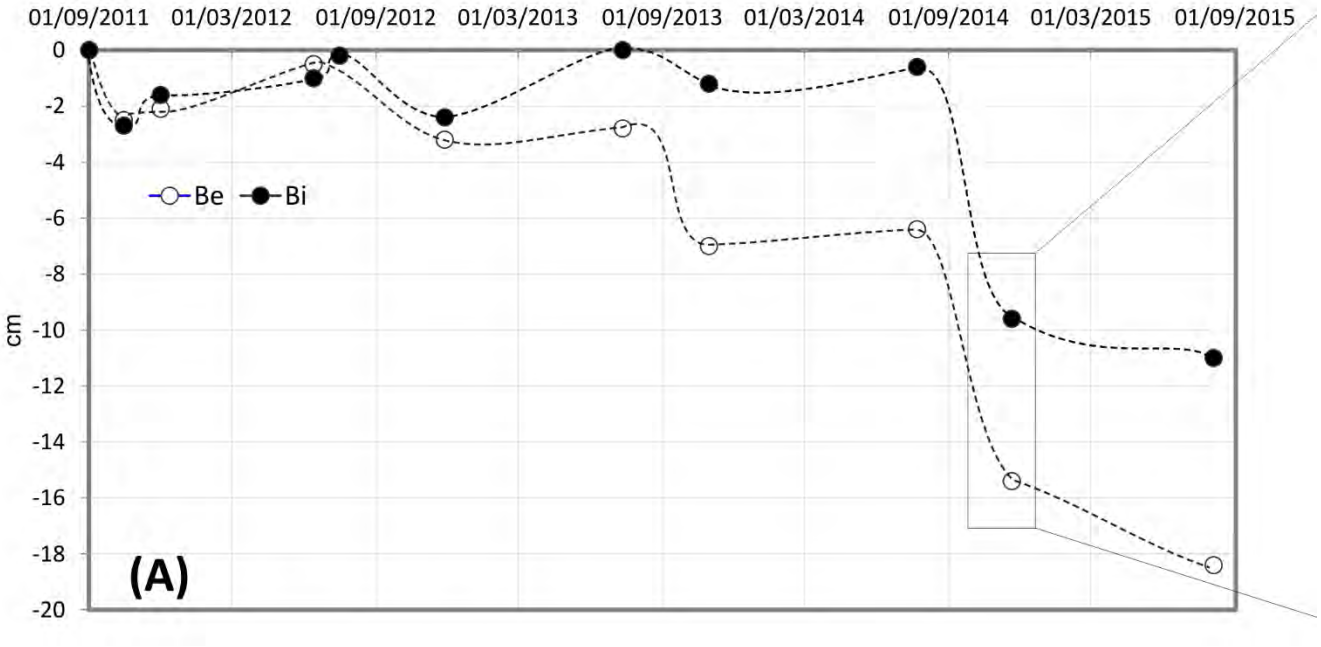



# LEUPA Ice Cave
# Mass balance

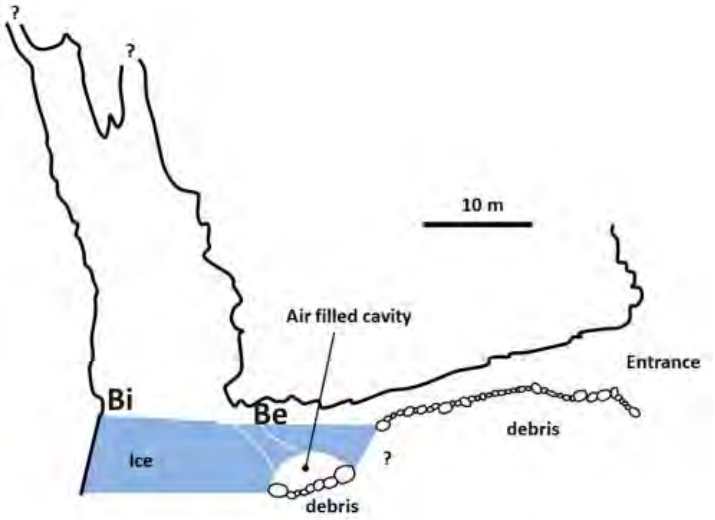



Bi = slight increase until 2014

- Annual cicle (autumn minima, summer maxima… 2-3-cm)
- - 9 cm 22 Jul 2014 – 20 Nov 2014



# LEUPA Ice Cave
# Mass balance

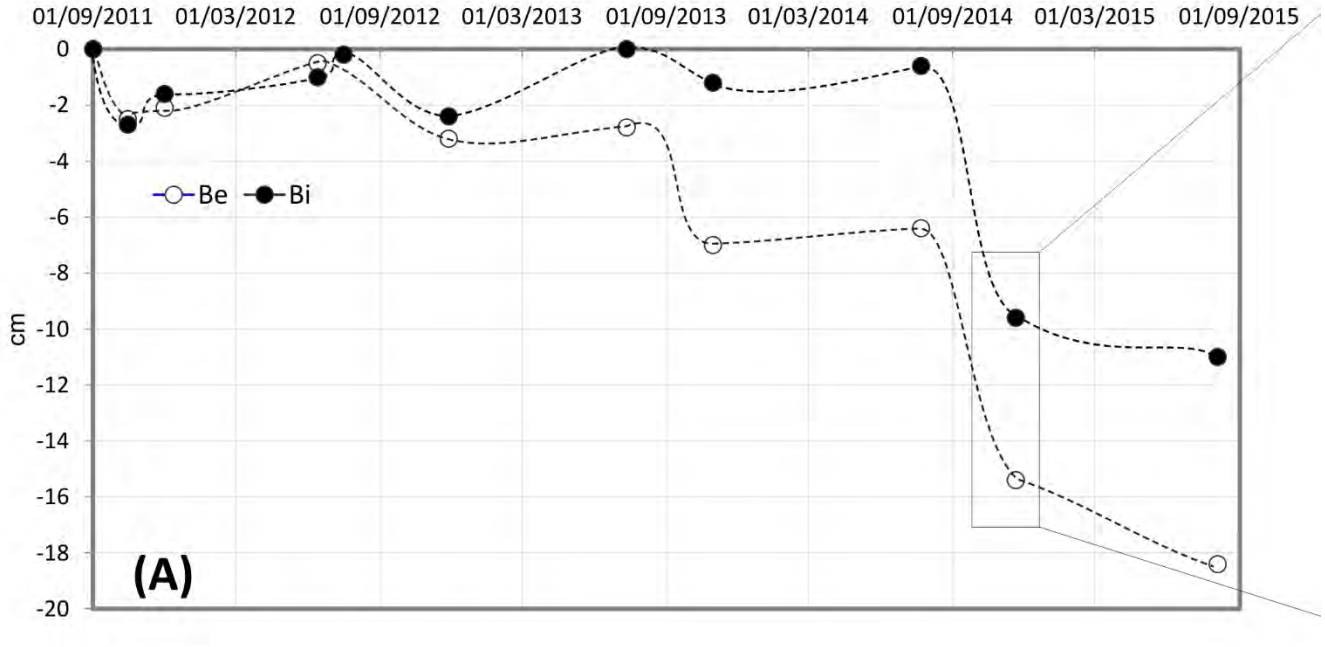



Bi = slight increase until 2014

- Annual cicle (autumn minima, summer maxima… 2-3-cm)
- - 9 cm 22 Jul 2014 – 20 Nov 2014

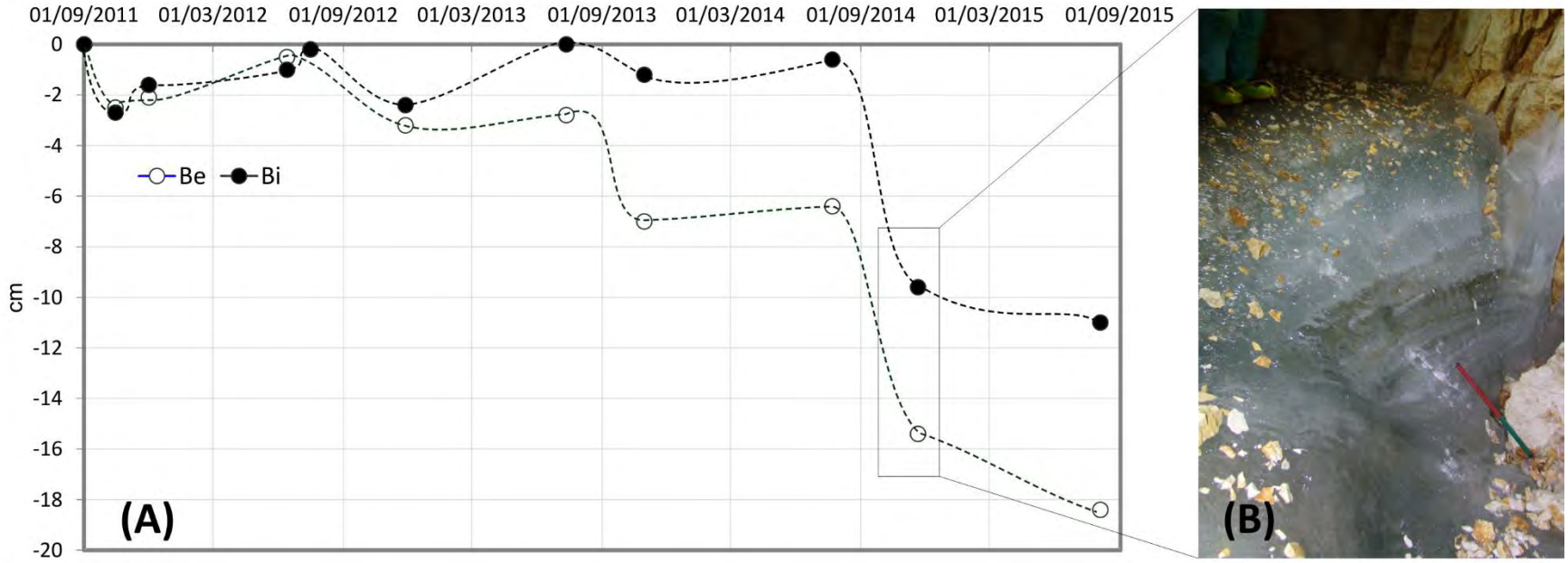
Be = slight increase until 2014

- Decrease already since 2013
- - 9 cm 22 Jul – 20 Nov 2014
- -4.2 cm 12 Jul – 30 Oct 2013



# LEUPA Ice Cave

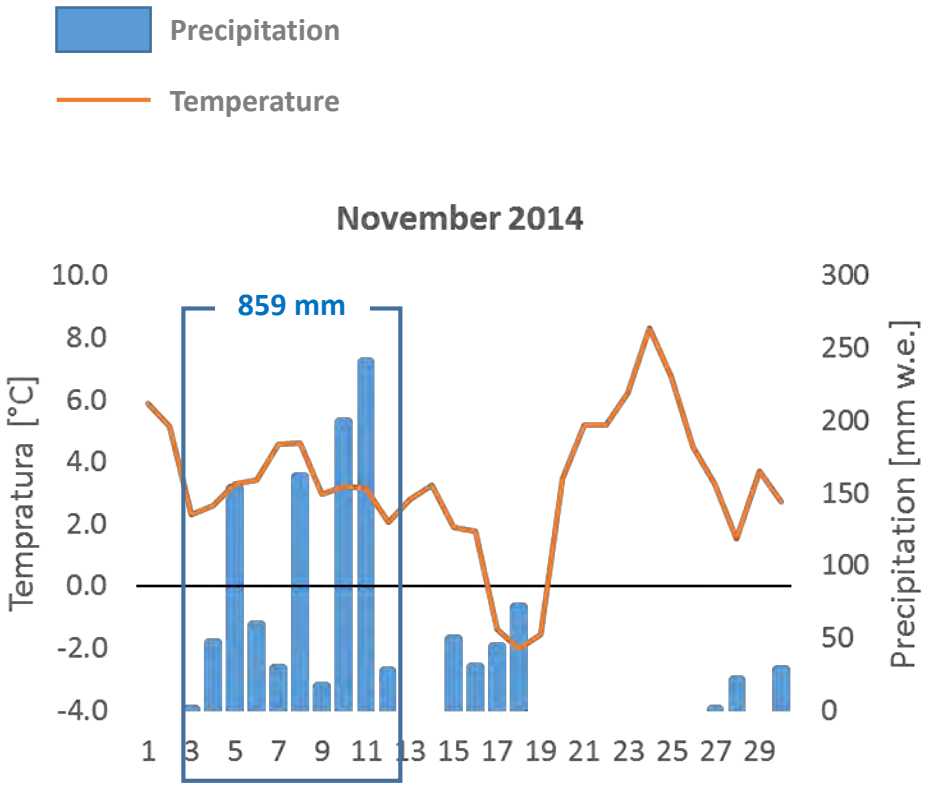


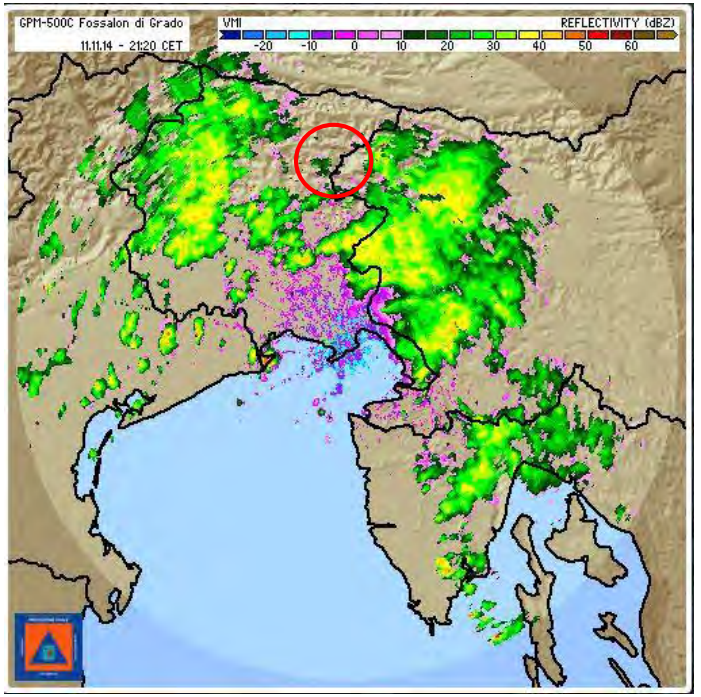



*Colucci et al., 2016 - Geomorphology*

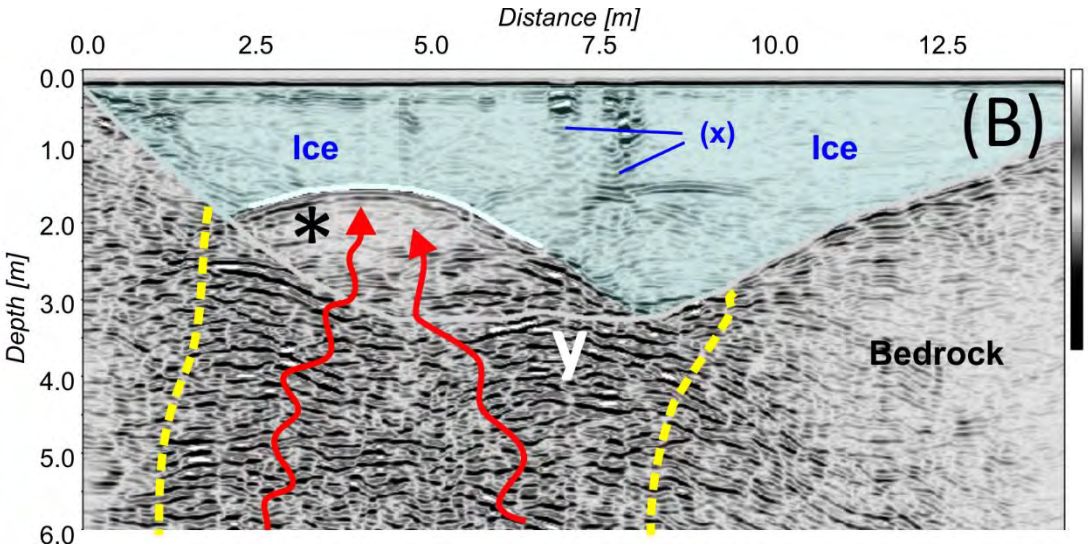
# LEUPA Ice Cave

heavy precipitation events in autumn are a normal characteristic of the area (e.g., Manzato, 2007), but a higher than average ML produces heavy rainfalls at altitudes normally interested by snowfalls



# LEUPA Ice Cave


*Bertozzi et al., submitted*

## VASTO Ice Cave

- MAX ice thickness 8.5 m
- High debris concentration within the first 2 m
- Weak reflection coefficient at the bottom → possible frozen ground at the bottom ? (Koh et al. 1996)

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- High debris concentration within the first 2 m
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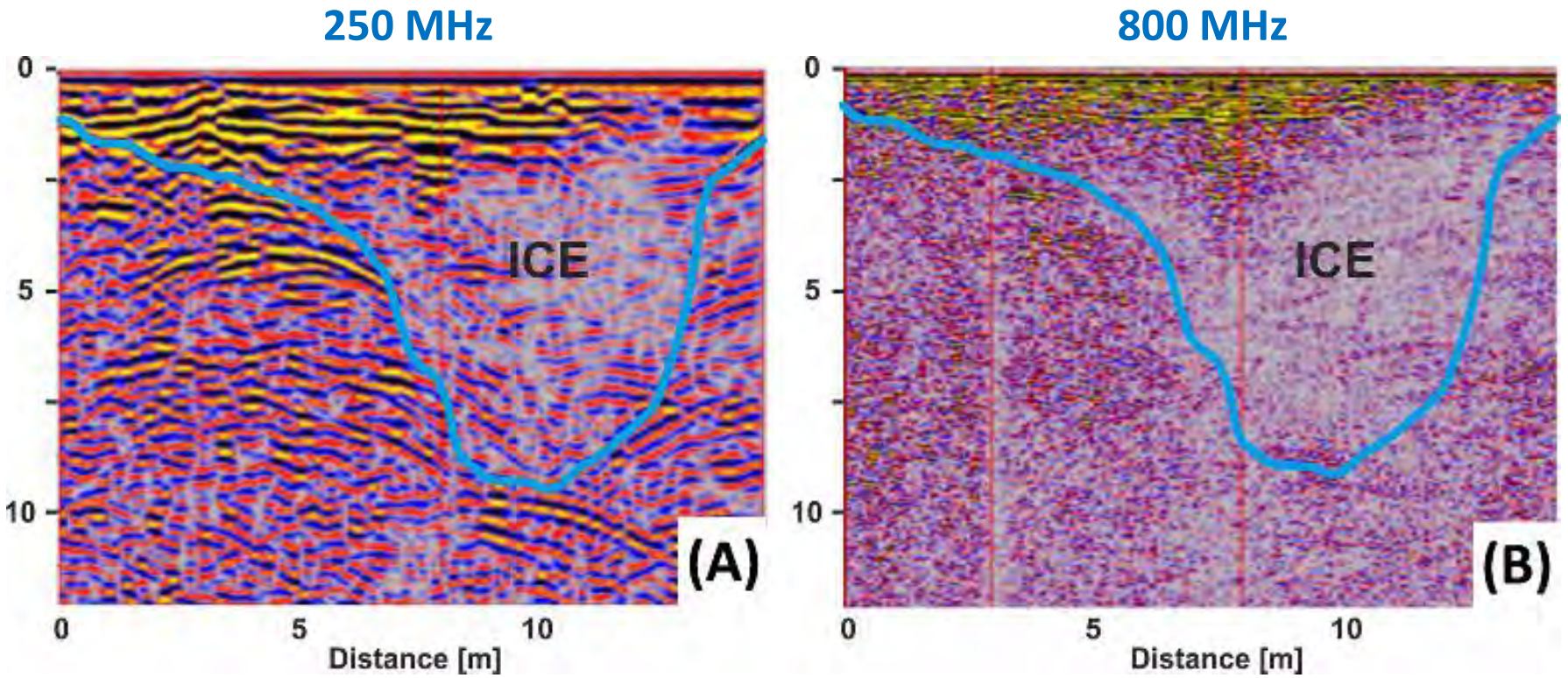
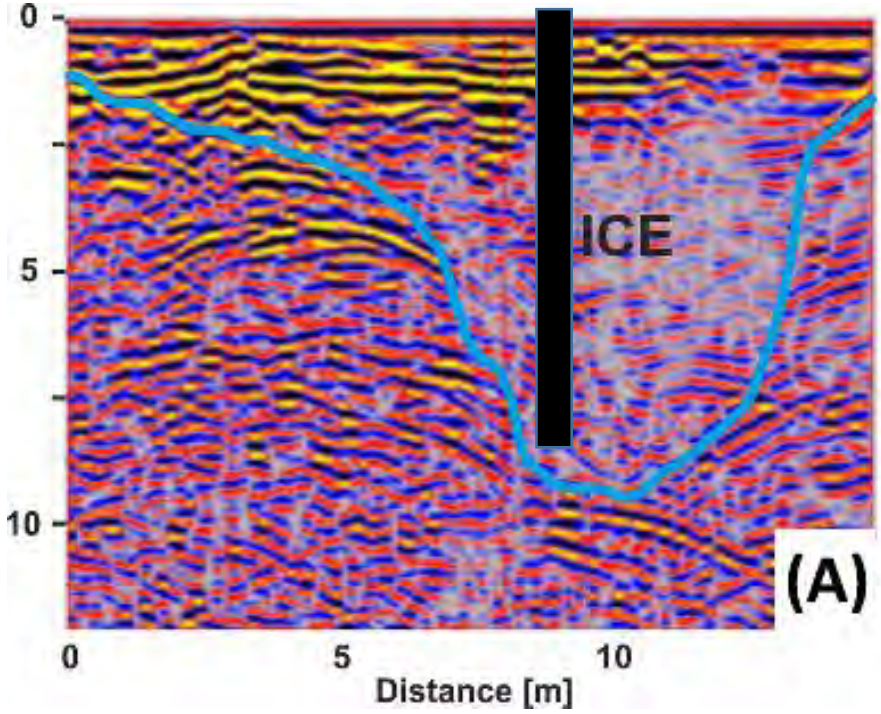


# VASTO Ice Cave

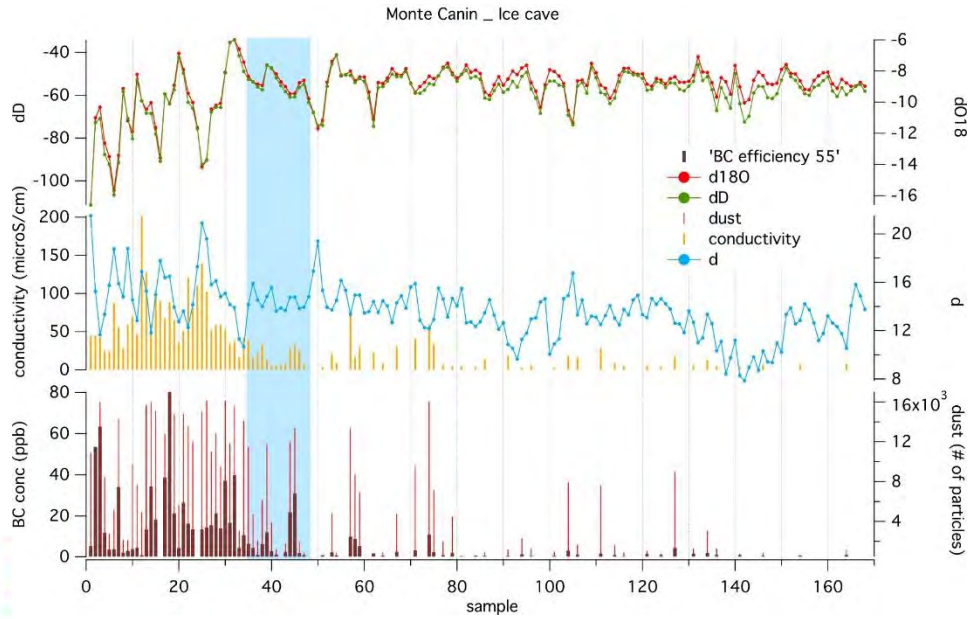
*Colucci et al., 2014, 2016*

**7.8 m ice core**

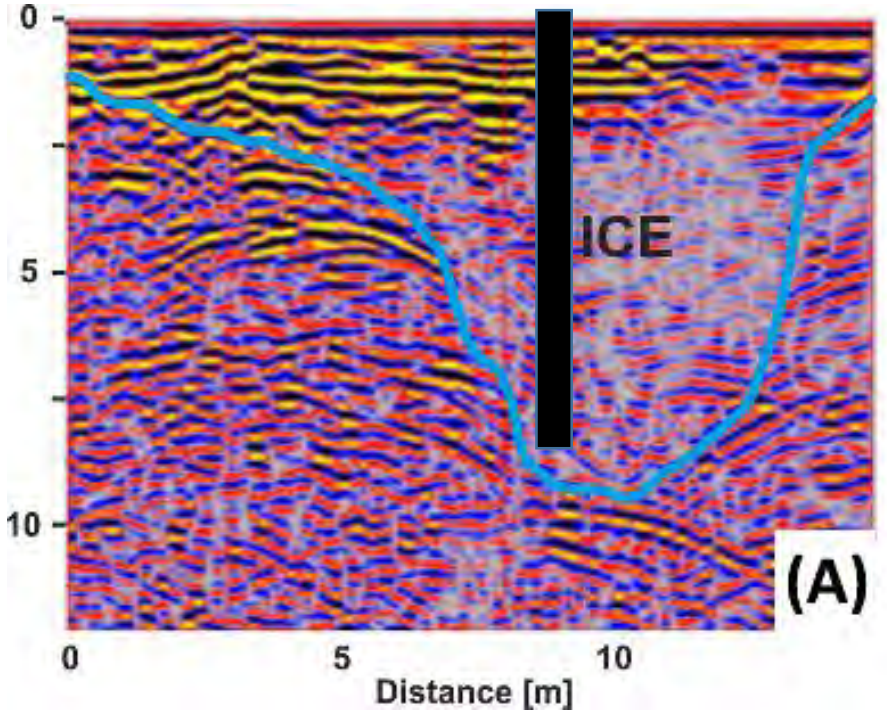


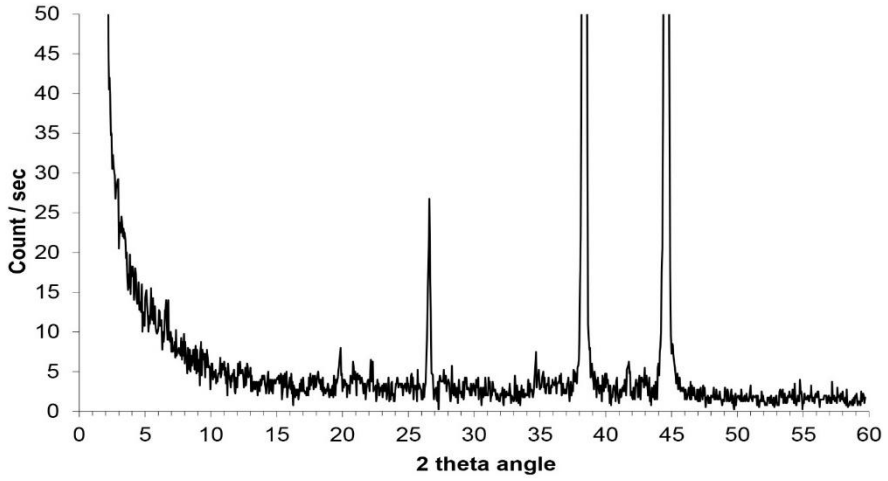

# VASTO Ice Cave

*Colucci et al., 2016*
*The Vasto ice cave in the south-eastern Alps, Europe: preliminary results from an ice core analysis*
*IWIC VII Postojna (Slo)*




## 7.8 m ice core



# Cryogenic calcite

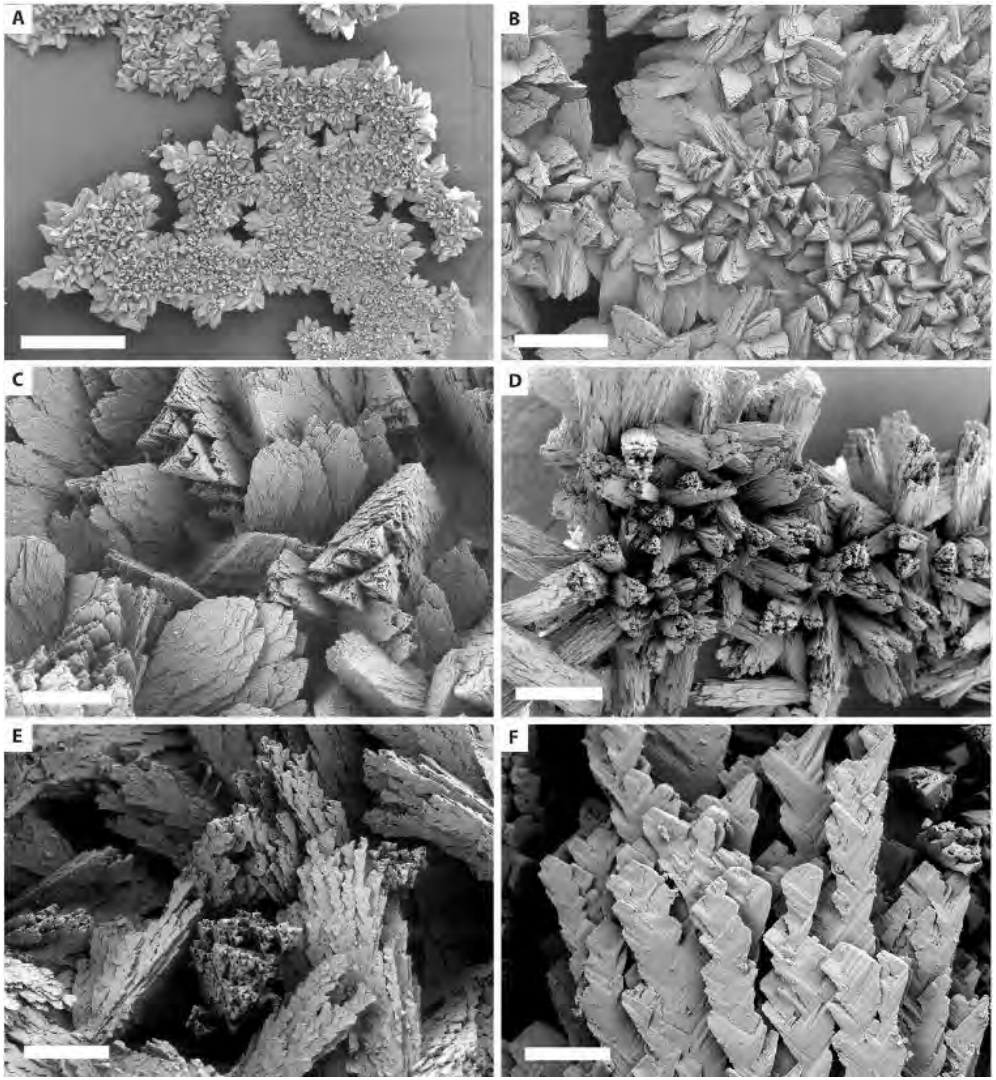

Cryogenic calcite deposits

**(a)** Typical occurrence of heaps of loose crystal aggregates (arrows)

**(b)** Close-up of cryogenic deposit consisting of brown and white crystal aggregates. Width of image 5 cm.

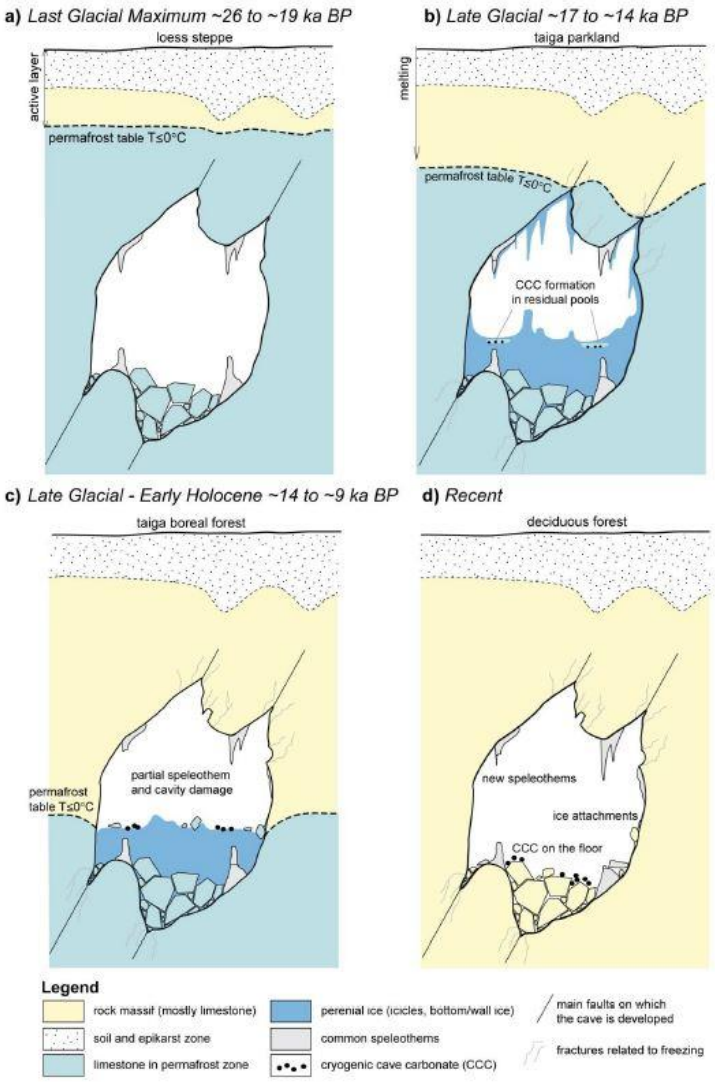
**(c)** Occurrence of loose brownish crystal aggregates intermixed with a few angular rock flakes on a boulder. Width of image 25 cm.

# Cryogenic calcite




Morphology of cryogenic calcite crystals seen under the FE-SEM.
**(a)** Calcite raft
**(b)** Closeup of (a). Scale bar 0.2 mm
**(c)** Stepped faces on individual rhombohedral crystals.Scale bar 0.1 mm
**(d)** White crystal Aggregate. Scale bar 0.2 mm
**(e)** Details of white crystal morphology. Scale bar 0.1 mm
**(f)** Close-up of (e), revealing chevron-type crystal habits. Scale bar 0.02 mm

# Cryogenic calcite



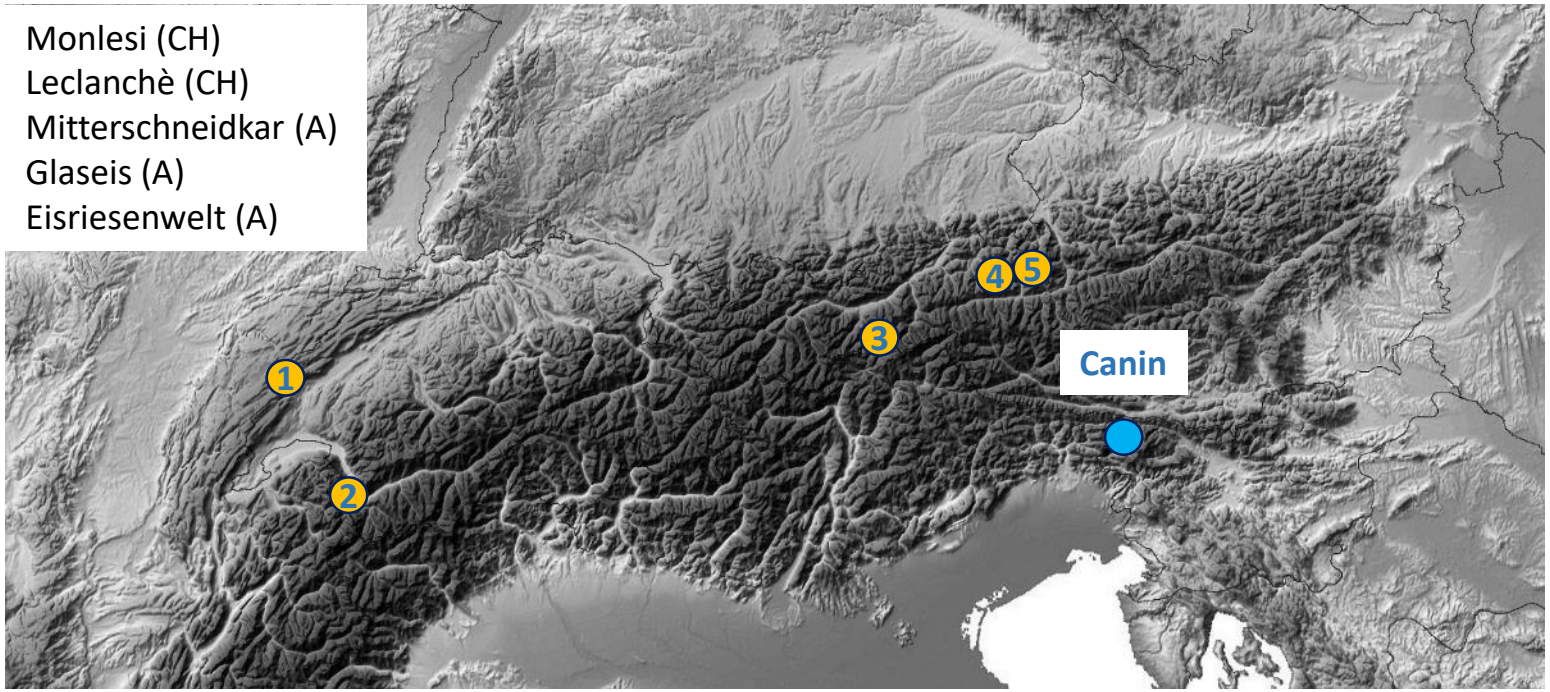

The youngest currently known occurrence is from a cave in the Swiss Alps located at the threshold of modern permafrost and dates from the medieval period
(Luetscher et al., 2013)

Characteristic stable isotopic composition with values supporting the model of very slow freezing and concomitant calcite precipitation

# LEUPA Ice Cave

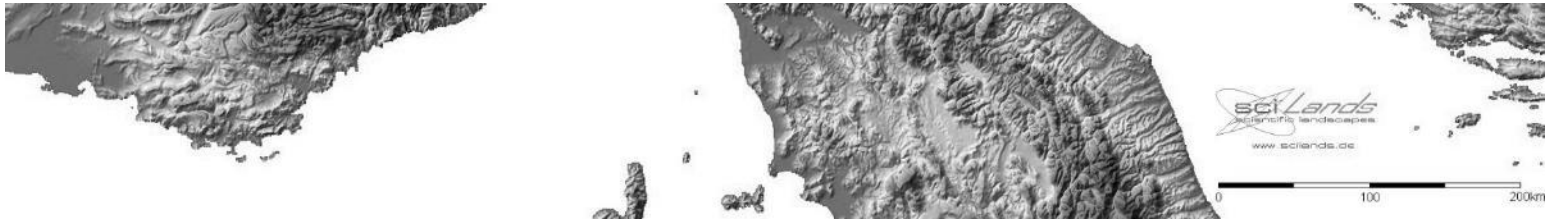
## Cryogenic calcite

1) Monlesi (CH)
2) Leclanchè (CH)
3) Mitterschneidkar (A)
4) Glaseis (A)
5) Eisriesenwelt (A)




**First evidence in Italy**

**First evidence in the southern Alps**

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Will be on-line soon
C3 Cave's Cryosphere and Climate
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project for the MONitoring of Ice within CAves
Finanziamento di ateneo per progetti di ricerca scientifica - FRA2012 and 2014 grant
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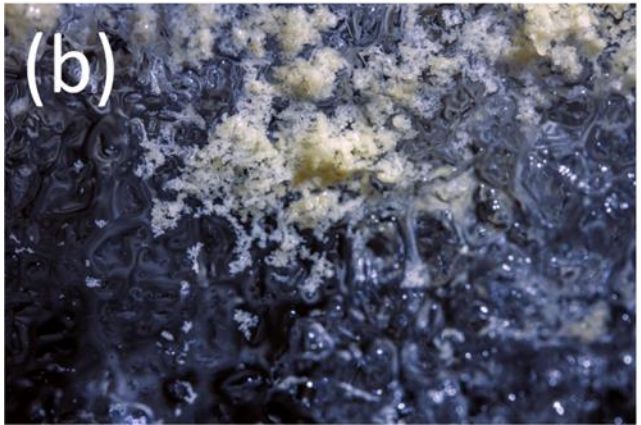
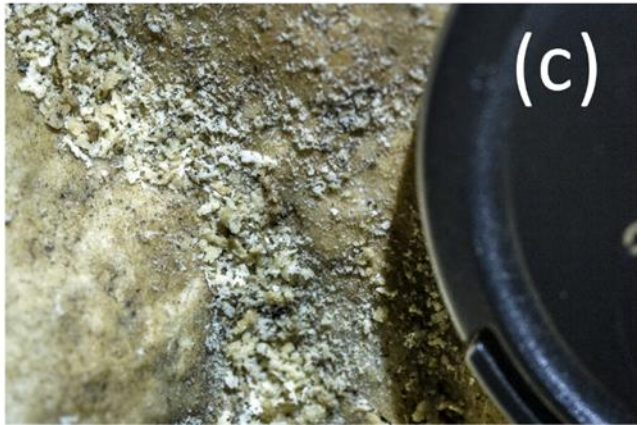
# LEUPA Ice Cave


**The cavity underneath the permanent ice deposit in the Leupa ice cave.**

**(a)** The internal layer of CCCcoarse

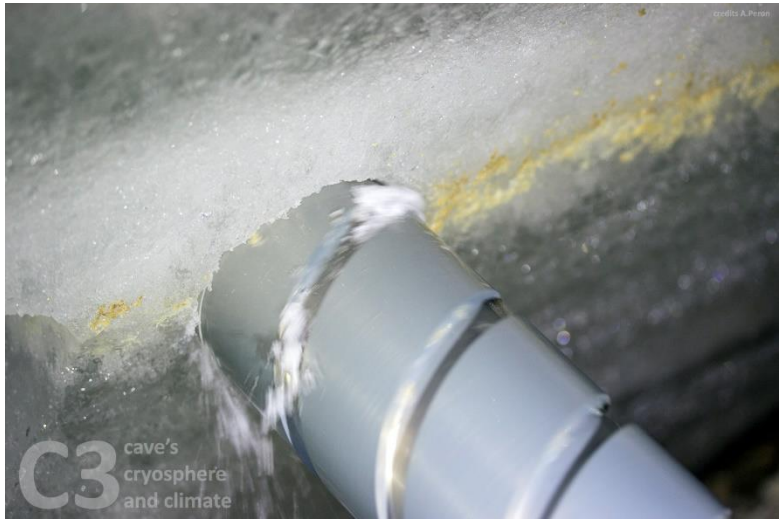
**(b)** Details of the in situ-crystals of coarser cryogenic calcite

**(c)** loose crystals recently deposited on clastic sediments

# LEUPA Ice Cave

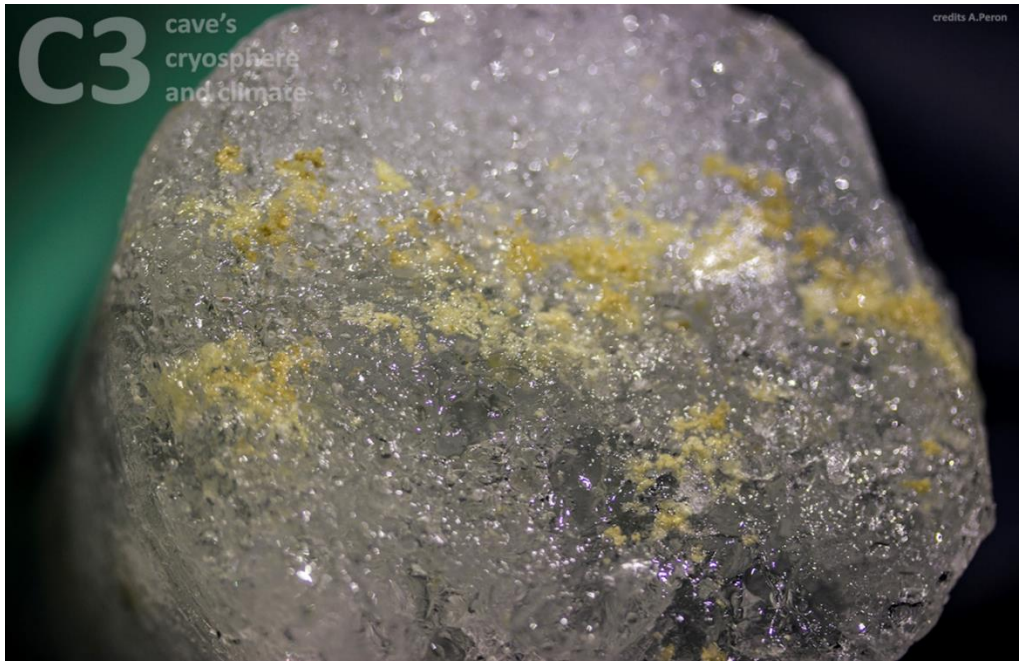



# LEUPA Ice Cave



# LEUPA Ice Cave


# LEUPA Ice Cave

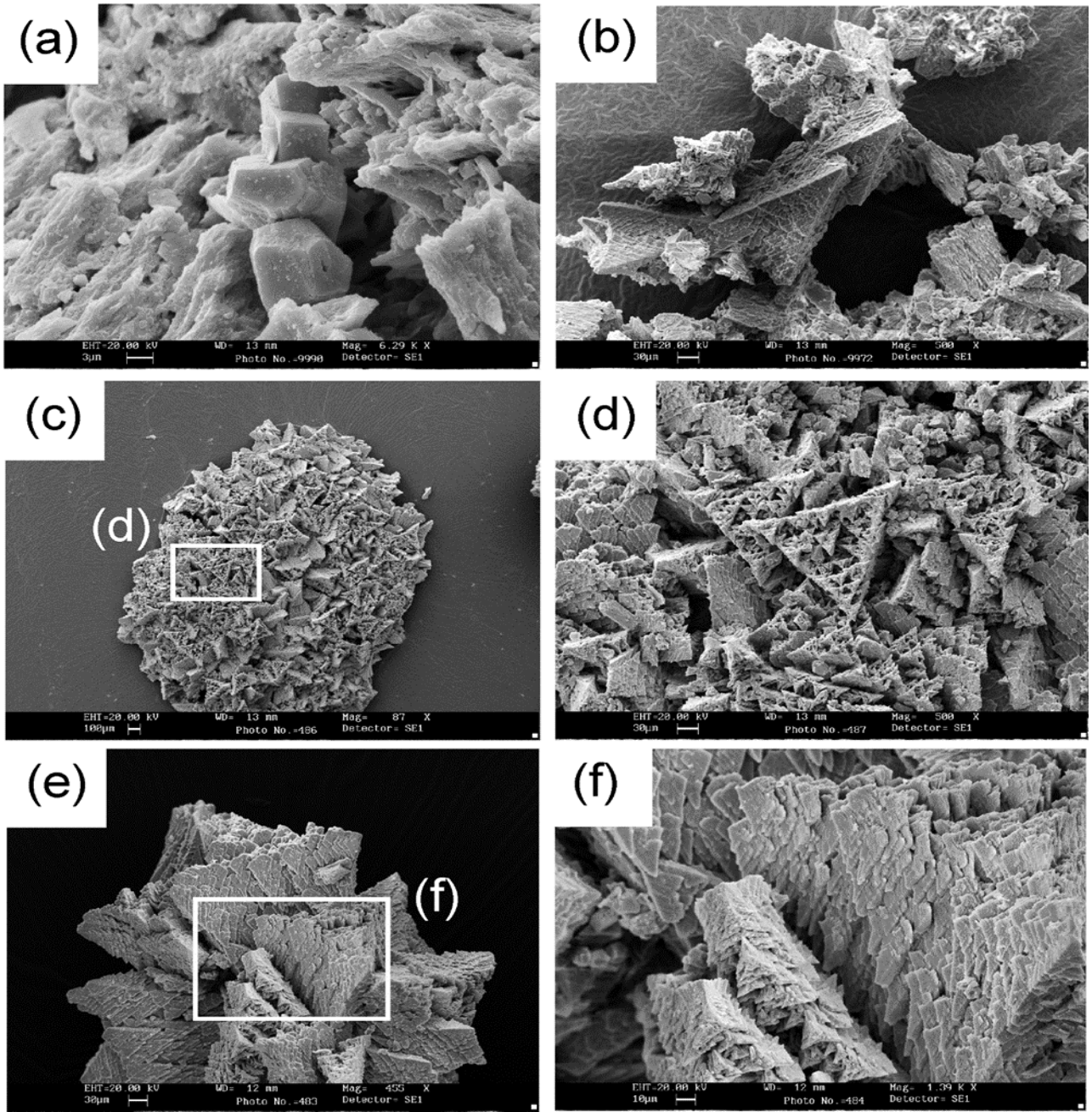


- $CCC_{coarse}$ datings (U/Th)
- C14 datings
- Polline analysis
- Microbiological community → DNA
- High resolution (1mm) chemistry

- others?

*Colucci et al., (2017)*
*First alpine evidence of in situ coarse cryogenic cave carbonates (CCCcoarse) GFDQ*

# LEUPA Ice Cave




**Morphology of calcite crystals as seen under SEM-EDX.**

**(a)** Detail of euhedral (rhombohedral) crystals;

**(b)** Detail of euhedral (scalenohedral) crystals;

**(c)** raft-like calcite aggregate consisting of calcite scalenohedra sometimes elongated in the direction of the vertical axis;

**(d)** close-up of (c) showing a fractal distribution of individual scalenohedral crystals with stepped faces;

**(e)** fan-like aggregate (calcite rose) with various intergrowths of scalenohedral crystals;

**(f)** close-up of (e) showing a chevron-type habits of the crystals surface.


# The C3 documentary

## Work in progress

## Stay tuned !!!

# Cooperations and Sponsors

**Società Alpina delle Giulie, Italy**
**Commissione Grotte E. Boegan** - Sponsor and Lead Partner
*contact person* **Dr. Mauro Vigini** and **Mr. Riccardo Corazzi**

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Climate and paleoclimate research group - Scientific Lead Partner
*contact person* **Dr. Renato R. Colucci, PhD**

**University of Trieste, Department of Mathematics and Geosciences, Italy**
Exploration Geophysics Group (EGG) - Scientific Partner
*contact person* **Dr. Emanuele Forte, PhD**

**Insubria University, Department of Theoretical and Applied Sciences, Italy**
Climate Change Research group - Scientific Partner
*contact person* **Prof. Mauro Guglielmin, PhD** and **Prof. Nicoletta Cannone, PhD**

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Quaternary Research Group - Scientific Partner
*contact person* **Dr. Marc Luetscher, PhD**
Palynology and Archaeobotany Research Group, Institut für Botanik
*contact person* **Dr. Daniela Festi, PhD**

**Cà Foscari University Venice, Italy**
Isotope geochemistry laboratory - Scientific Partner
*contact person* **Prof. Barbara Stenni** and **Dr. Giuliano Dreossi PhD**

**Paul Scherrer Institut, Switzerland** - link
Laboratory of Environmental Chemistry - Scientific Partner
*contact person* **Prof. Margit Schwikowski, PhD**

**Bologna University, Italy - Dedicated M.Sc thesis project**
***Thermodynamic modeling of an ice cave in the Eastern Alps***
*student* **B.Sc. Barbara Bertozzi**
*contact person* **Prof. Silvana Di Sabatino**

**Geological Survey of Slovenia, Slovenia** - link
Electron microscopy laboratory and geomorphology - Scientific Partner
*contact person* **Miloš Miler, PhD** and **Manja Žebre, PhD**

**Parco Naturale delle Prealpi Giulie, Italy** - link
*contact person* **dr. Stefano Santi** - Sponsor and Logistic Partner

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Chemical Laboratory - Scientific Partner
*contact person* **Prof. Carlo Barbante, PhD** and **Dr. Jacopo Gabrieli, PhD**

**Milano Bicocca University, Italy**
EUROCOLD Laboratory - Scientific Partner
*contact person* **Prof. Valter Maggi, PhD**

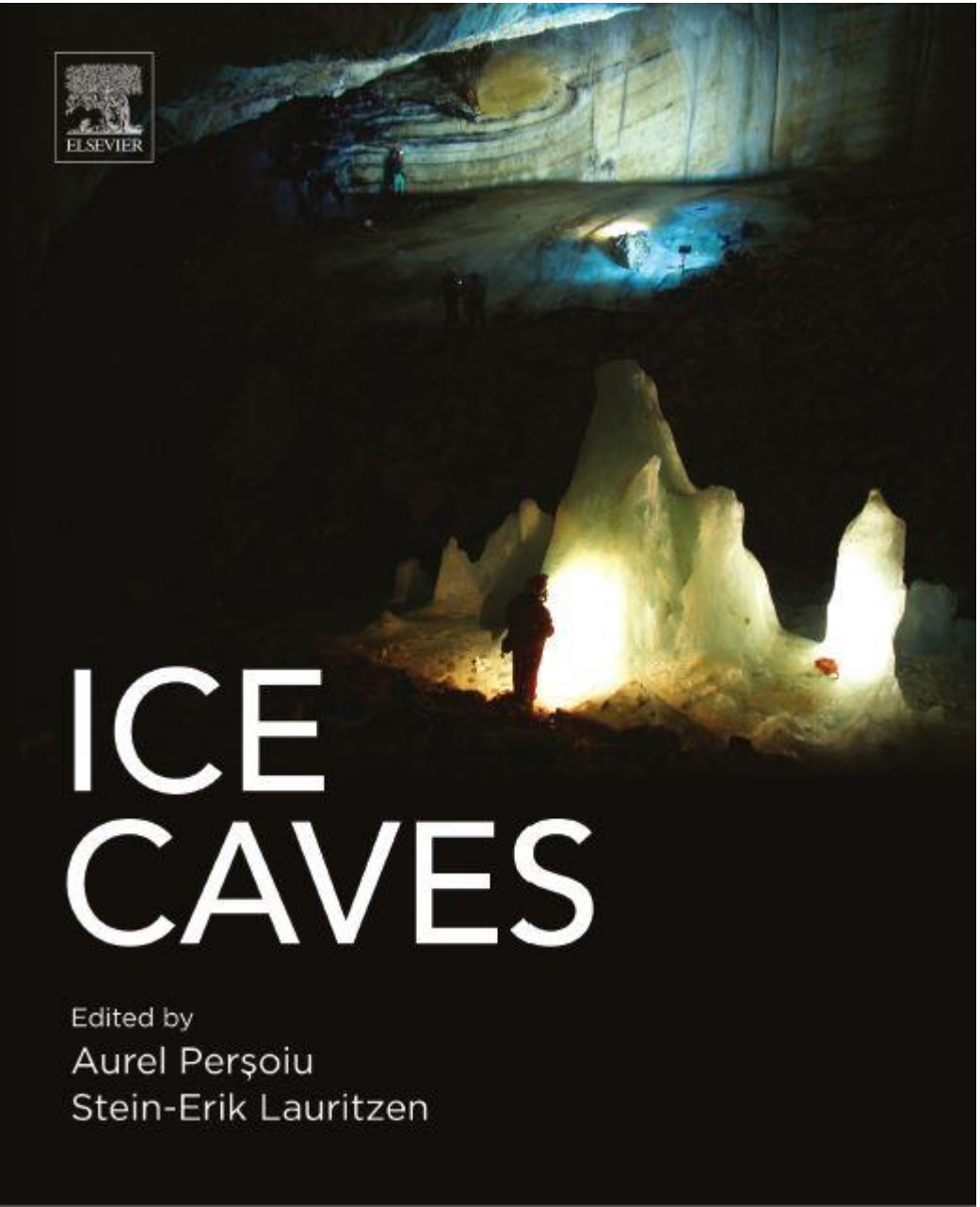
# Future challenges

- Timing of underground glaciation

- Relation with thermal conditions of the rock

- Dating methodologies

- Biology of ice caves

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Contributors:
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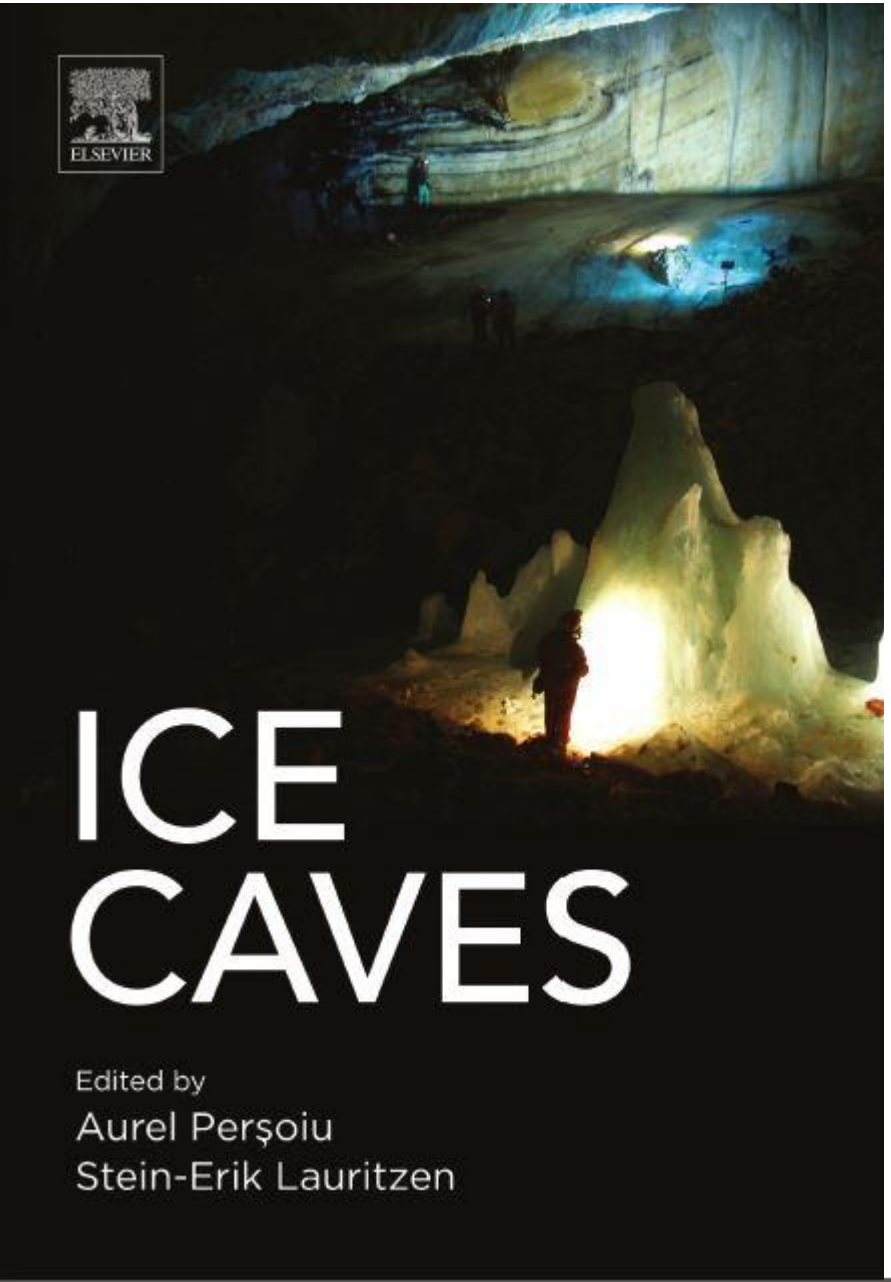
Covers various aspects of ice occurrence in caves, including cave climate, ice genesis and dynamics, and cave fauna

Features an overview of the paleoclimatic significance of ice caves

Includes over 100 color images of ice caves around the world




CHAPTER

# ICE CAVES IN ITALY

# 19

Valter Maggi[*,†], Renato R. Colucci[‡,§§], Federico Scoto[¶,‖], Gaetano Giudice[**,††], Luca Randazzo[††]
*University of Milano-Bicocca, Milano, Italy[*] Institute of Geosciences and Earth Resource (CNR), Pisa, Italy[†] ISMAR-CNR, Trieste, Italy[‡] Ca' Foscari University of Venice, Venezia Mestre, Italy[§] Fondazione CMCC Centro euro-Mediterraneo sui Cambiamenti Climatici, Bologna, Italy[¶] Istituto Nazionale di Geofisica e Vulcanologia sezione di Palermo – Geochimica (INGV), Palermo, Italy[**] Centro Speleologico Etneo (CSE), Catania, Italy[††] Commissione Grotte E. Boegan, Società Alpina delle Giulie, Trieste, Italy[§§]*

## CHAPTER OUTLINE



## 19.1 INTRODUCTION

Italy presents one of the largest variabilities of karstic features in the world. There are limestone outcroppings all over the country, from the Alps to Sicily, as well as in the Pantelleria Island, located in the center of the Mediterranean Sea. Karstic features are also present in the evaporates in the Northern Apennines, and in the marbles in the Apuane mountains. However, lava tube systems are also present on Etna Volcano in Sicily, and because it is active, their formation is still ongoing. Officially, 34,669 caves are included in the national speleological database (WISH, www.speleo.it), with development up to 50 km, such as the Corchia System (Apuane Mountains, Tuscany), and depth up to 1313 m, such as the Releccio Alfredo Bini system (Grigna Settentrionale, Lombardy) (Ferrario and Tognini, 2016).

Ice caves are distributed along the entire karstic area, mainly in the Central-Eastern Alps (Lombardy, Veneto, Trentino-Alto Adige-Südtirol, and Friuli Venezia Giulia regions) with probably more than 1600 existing cryo-caves, having within them permanent (multiyear) masses of ice, firn or permanent snow. In such areas, the ice deposits recorded on occasions of speleological surveys or research studies are

Ice Caves. https://doi.org/10.1016/B978-0-12-811739-2.00019-X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