# Recent Increases in Winter Snowfall Provide Resilience to Very Small Glaciers in the Julian Alps, Europe

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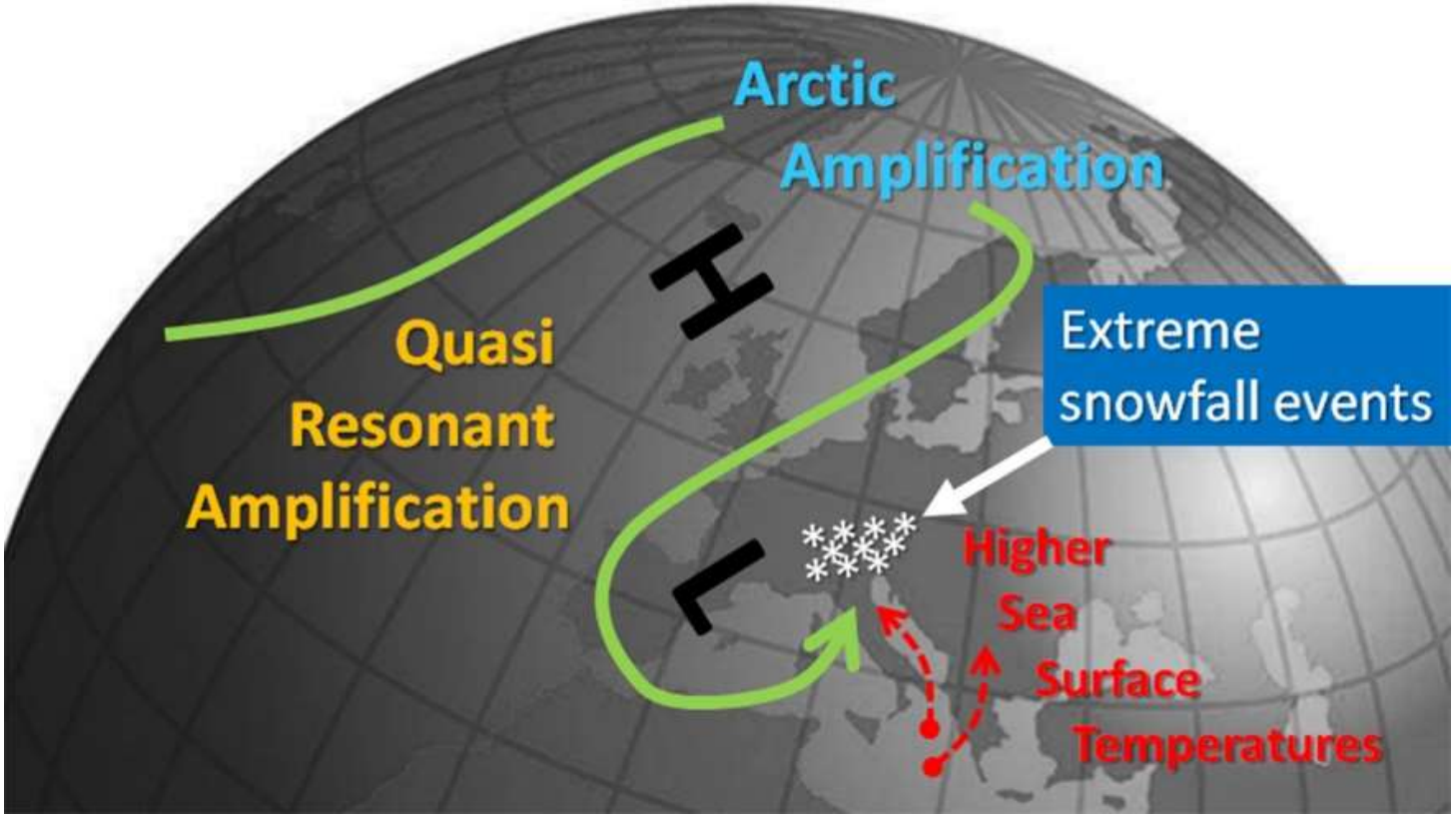
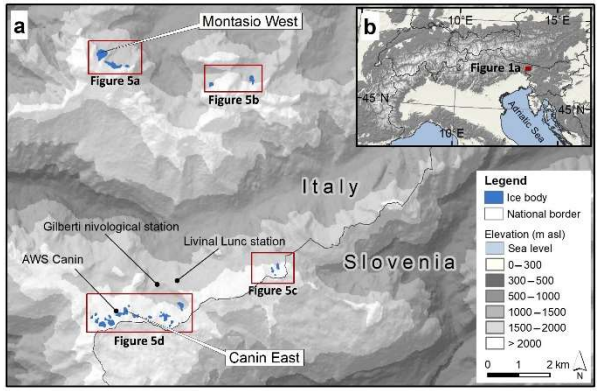
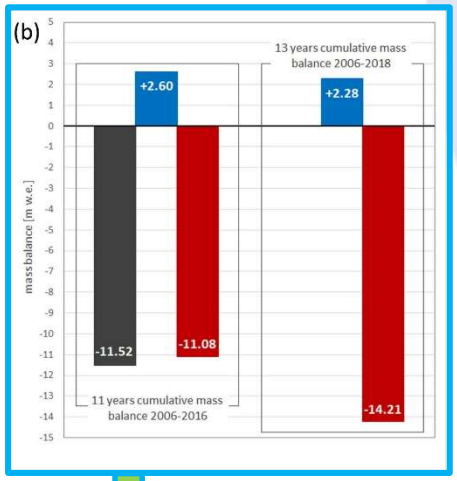
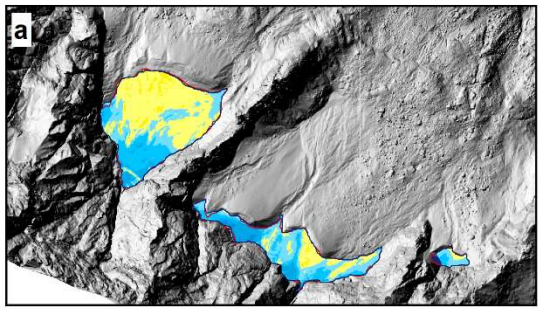
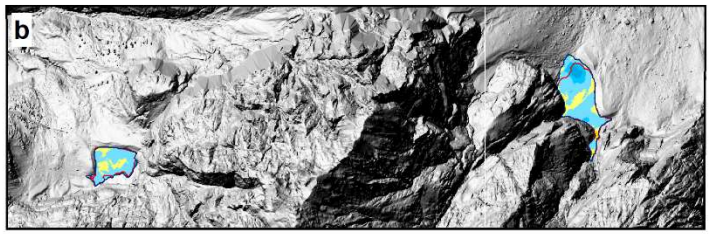


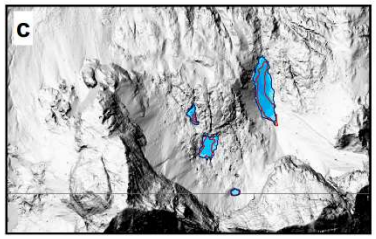


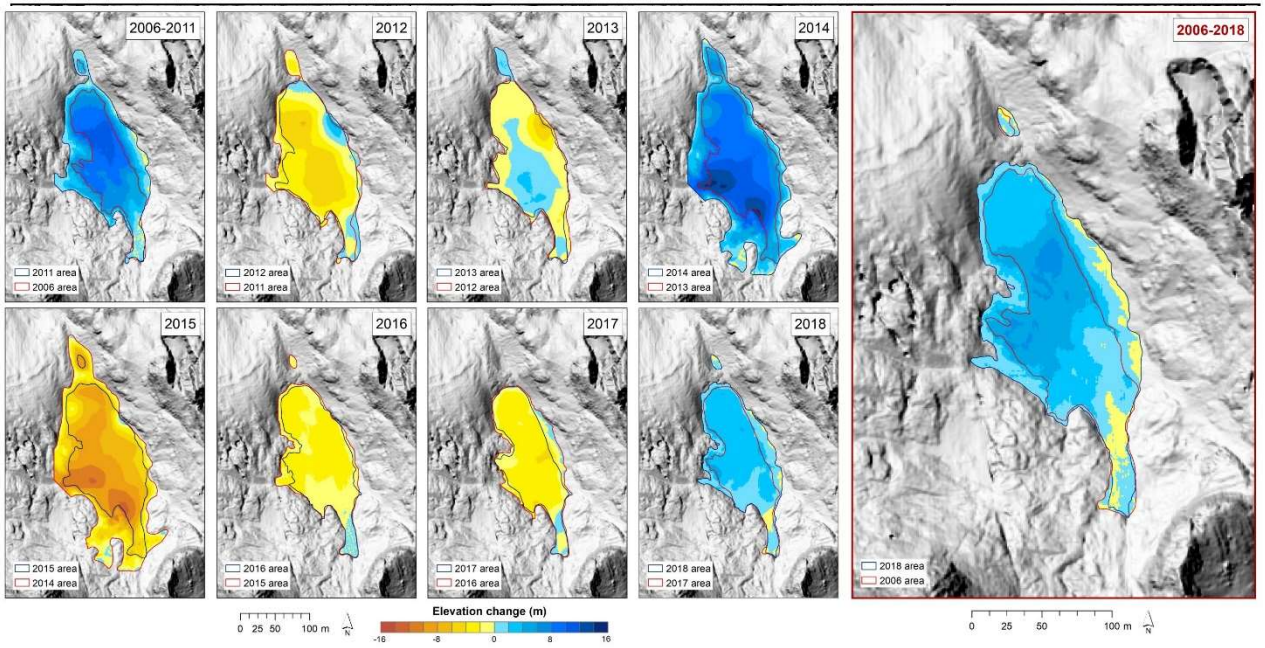


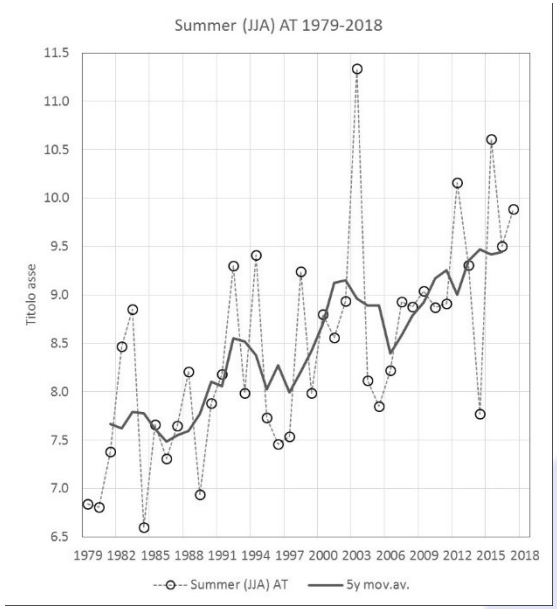



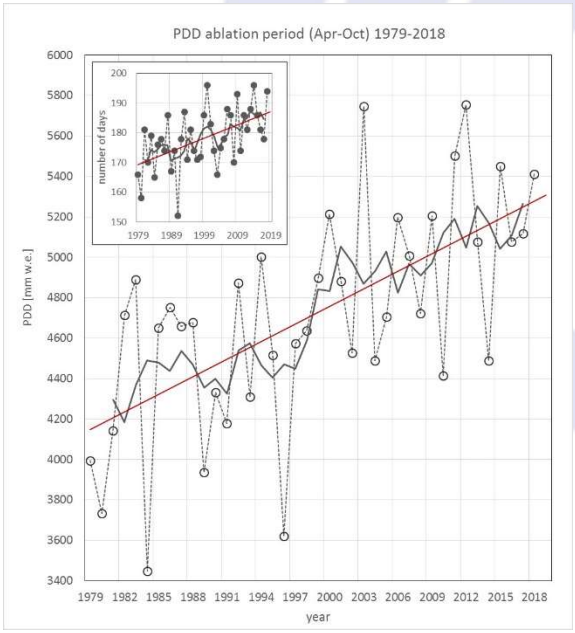



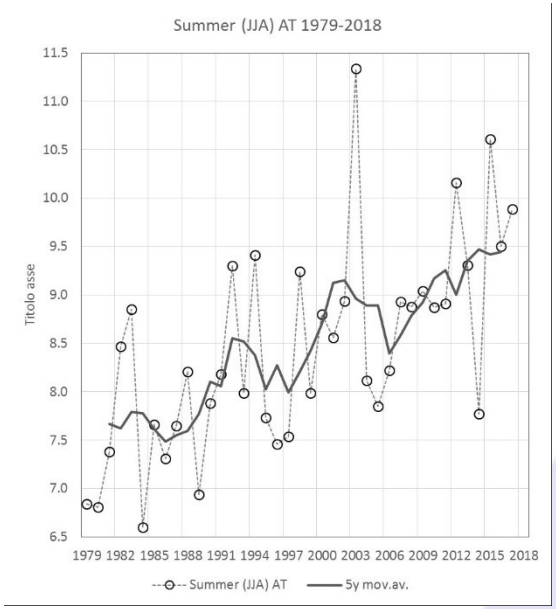




Long-term cumulative mass-balance compared to **2000-2018**
**WGMS (red bars)** and **2000-2016 optical satellite images**

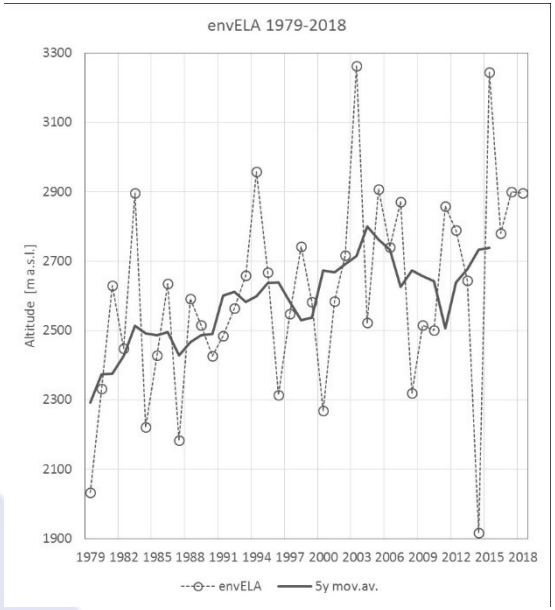
ISP Istituto di Scienze Polari
Consiglio Nazionale delle Ricerche

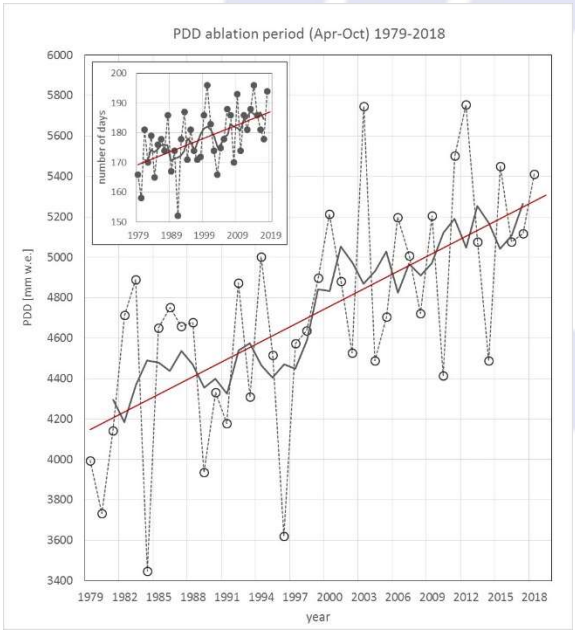

Summer (JJA) AT 1979-2018
Titolo asse
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012 2015 2018
Summer (JJA) AT
5y mov.av.

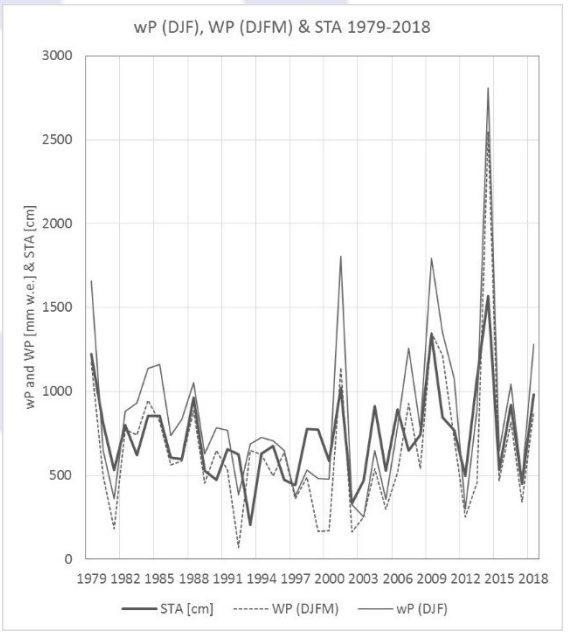

PDD ablation period (Apr-Oct) 1979-2018
PDD [mm w.e.]
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
3800
3600
3400
1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012 2015 2018
year
number of days
200
190
180
170
160
150
1979 1989 1999 2009 2019

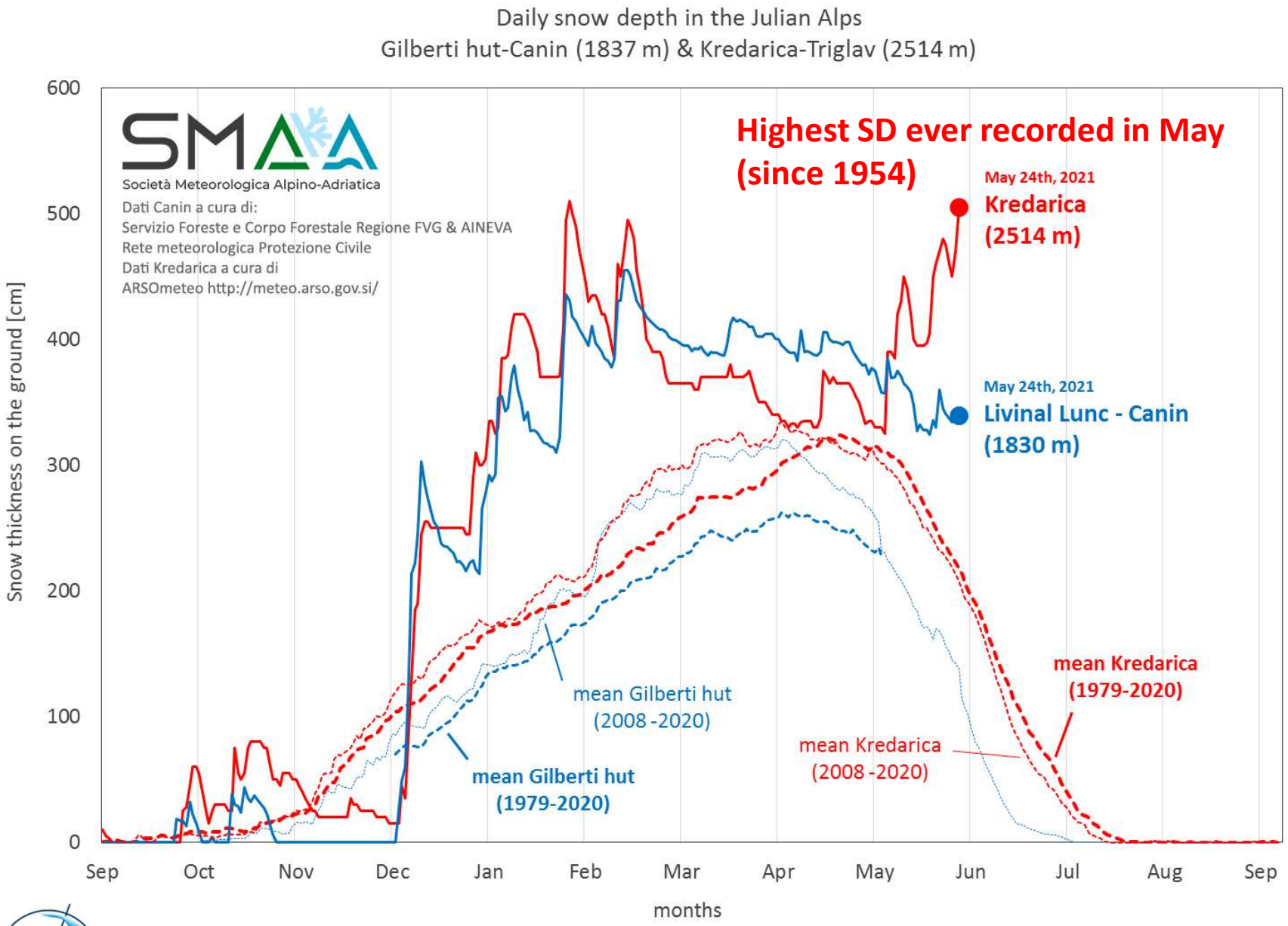


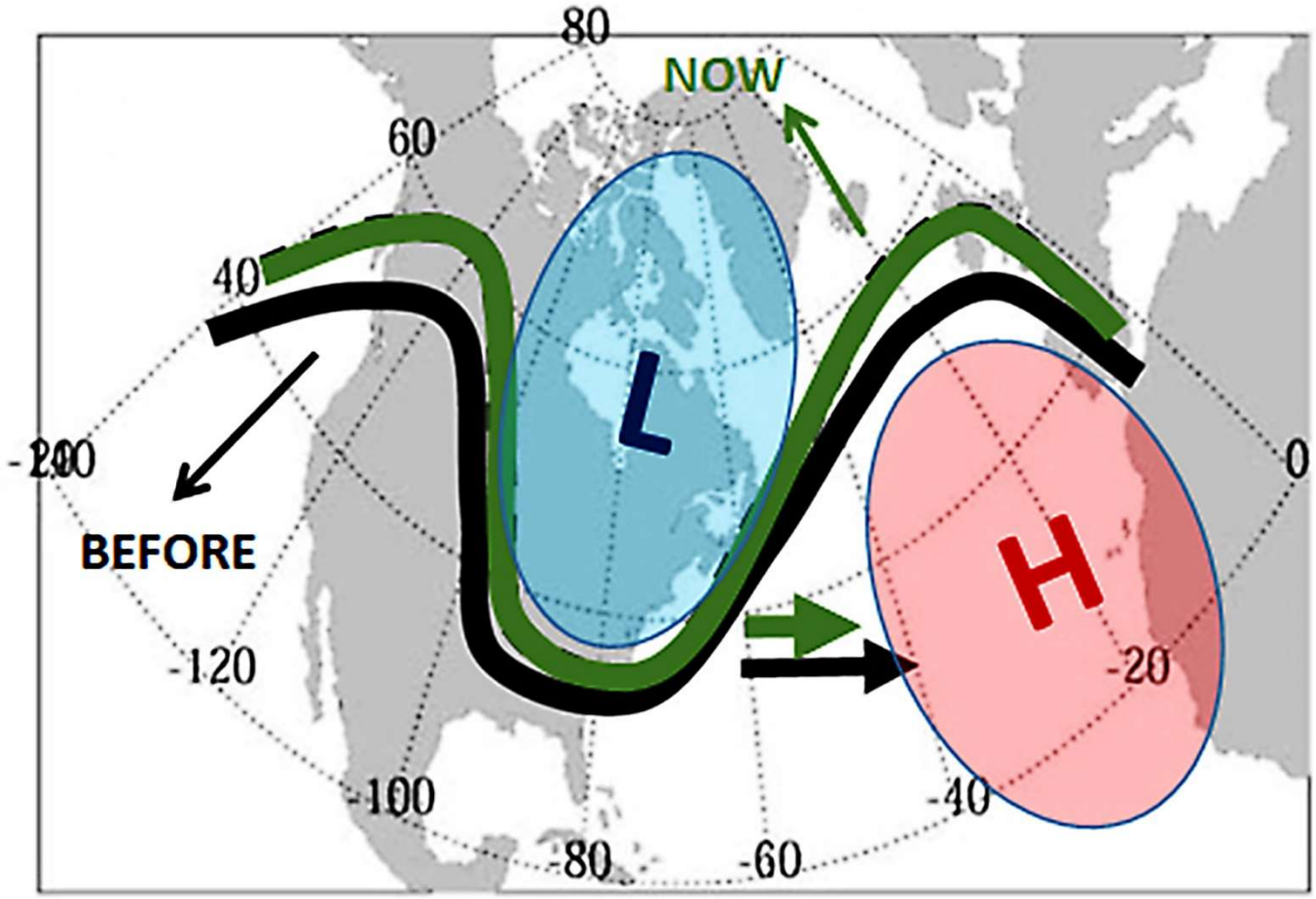

## envELA stabilization




Daily snow depth in the Julian Alps
Gilberti hut-Canin (1837 m) & Kredarica-Triglav (2514 m)
SMAA
Società Meteorologica Alpino-Adriatica
Dati Canin a cura di:
Servizio Foreste e Corpo Forestale Regione FVG & AINEVA
Rete meteorologica Protezione Civile
Dati Kredarica a cura di
ARSOmeteo http://meteo.arso.gov.si/
Highest SD ever recorded in May (since 1954)
May 24th, 2021
Kredarica (2514 m)
May 24th, 2021
Livinal Lunc - Canin (1830 m)
mean Gilberti hut (2008 -2020)
mean Gilberti hut (1979-2020)
mean Kredarica (1979-2020)
mean Kredarica (2008 -2020)
Snow thickness on the ground [cm]
600
500
400
300
200
100
0
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
months




Possible causes

**GLOBAL**

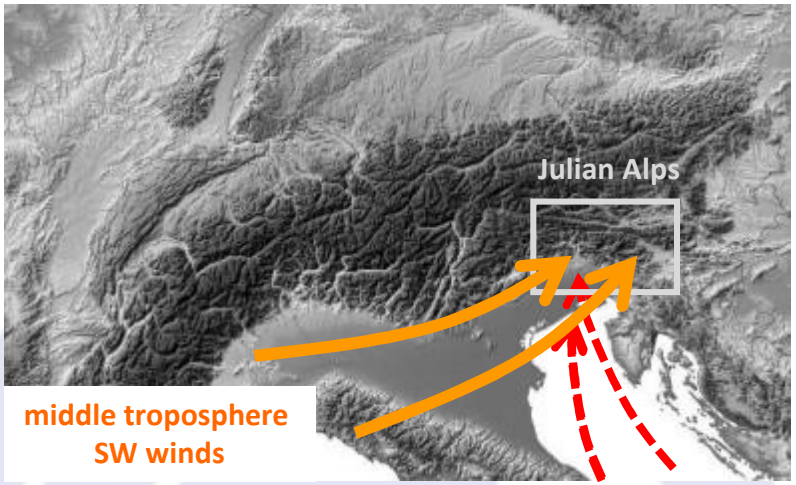
AA

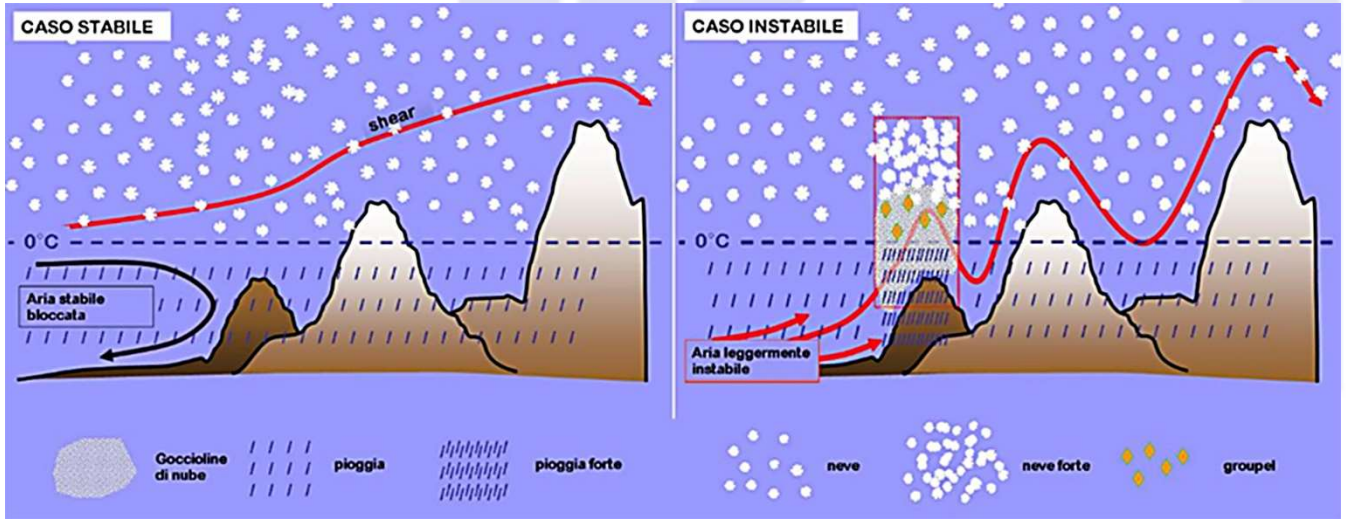
Arctic Amplification

QRA

Quasi Resonant Amplification

Increased frequency of Extreme events




## Possible causes

**LOCAL**

warmer SST

Raicich & Colucci (2020)

Conditions of the **Low Level Jet** below the boundary layer

Increased frequency of Extreme events

*atmosphere*

MDPI

*Article*

# Recent Increases in Winter Snowfall Provide Resilience to Very Small Glaciers in the Julian Alps, Europe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**Abstract:** Very small glaciers (<0.5 km$^2$) account for more than 80% of the total number of glaciers and more than 15% of the total glacier area in the European Alps. This study seeks to better understand the impact of extreme snowfall events on the resilience of very small glaciers and ice patches in the southeastern European Alps, an area with the highest mean annual precipitation in the entire Alpine chain. Mean annual precipitation here is up to 3300 mm water equivalent, and the winter snow accumulation is approximately 6.80 m at 1800 m asl averaged over the period 1979–2018. As a consequence, very small glaciers and ice/firn patches are still present in this area at rather low altitudes (1830–2340 m). We performed repeated geodetic mass balance measurements on 14 ice bodies during the period 2006–2018 and the results show an increase greater than 10% increase in ice volume over this period. This is in accordance with several extreme winter snow accumulations in the 2000s, promoting a positive mass balance in the following years. The long-term evolution of these very small glaciers and ice bodies matches well with changes in mean temperature of the ablation season linked to variability of Atlantic Multidecadal Oscillation. Nevertheless, the recent behaviour of such residual ice masses in this area where orographic precipitation represents an important component of weather amplification is somehow different to most of the Alps. We analysed synoptic meteorological conditions leading to the exceptional snowy winters in the 2000s, which appear to be related to the influence and modification of atmospheric planetary waves and Arctic Amplification, with further positive feedbacks due to change in local sea surface temperature and its interactions with low level flows and the orography. Although further summer warming is expected in the next decades, we conclude that modification of storm tracks and more frequent occurrence of extreme snowfall events during winter are crucial in ensuring the resilience of small glacial remnants in maritime alpine sectors.



**Keywords:** small glaciers; glacier mass balance; climate; AMO; precipitation; climate change


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## 1. Introduction

Ice bodies in the Julian Alps are typically in the smallest size category of glaciers, with several glacial and nival ice patches [1] and one small mountain glacier [2]. These very small ice masses have gained an increasing scientific importance in the last few decades e.g., in the studies of Mediterranean [3] glaciation during the Pleistocene and the Holocene [4]



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