Institute for Atmospheric and Climate Science (IAC)
and Center for Climate Systems Modeling (C2SM)

The influence of subseasonal to seasonal atmospheric temperature variability on alpine permafrost

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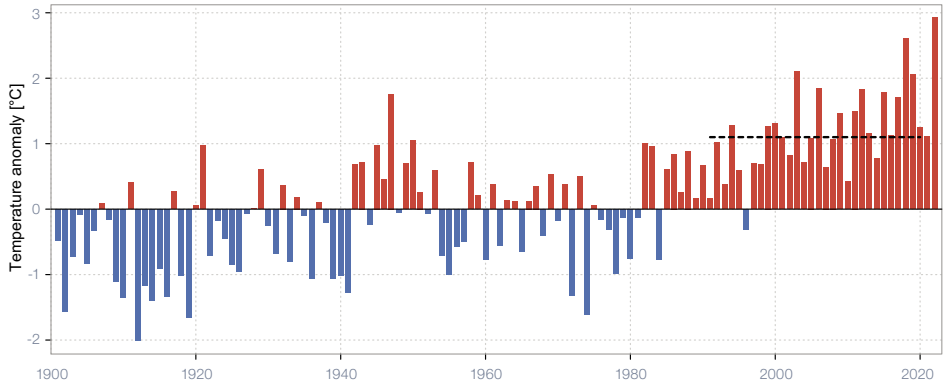
EGU General Assembly, Vienna, Austria, 17 April 2024

Schilthorn, Switzerland, Schilthornbahn AG

Observed (and projected) climate change in the Alps

Summer (MJJASO) temperature anomalies averaged over various alpine stations (>1500m)



DWD / MeteoSwiss / ZAMG, 2022

High altitudes (and Switzerland as a whole) **warm more than twice as fast as globe**, including **more frequent and intense heatwaves**

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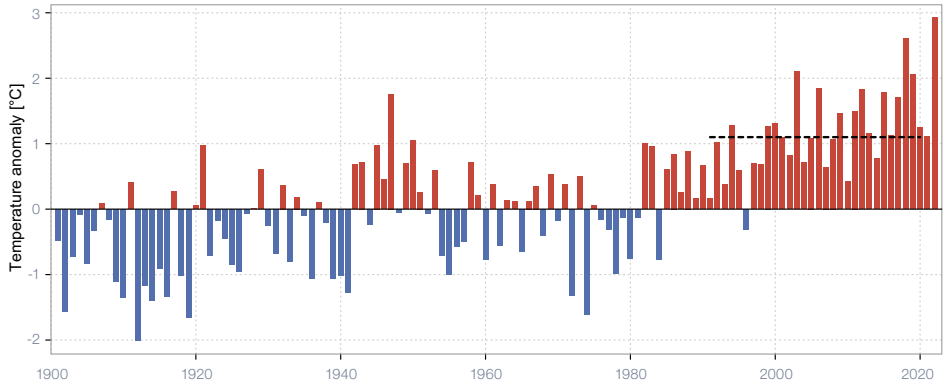

DWD / MeteoSwiss / ZAMG, 2022

Highest measured zero-degree lines in Switzerland

Rang		
1	5298 m	21.08.2023
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3	5117 m	20.07.1995
4	4985 m	24.07.2019
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(Messbeginn im Jahr 1954)

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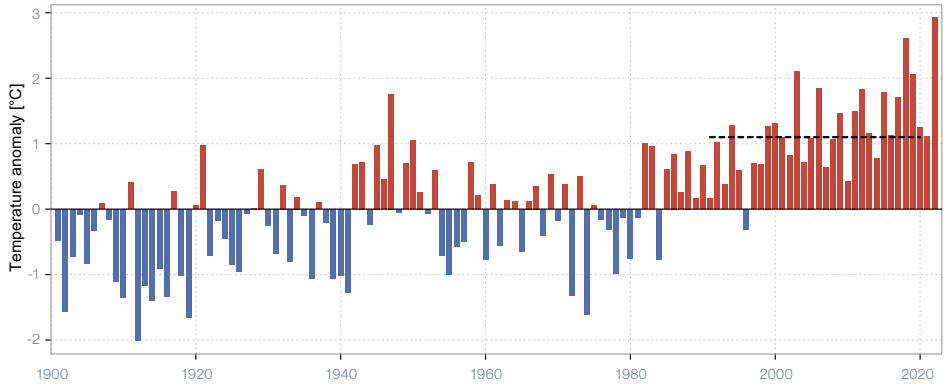

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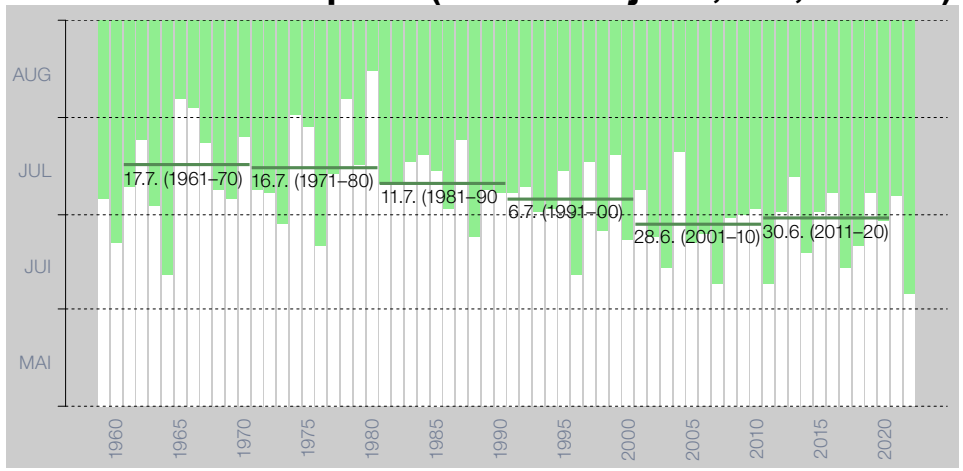
First snow-free day of the year at exemplary Swiss mountain peak (Weissfluhjoch, GR, 2540m)



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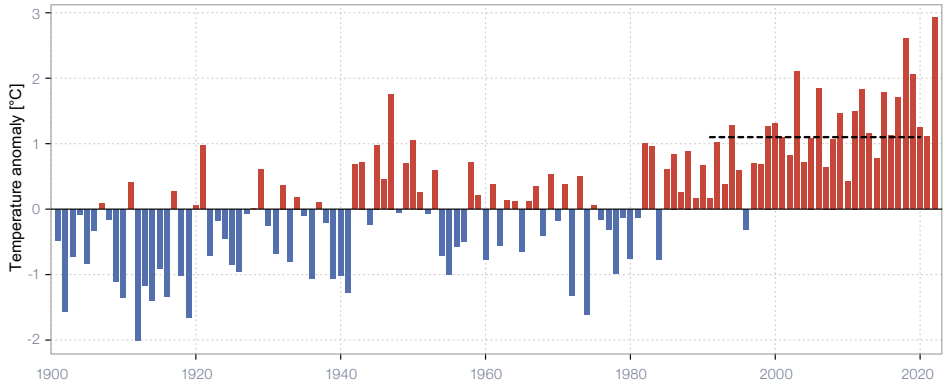

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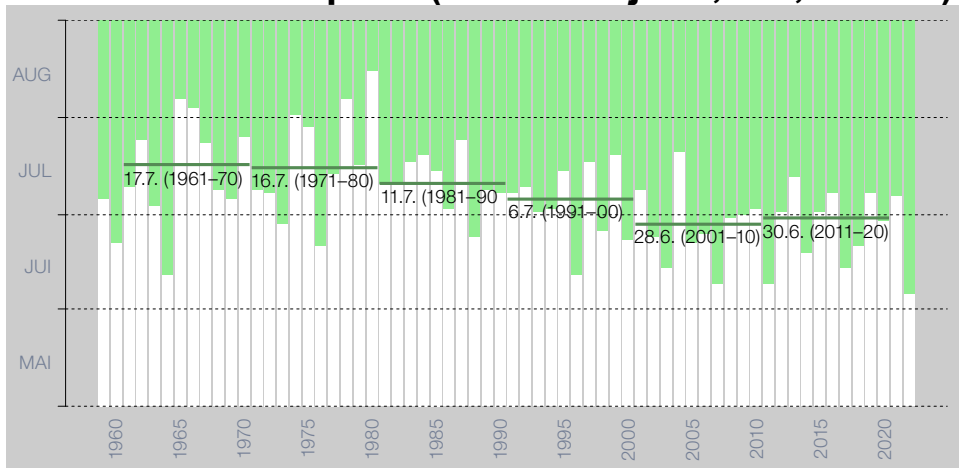

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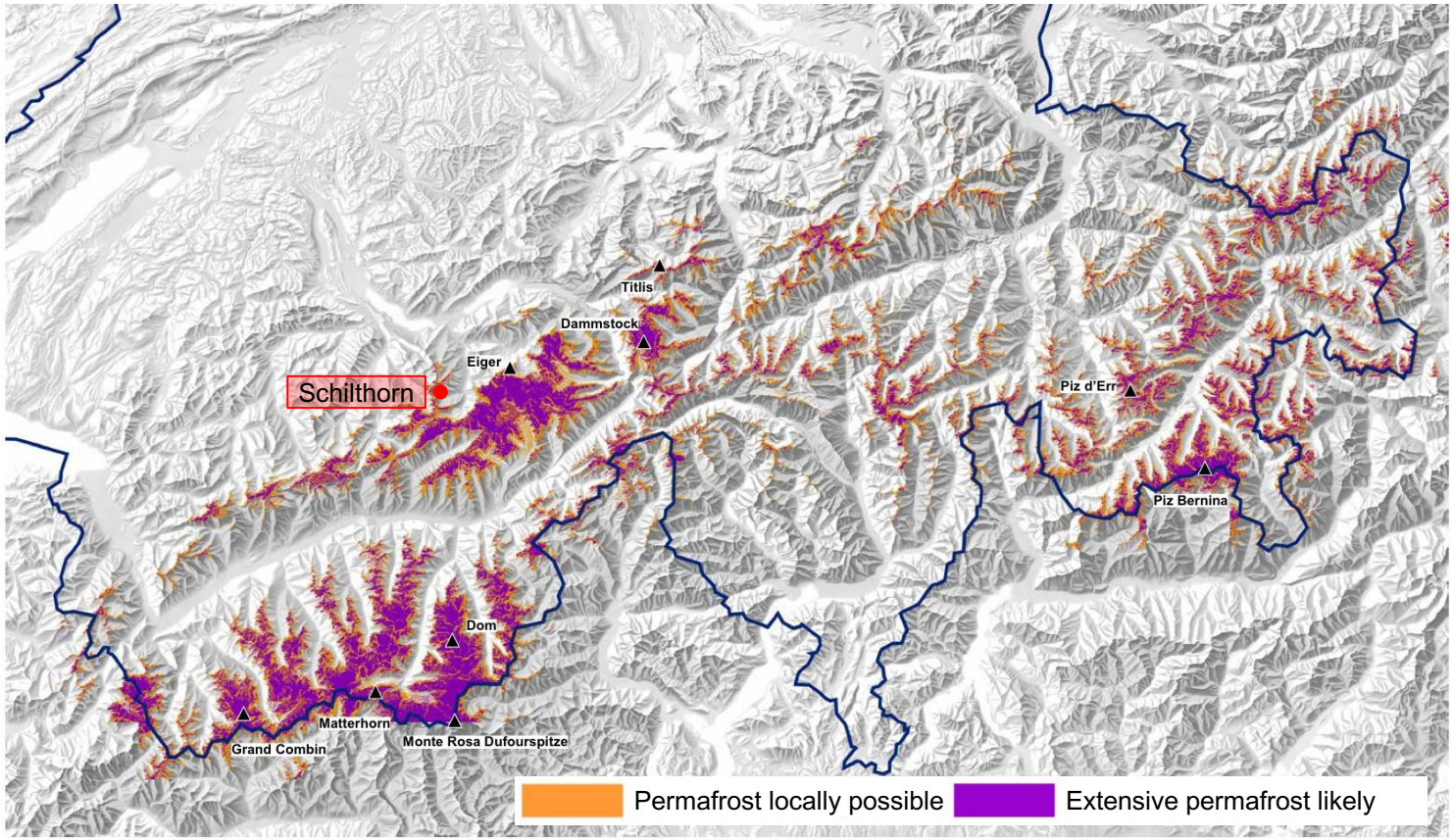
→ **Alpine permafrost is thawing, with possibly still unknown consequences** for alpine hazards (e.g., rockfalls), infrastructure, ecosystems, and tourism

Permafrost in the Swiss Alps and at our PERMOS study site Schilthorn

Approximately 5% of Switzerland's area is covered by permafrost, which is monitored by PERMOS at about 27 borehole sites



Swiss Federal Office of Environment / PERMOS / swisstopo

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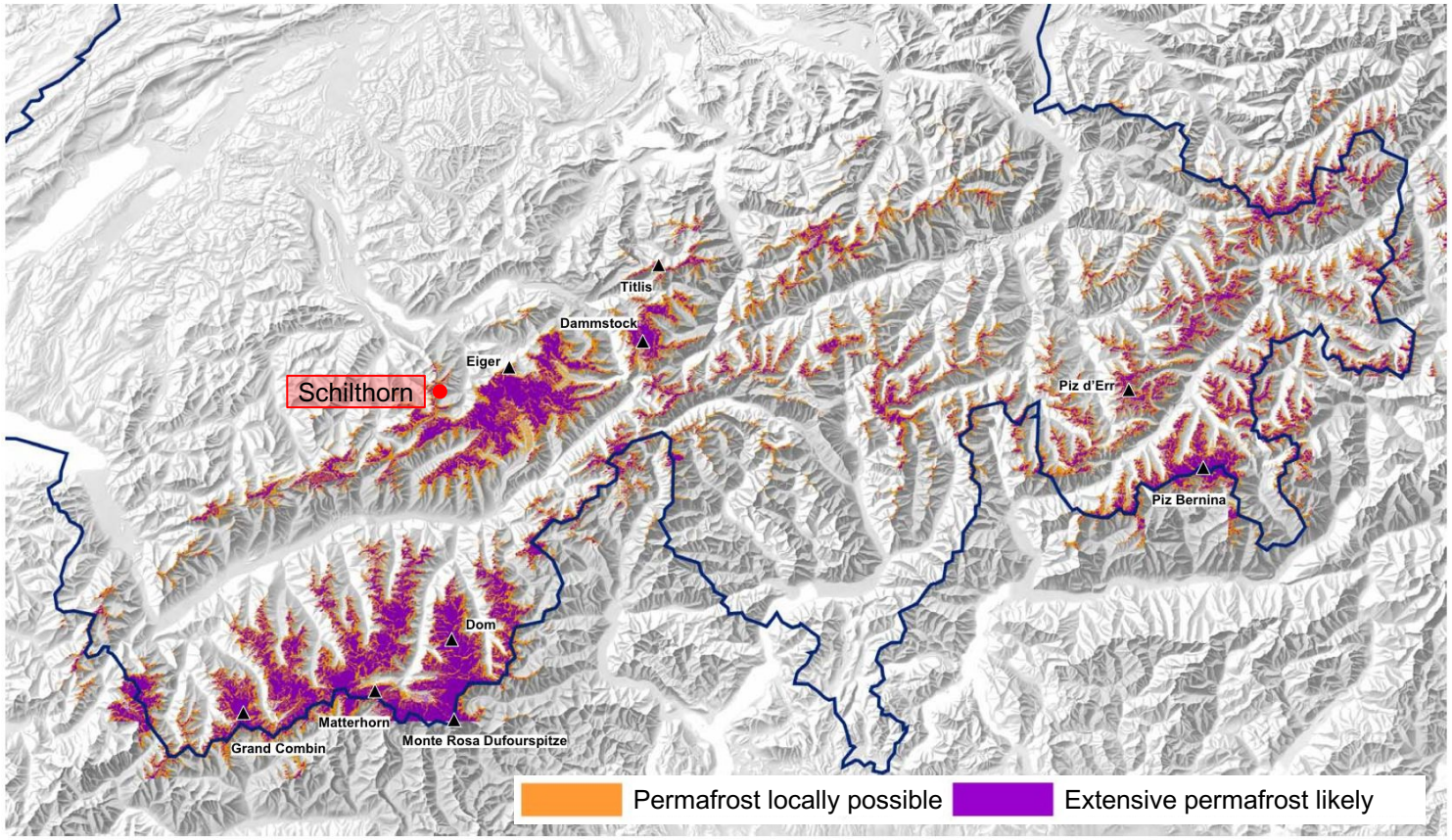
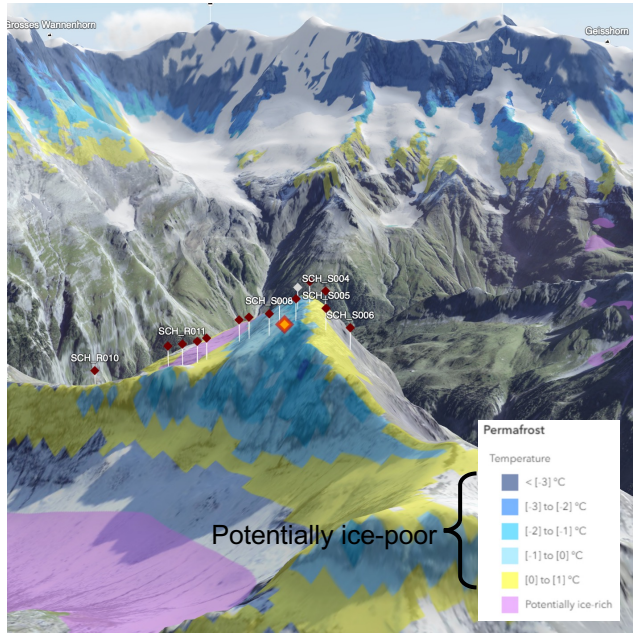


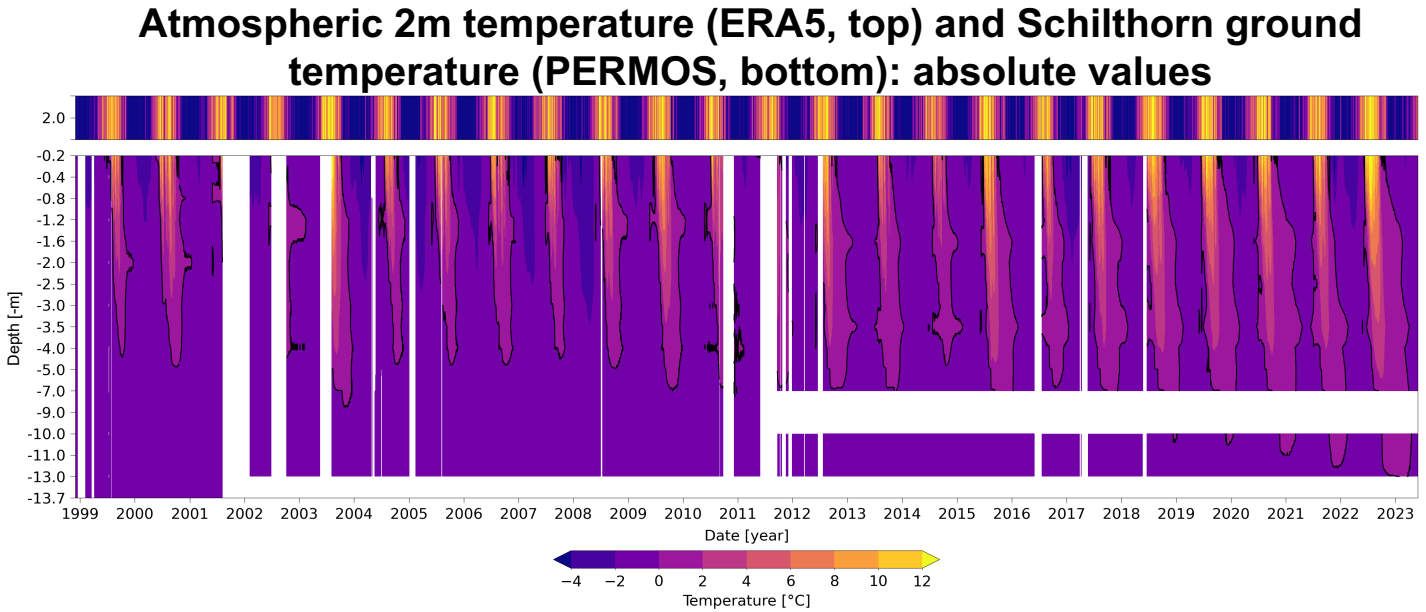
Swiss Federal Office of Environment / PERMOS / swisstopo

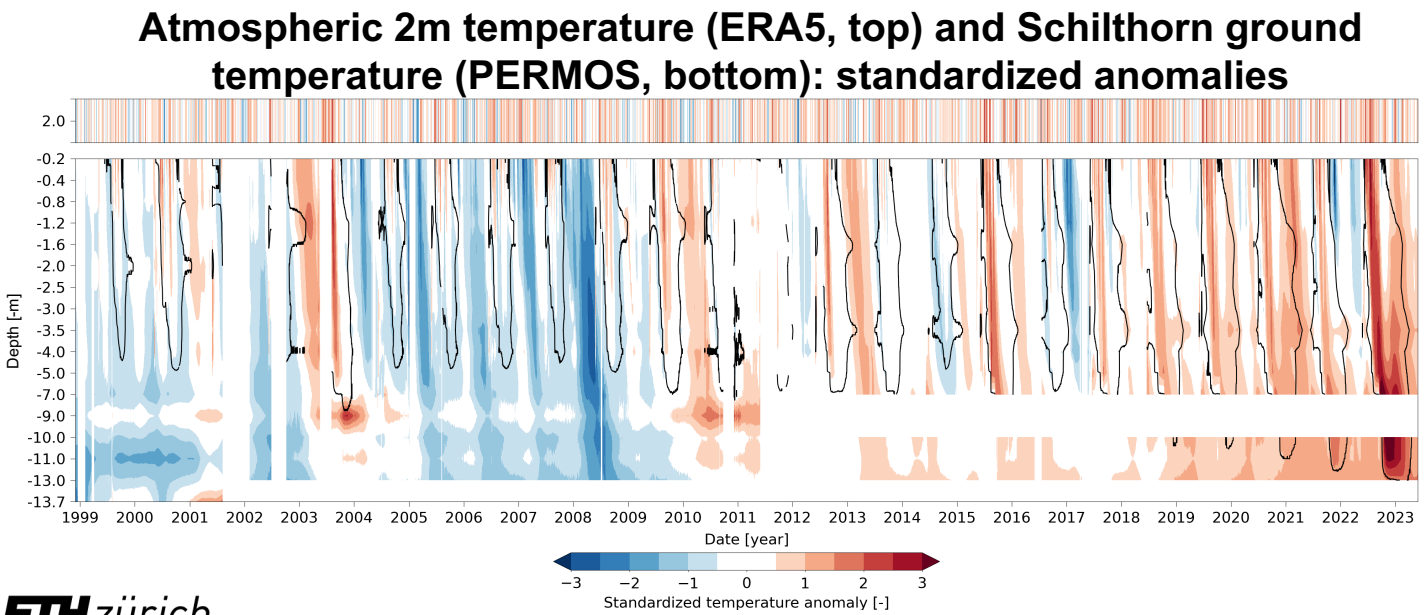
Borehole(s) at Schilthorn (BE, 2970m) with largely ice-poor permafrost



PERMOS / WSL SLF
Photos: Cécile Pellet / Andi Hasler

Schilthorn, a rapidly (!) changing mountain



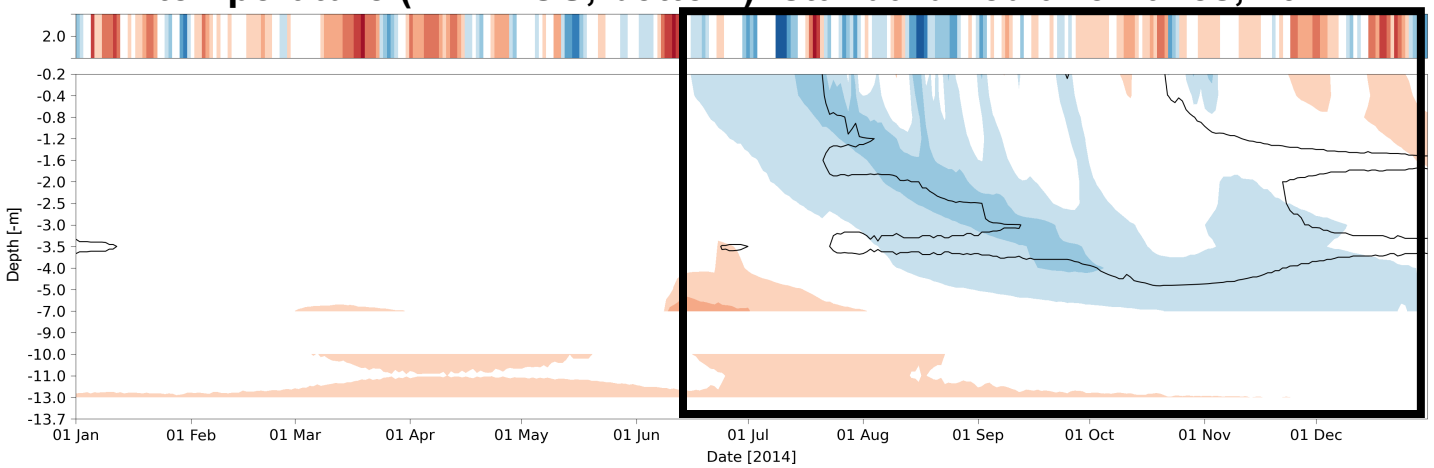


Strong trend particularly in last 10 years: **rapid thickening of active layer** and **subsidence of permafrost table** (borehole is not deep enough anymore!)

Long-term changes in annual / summer mean temperature (and potentially also in snow cover) are likely the **first-order drivers** of this permafrost thawing

Schilthorn, a rapidly (!) changing mountain

Atmospheric 2m temperature (ERA5, top) and Schilthorn ground temperature (PERMOS, bottom): standardized anomalies, 2014



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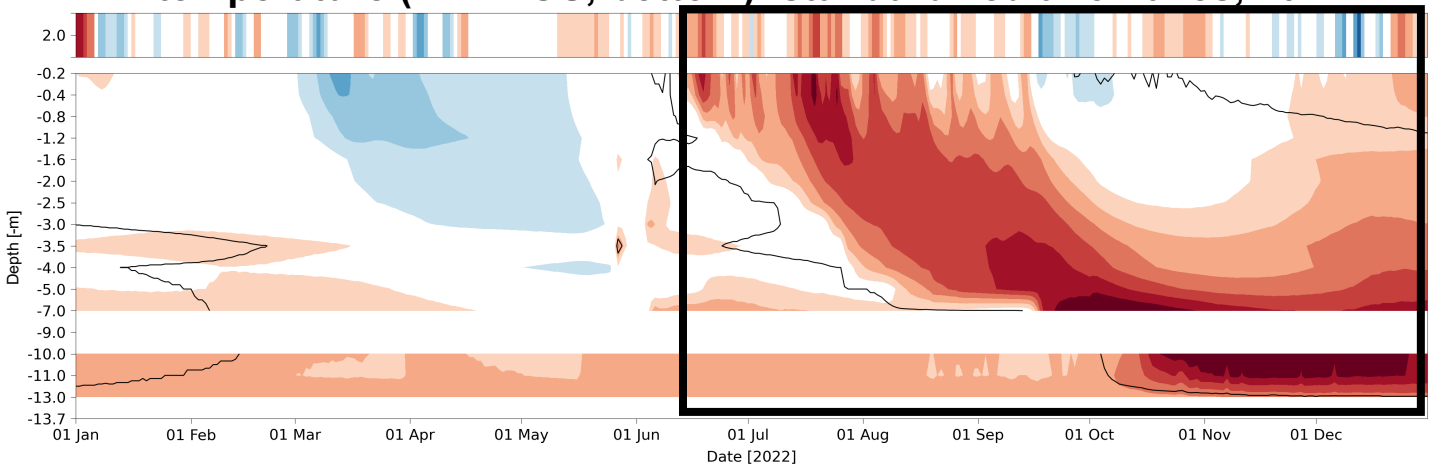

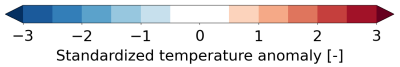

However, strong interannual variability of ground temperature evolution

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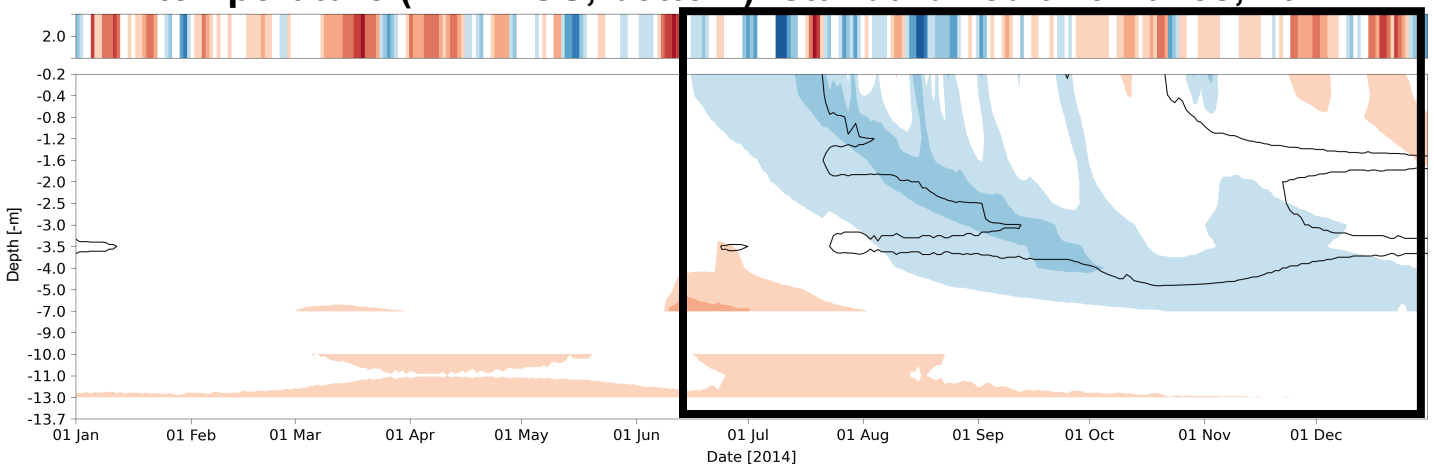

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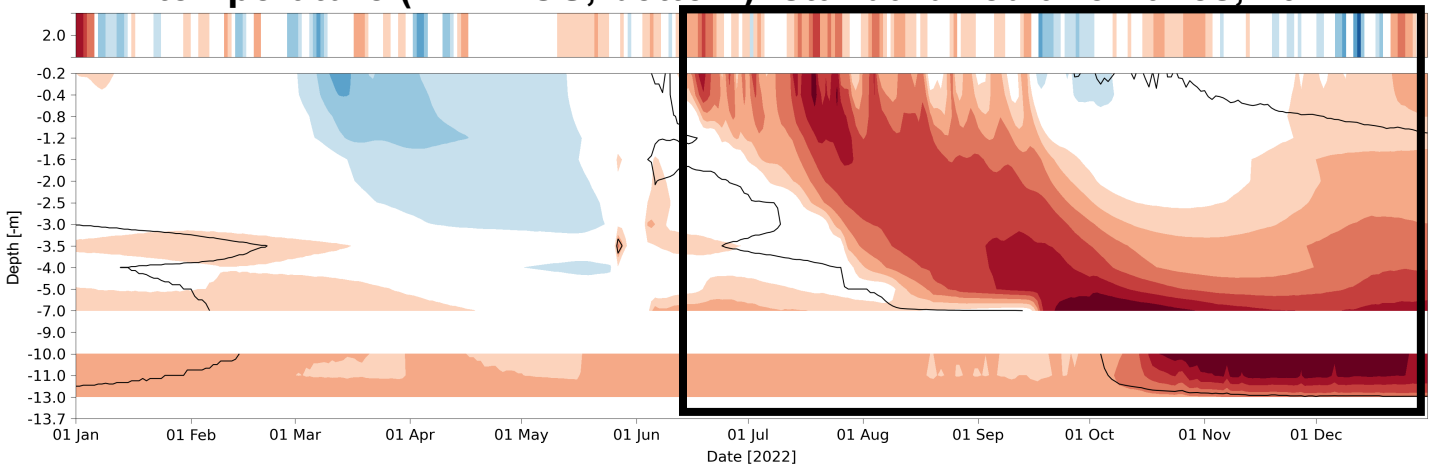
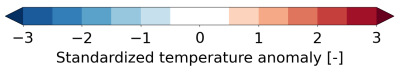




However, strong interannual variability of ground temperature evolution

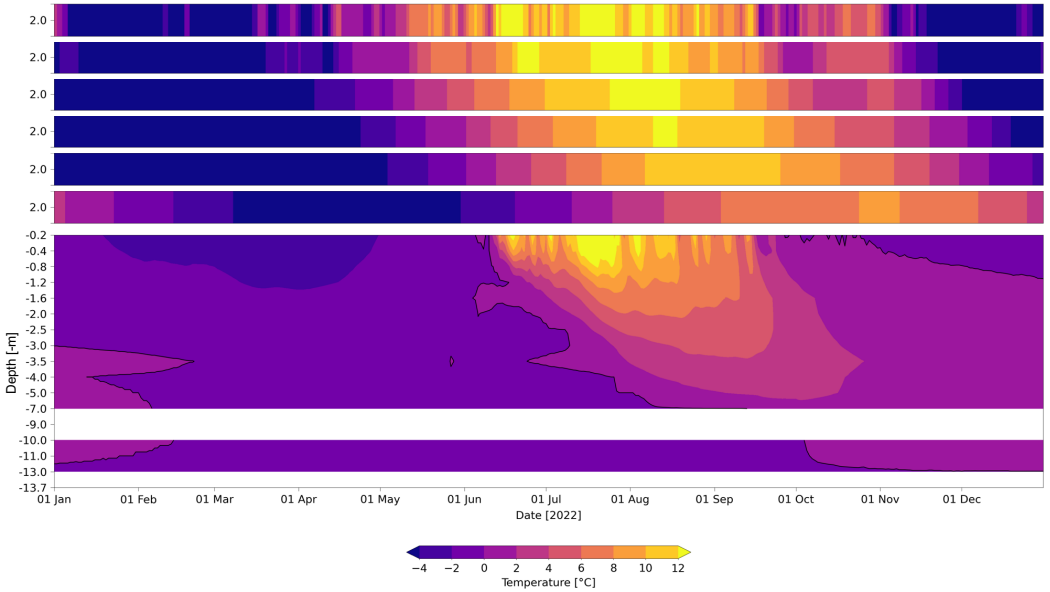
→ **Research question: role of subseasonal to seasonal atmospheric temperature variability** – in particular of **multi-weekly summer heatwaves** – for ground temperature / permafrost (and its changes)?

→ **Subproject of interdisciplinary project HEATaware**, which aims to investigate predictability of heatwaves and impacts in Switzerland several weeks ahead

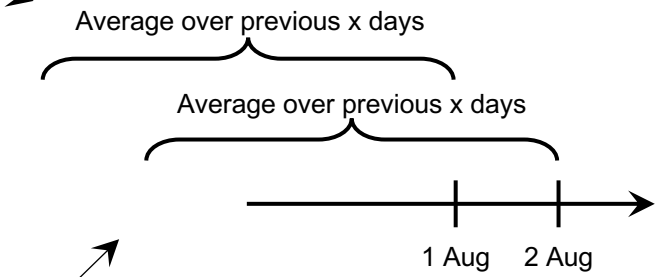
Scan for more details about HEATaware

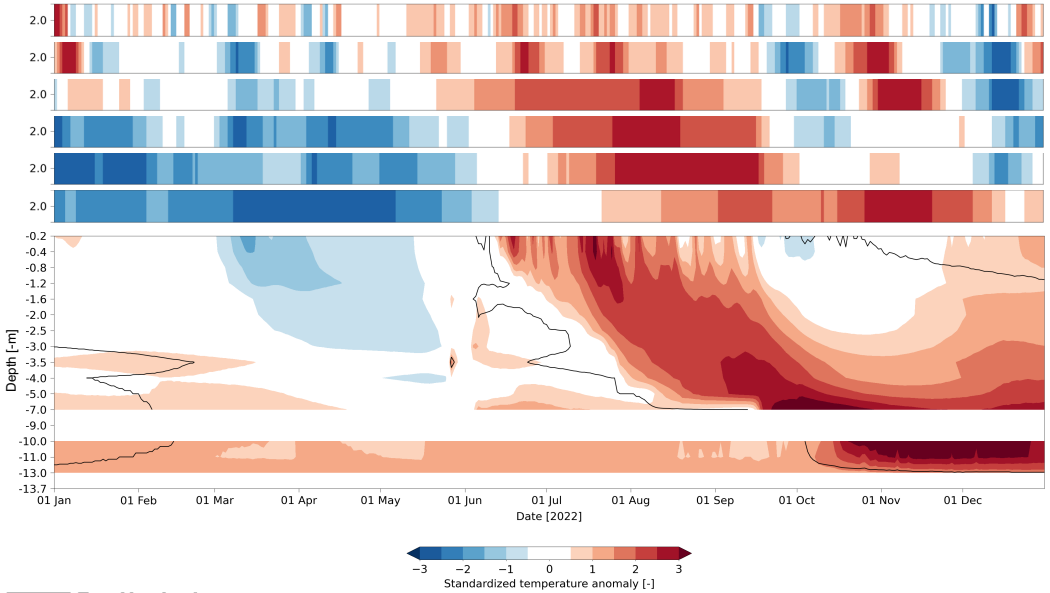
ETH zürich

Role of atmospheric timescales for ground temperature (Schilthorn)



0d running mean atmospheric 2m temperature
10d …
30d …
60d …
90d …
180d …





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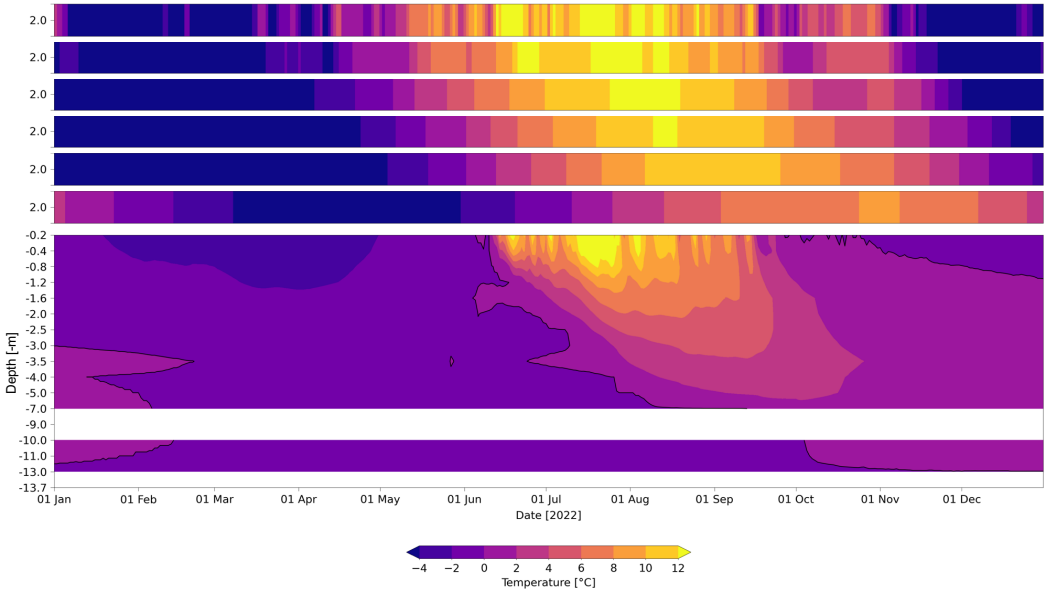

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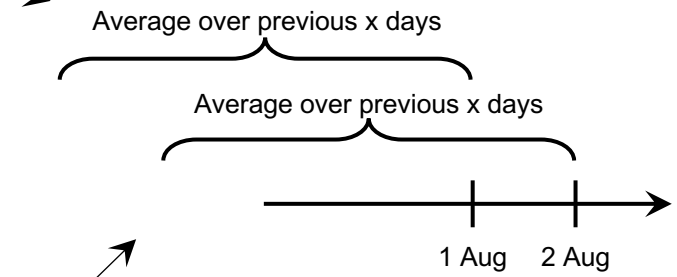

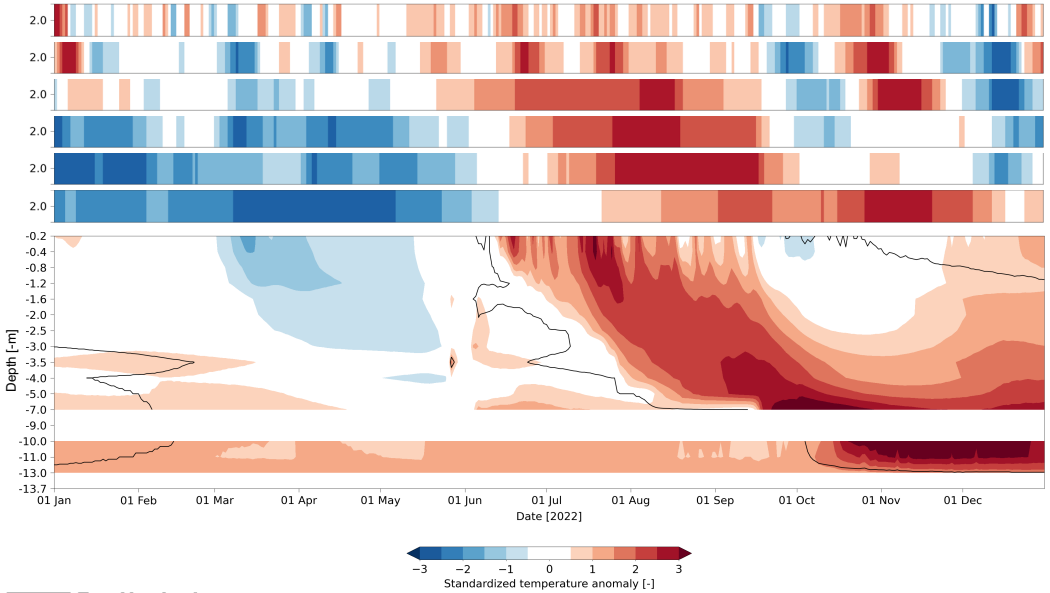

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→ Correlation between **daily ground temperatures at different depths** and **daily atmospheric temperatures averaged over different windows**?

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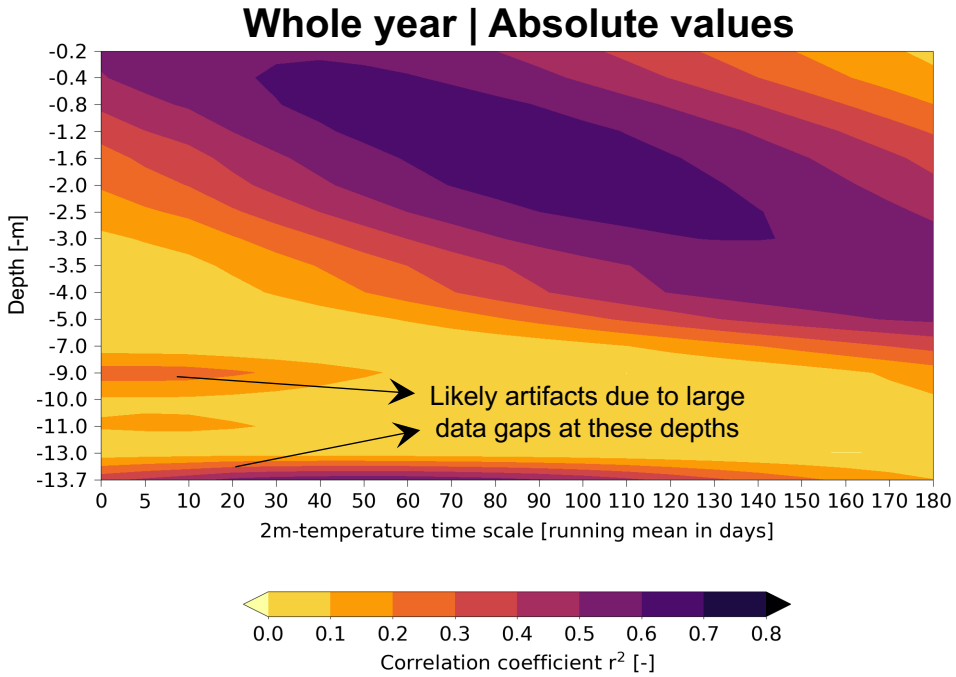

Well-known quasi-linear relationship: **the longer the atmospheric timescale, the larger the impacted ground depth** → ground temperature driven by **heat conduction**

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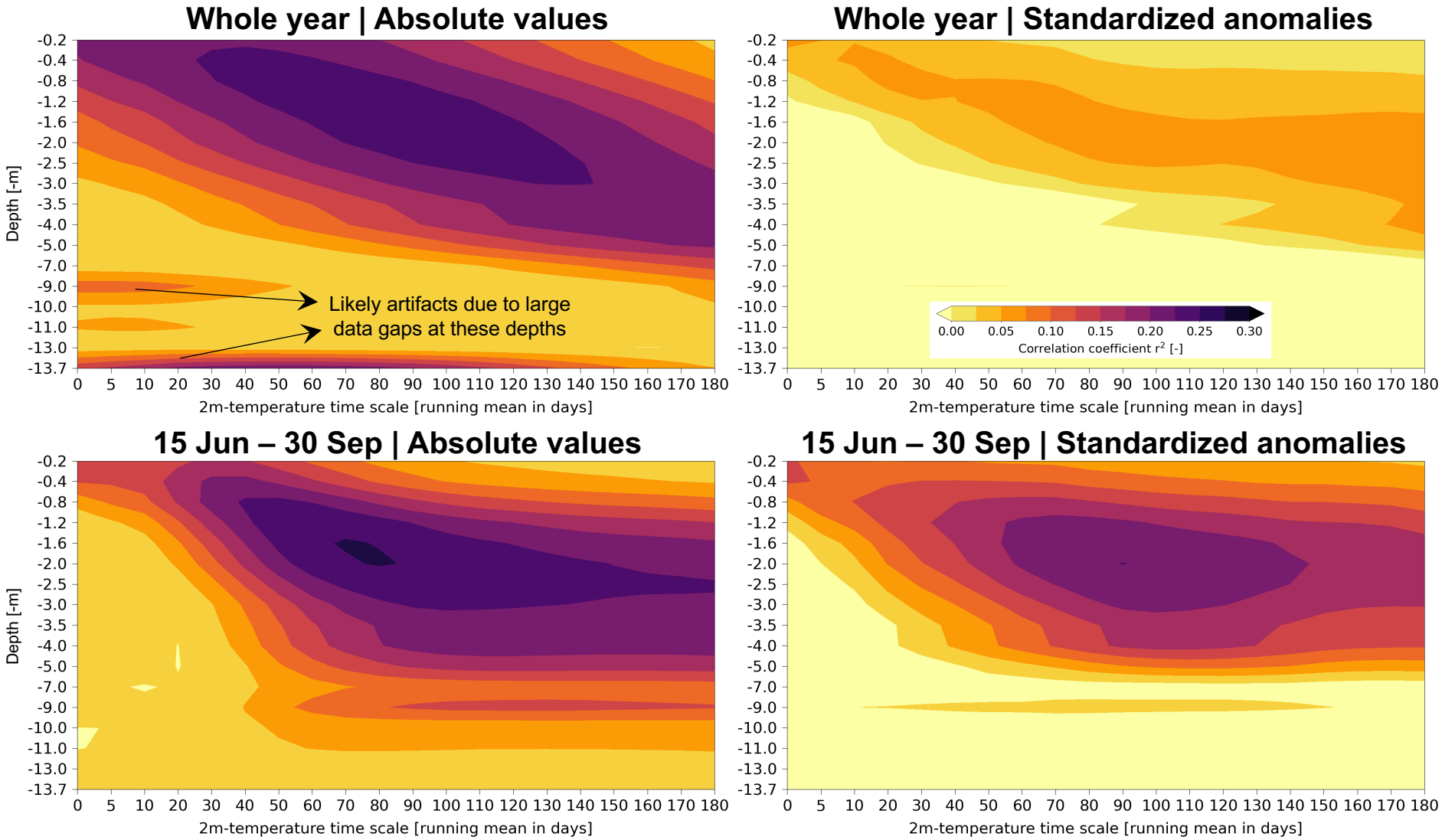

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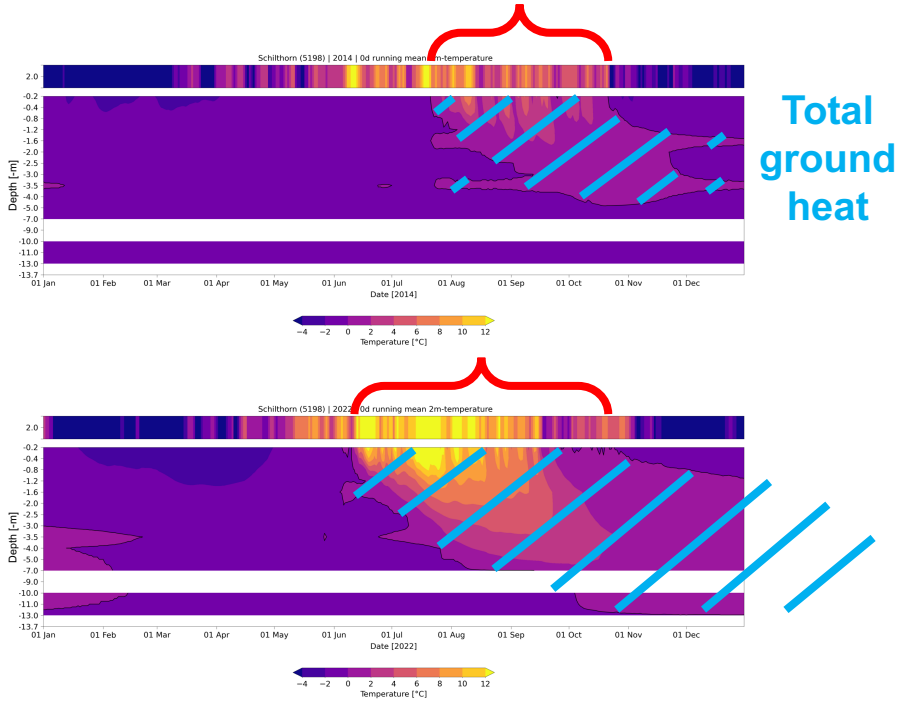
Relationship more **more pronounced for absolute values**, **except for summer,** when anomalies also strongly correlate

Role of accumulated atmospheric summer heat for “total ground heat”

Seasonally accumulated atmospheric heat over “snow-free period”



Total ground heat

Simple definition of “snow-free period”: period between first and last time when ground temperature at highest sensor (0.2m depth) is equal to or larger than 0°C

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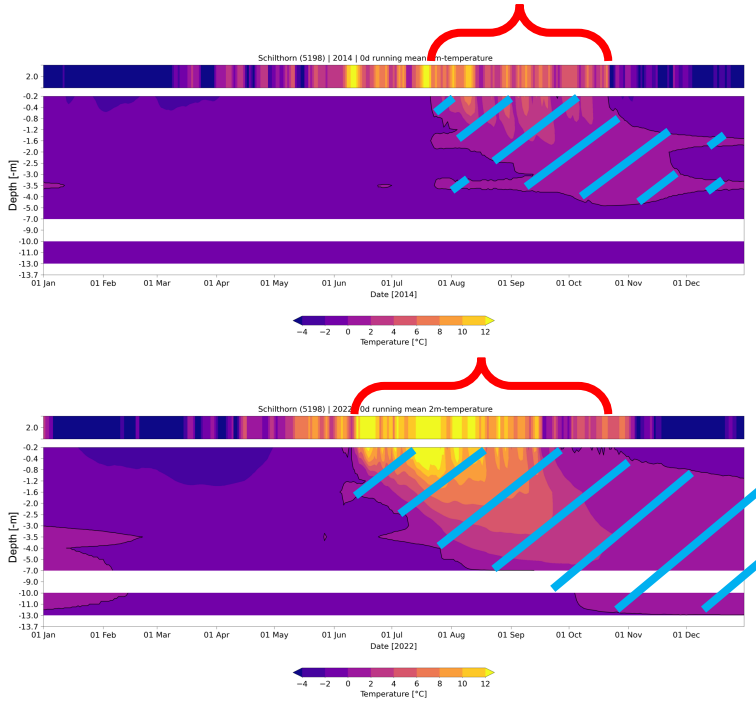

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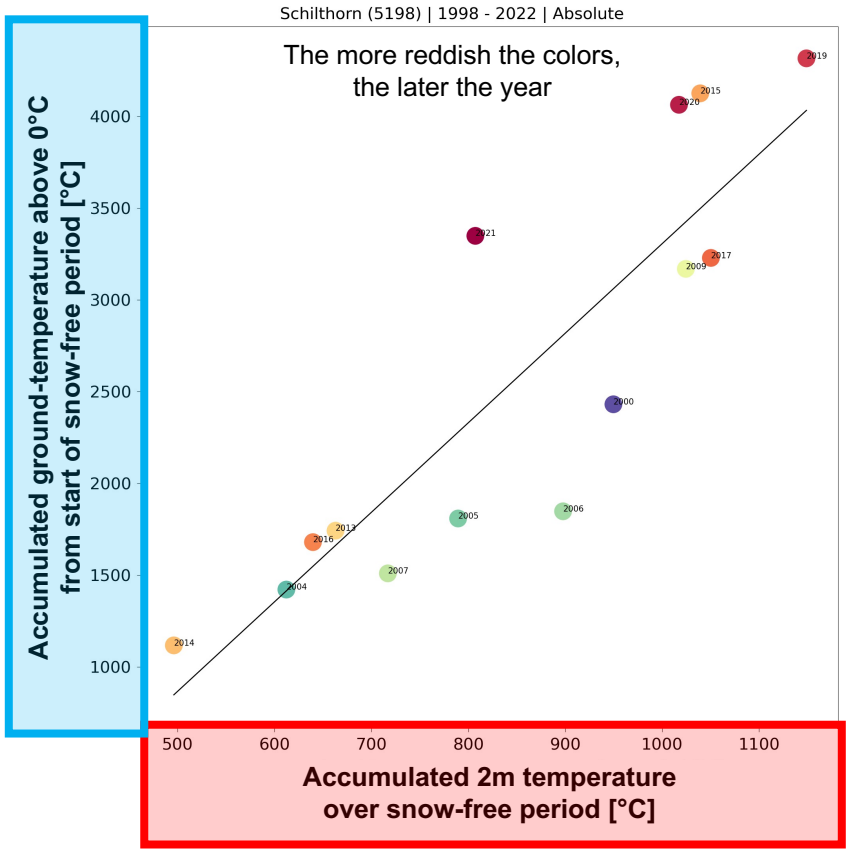
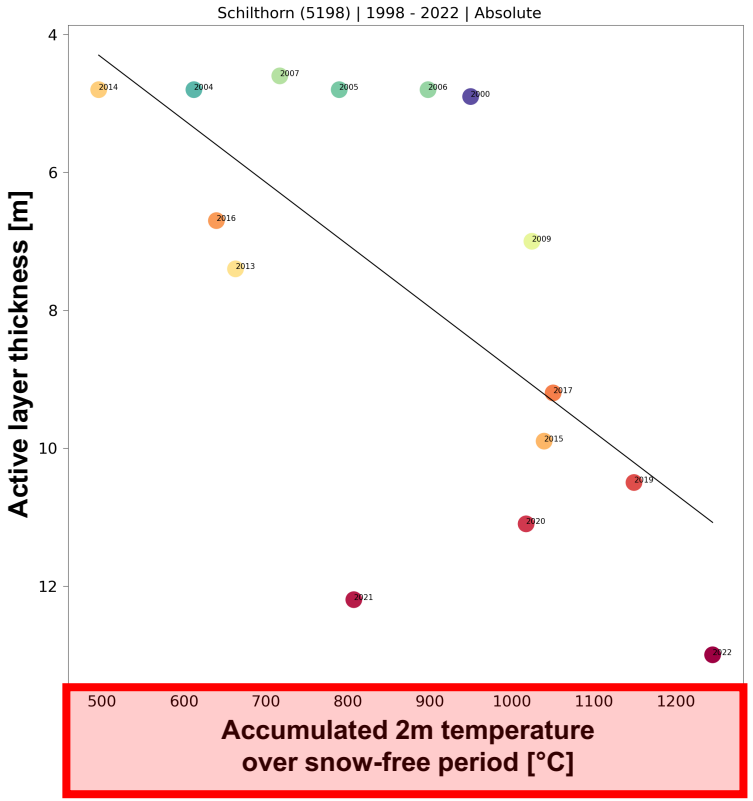


Quite strong linear relationship: **the more atmospheric heat** is available over “snow-free period”, **the more heat (>0°C) is subsequently available in the ground**

Role of accumulated atmospheric summer heat for active layer thickness (ALT) / permafrost table



Much weaker linear relationship: **ALT (and its changes) not just driven by atmospheric heat available over snow-free period,** but rather a **result of longer-term (and probably non-linear) processes**

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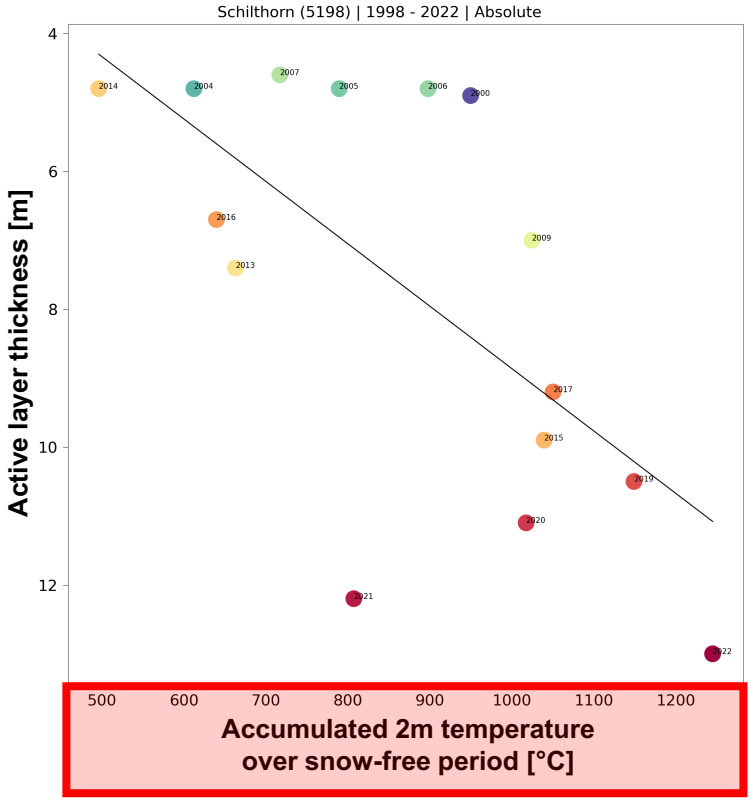

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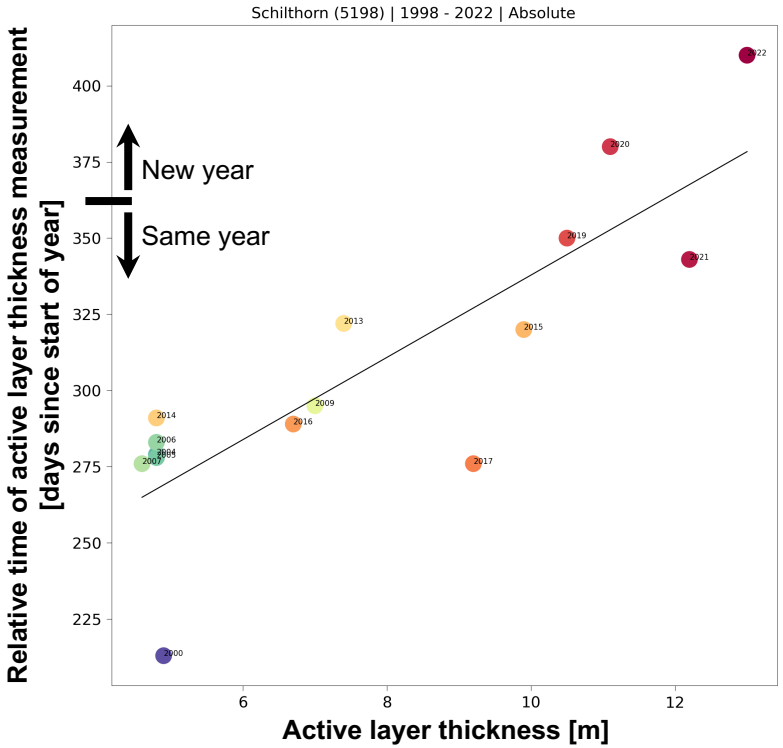
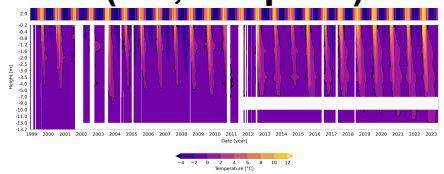
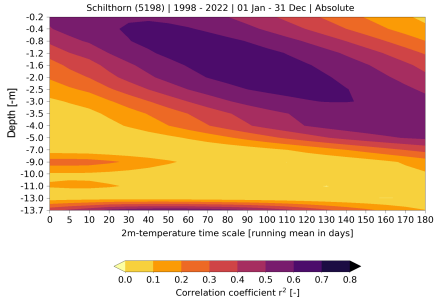


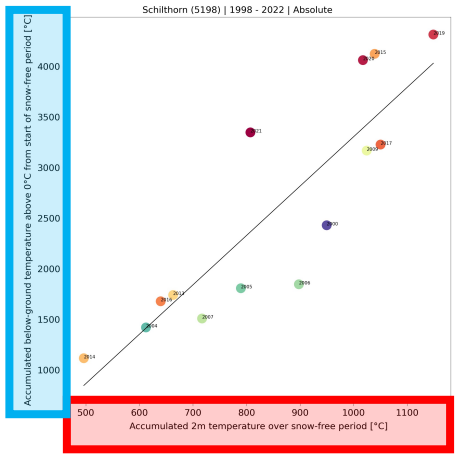
Larger ALT typically measured at **later time** → 2020 and 2022 = first years when ALT was measured in following year!

What about other PERMOS sites?

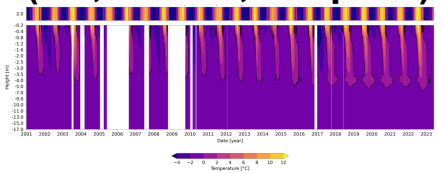
Schilthorn (BE, ice-poor)

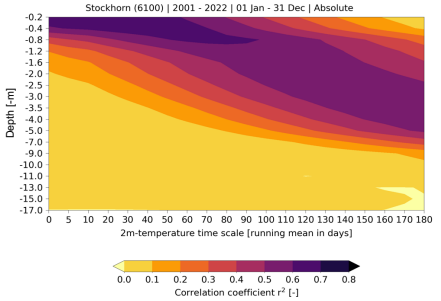


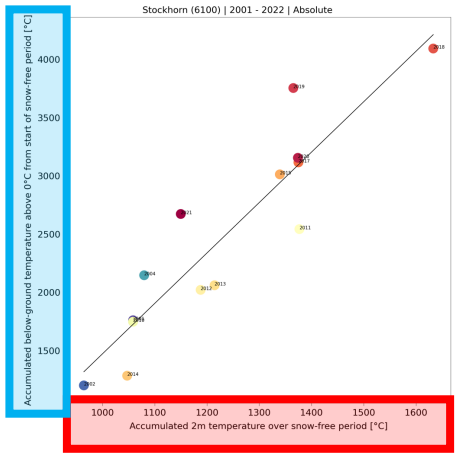




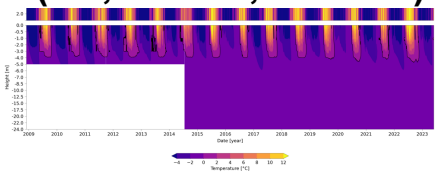
Stockhorn (VS, 3410m, ice-poor)

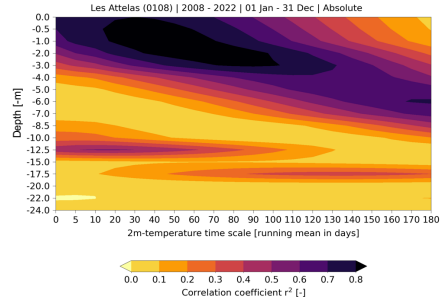


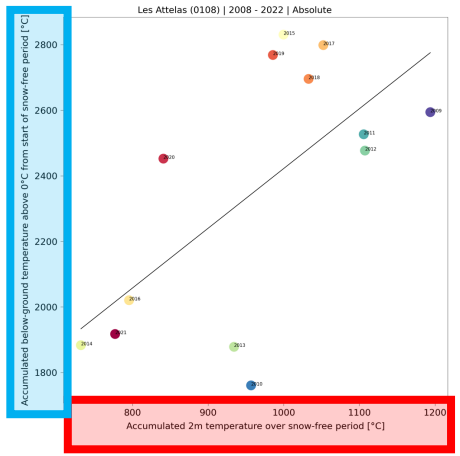




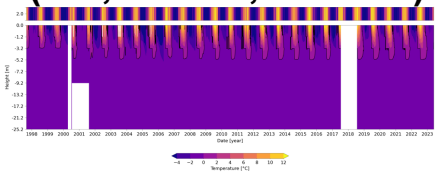
Les Attelas (VS, 2661m, ice-rich)

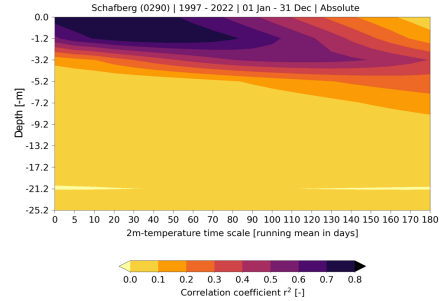


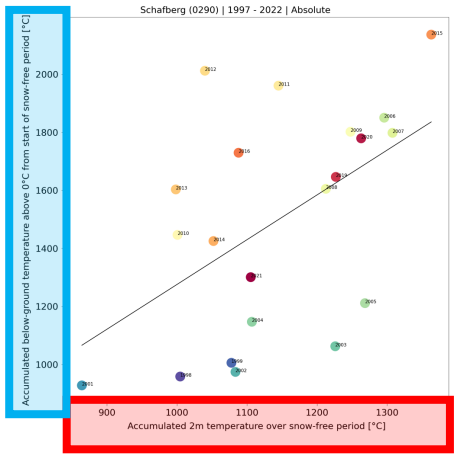




Schafberg (GR, 2732m, ice-rich)



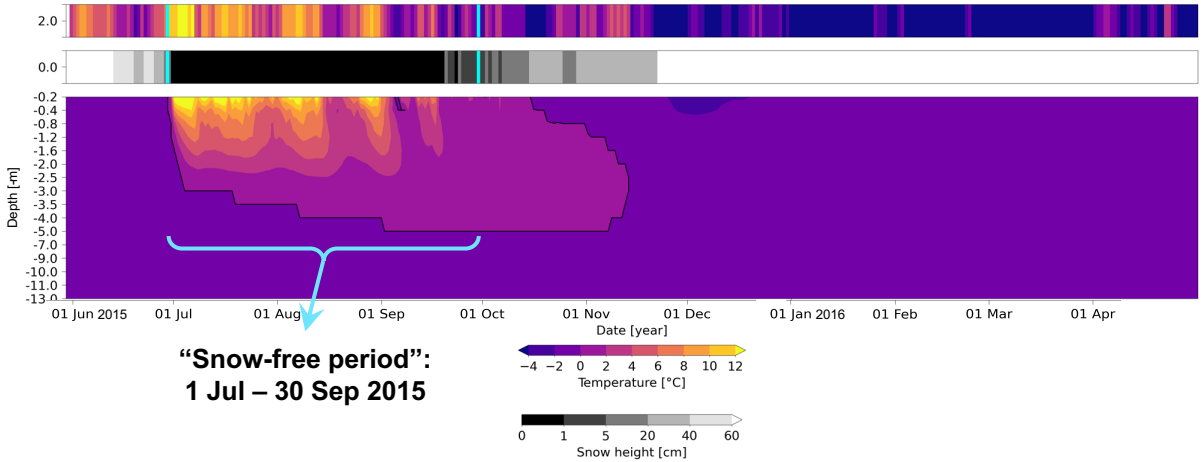




Very different behavior from PERMOS site to PERMOS site **due to their very different ground characteristics**:
ice content, mountain/rock type, snow cover characteristics, …

Role of subseasonal atmospheric temperature variability for “total ground heat” at Schilthorn? → SNOWPACK simulations for 2015/2016

1D SNOWPACK model (Lehning et al., 1999) control simulation based on atmospheric and snow measurements from meteorological station (1 June 2015 – 30 April 2016)



“Snow-free period”: 1 Jul – 30 Sep 2015

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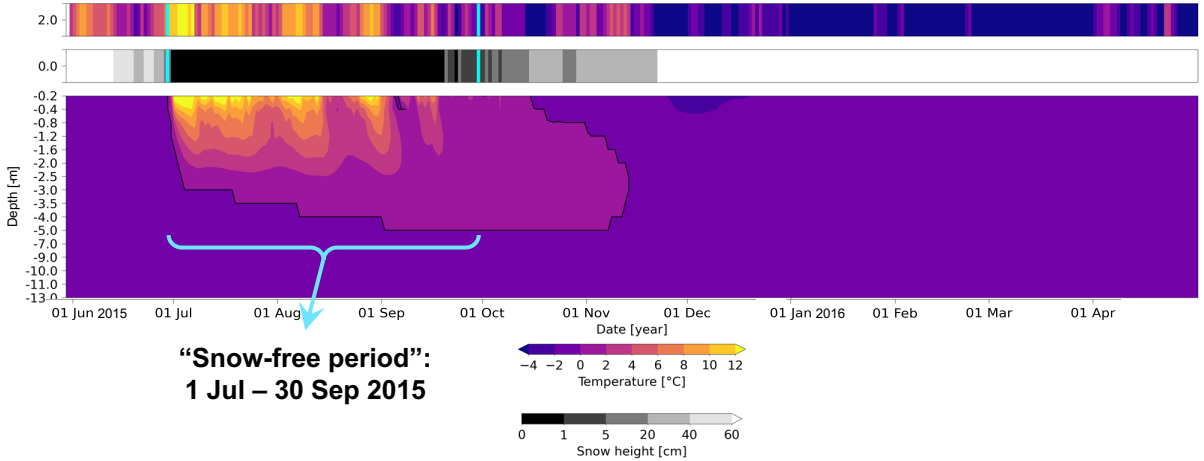

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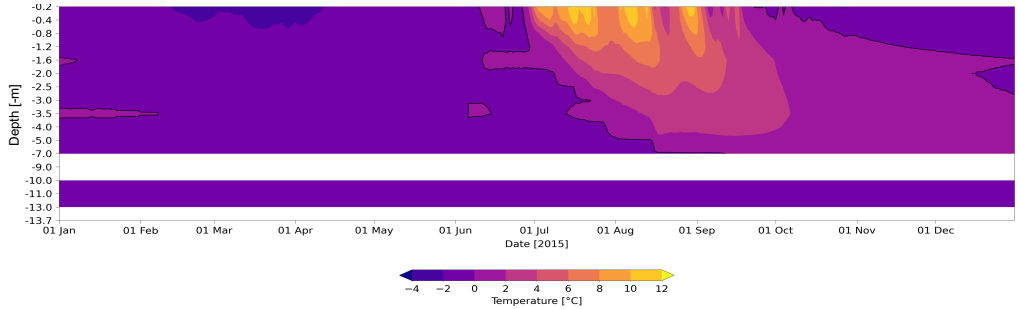
SNOWPACK simulations performed/led by Elizaveta Sharaborova → see her presentation EGU24-13291 (CR4.1) for further details on Schilthorn setup

PERMOS measurements for verification



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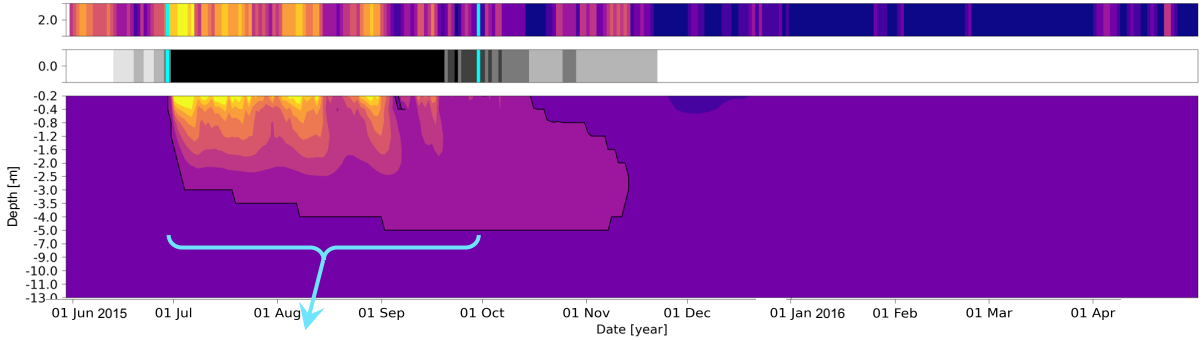

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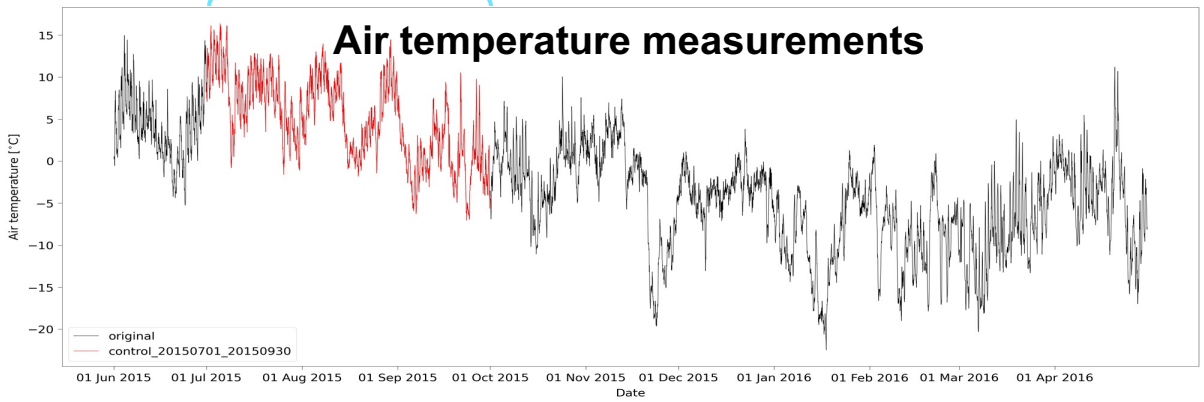

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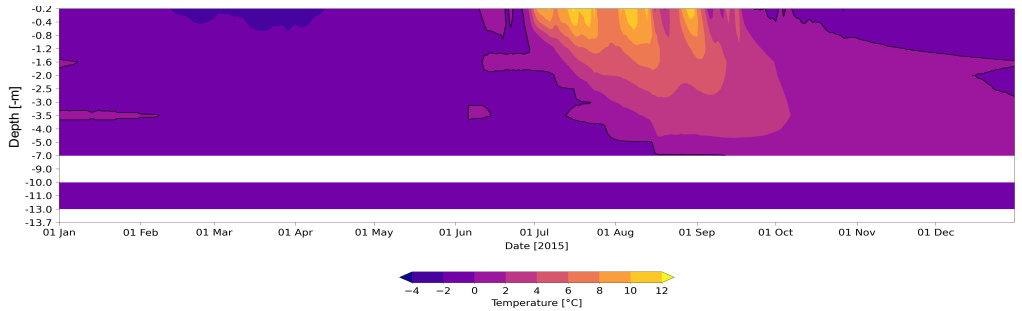
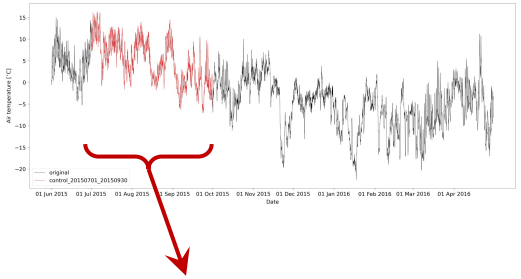


SNOWPACK does a reasonable job in simulating ground temperature evolution, despite potentially important biases (underestimation of ALT as well as temporal extent of ground heat reservoir) → use it for sensitivity simulations with modified atmospheric input over snow-free period (see next slide)

Setup of idealized SNOWPACK sensitivity simulations for summer 2015

Control



“Snow-free period”:
1 Jul – 30 Sep 2015

Approach: Simulate summer 2015 ground temperatures multiple times **with same total atmospheric heat/temperature (and precipitation, radiation, …) input over snow-free period,** but with **different subseasonal variability** → How does this affect (previously introduced) **“total ground heat”**?

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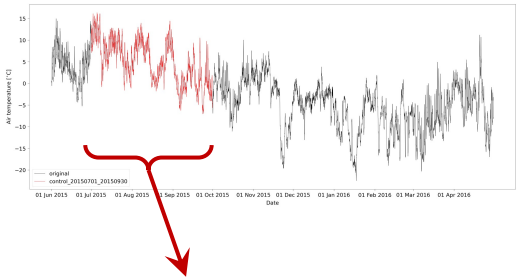

“Snow-free period”:
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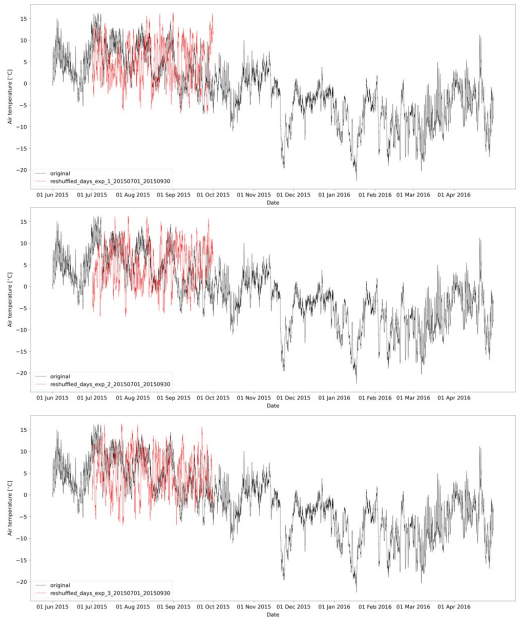
Role of daily atmospheric variability (random reshuffling of days)



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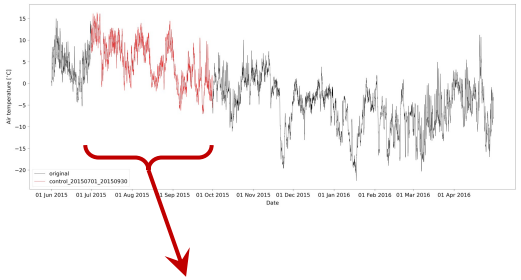

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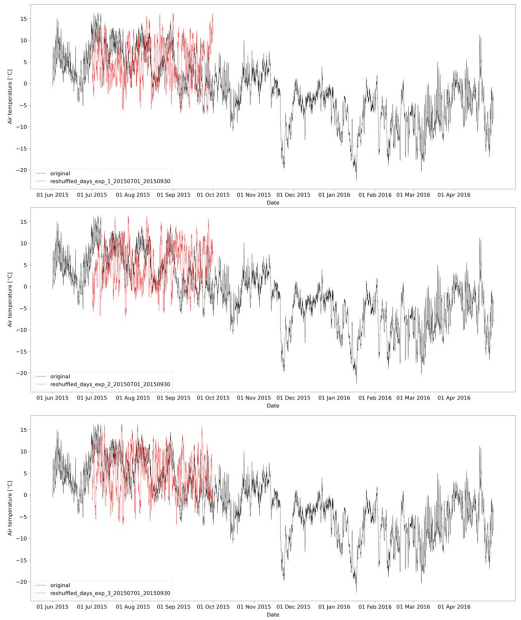

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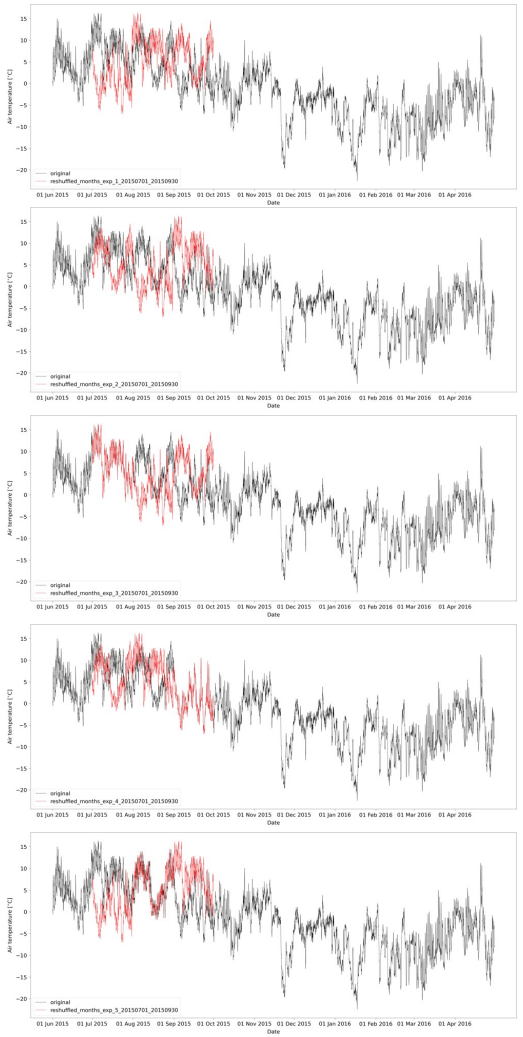

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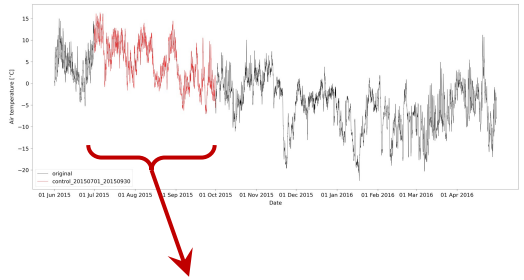

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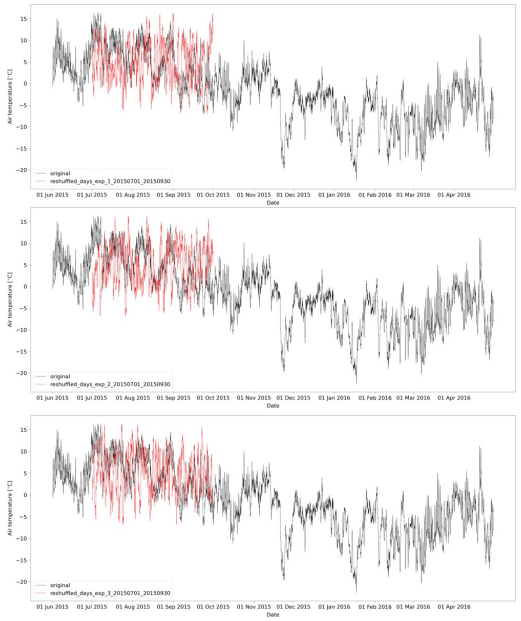

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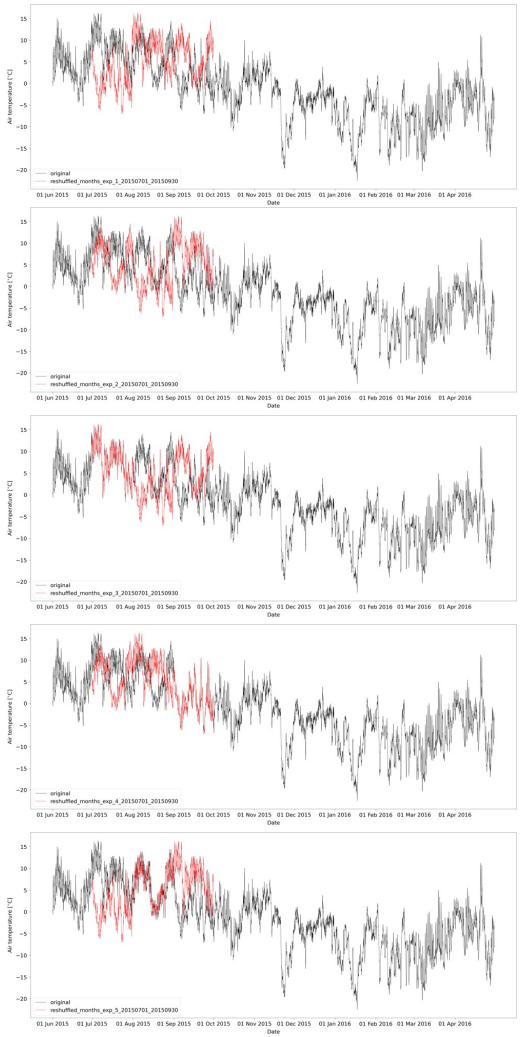
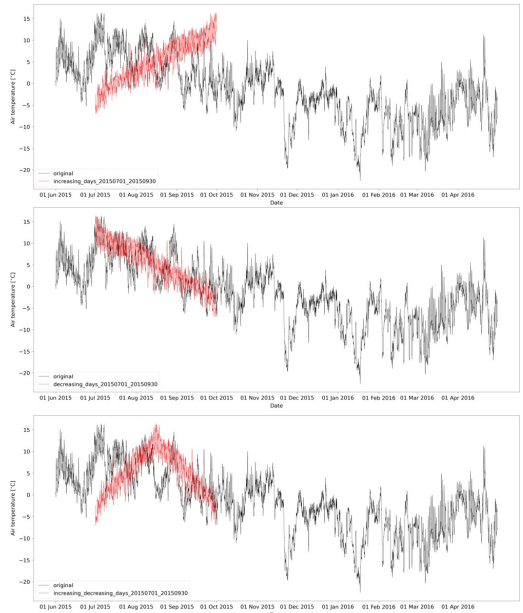


Role of timing of atmospheric heat (sorting of days)



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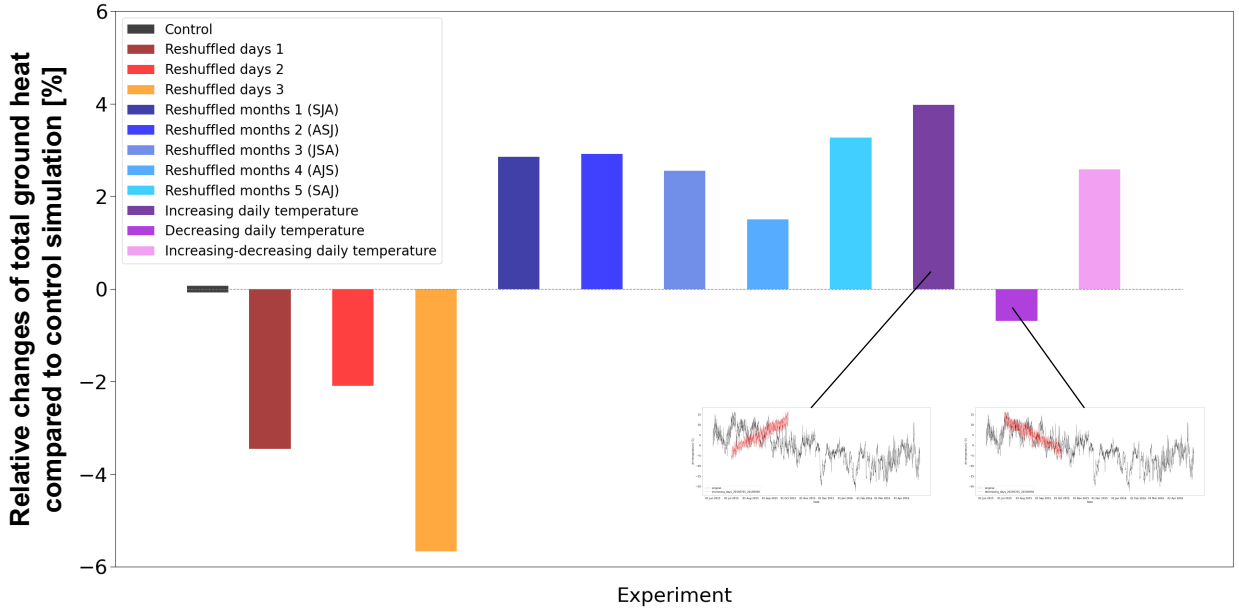
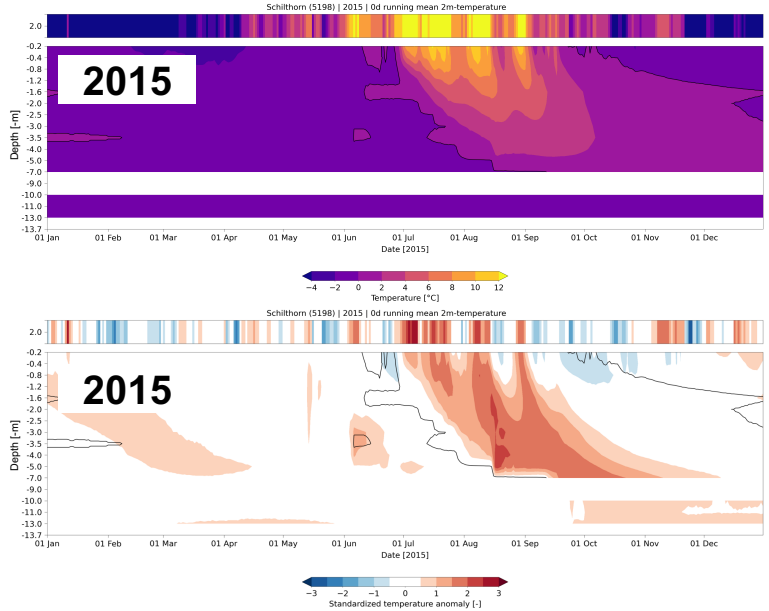
Role of subseasonal atmospheric temperature variability for “total ground heat” at Schilthorn in 2015/2016





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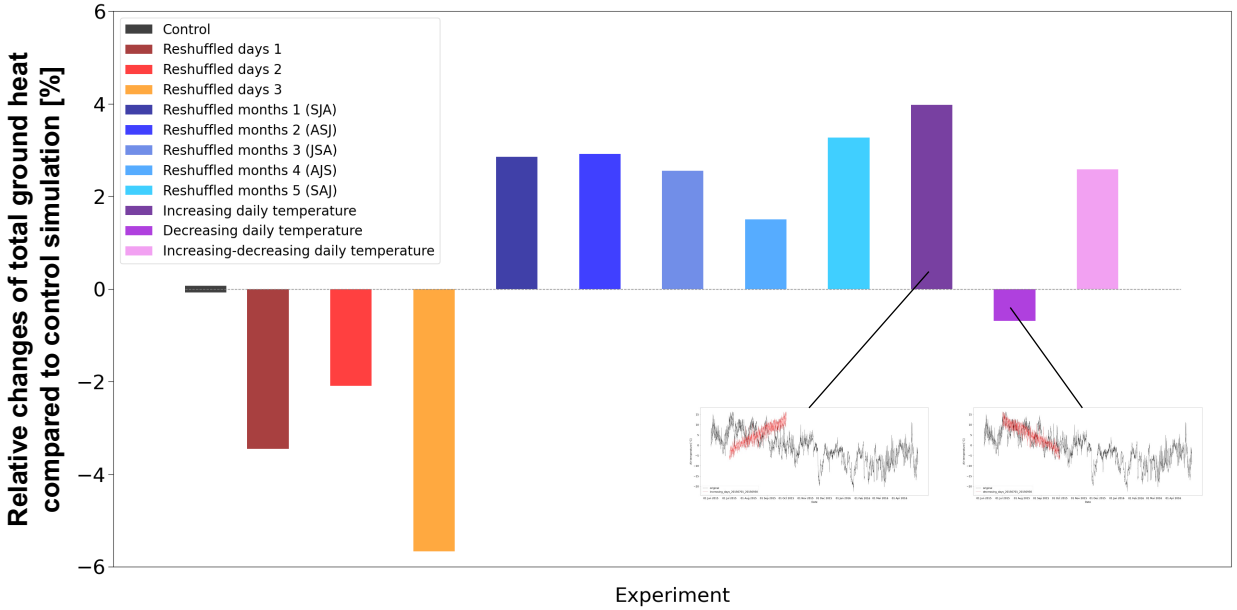

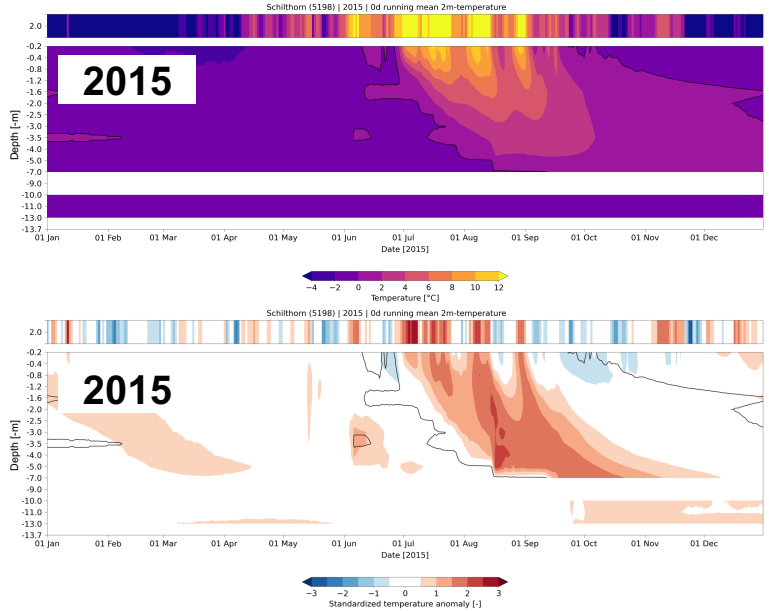

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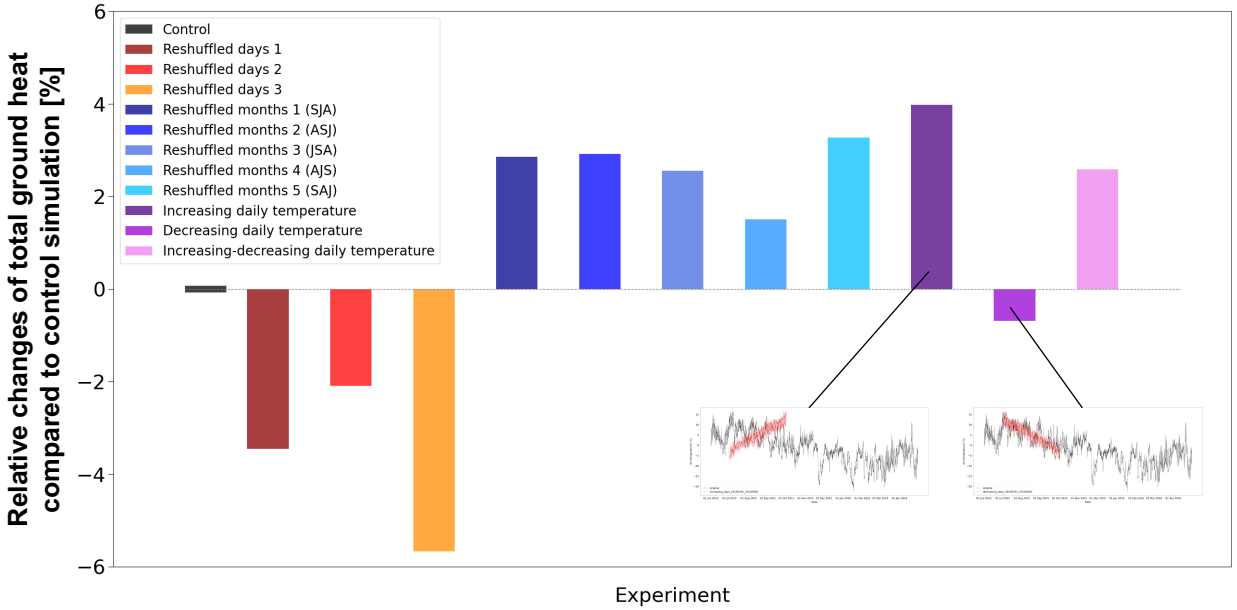

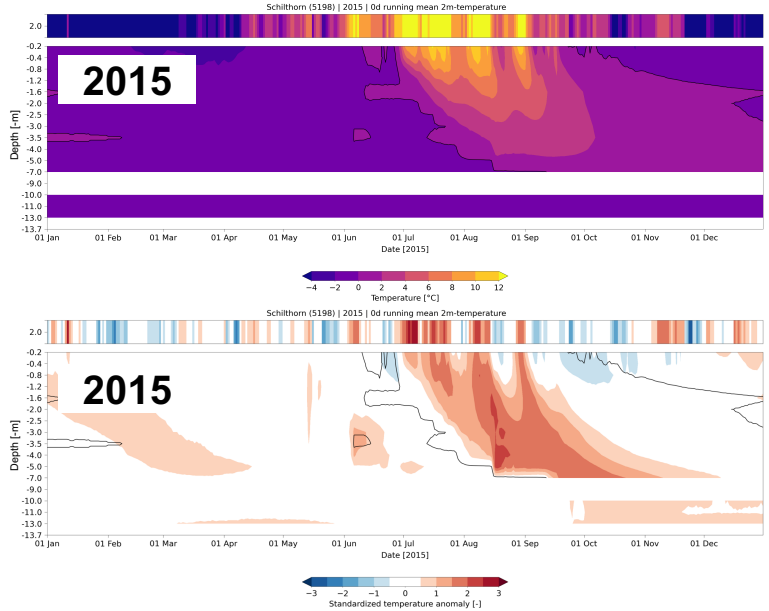

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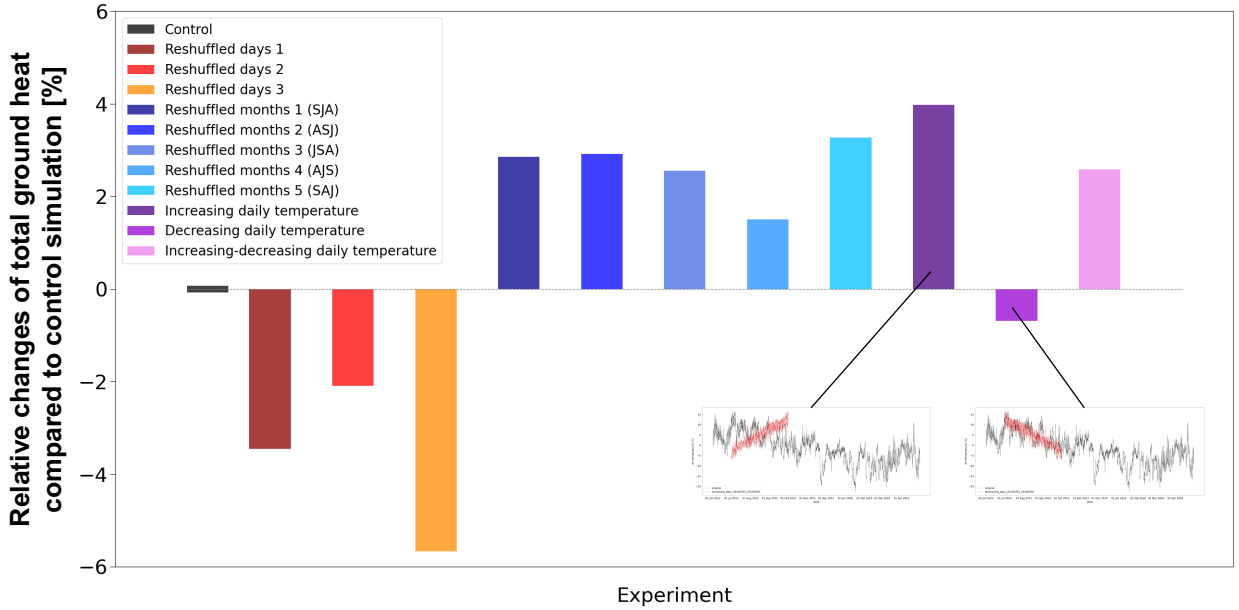

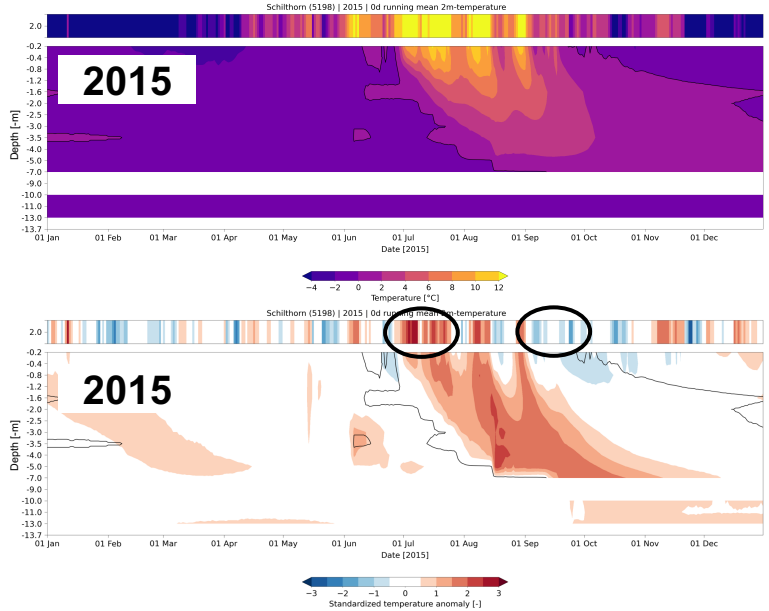

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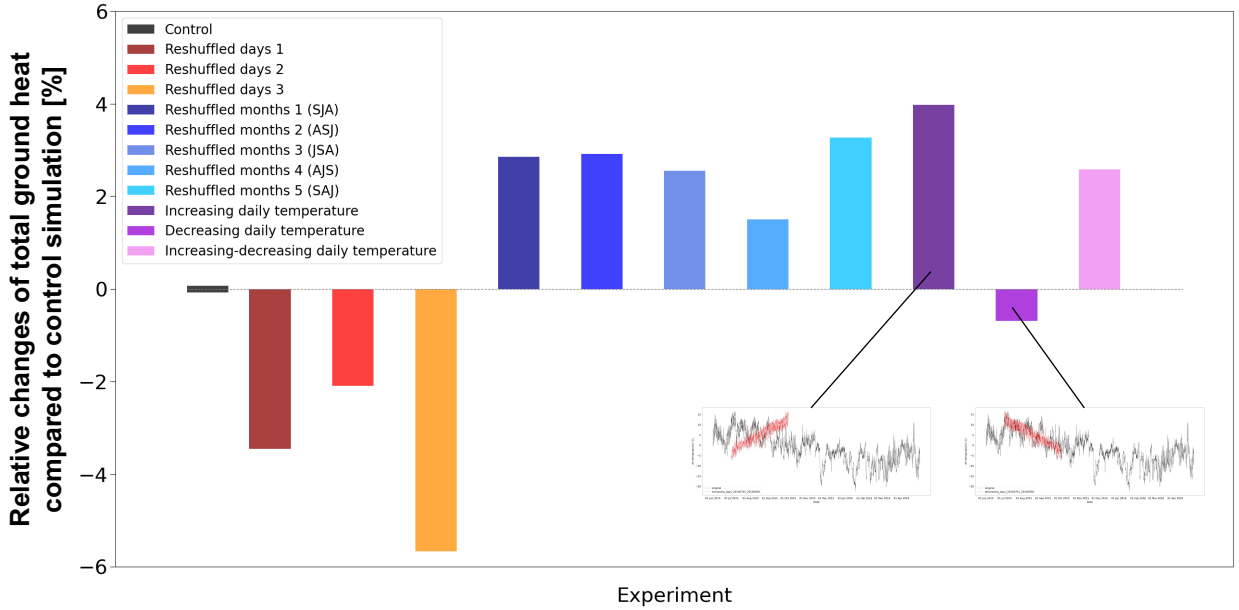

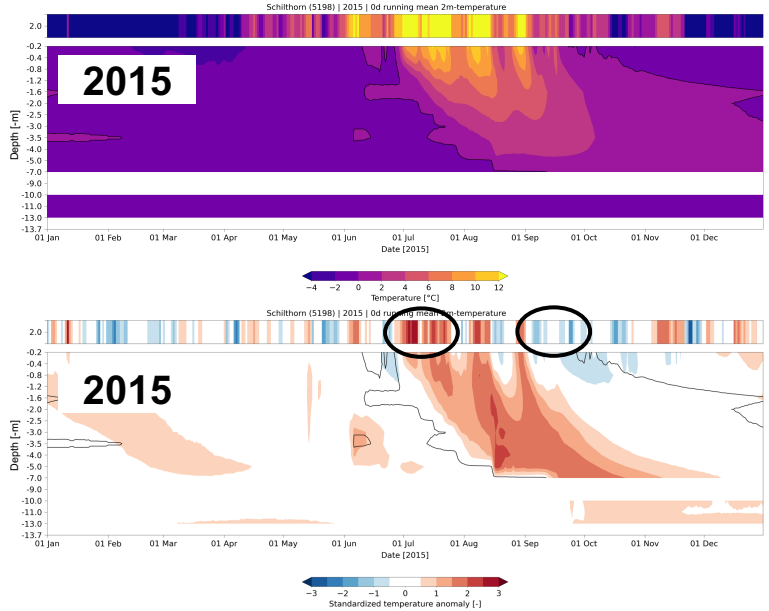

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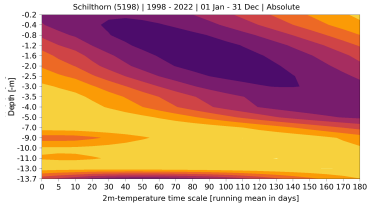
→ **Atmospheric heat is more important** for total ground heat **if it comes in (multi-)weekly waves than in individual days**
→ **Late-summer heatwaves increase total ground heat more**
→ **Early-summer heatwaves are less crucial for total ground heat**, likely because heat is “wasted” to melt ice and heat up melt water first (latent heat of melting, heat capacity of water)

Some first conclusions for Schilthorn



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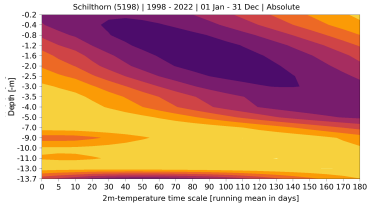

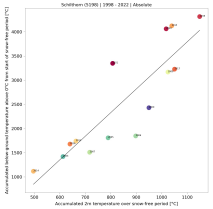

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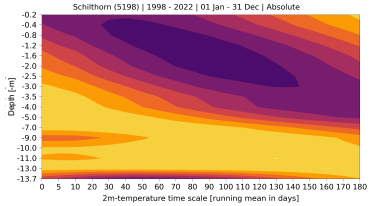

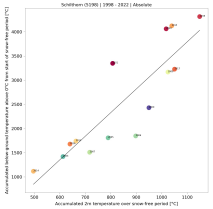

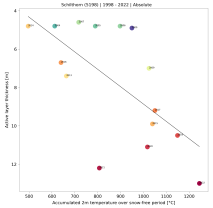

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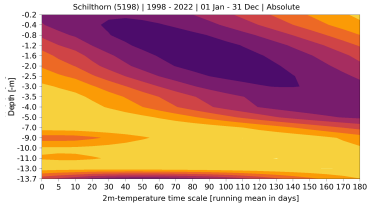

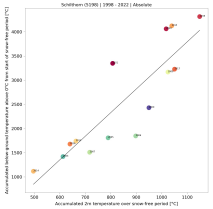

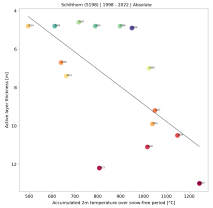

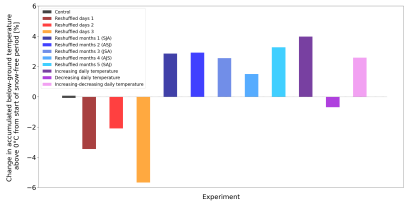

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Open questions for future research

- Role of subseasonal to seasonal atmospheric temperature variability for **other, for instance more ice-rich or rock glacier PERMOS sites**?

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- Can we **couple the SNOWPACK model to operational subseasonal numerical weather prediction models** (which are able to predict probability for heatwaves up to 3 weeks ahead; e.g., Pyrina & Domeisen 2023) to **operationally predict ground temperature**? Could such predictions **support early warning systems** for permafrost-related alpine hazards in some way?

Contact

Contact information

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References and data sources

References

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