Post-glacial dynamics of alpine Little Ice Age glacitectonized frozen landforms (Swiss Alps)

A glacial-to-periglacial or a glacial-to-post-periglacial transition?

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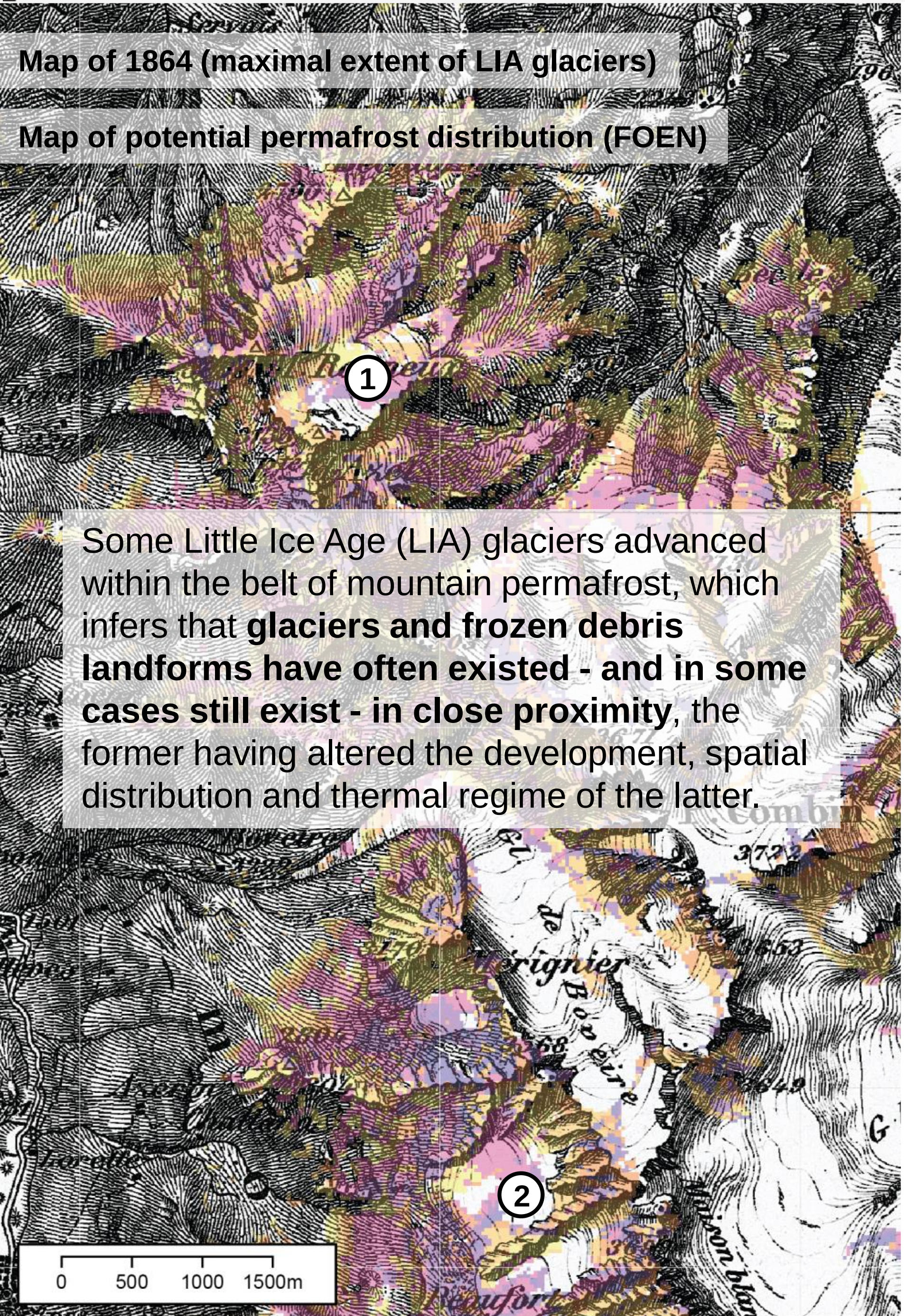
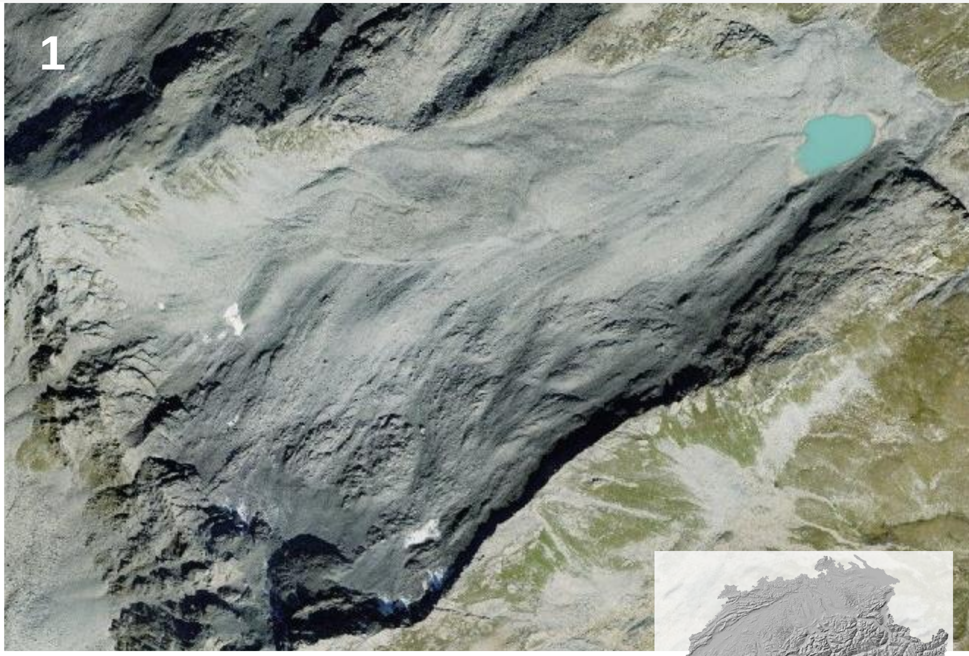
Back-creeping LIA glacitectonized frozen landform (push-moraine) © PERMOS

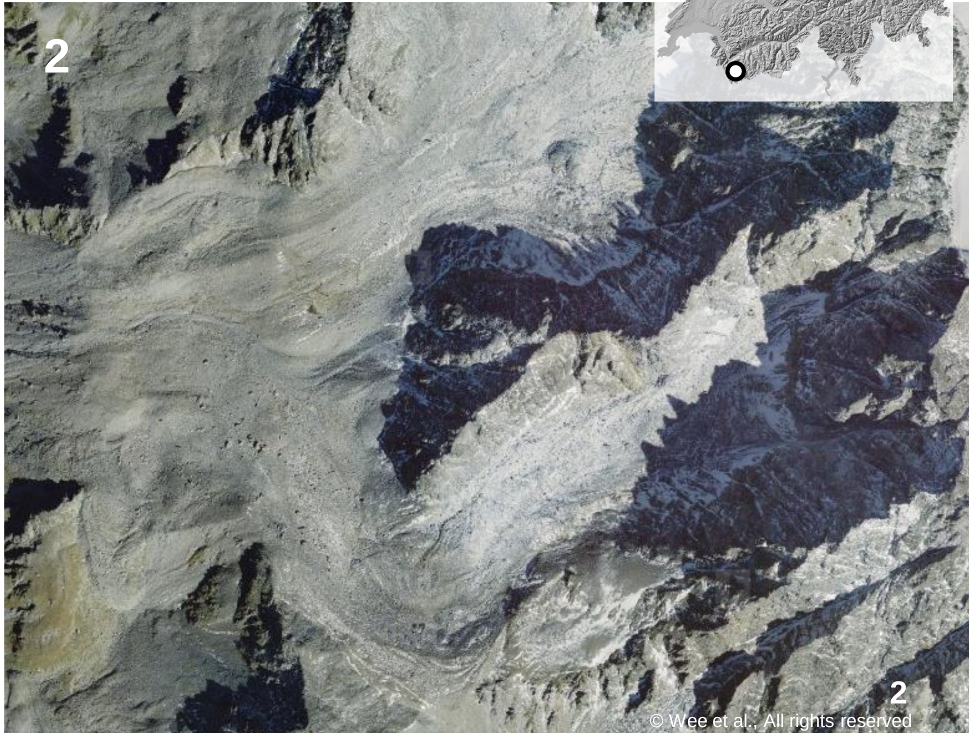
Map of 1864 (maximal extent of LIA glaciers)

Map of potential permafrost distribution (FOEN)



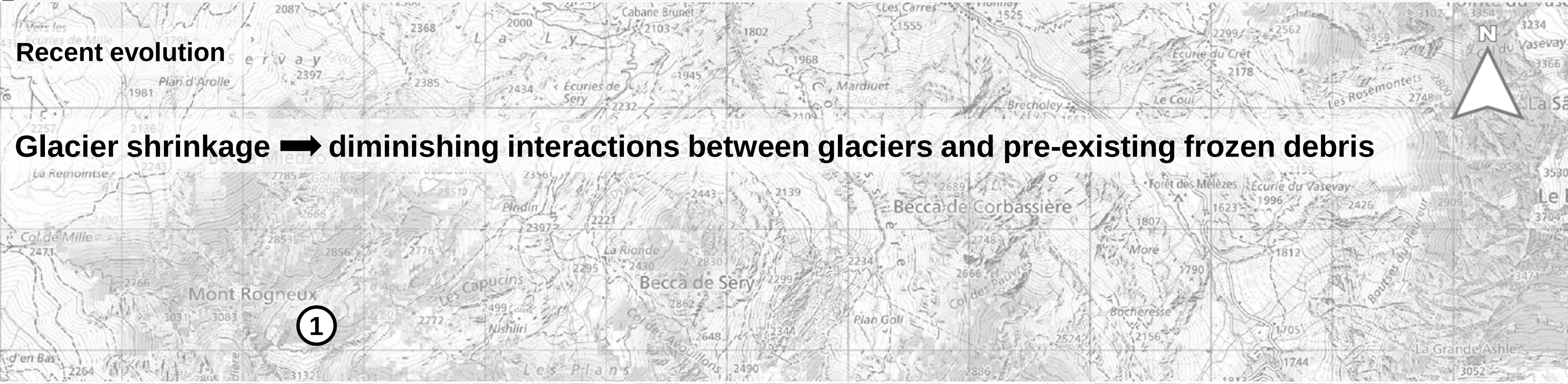
Some Little Ice Age (LIA) glaciers advanced within the belt of mountain permafrost, which infers that **glaciers and frozen debris landforms have often existed - and in some cases still exist - in close proximity**, the former having altered the development, spatial distribution and thermal regime of the latter.

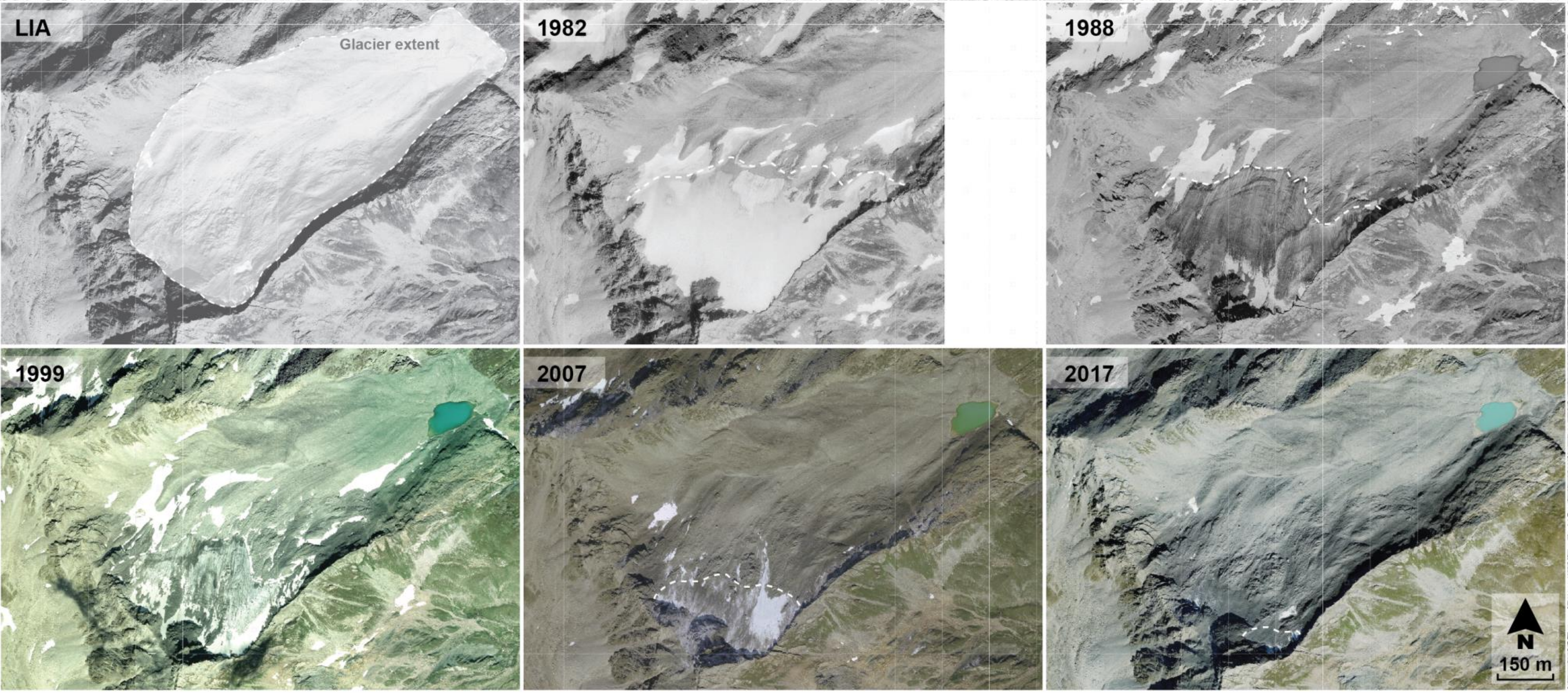




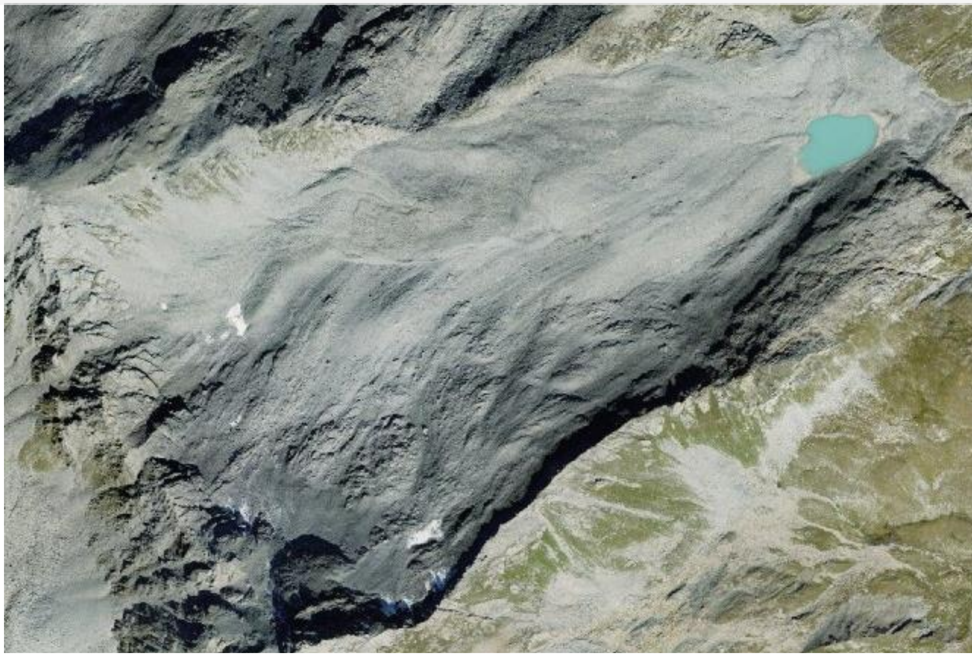
Recent evolution

Glacier shrinkage ➡ diminishing interactions between glaciers and pre-existing frozen debris



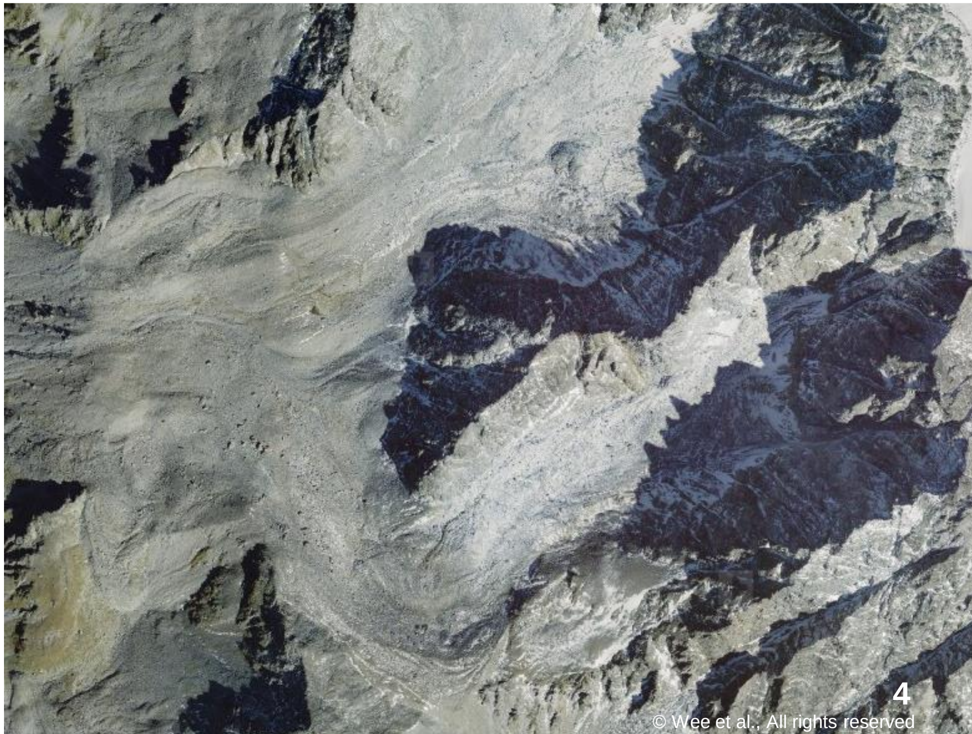


Post-LIA glacier forefields in permafrost environments
&
Associated glacitectonized frozen landforms (GFL)



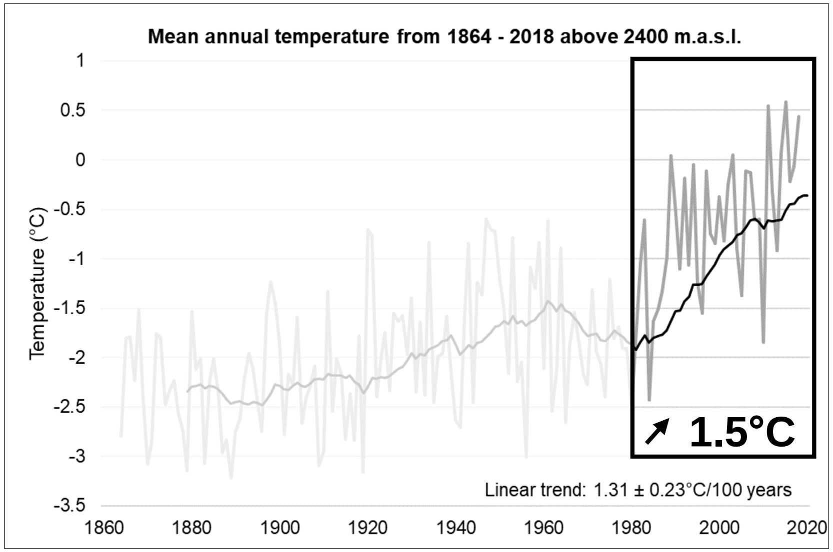
Glacier dominant regime

Periglacial (under permafrost conditions) **or even post-periglacial** (permafrost-deprived) **regime**



Long-term glacier recession

&

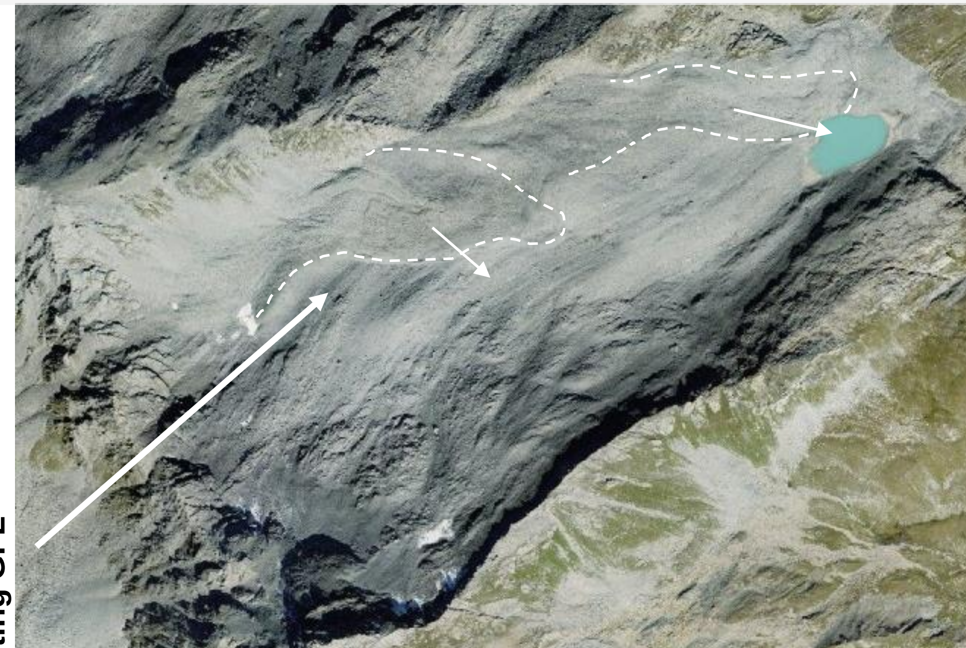


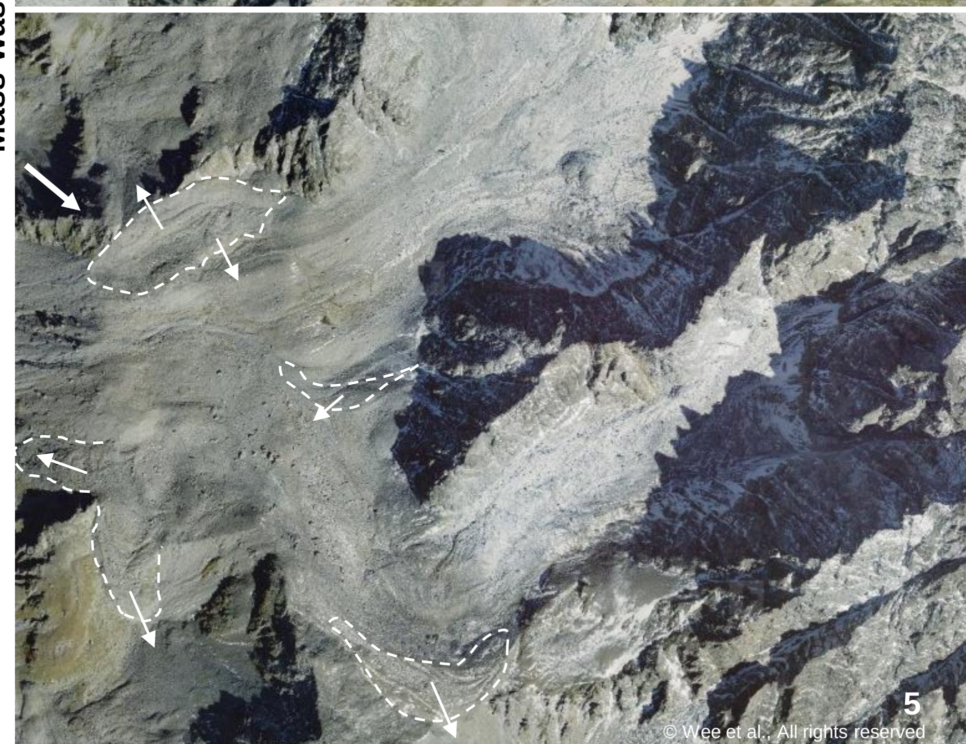
Adapted from Begert and Frei (2018) and MeteoSwiss (2019)

Thermal and mechanical readjustments

Expressed by a combination of **mass-wasting processes** and **ice melt or thaw-induced subsidence**

Mass-wasting GFL

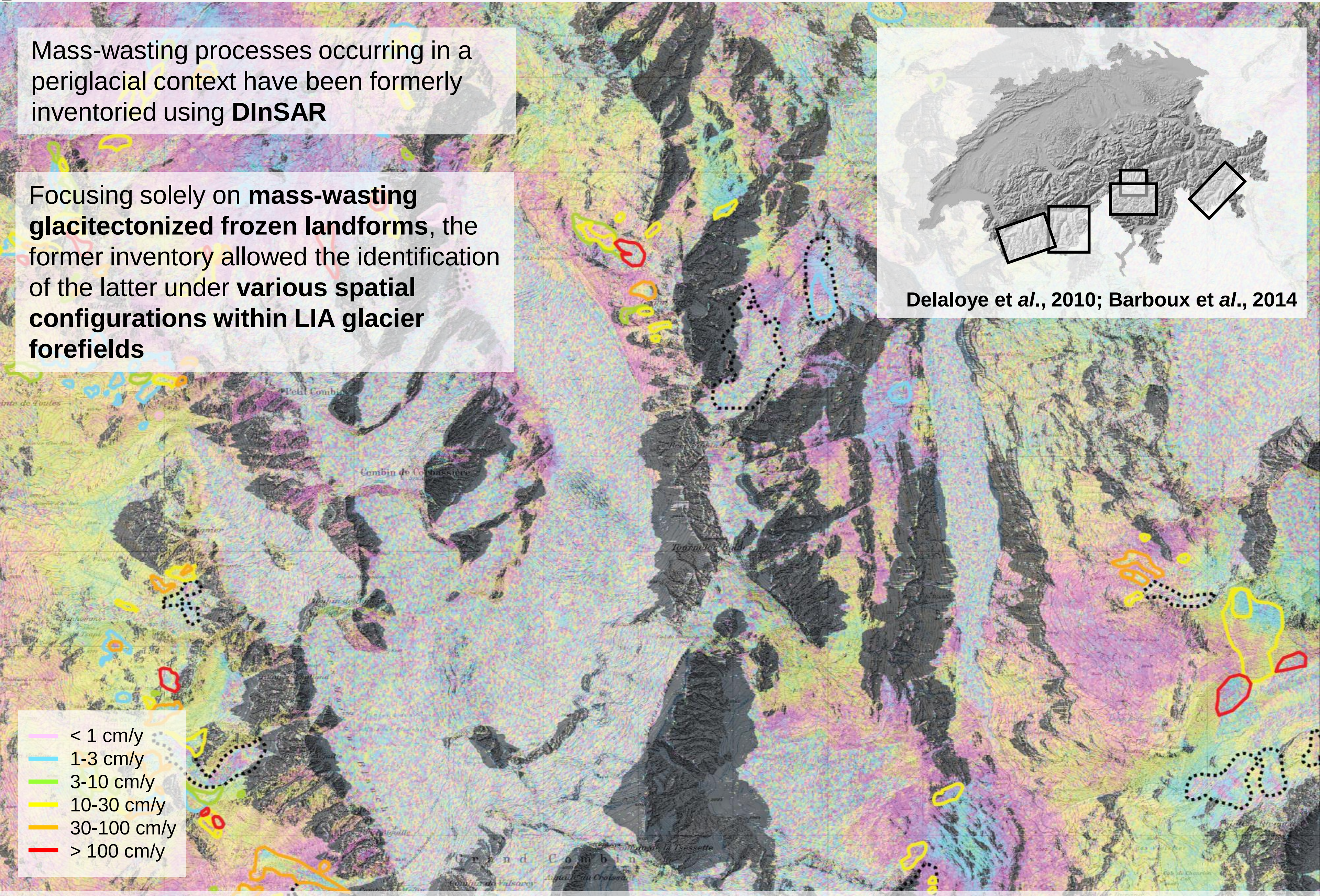




Mass-wasting processes occurring in a periglacial context have been formerly inventoried using **DInSAR**

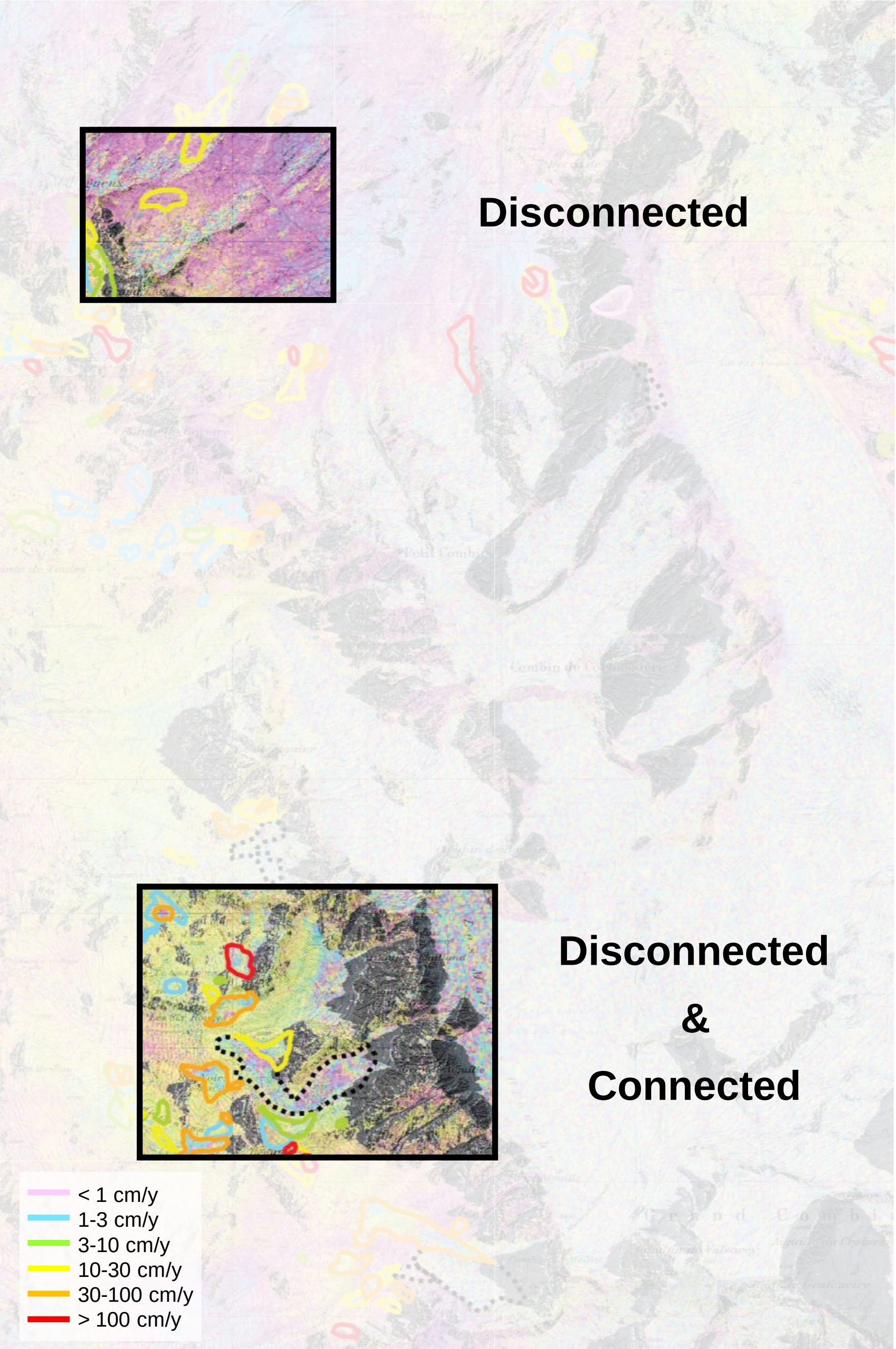
Focusing solely on **mass-wasting glacitectonized frozen landforms**, the former inventory allowed the identification of the latter under **various spatial configurations within LIA glacier forefields**

Delaloye et *al*., 2010; Barboux et *al*., 2014



InSAR image: 24.09.2017-06.10.2017 (12 days)

Sentinel-1 descending mode



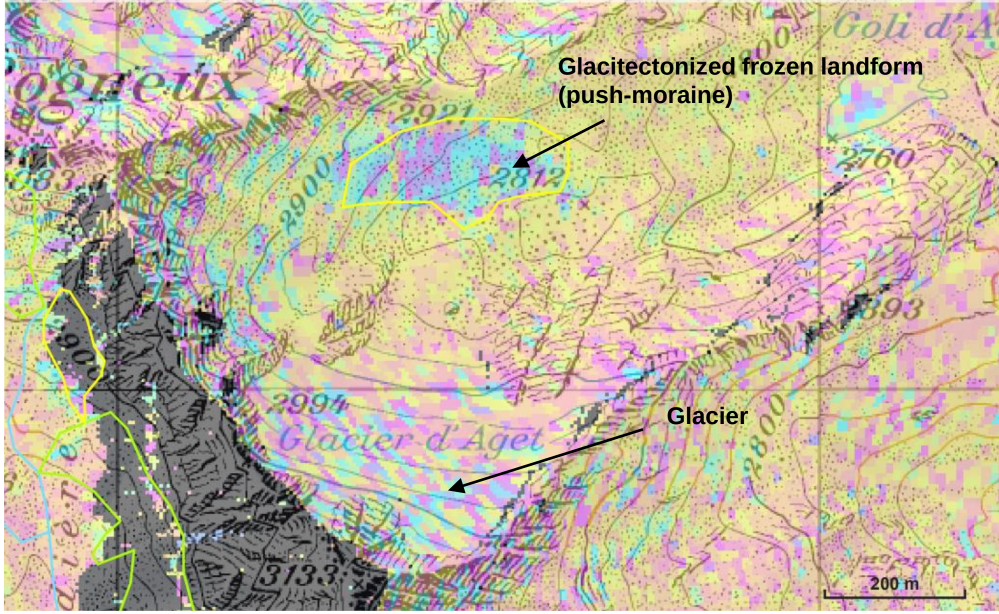
Disconnected

Disconnected

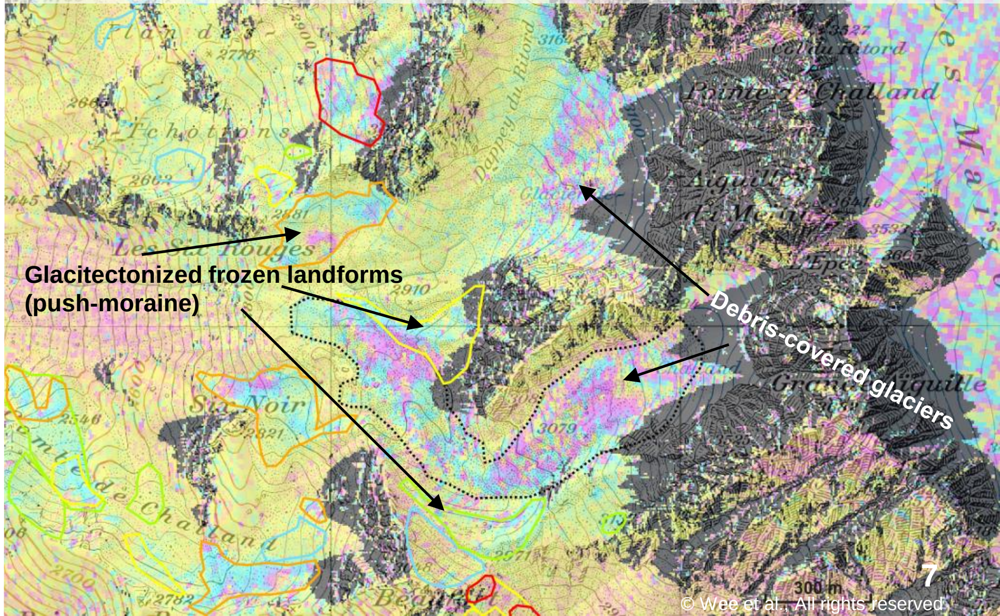
&

Connected

InSAR image: 07.09.2017-01.10.2017 (24 days)
Sentinel-1 ascending mode



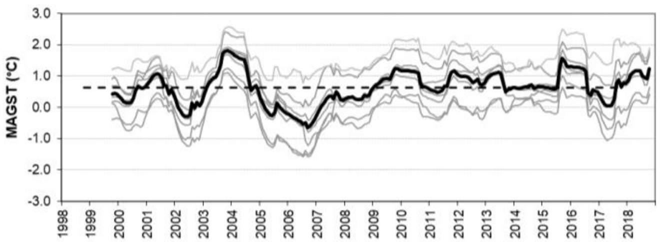
InSAR image: 24.09.2017-06.10.2017 (12 days)
Sentinel-1 descending mode

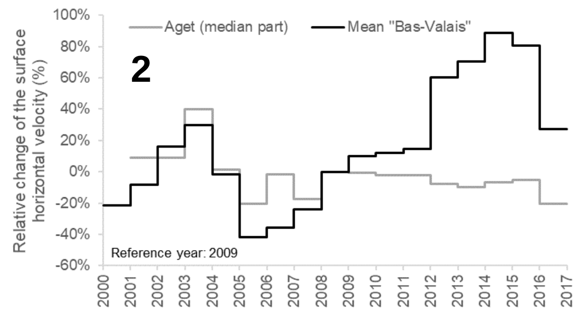


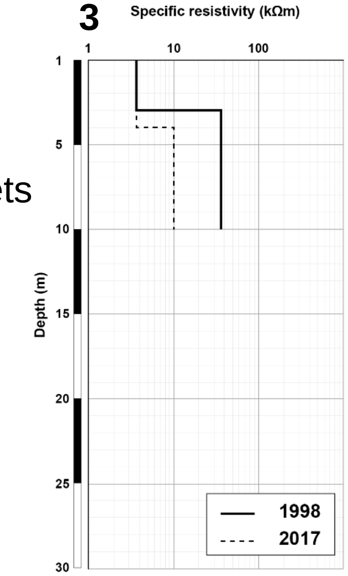
Compilation and analysis of existing datasets

Over 20-year of permafrost monitoring in glacier forefields

1) ground surface temperature (GST), 2) kinematical and 3) electrical resistivity datasets

1


2


3


Analysis of high-resolution and historical aerial images

- Generation of multi-temporal Digital Elevation Models (DEMs)

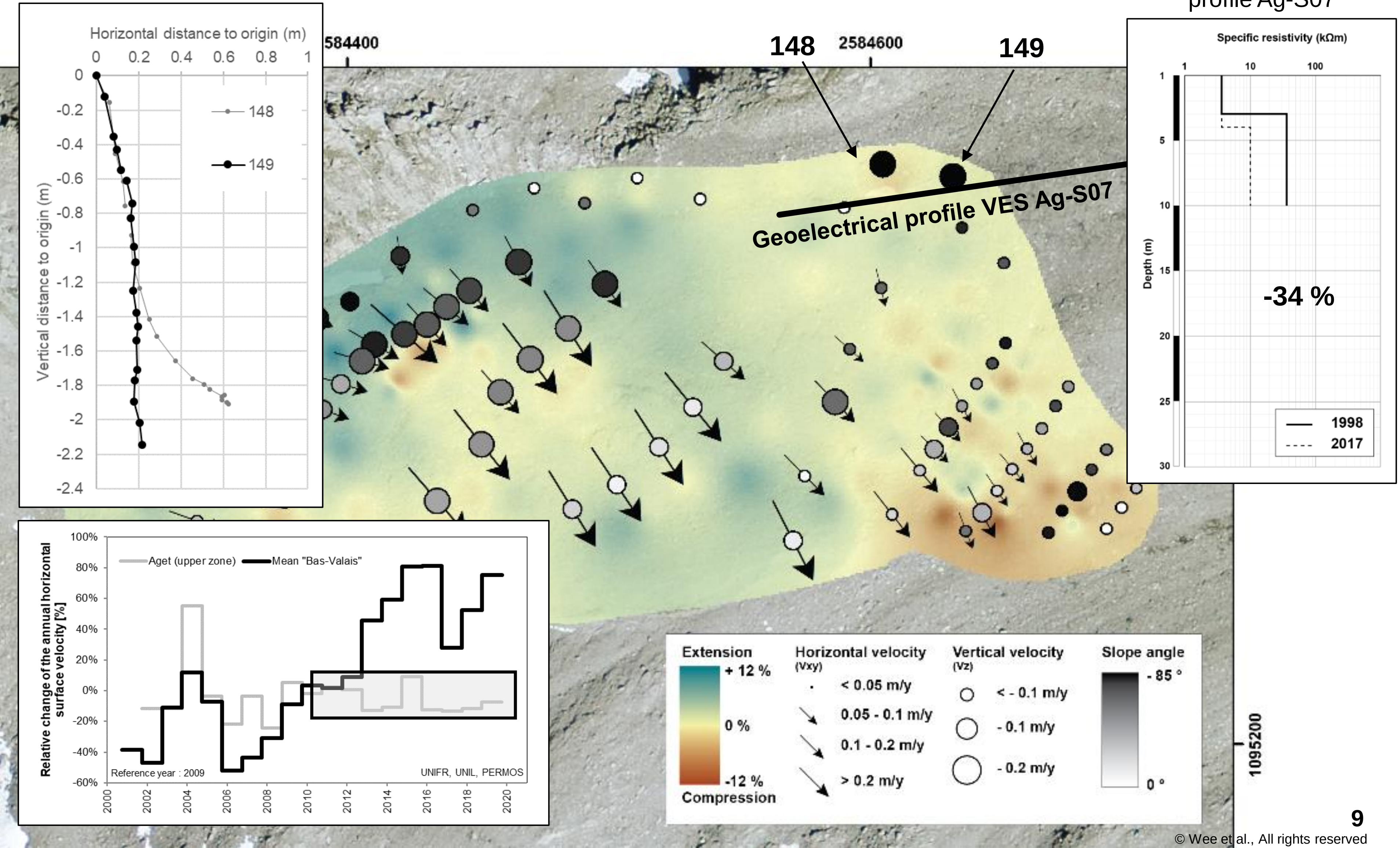
- Assess spatio-temporal geomorphological changes

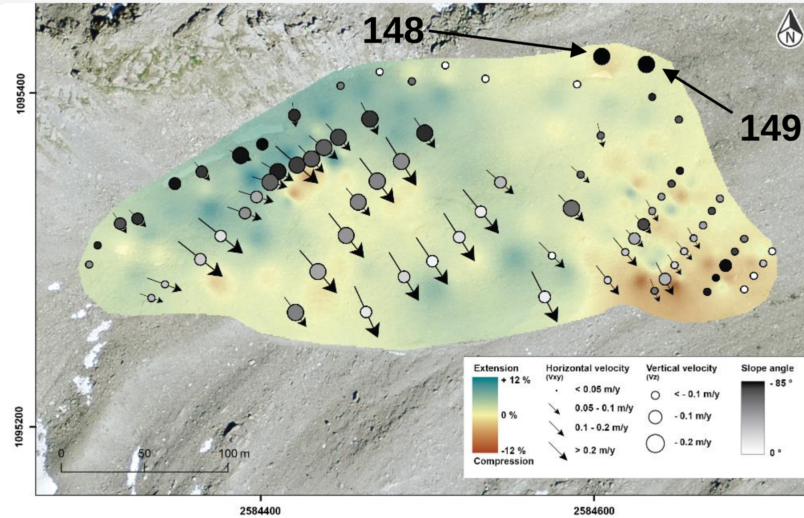
  Processing and analysis of UAV-derived images and LiDAR-derived DEMs

Aget Deceleration and ice melt-driven subsidence

Displacement profiles
(annual position 2002-2019)

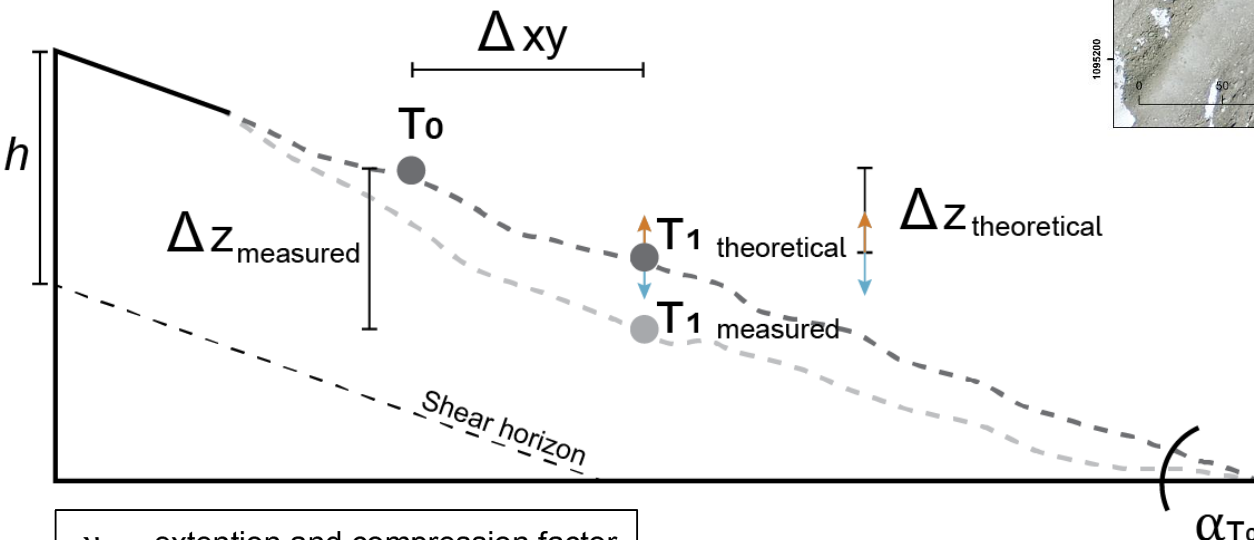
Change in resistivity
profile Ag-S07





Processes influencing change in surface elevation:

1. Loss in elevation due to downslope movement
2. Decrease or increase in elevation due to extending or compressing flow
3. Change in elevation in response to melting of ground ice



ν	extention and compression factor
α_{T_0}	shear horizon slope angle proxy

$$\Delta z_{theoretical} = \Delta xy \times \tan(\alpha_{T_0}) \pm \nu_{extension/compression} \times h$$

Contribution of ice melt-induced subsidence to vertical component of surface displacement [m] $= \Delta z_{measured} - \Delta z_{theoretical}$

Contribution of ice melt-induced subsidence to vertical component of surface displacement [%] $= \dfrac{\Delta z_{measured} - \Delta z_{theoretical}}{\Delta z_{measured}} \times 100$

Contribution of ice melt-induced subsidence to vertical component of surface displacement:

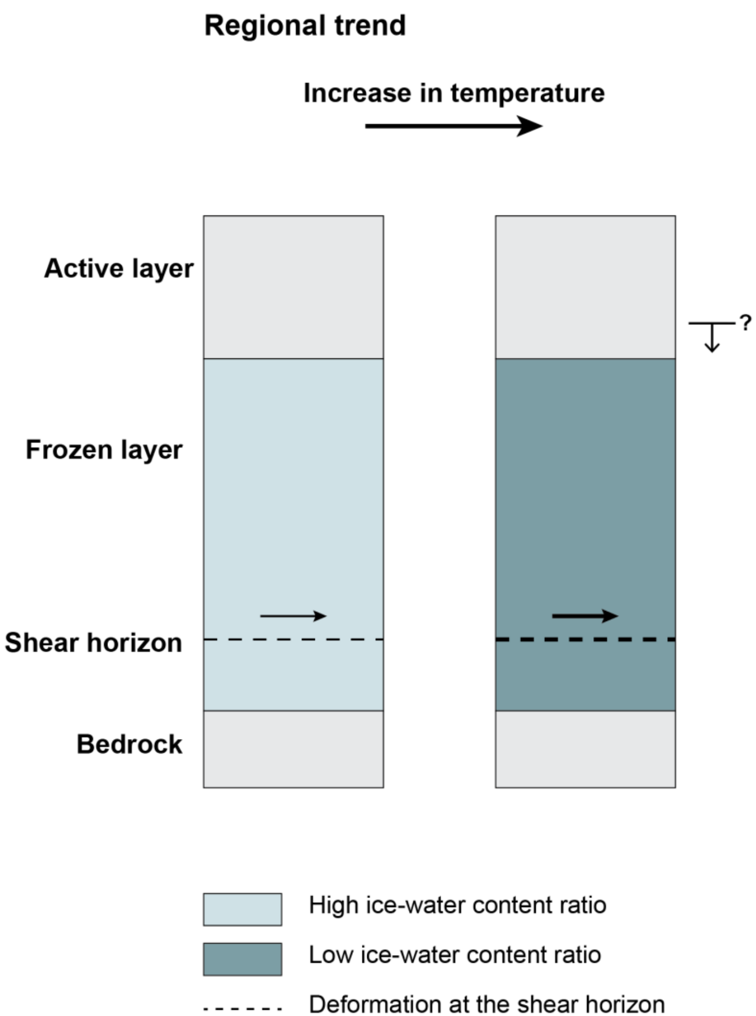
- **Point Ag-148 = 100 %**
- **Point Ag-149 = 92.7 %**

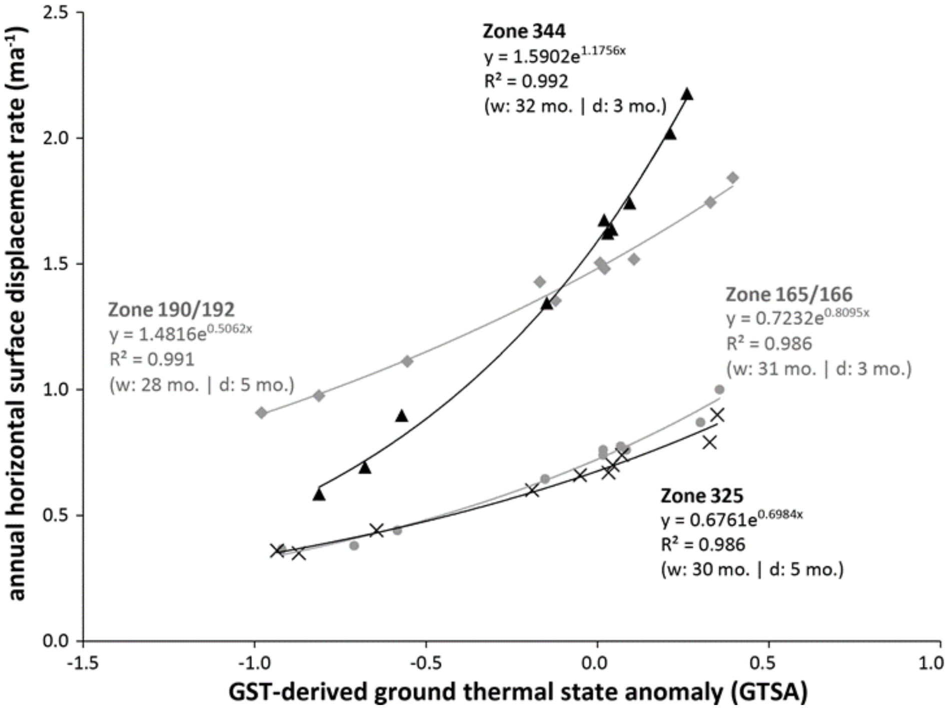
Decrease of resistivity values

Subsidence due to **ice melt**

Overall permafrost **degradation**

Accelerating creep velocities





Staub et *al*., 2016

The observed ground warming is in line with an increasing fraction of water relative to the ground ice content as well as an acceleration of rock glacier creep (Staub, 2015)

Decrease of resistivity values

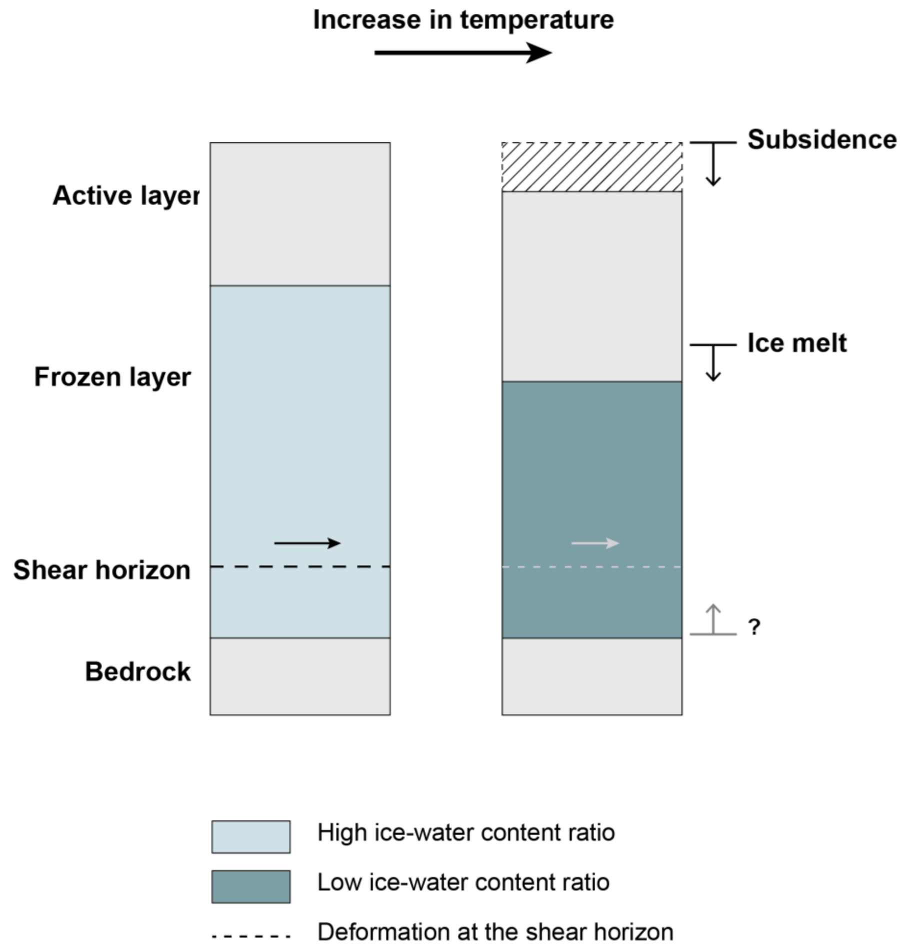
Subsidence due to **ice melt**

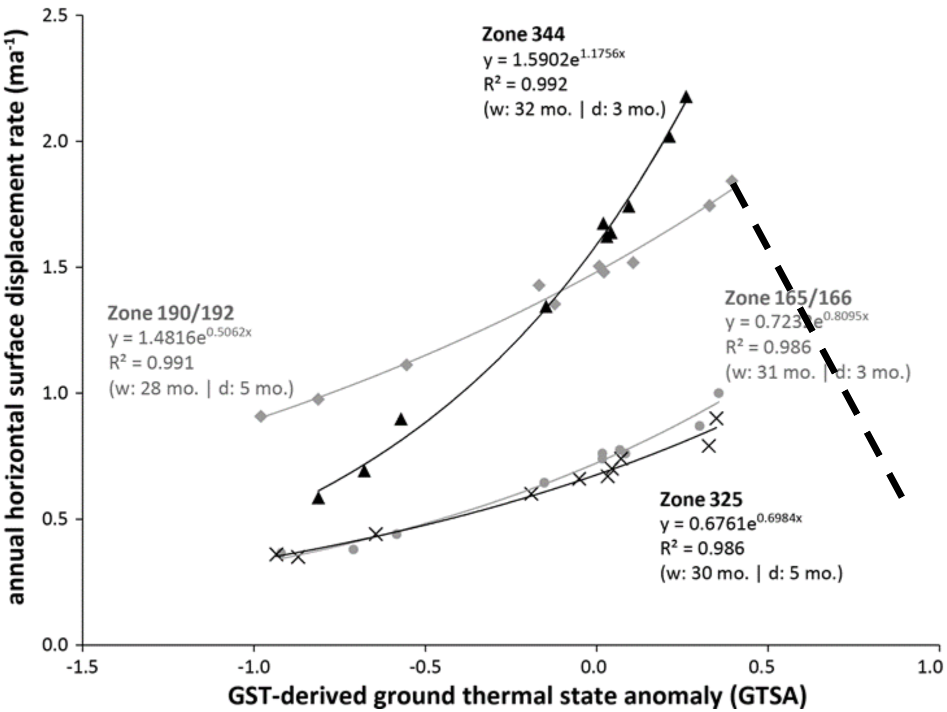
Advanced permafrost **degradation**

Decelerating creep velocities

… beyond the peak ?

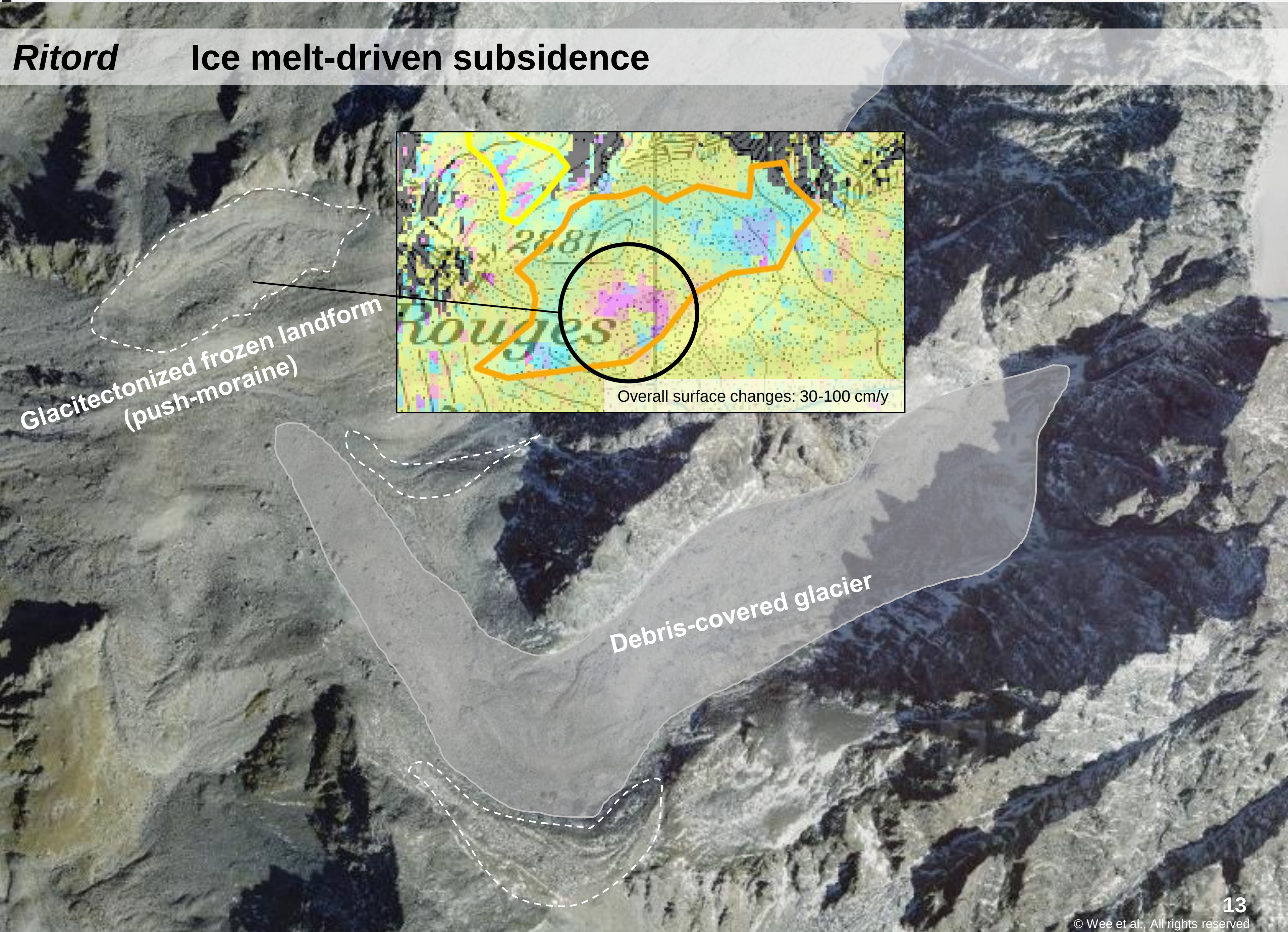
Aget

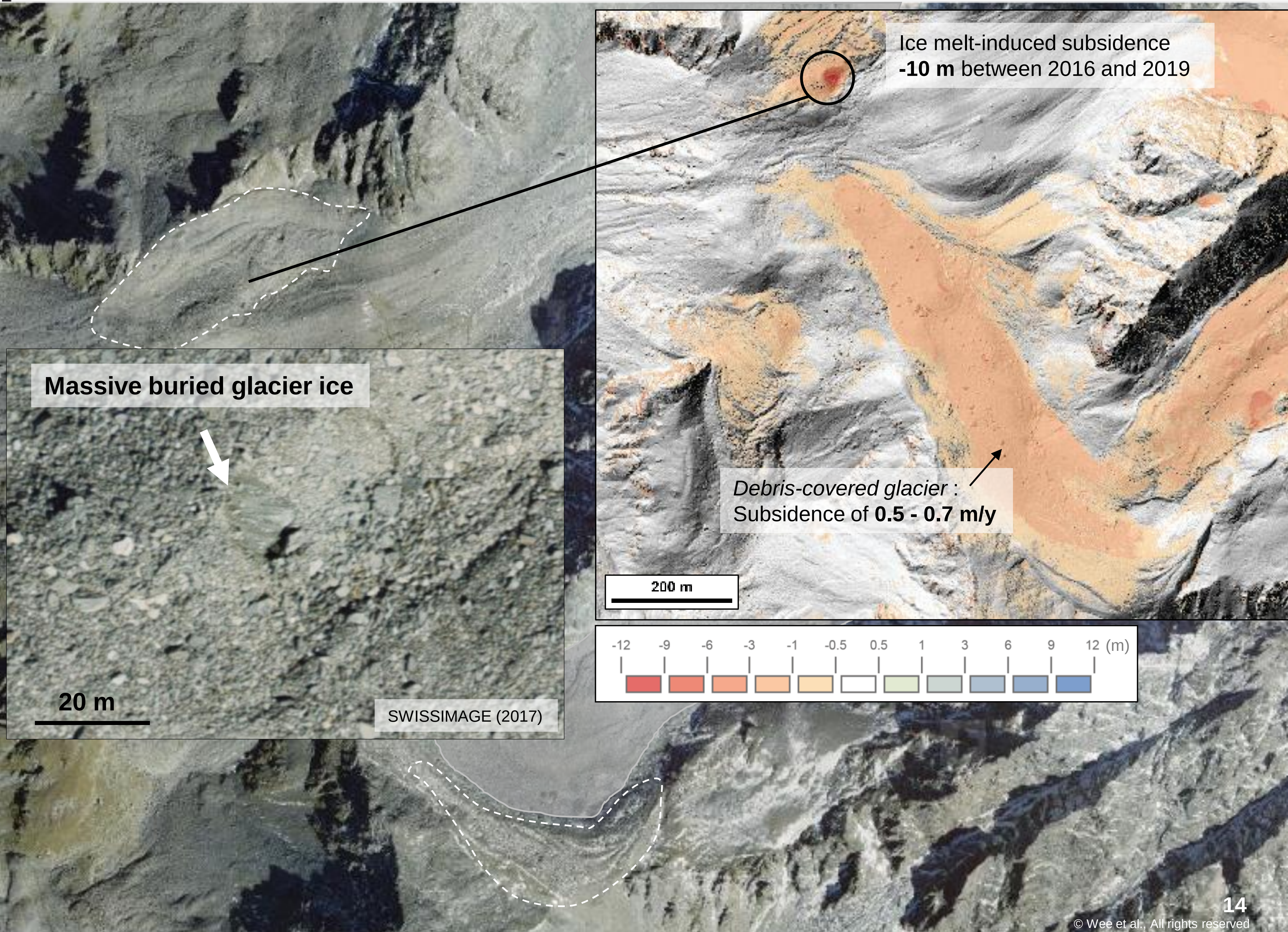




Staub et *al*., 2016

Ritord Ice melt-driven subsidence




Ice melt-induced subsidence
-10 m between 2016 and 2019
Massive buried glacier ice
Debris-covered glacier :
Subsidence of **0.5 - 0.7 m/y**
200 m
-12 -9 -6 -3 -1 -0.5 0.5 1 3 6 9 12 (m)
20 m
SWISSIMAGE (2017)

Aget

- Go further in the past by analysing historical aerial images (Swisstopo)
- Gather high-resolution aerial images (UAV-flights) – *1st flight was in 2019*

Ritord

- Repeat geoelectrical measurements throughout the entire glacier forefield
- Install permanent dGPS to capture in-situ kinematical changes
- Go further in the past by analysing historical aerial images (Swisstopo)
- Gather high-resolution aerial images (UAV-flights)

Extend similar analyses to ***other sites***