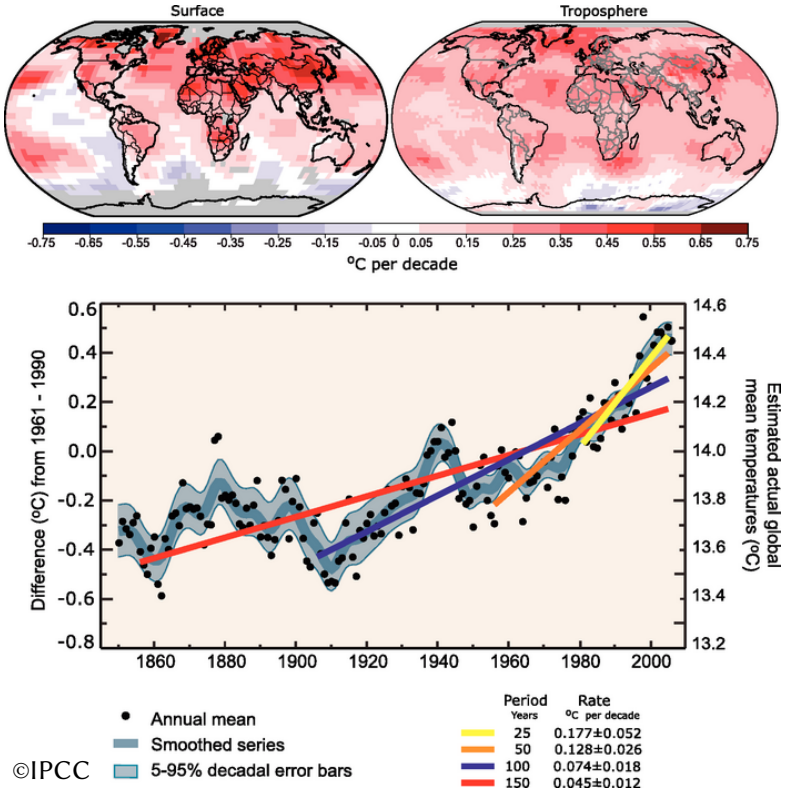
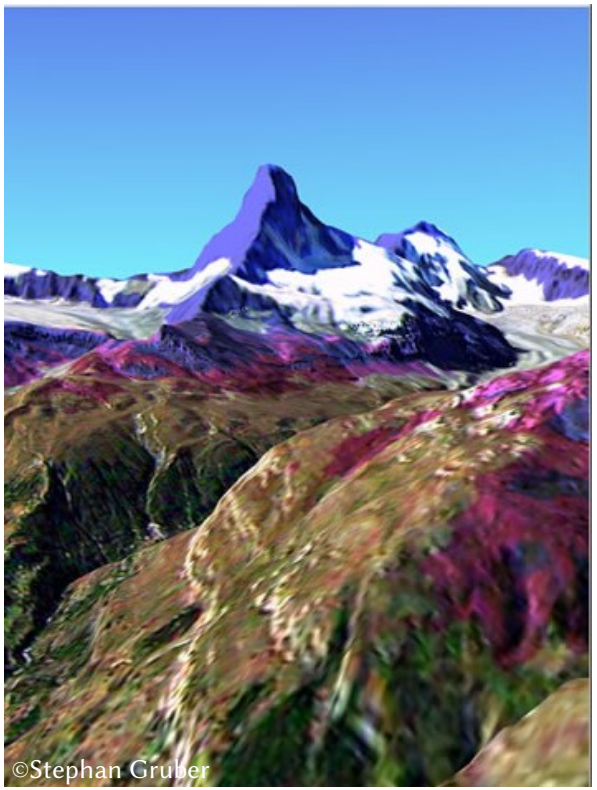
Fracture dynamics in steep bedrock permafrost



©IPCC

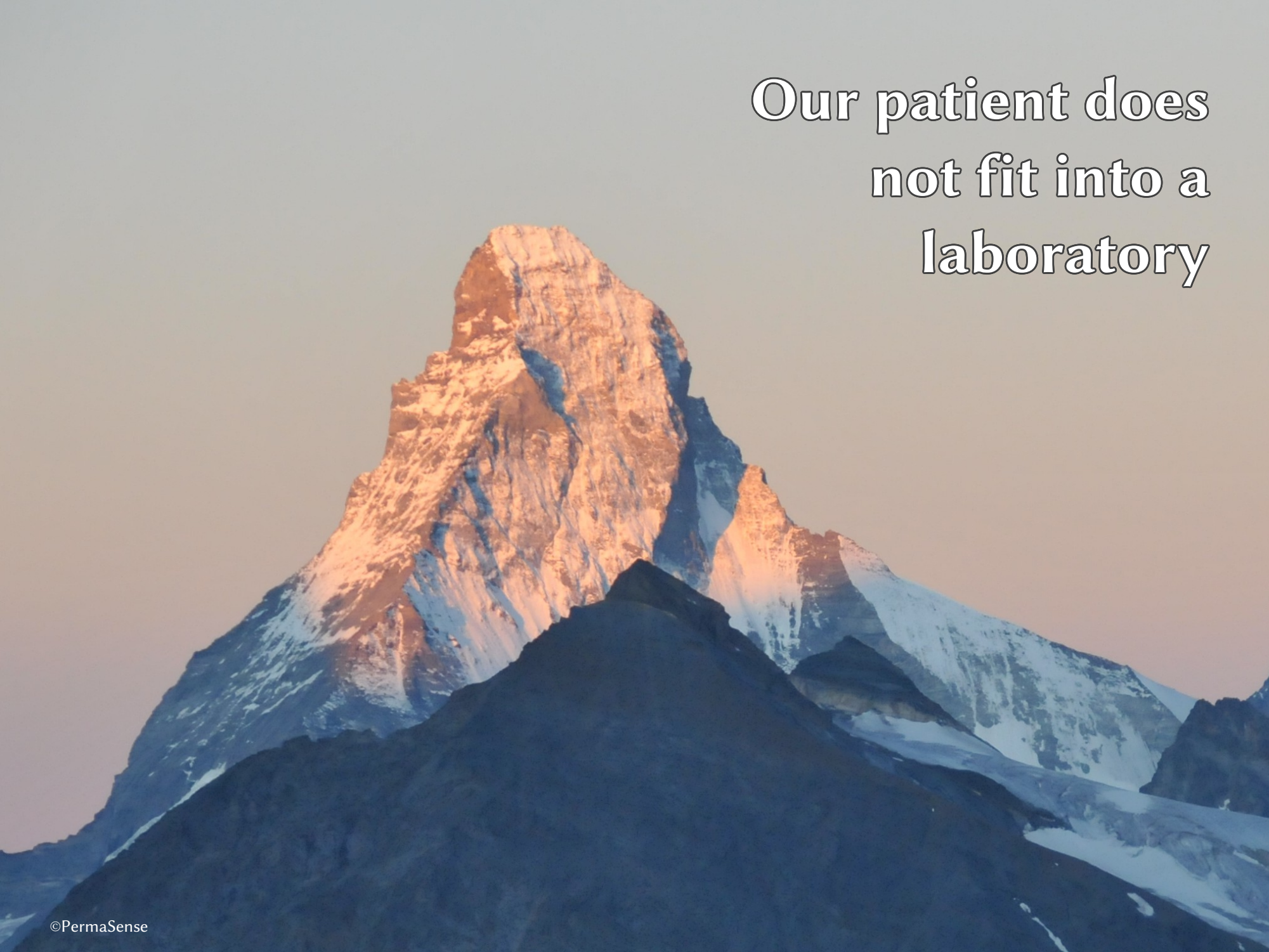


Samuel Weber

Glaciology & Geomorphodynamics Group, University of Zurich

January 23, 2016

Debris fall summer 2003 $1500\,\mathrm{m}^3$, *ice-containing scarp*

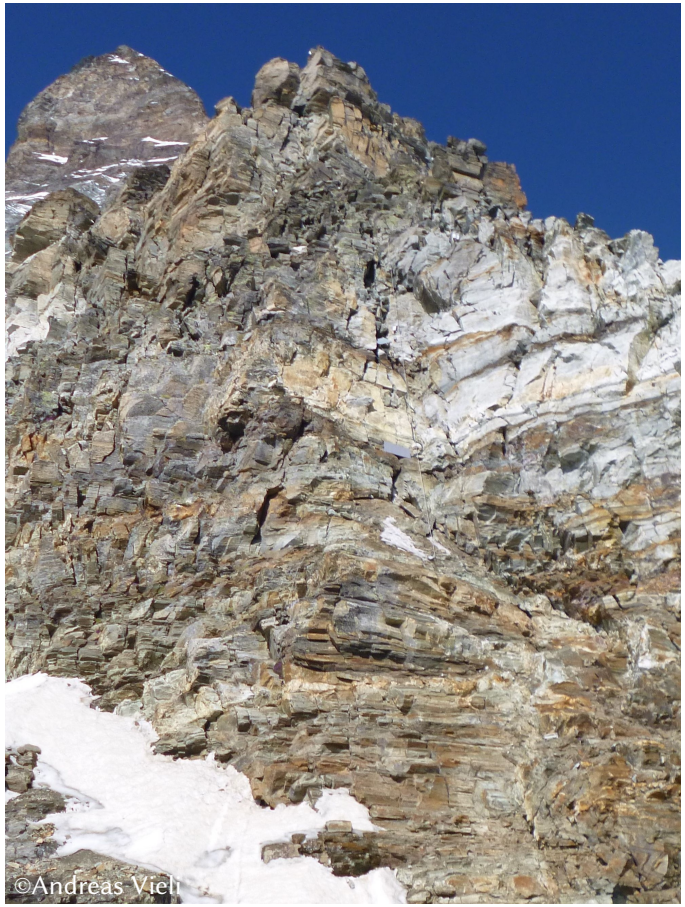

Our patient does
not fit into a
laboratory
©PermaSense


So the laboratory
has to go on the
mountain
©Noe Flum

Rock-slopes in alpine environments *debris, rock-glacier, rock-wall*

steep (structured) rock-wall

debris slope

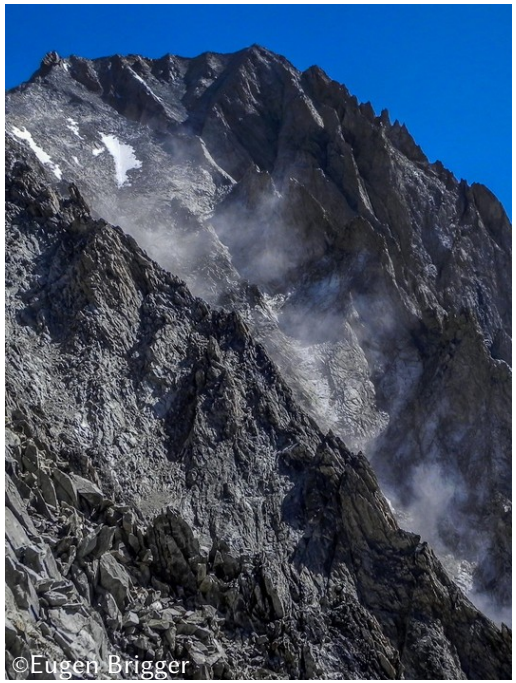


near vertical rock-wall

snow, debris, heterogeneous

Rockfall *rupture/failure → different processes pre-condition and trigger*

*debris/boulder fall**

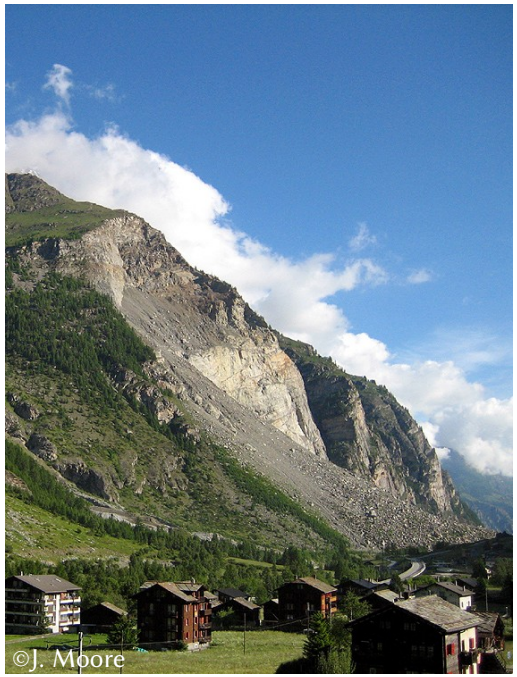


→ thermal forcing?

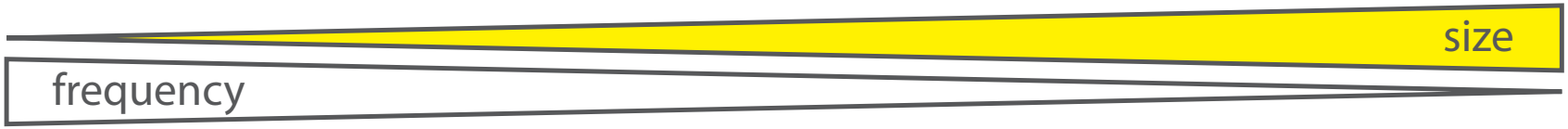
*block fall**

→thawing related failure?

*bergsturz**



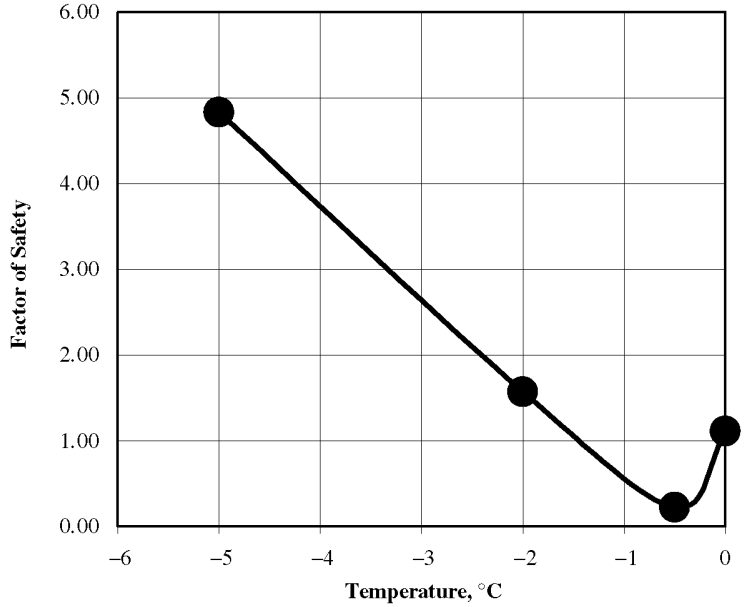
→ debutressing?



* volumetric classification by Whalley (1974, 1984)

Effect of rise in temperature on stability *Strength reduction by*

warming ice-filled fractures

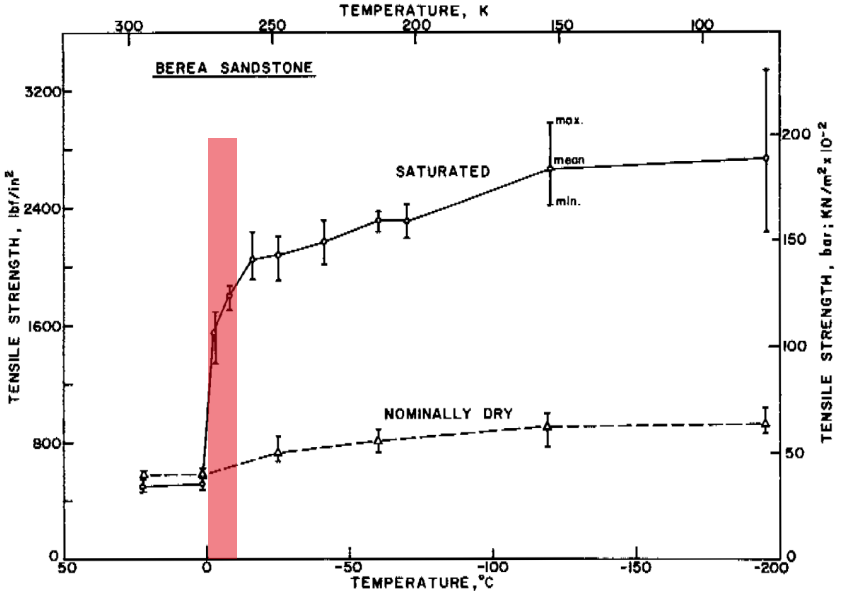


Davies et al. (2001)

At $-0.5^\circ\, C$:

$\tau_{icefilled} < \tau_{icefree}$

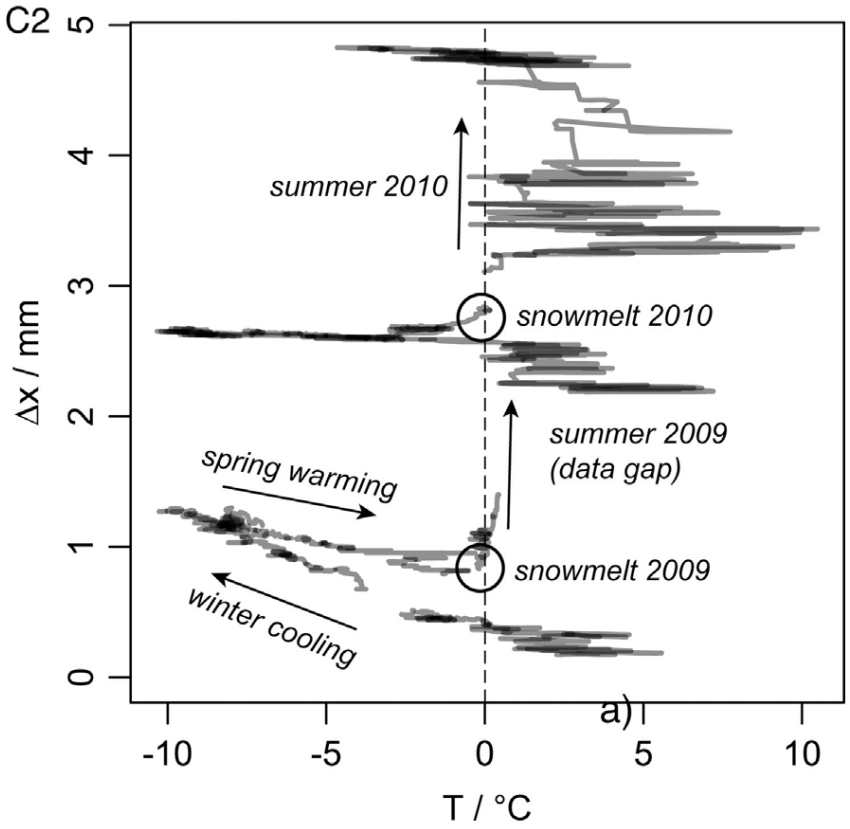
thawing permafrost bedrock



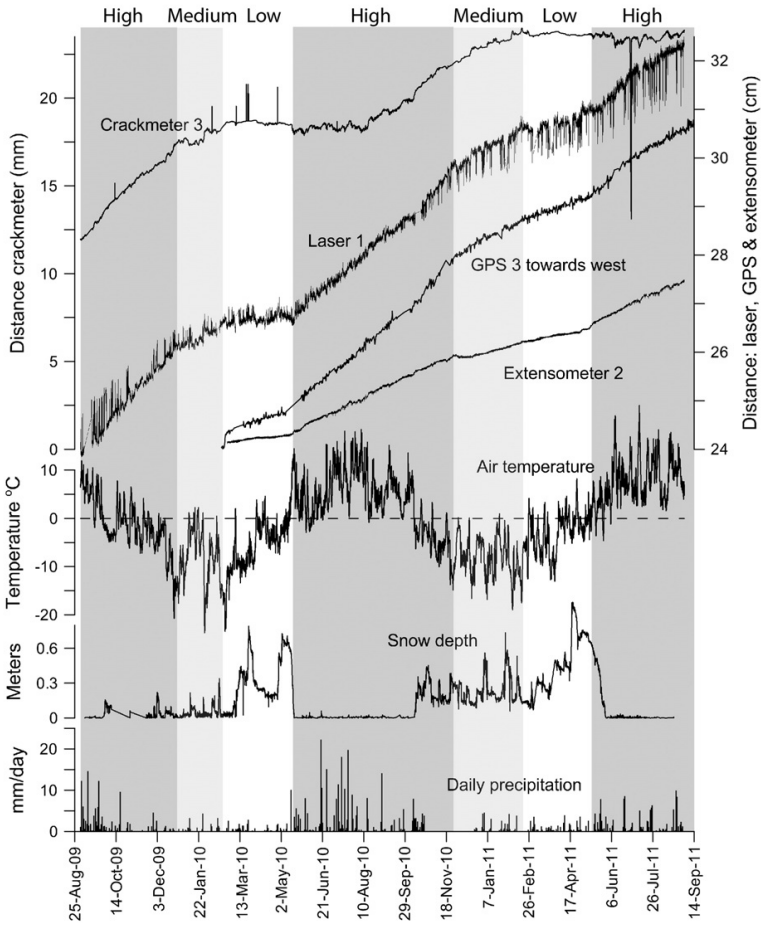
Mellor (1973)

Increase temperature ($-10^\circ\, C$ to $0^\circ\, C$):
→ drop in compressive strength 20-50%
→ drop in tensile strength 15-70%

Summer deformation initiated by thawing

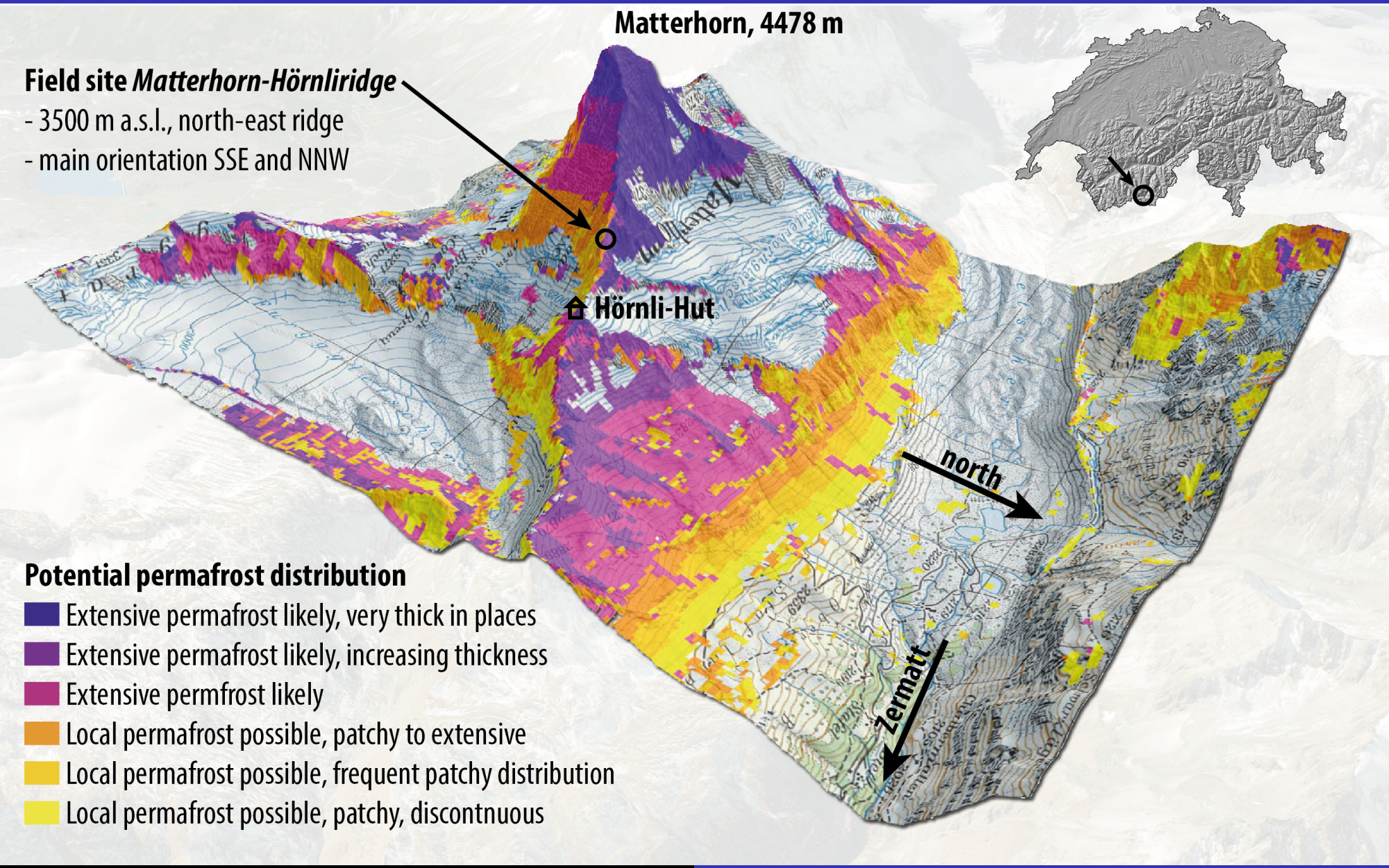


Hasler et al. (2012)



Blikra & Chrstiansen (2014)

Field site *Hörnligrat, Matterhorn, Switzerland*



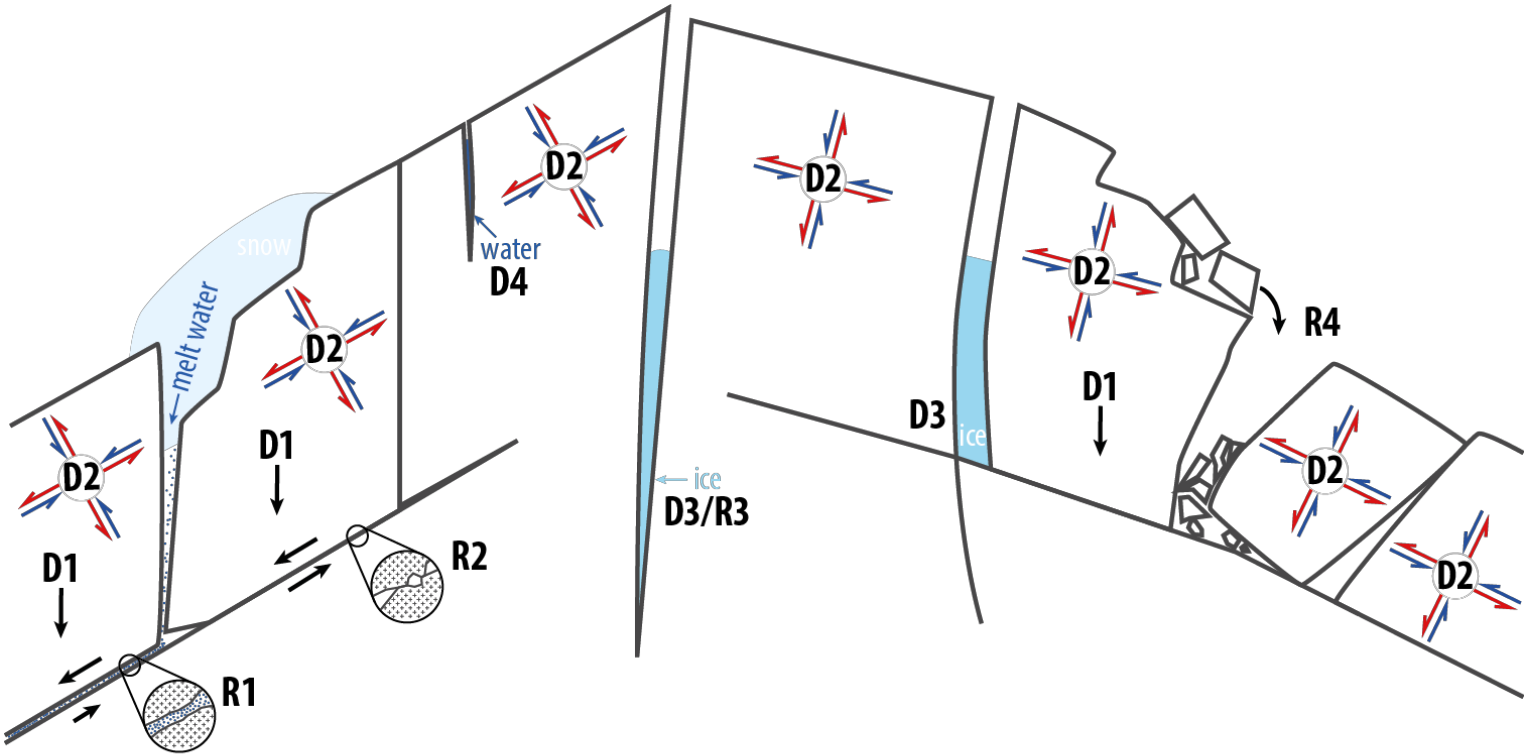
Fracture dynamics *statistical analysis of kinematics considering temperature*

Motivation
Gain better process understanding of rock-slope movement in ice-rich fractured bedrock permafrost.

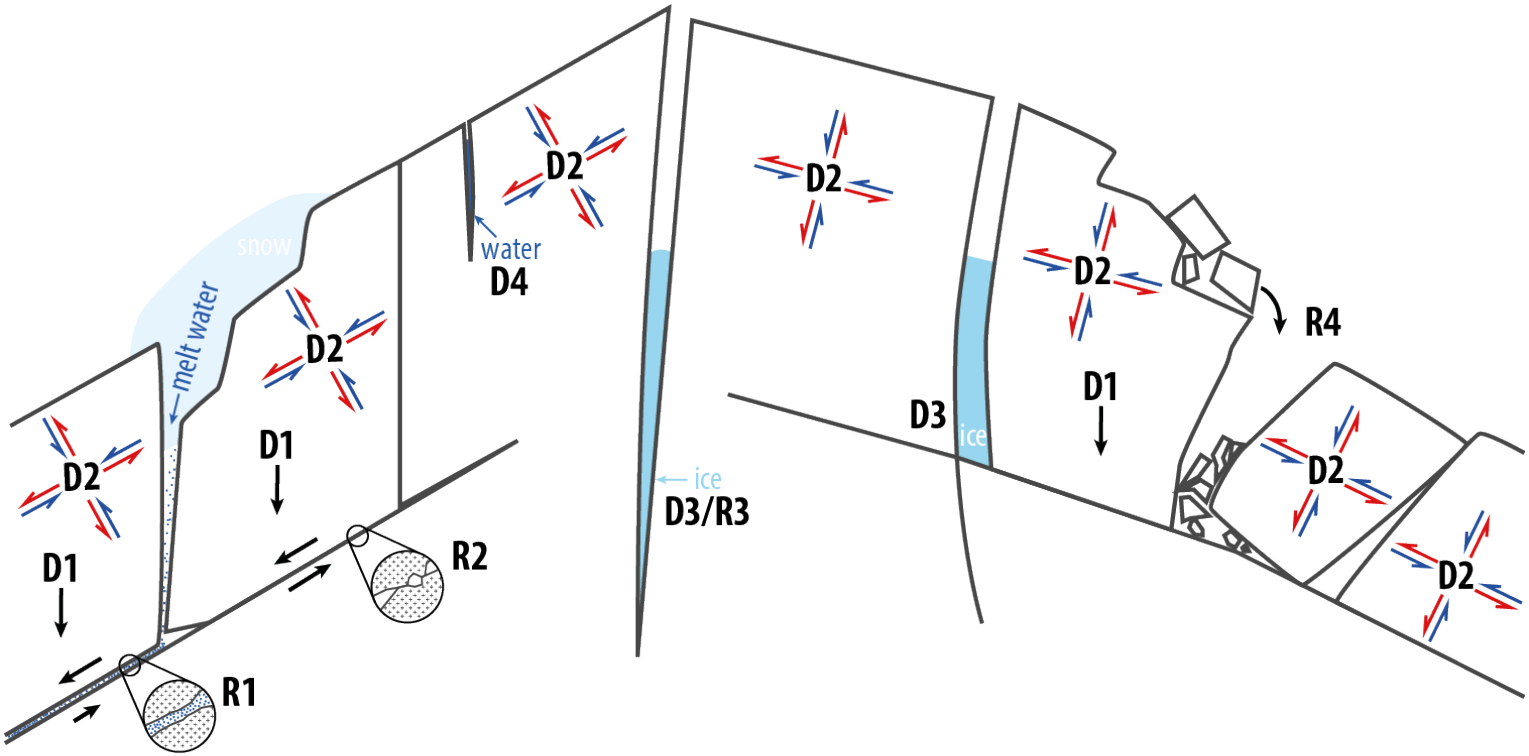
Approach
Statistical analysis of relative fracture movement.

Target
Deciphering mechanical controls in steep frozen rock-walls.

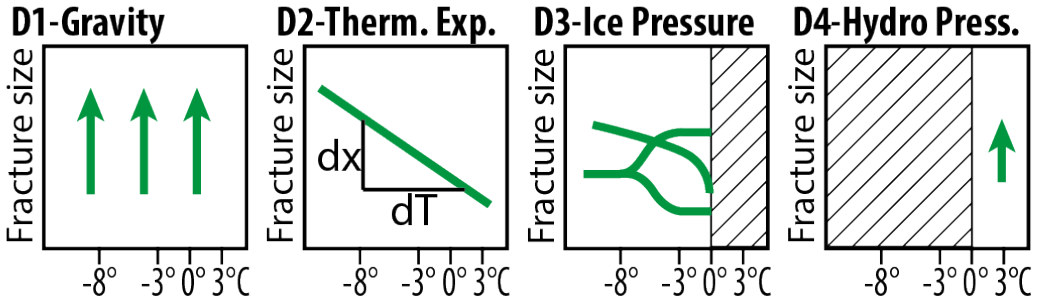
Conceptual approach *driving forces vs. resistive forces*



Conceptual approach *driving forces vs. resistive forces*



Driving forces



Resistive forces

R1-Shear Resistance along Fracture
R2-Fracture Toughness
R3-Ice Deformation
R4-Fracture Infill

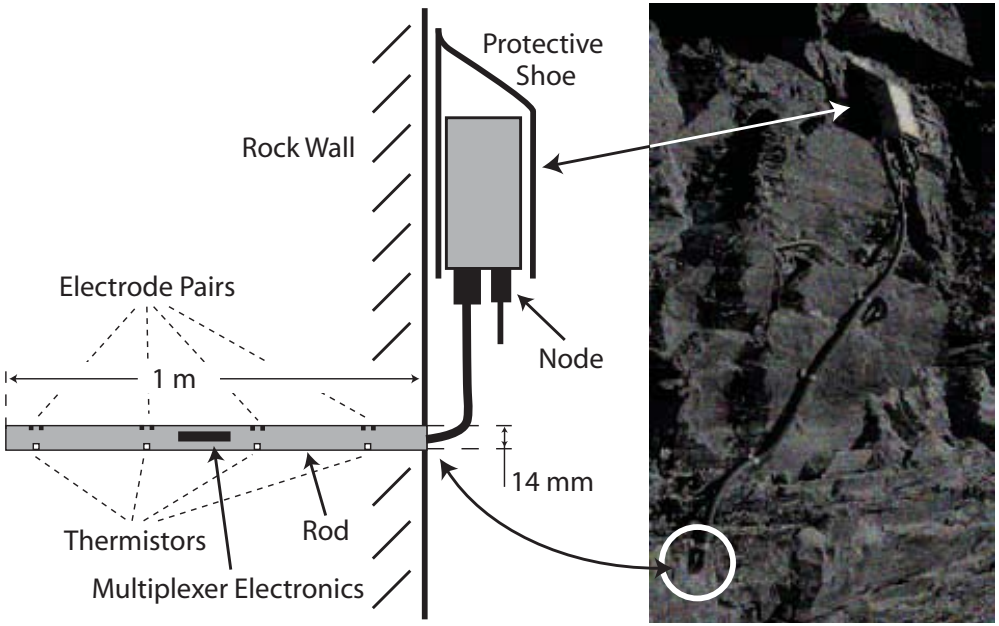
Measurement setup *surface displacement and temperature*

Crackmeter

- accuracy: 0.01 mm
- relative displacement

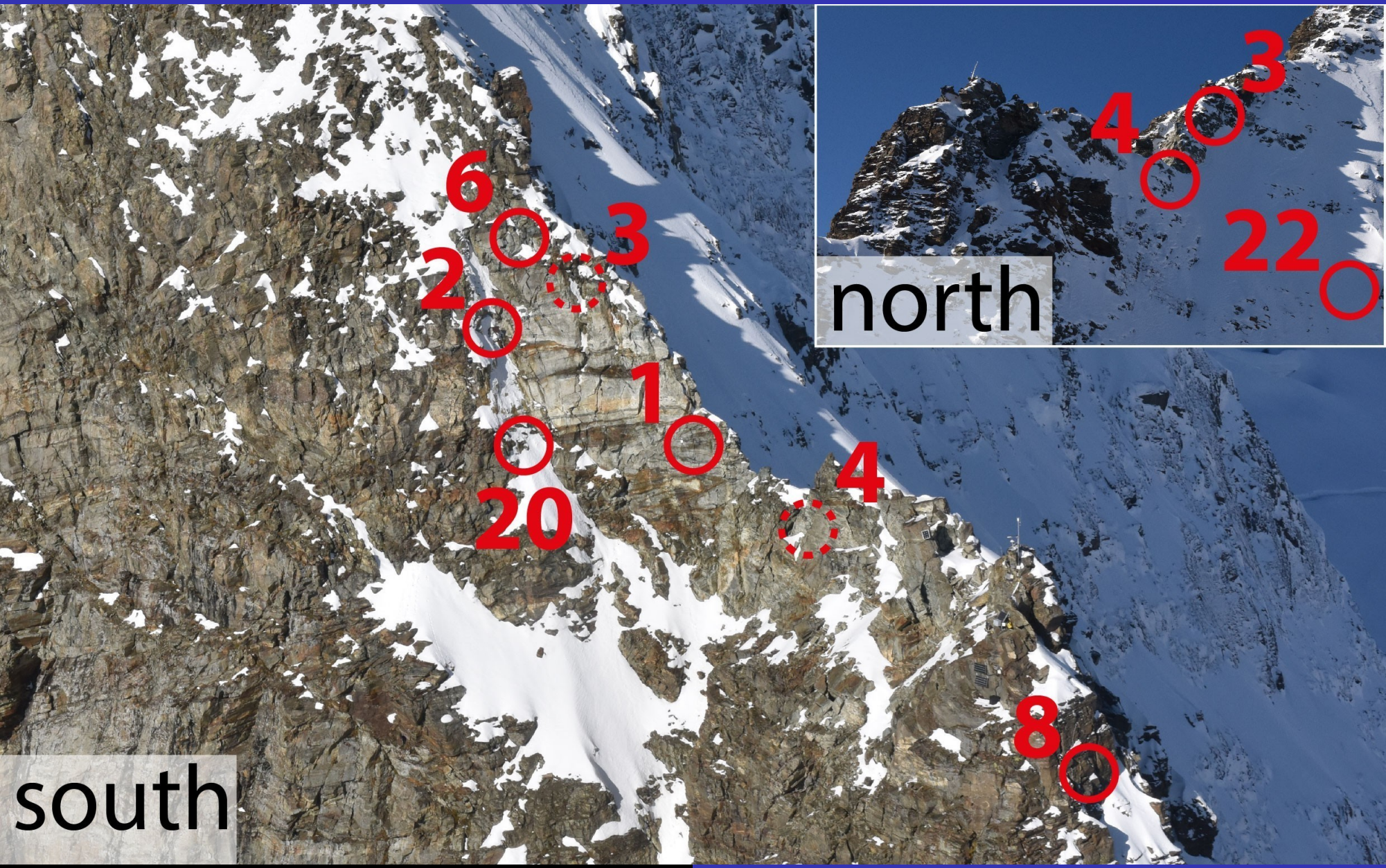
Temperature

- ground surface temperature
- temperature at depth

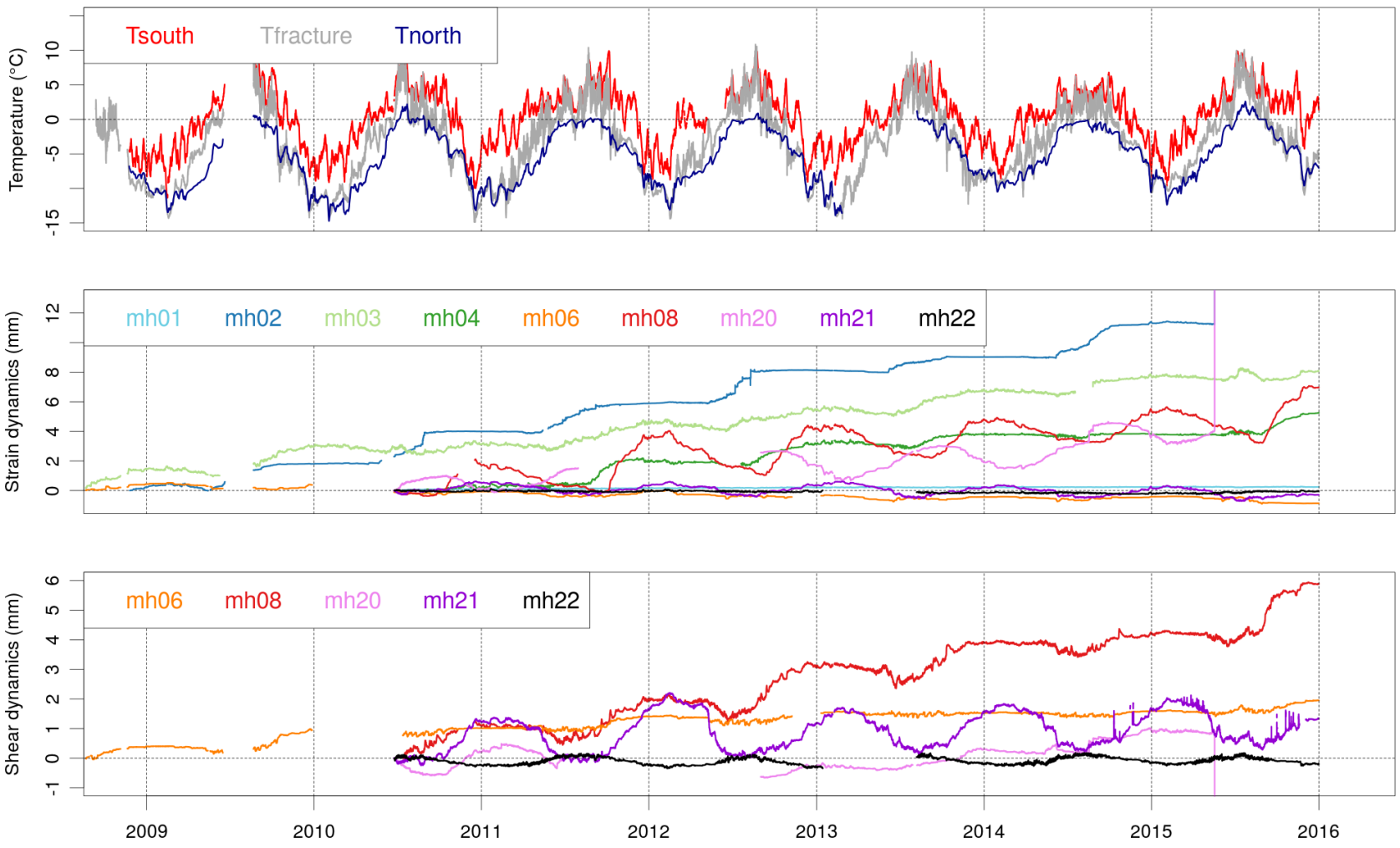


Beutel et al. (2009)

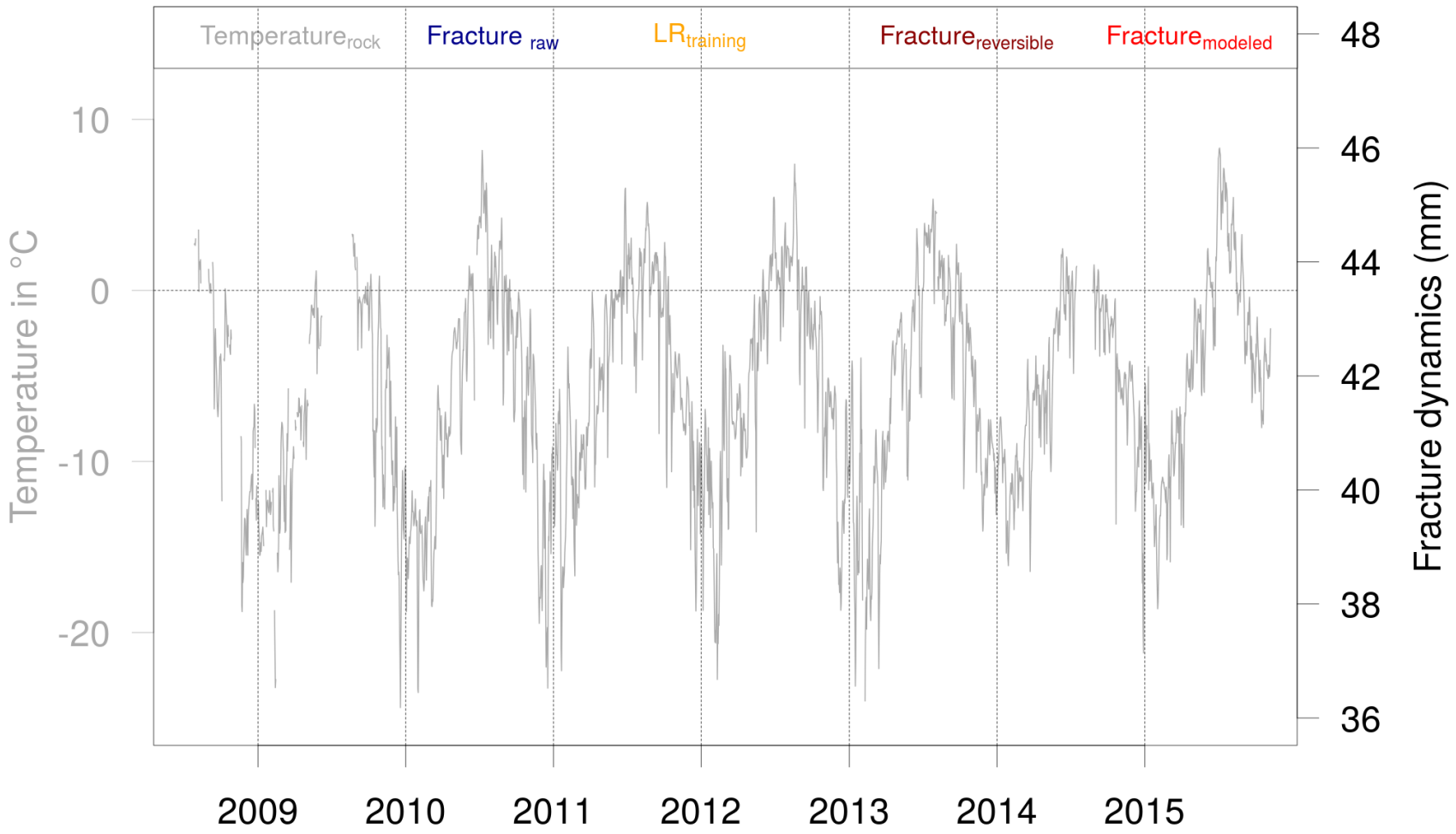
Existing installation *crackmeter & temperature measurement (2' intervall)*



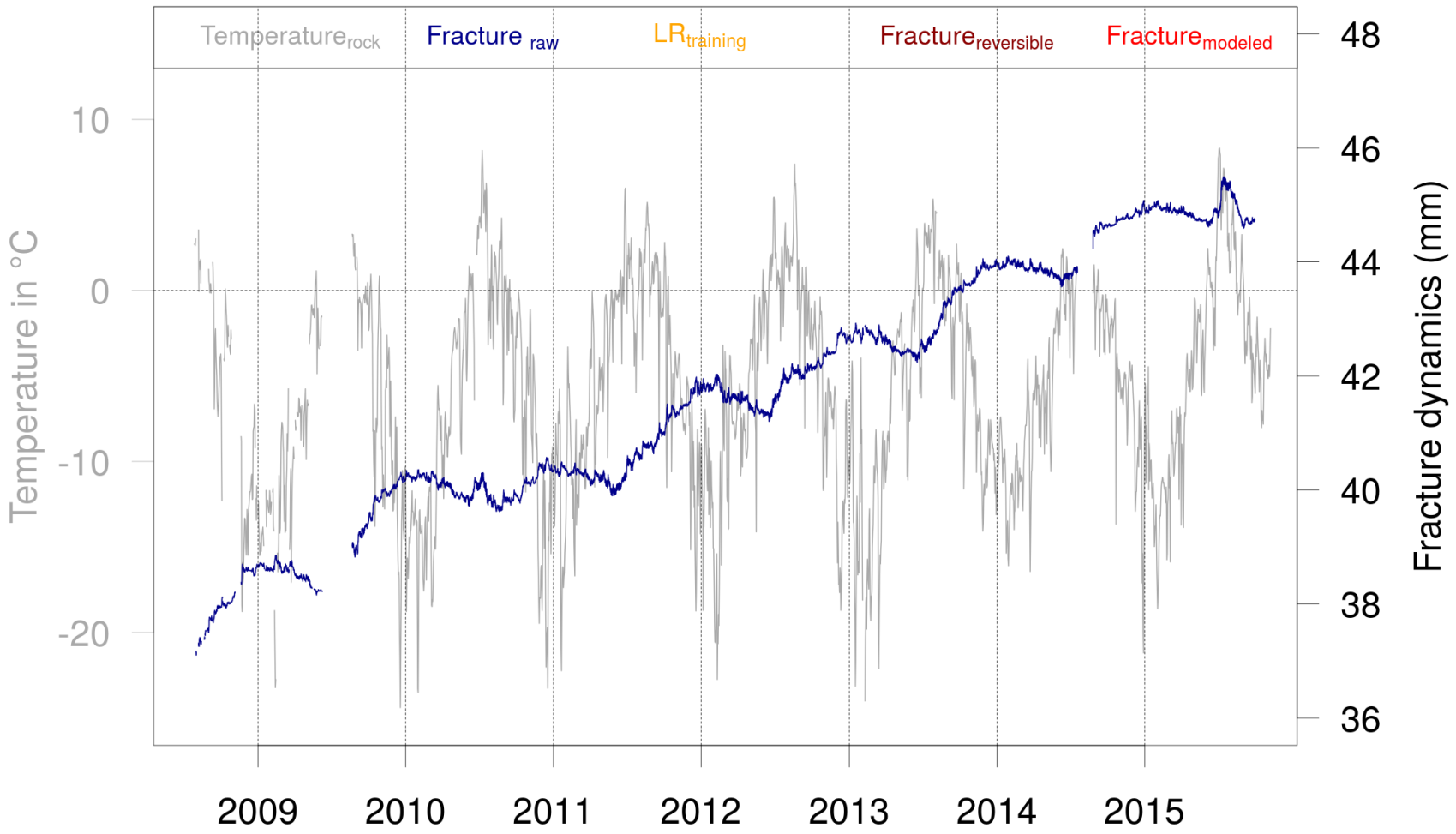
Raw data *temperature and relative fracture movement*



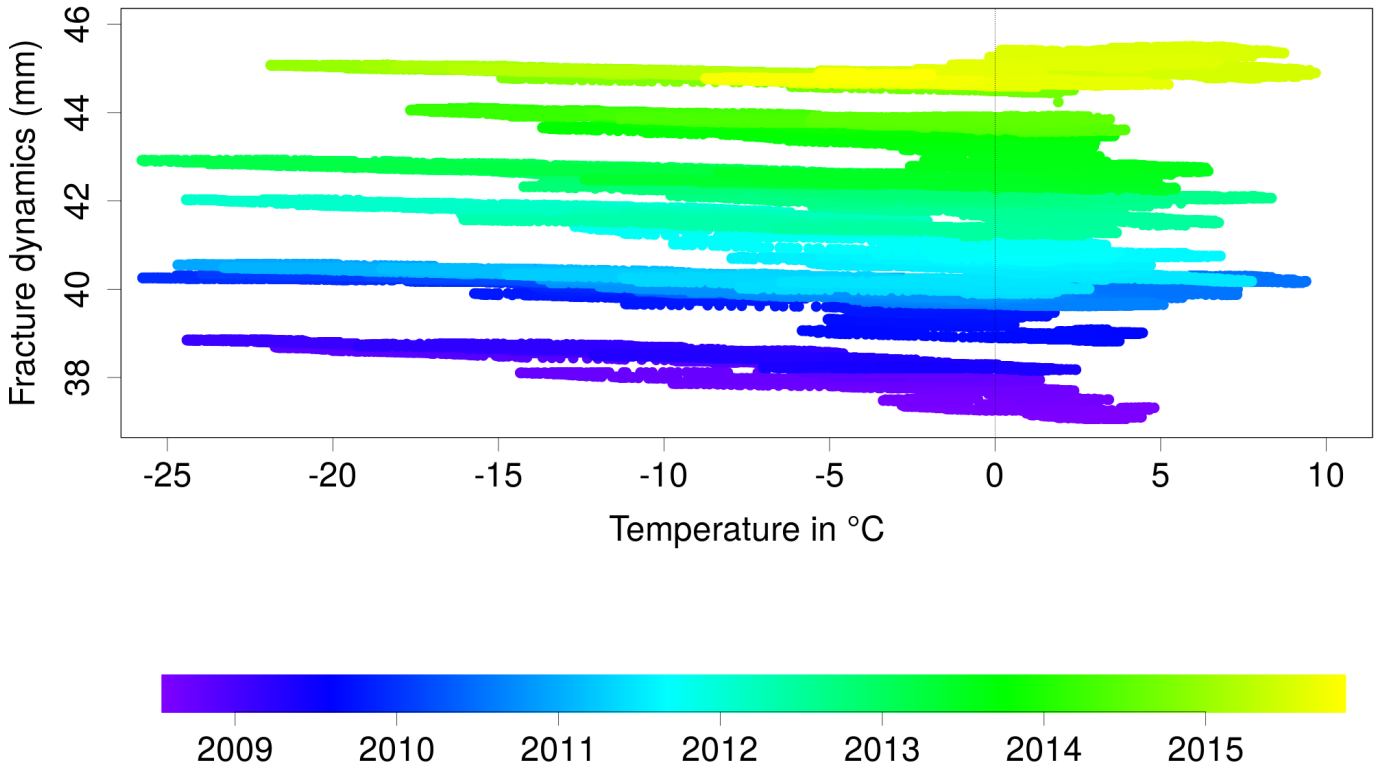
Model fracture dynamics *apply linear regression and sum with trend*



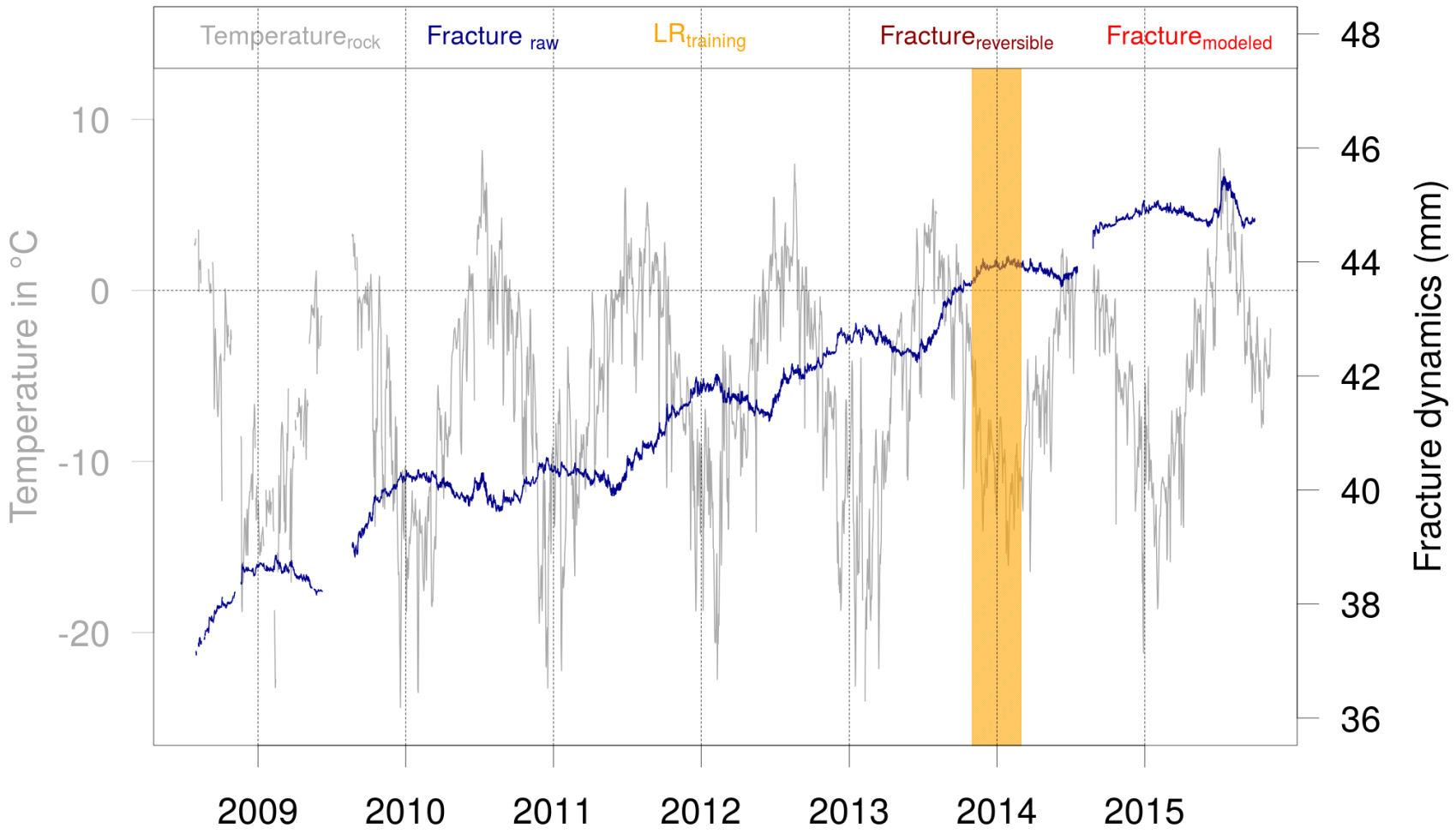
Model fracture dynamics *apply linear regression and sum with trend*



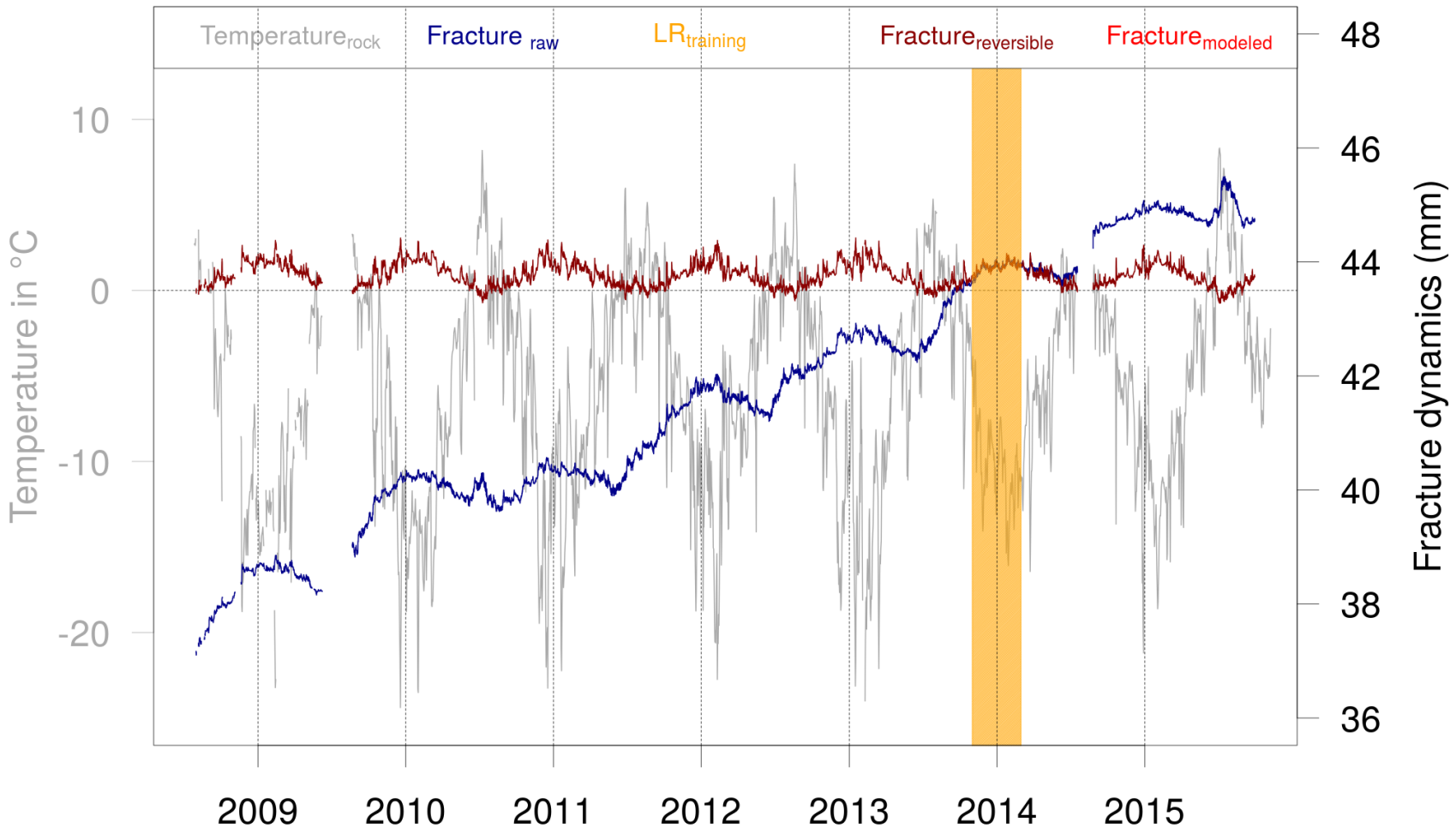
Model fracture dynamics *apply linear regression and sum with trend*



Model fracture dynamics *apply linear regression and sum with trend*



Model fracture dynamics *apply linear regression and sum with trend*



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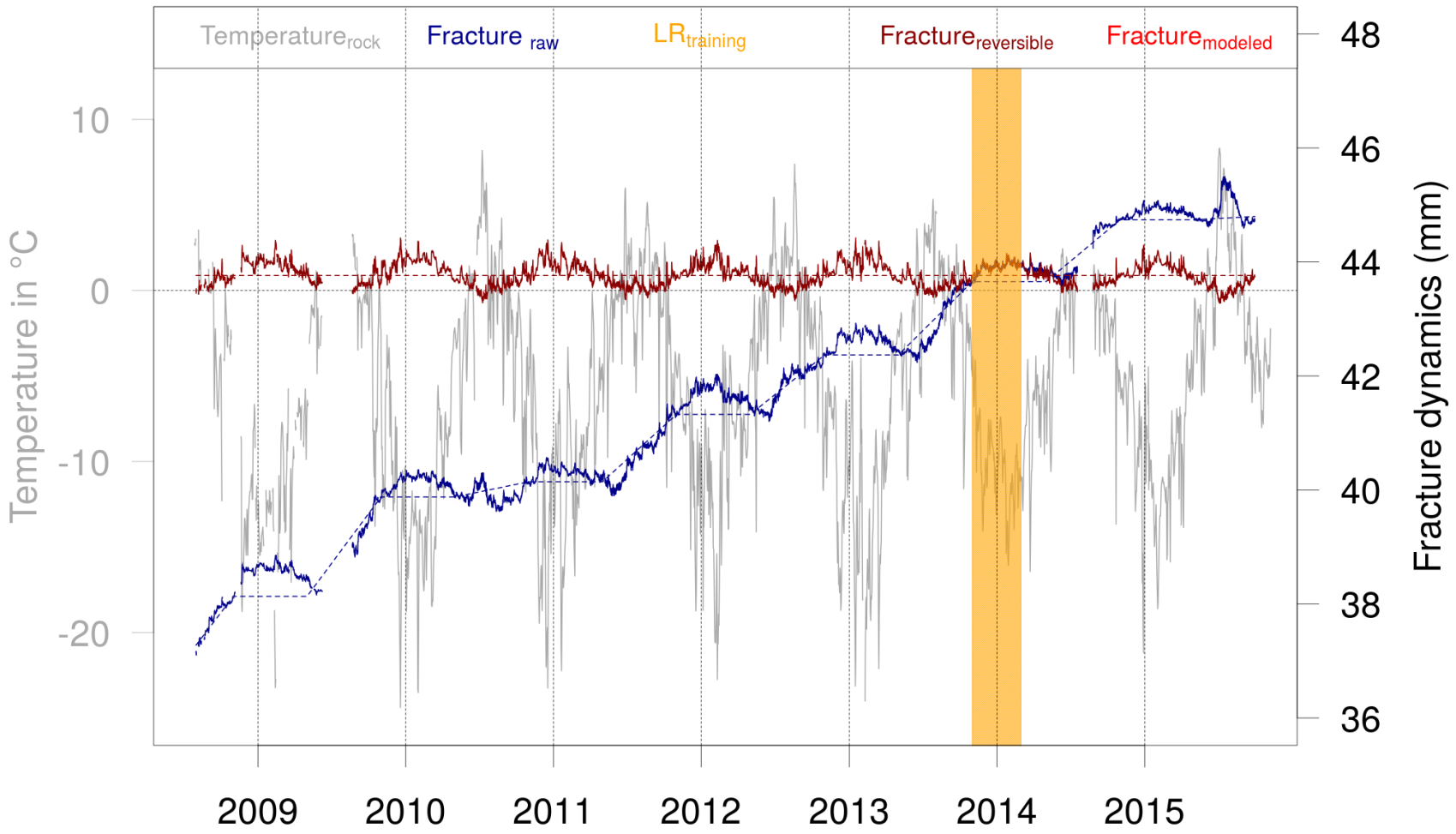
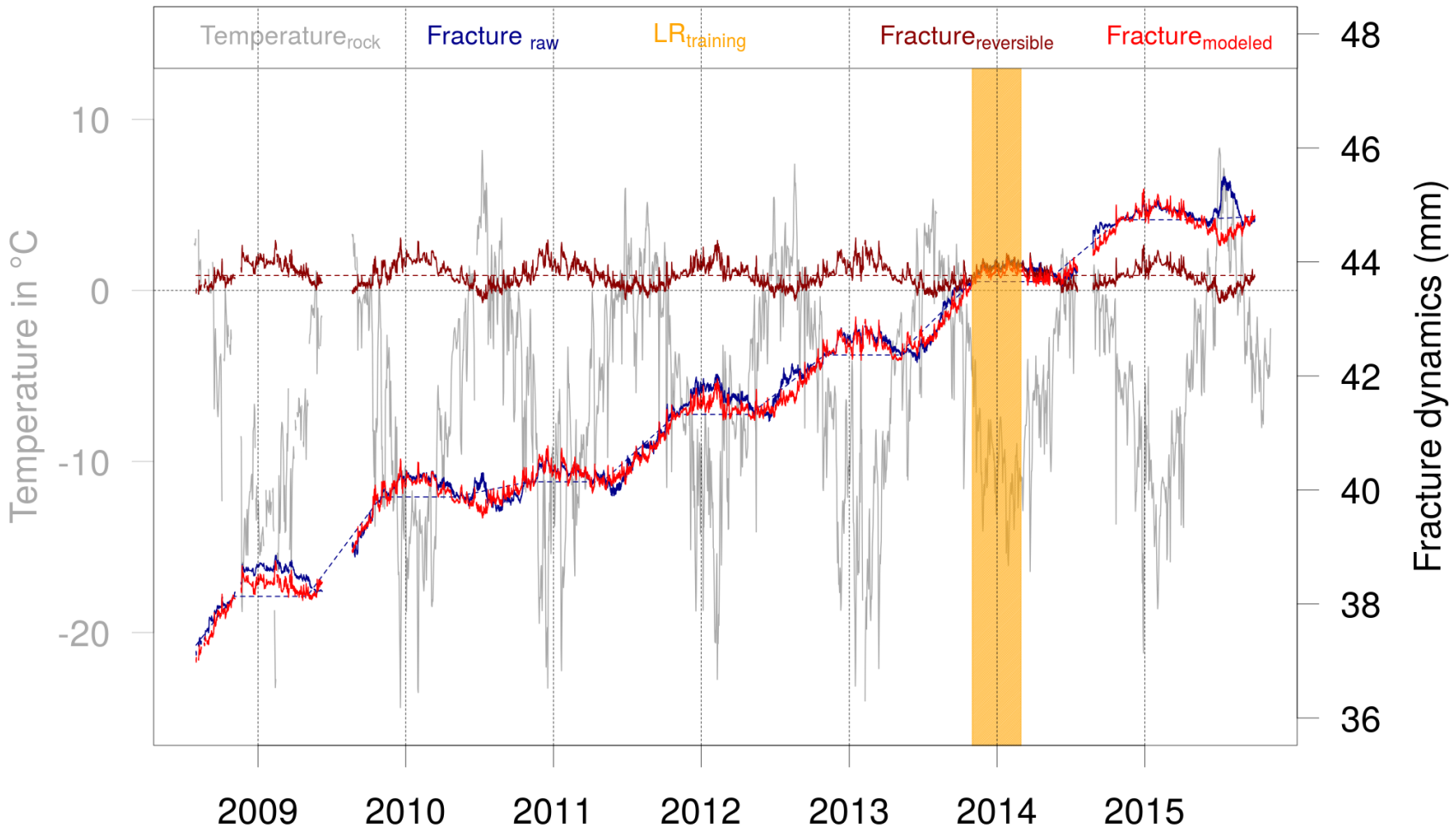
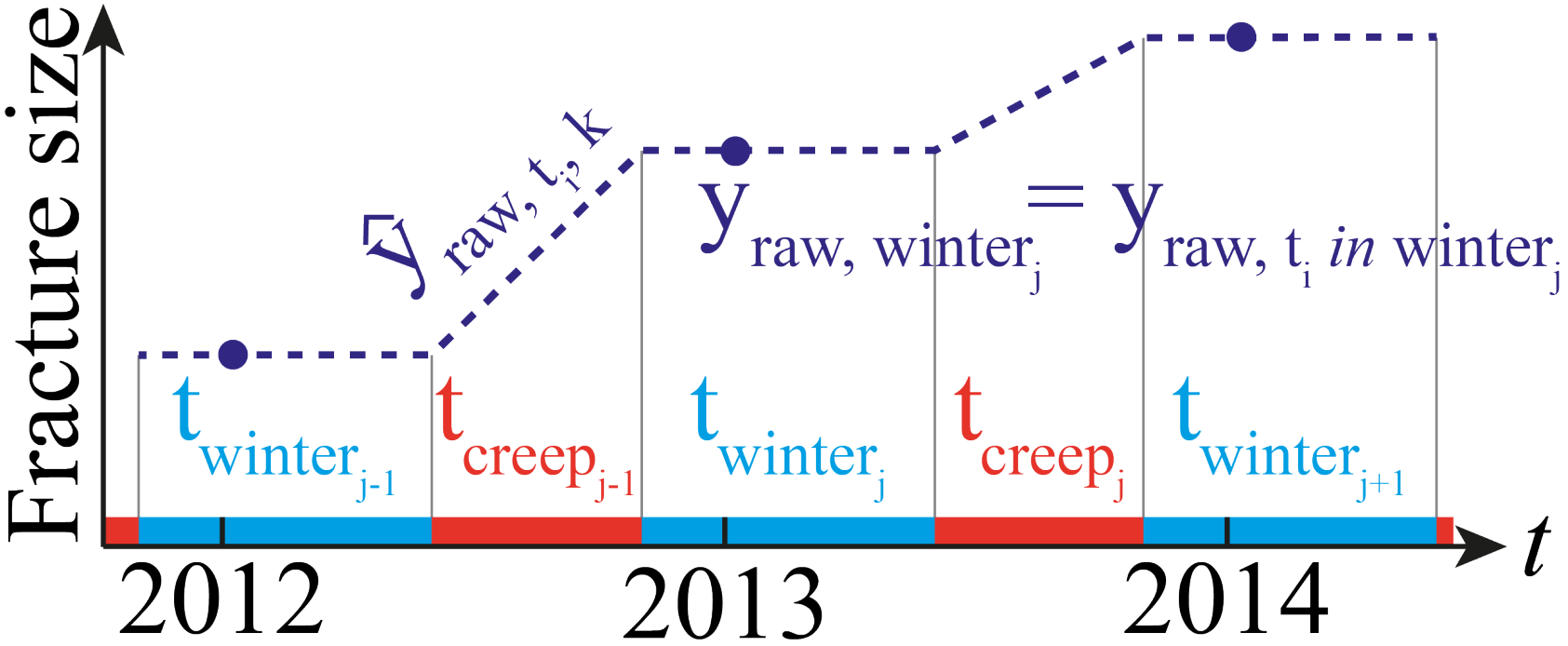


Model fracture dynamics *apply linear regression and sum with trend*



Summer creep *offset in summer related to thawing*



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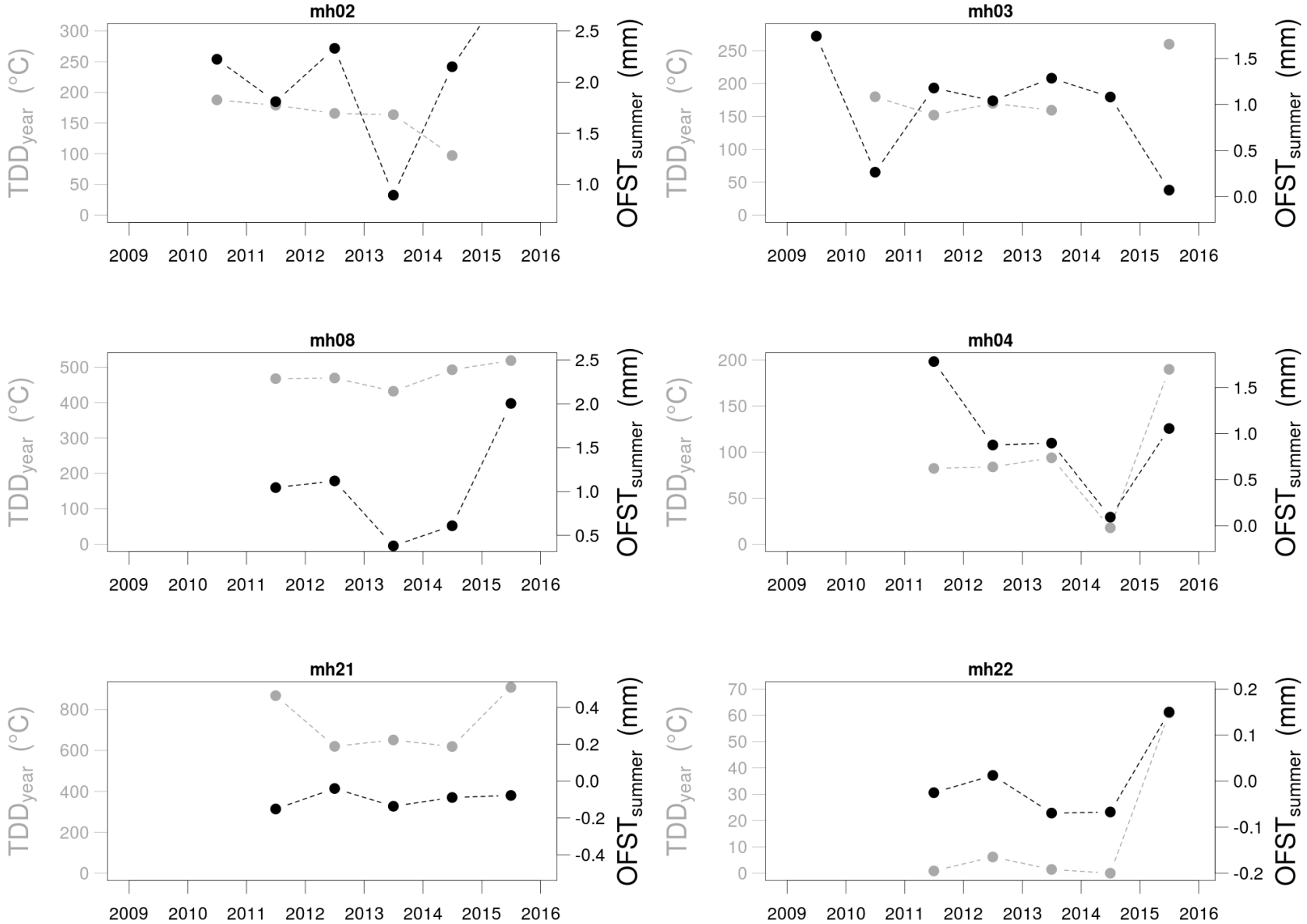

Limits of existing field experiment *extend measurement setup*

Fracture dynamics

- 7 years of data
- statistical analysis

⇒ limits

! point measurement

! "only" at surface

! 2' sampling rate

pilot study 2011 on Jungfraujoch

pilot study 2012 at Matterhorn

MS/AE field experiment

Limits of existing field experiment *extend measurement setup*

Fracture dynamics
- 7 years of data
- statistical analysis

↓

⇒ limits

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! "only" at surface

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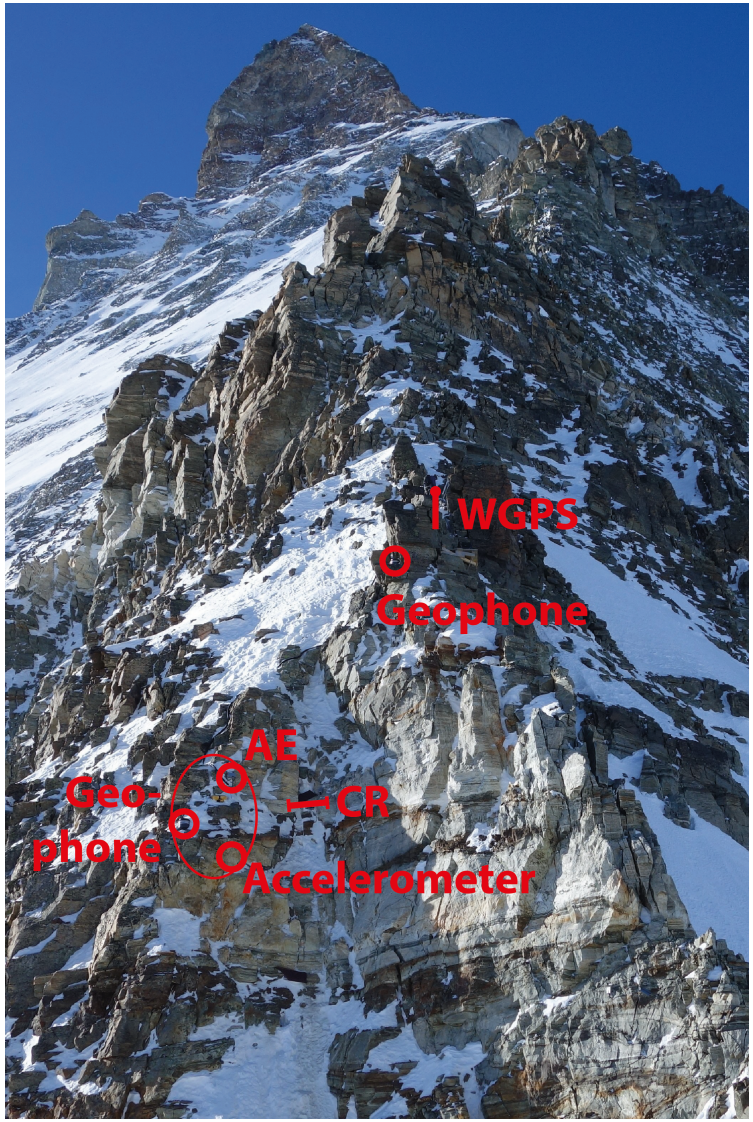
pilot study 2011 on Jungfraujoch ↘

↙ pilot study 2012 at Matterhorn

↓

MS/AE field experiment



Damage activity in rock *micro-seismic/acoustic emission (MS/AE) approach*

powerful technique to early detect/track the evolution of damage

+ passive and non-destructive
+ look inside the rock mass

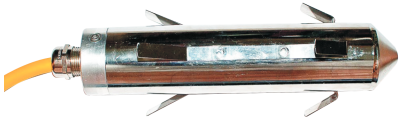
MS/AE = transient elastic waves generated by the release of energy during rapid local changes of strains in solid materials

FAILURE/RUPTURE

↓

MS/AE •))) source

⇒



detection range

frequency

Thanks for your attention!

Overall aim: improve understanding of preconditioning processes in alpine environments that can result in rock-slope movements

Acknowledgment:

PermaSense

University of Zurich[UZH]

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

TUM

AIR ZERMATT

44 78 Stiftung Hörnlihütte Zermatt Base Camp Matterhorn

nano-tera.ch

FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Umwelt BAFU
Office fédéral de l'environnement OFEV
Ufficio federale dell'ambiente UFAM
Uffizi federal d'ambient UFAM

HFSJG High Altitude Research Stations Jungfraujoch & Gornergrat

Surface displacement & temperature *in-situ*

Crackmeter

- accuracy: 0.01 mm
- relative displacement
- status quo:
  measures in 2' intervall

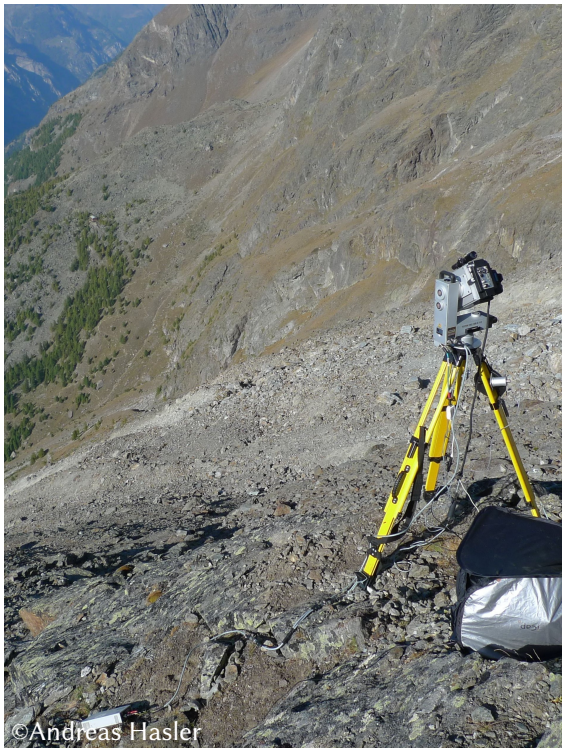
L1-GPS

- accuracy: few mm
- absolute displacement
- status quo:
  daily position solution relative to fix point

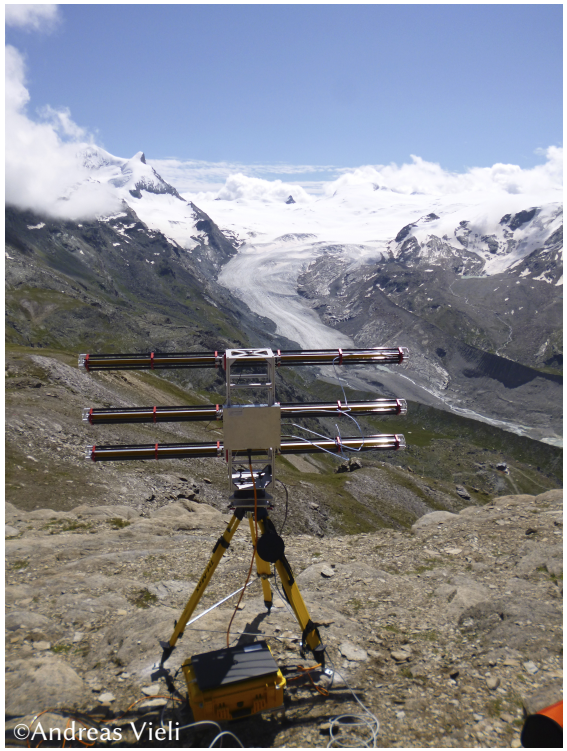
Surface displacement *remote*

Photogrammetry

Laserscan



Radarinterferometer



spatial resolution

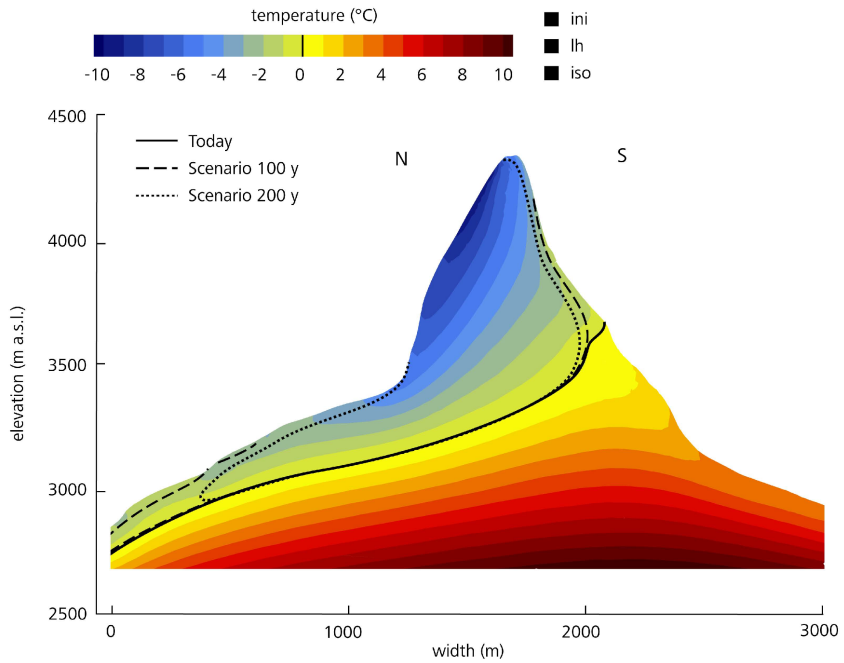
temporal resolution

Terrestrial Laser Scan *1st scan autumn 2015*

Terrestrial Laser Scan *1st scan autumn 2015*

Temperature Matterhorn *cross section and surface*

Modeled subsurface temperature
(north-south cross section)



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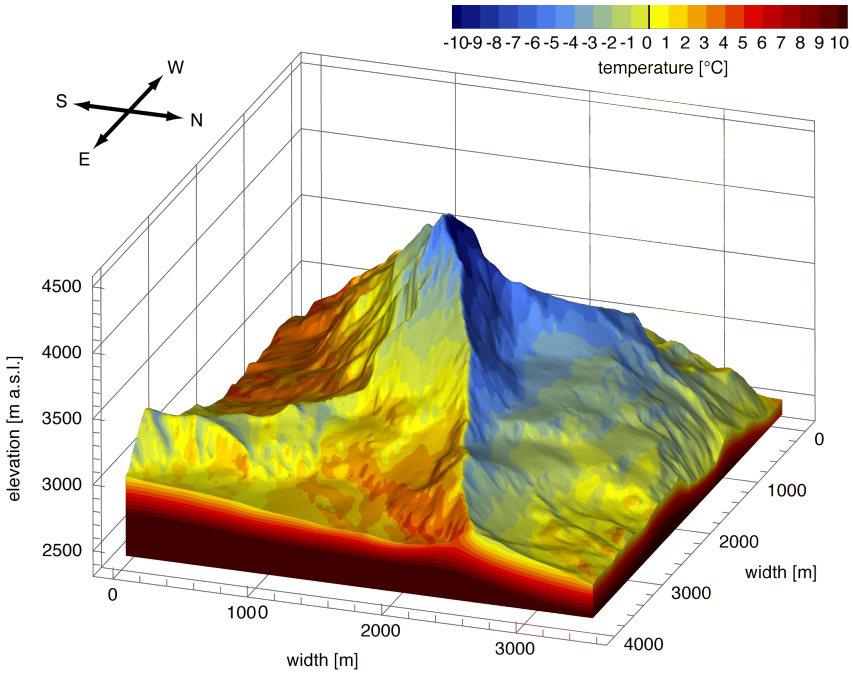
Modeled surface temperature
(view on north-east ridge)



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Damage activity in rock *micro-seismic/acoustic emission (MS/AE) approach*

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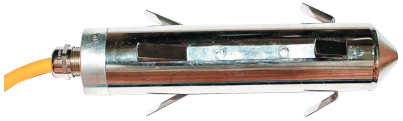


detection range

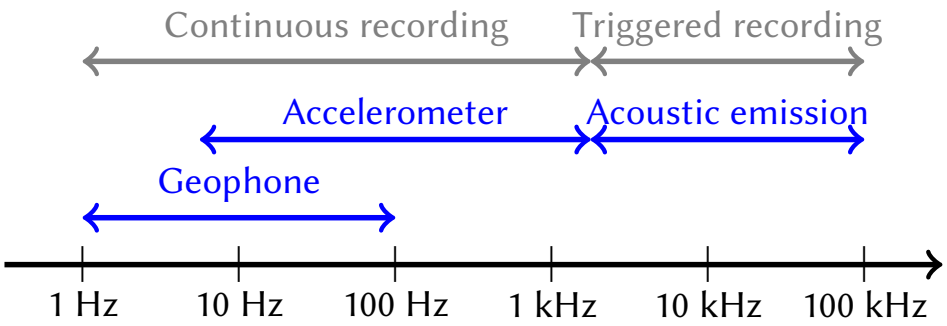
frequency

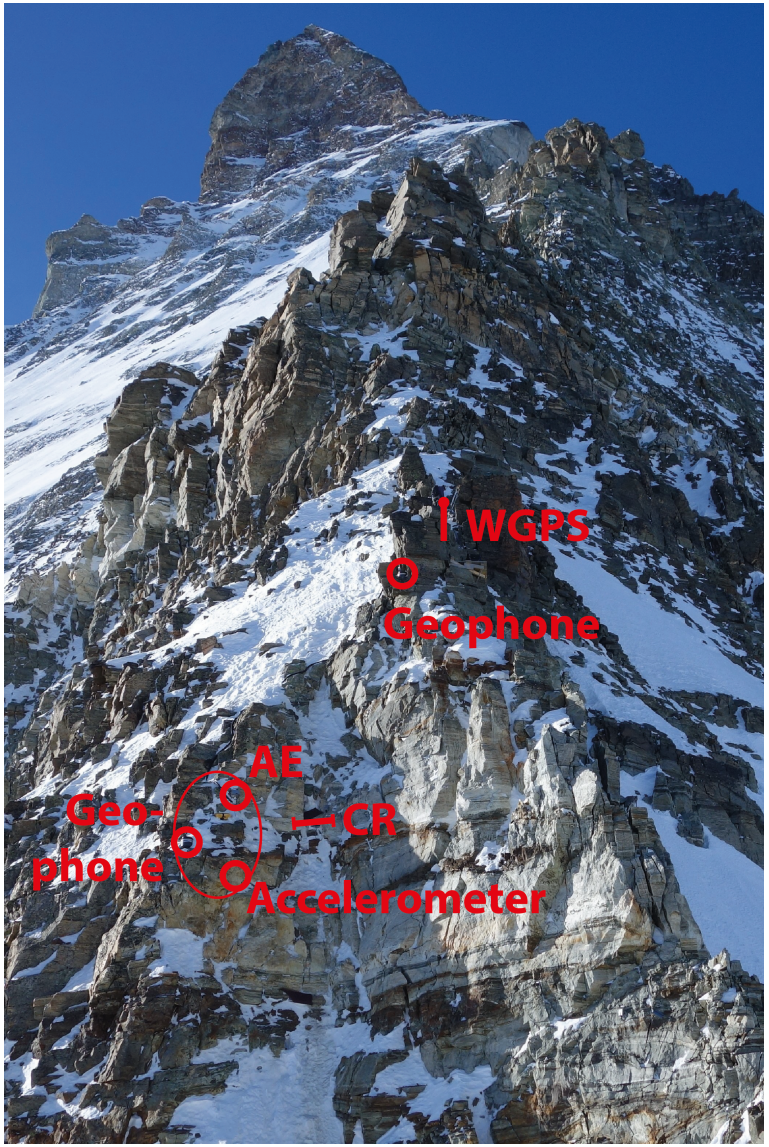
Experiment setup *instalation overview*

Measure/model temperature
- ground surface temperature
- temperature at different depth

Measure surface displacement
- crackmeter *short time scale*
- GPS *long time scale*
- TLS *long time scale, spatial coverage*

Capture acoustic/seismic activity in all frequency range

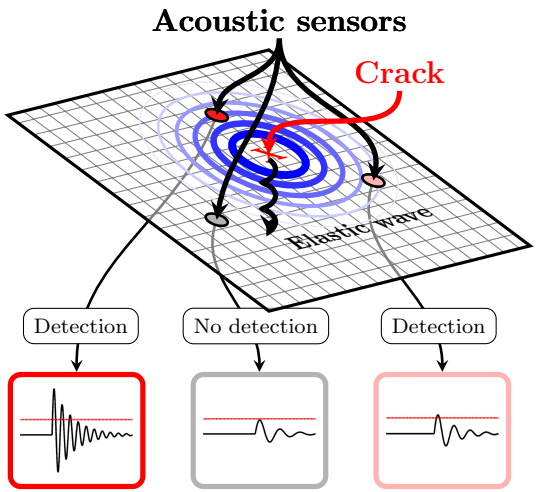




Monitor rock-slope *work in progress*

1 – data processing

How to cope with attenuation?

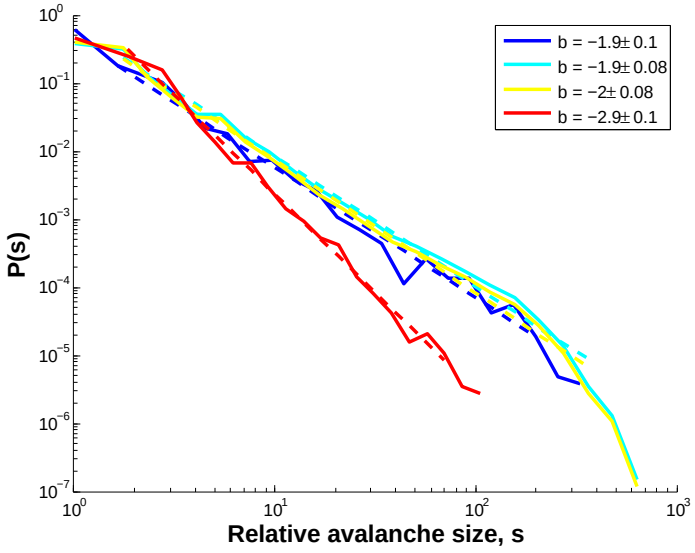


Natural medium = low pass filter,

depends on distance of the source

2 – data analysis

e.g. size frequency distribution with evolution of b-exponent



3 – event detection

How can we distinguish events from noise?

MS/AE challenges *work under progress*

Longterm field experiment

Fracture dynamics
- existing setup
- 6 years of data
- statistical analysis

pilot study 2011 on Jungfraujoch

pilot study 2012 at Matterhorn

MS/AE field experiment
+ spatial coverage
+ information at depth
+ high temp. resolution

⇒ limits
! point measurement
! "only" at surface
! 2' sampling rate

⇒ challenges
! lot of noise
! big data (30 GB/day)

MS/AE challenges *work under progress*

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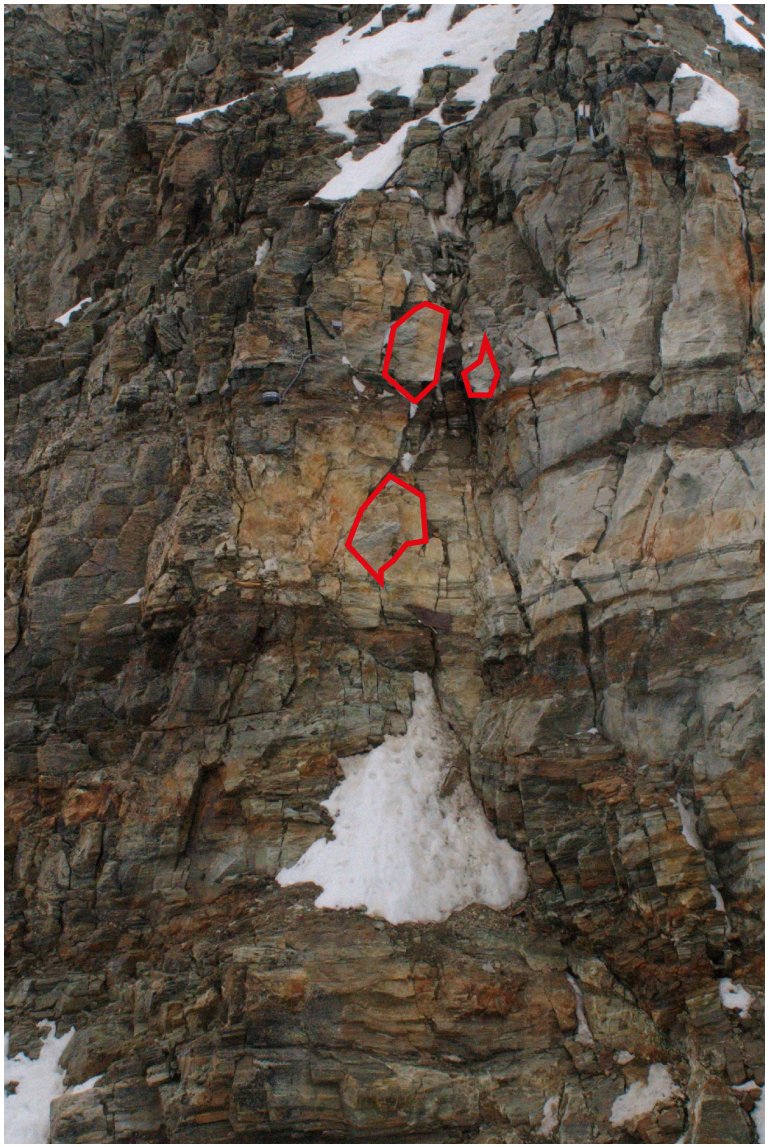
! point measurement
! "only" at surface
! 2' sampling rate

⇒ challenges
! lot of noise
! big data (30 GB/day)

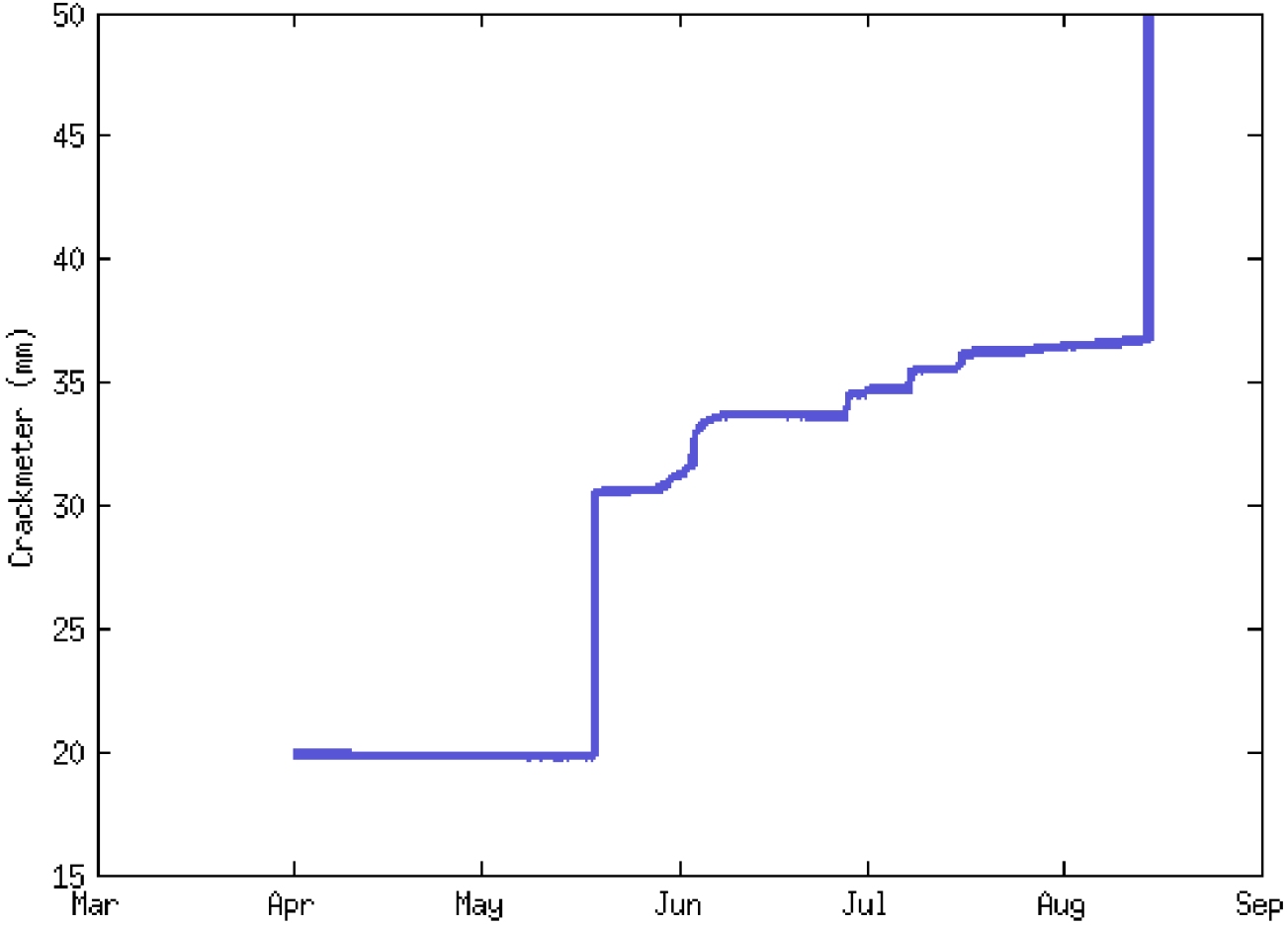
Boulder fall *small event on May 18, 2015*

Before the event

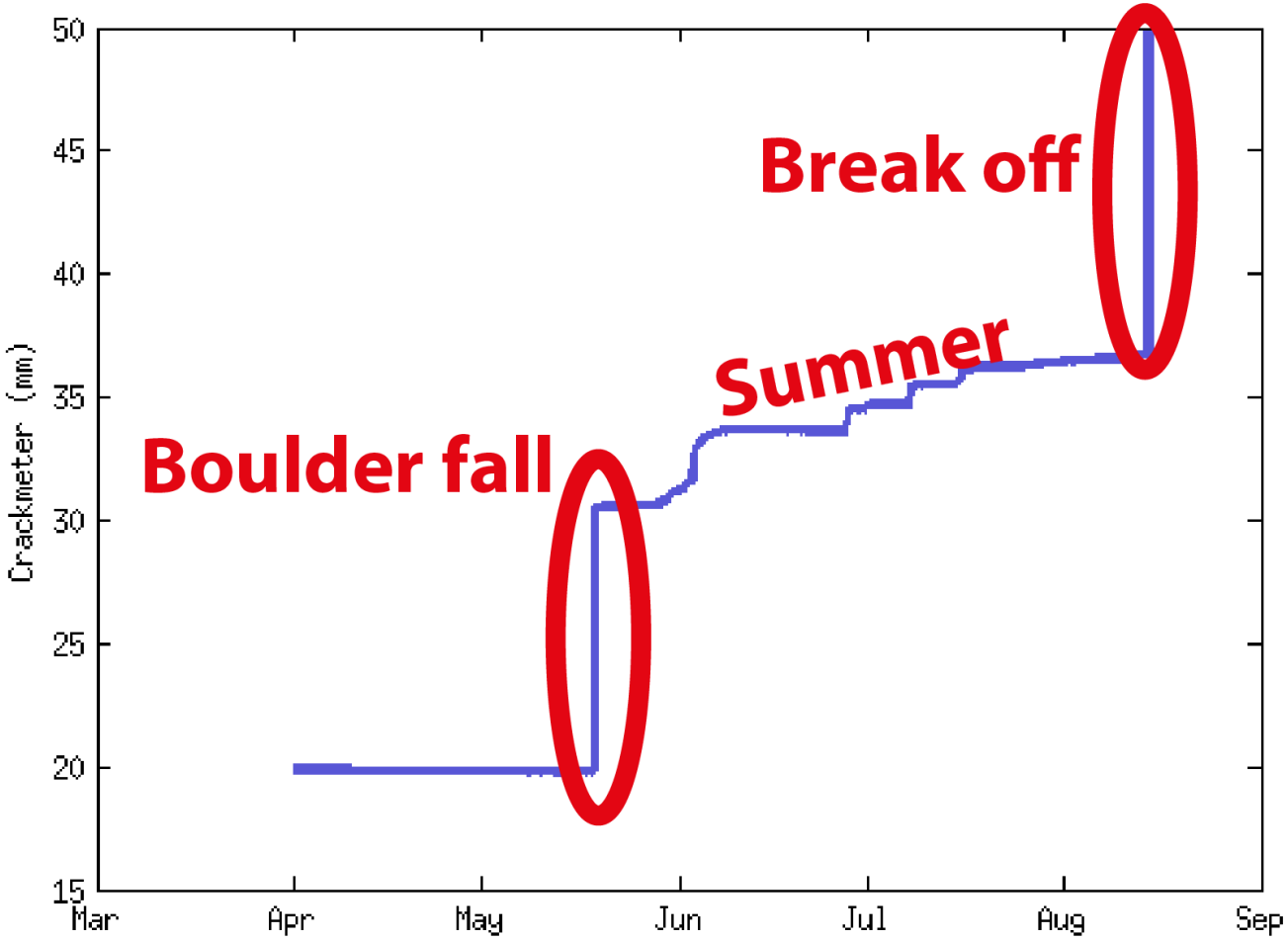


After the event

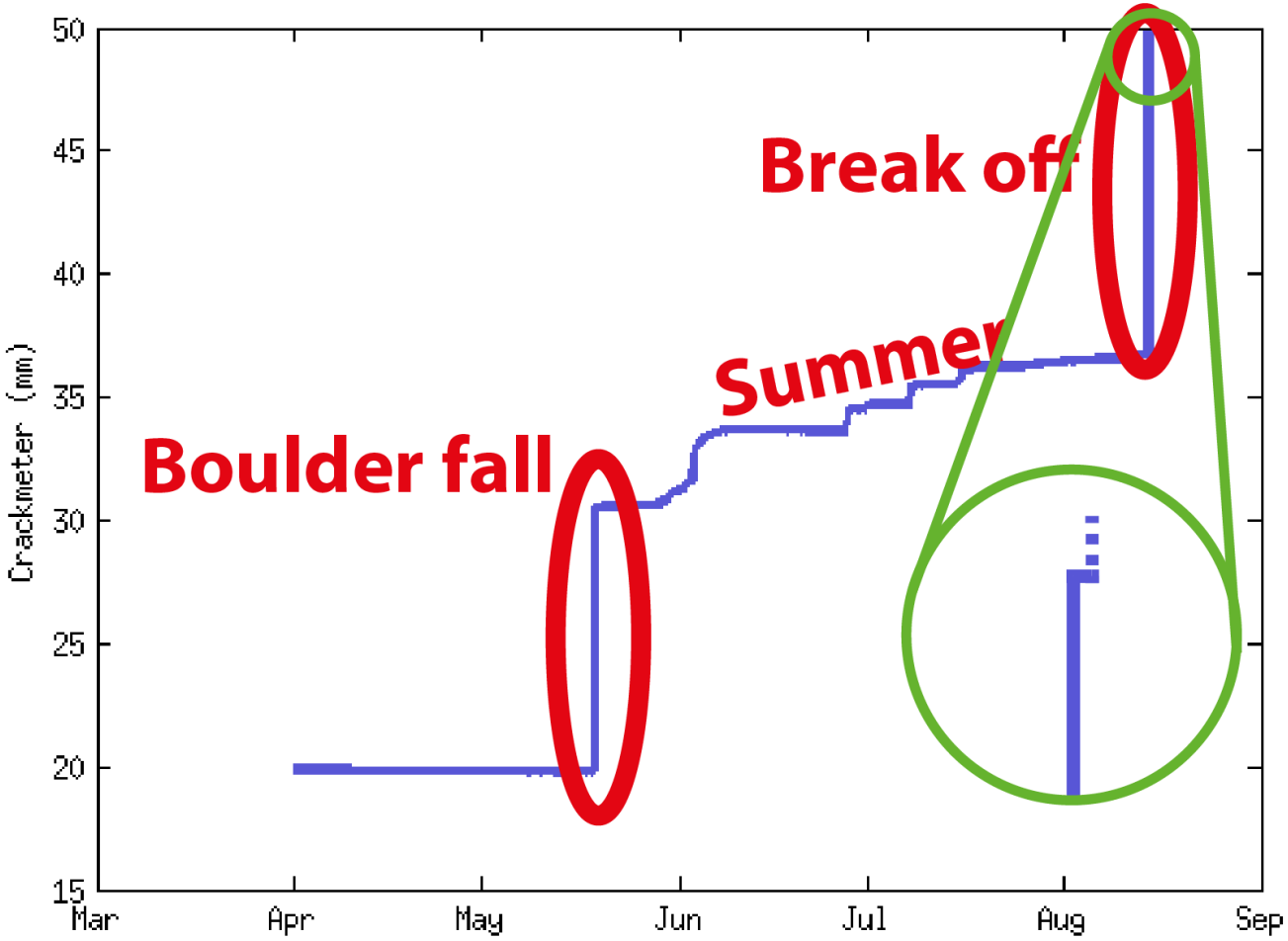
Fracture dynamics *summer 2015*



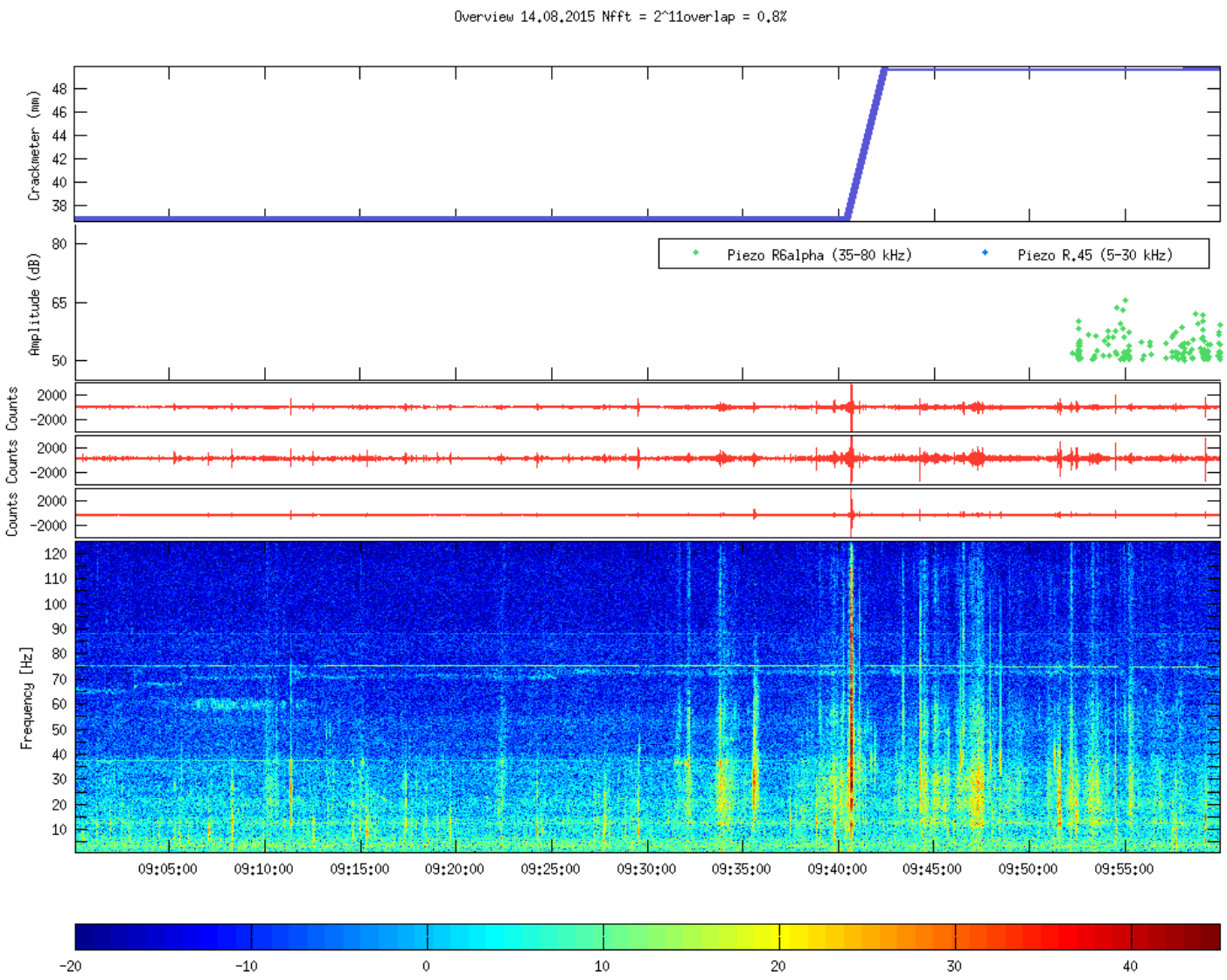
Fracture dynamics *summer 2015*



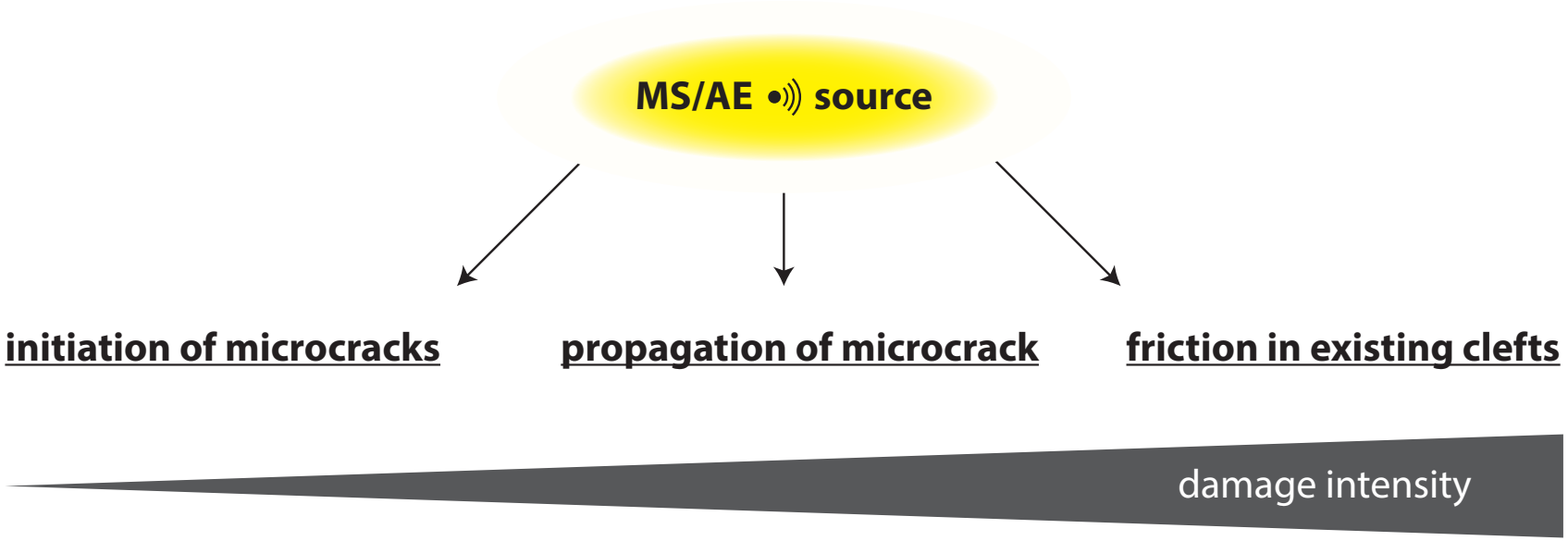
Fracture dynamics *summer 2015*



MS/AE activity *August 14, 9-10 am*

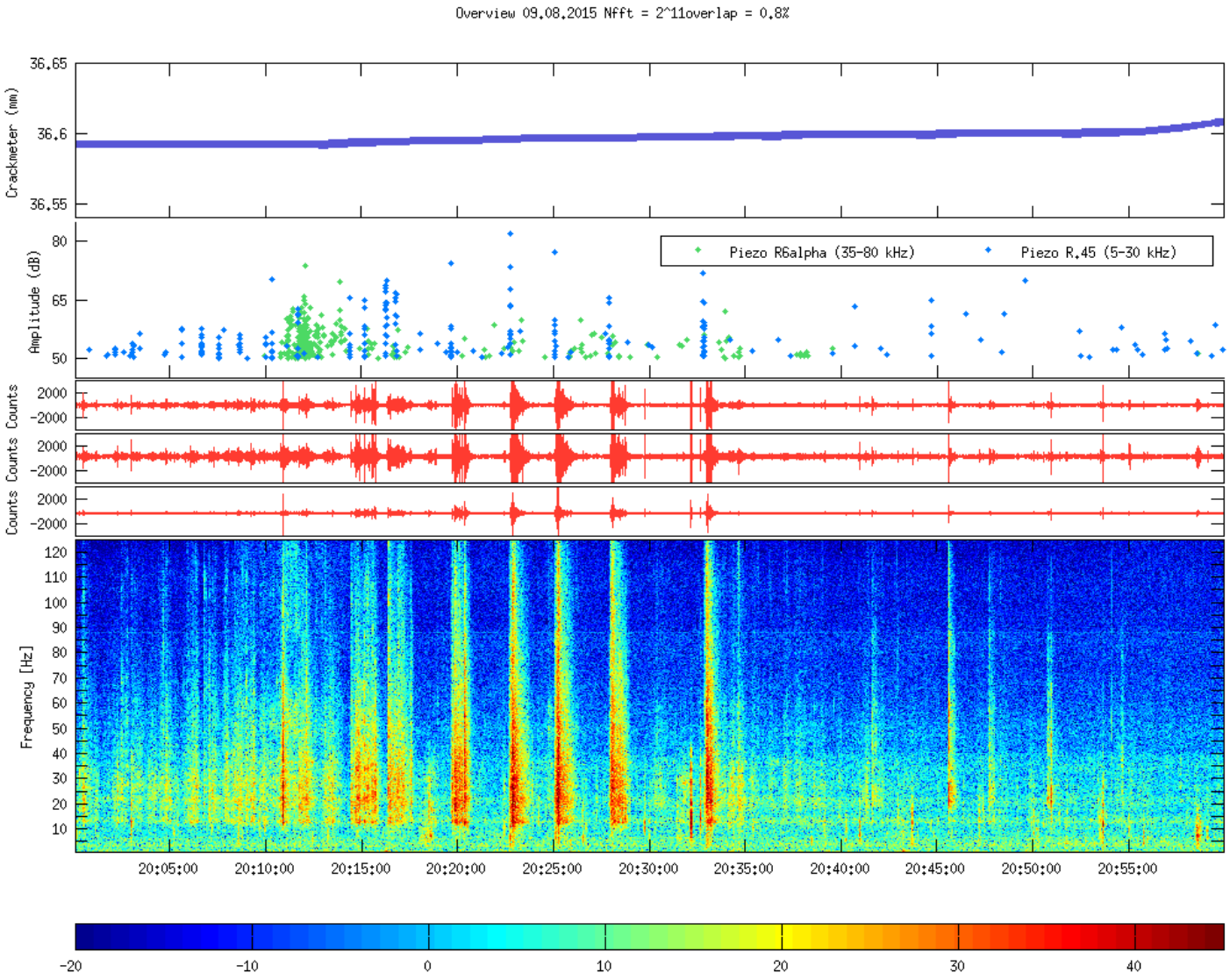


What's the source of the MS/AE signal?



→ **need of lab experiments**

MS/AE activity *August 09, 20-21 pm*



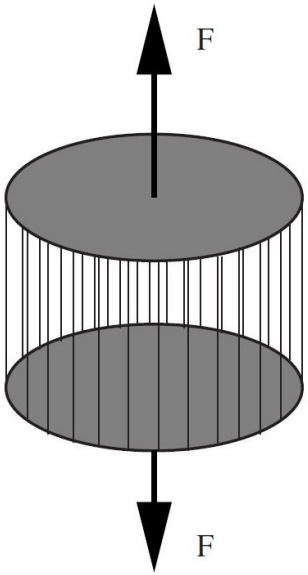
Fiber Bundle Model *tool to deal with attenuation and heterogeneity*

Different types of rupture model dealing with heterogeneity exist.

(Percolation Model, Thermal Fuse Model, Sand Pile Model, Fiber Bundle Model, etc.)

choose to study **Fiber Bundle Models (FBM)**:

(i) simplest model of rupture
(ii) naturally includes heterogeneities
(iii) effect of stress redistribution
(iv) direct link to acoustic emissions

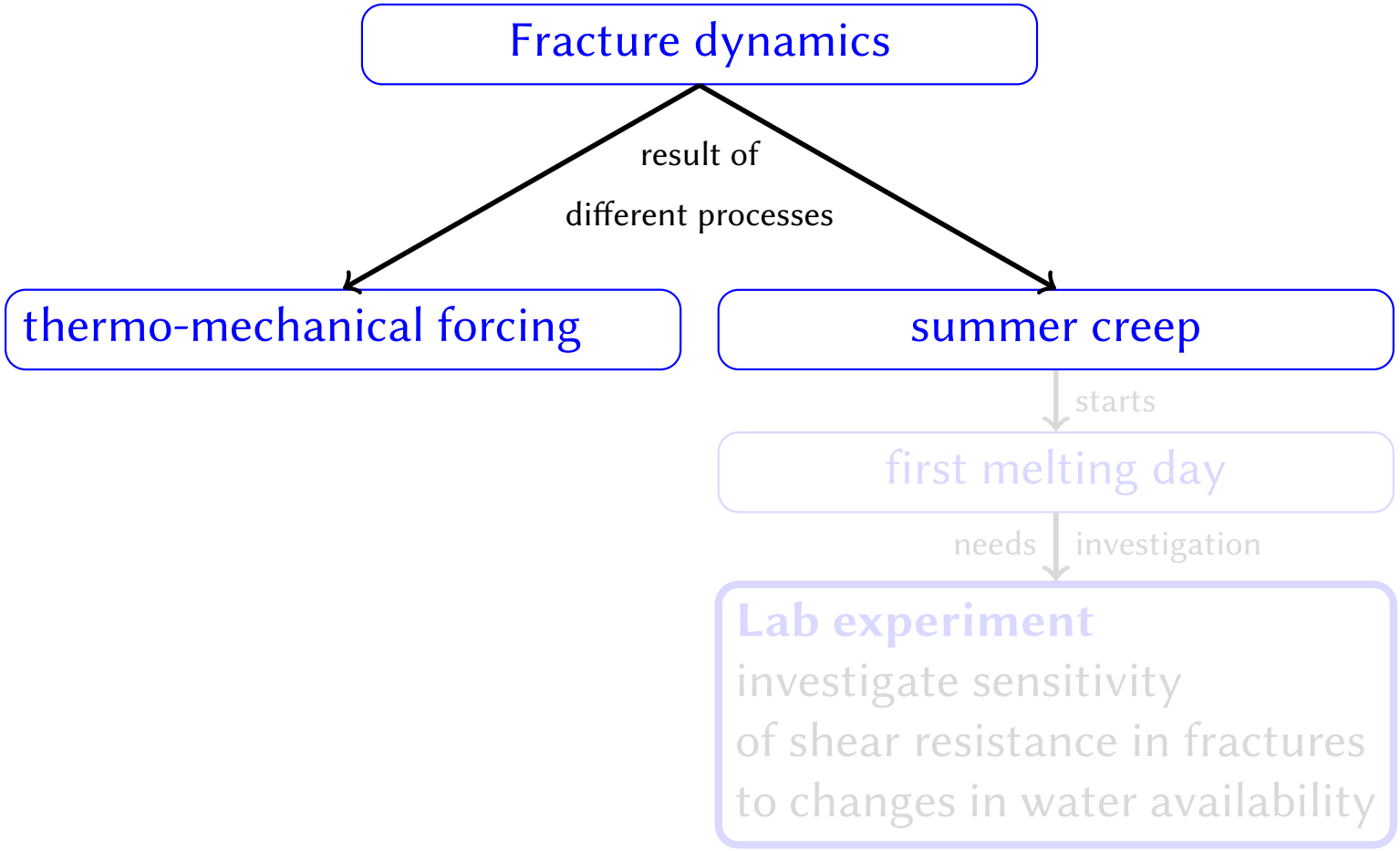


Fiber Bundle Model (FBM)= collection of **elastic-brittle** objects connected in parallel and clamped to a medium that transmits forces between the fibers.

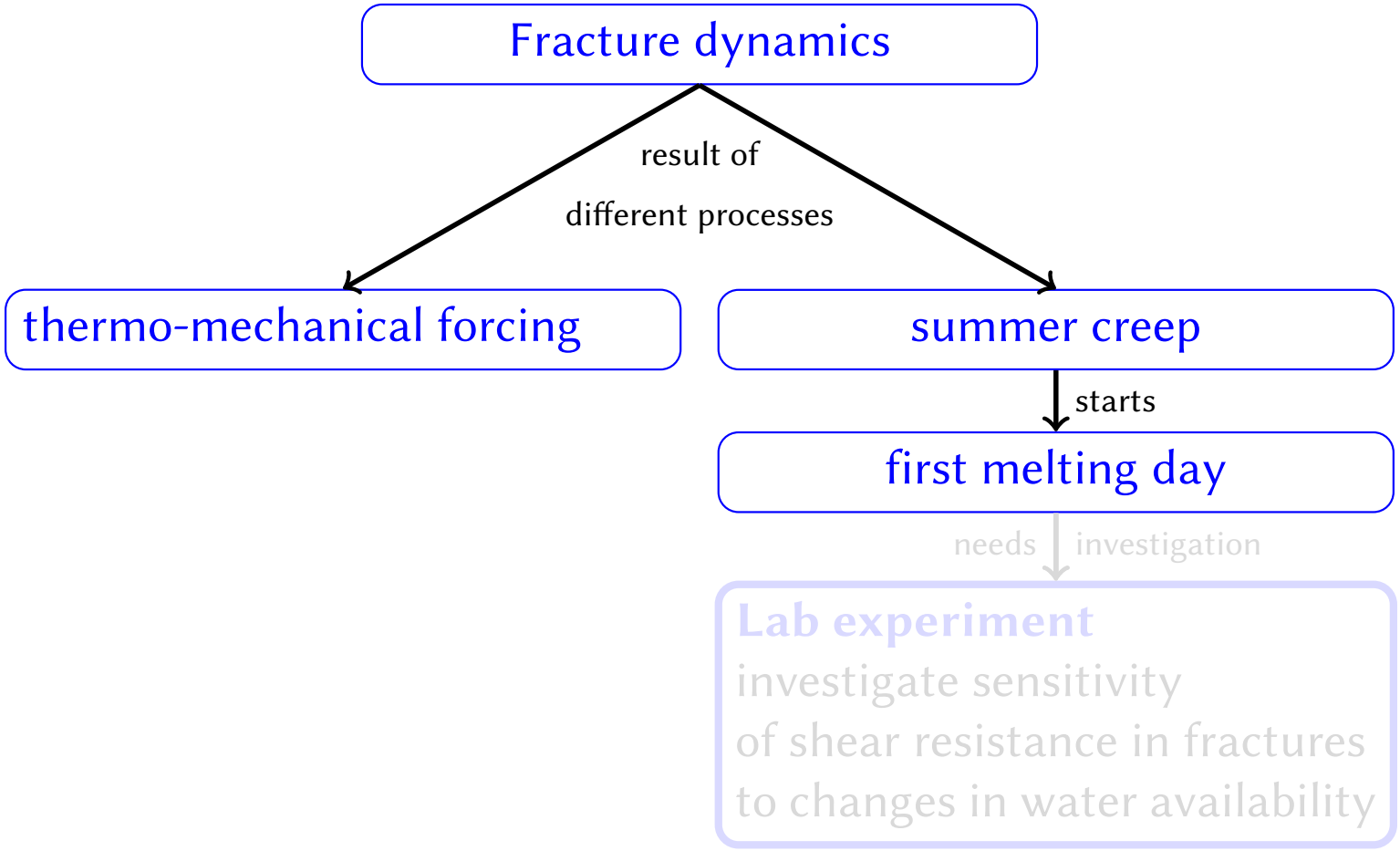
Each fiber can deform linearly up to a threshold value.

When this value is reached, the fiber fails by no longer being able to carry any force.
The force it carried is then *redistributed*.

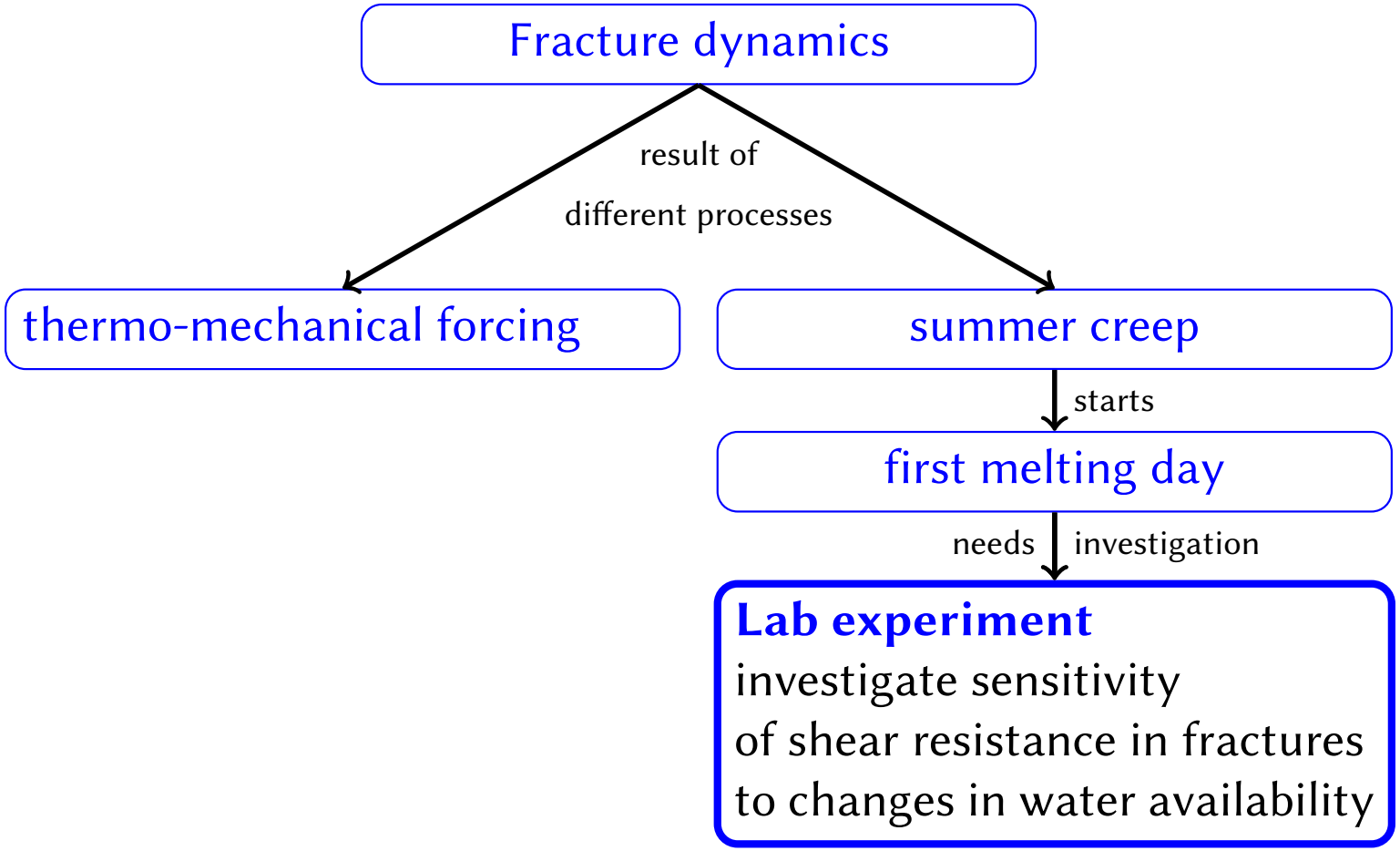
Lab experiment *why?*



Lab experiment *why?*



Lab experiment *why?*



Lab experiment *friction in fractures, sensitivity to changes*

Motivation
Linking field observations with mechanical laboratory observations

Approach
Friction test in lab

Methodology
Shear tests under different temperature condition with varying water/ice availability