Risk assessment and adaptation strategies for infrastructure on permafrost in the French Alps

Pierre-Allain Duvillard[1,2]
Ludovic Ravanel[1]
Philippe Schoeneich[2]
Philip Deline[1]
Marco Marcer[2]
Florence Magnin[1]
pierre-allain.duvillard@univ-smb.fr

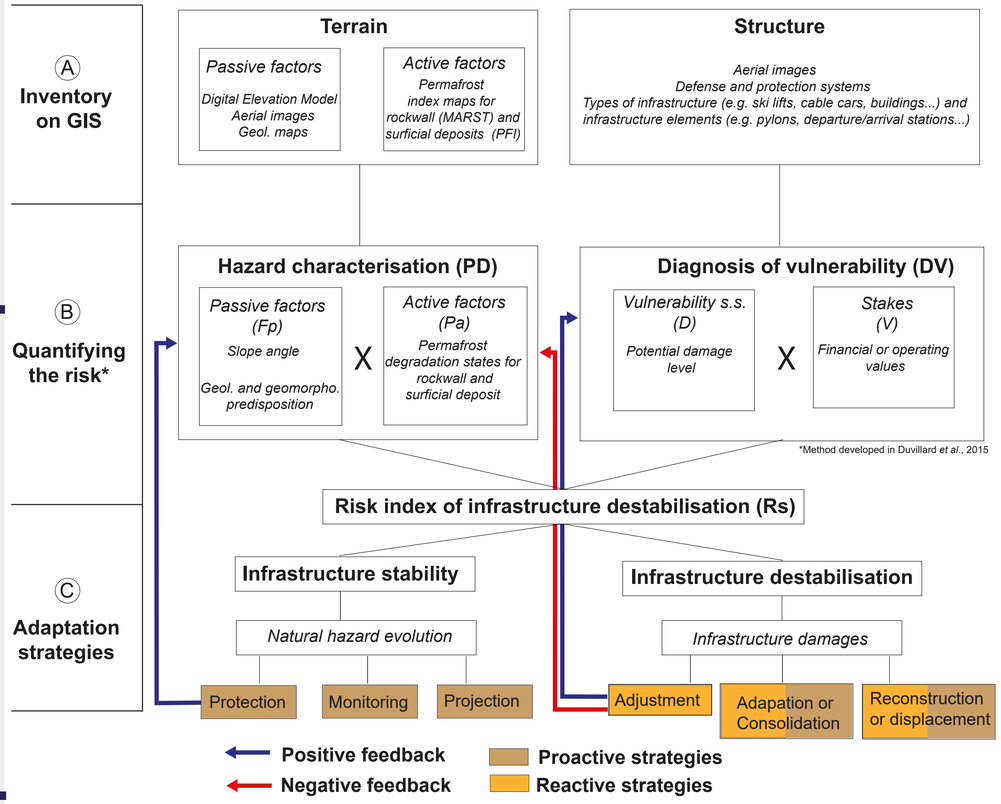
A Inventory of infrastructure elements

- An inventory of infrastructure elements located in permafrost areas using a Geographical Information System (Duvillard *et al.*, 2015)

- **947 infrastructure elements** (between 2430 and 4363 m a.s.l.)

- 74 % of the infrastructure inventoried involve ropeway transport systems located in high-altitude ski resorts

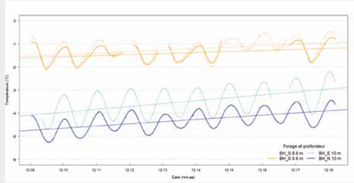
3 different steps:



C Adaptation strategies

Proactive ("response capacity")

to prevent a destabilization with the monitoring of thermal permafrost state and small movements



3 infrastructures elements

e.g. monitoring of thermal permafrost state since 10 years in the Aiguille du Midi (3842 a.s.l.)

Reactive ("coping capacity")

after damages requiring repairs or adjustments of the structure

16 infrastructures elements

e.g. laterally adjustable pylons

A coupling of proactive and reactive resiliences

7 infrastructures elements

B Risk index application

- Application of the risk index proposed by Duvillard *et al.* (2015) and updated for this hazard characterisation using recent permafrost maps

- 16 % are characterised by a high risk of destabilization, and one infrastructure by a very high risk

- 84 % of the infrastructure elements are indicated as stable according to the risk index (4 % low, 35 % limited and 45 % marked)

e.g. Grands Montets cable-car (3275 m a.s.l, Mont Blanc massif)

Rs = (PD × DV)
with PD = Fp x Pa

Granite very fractured with rock slope around 39° ⟶ Fp = 0.8

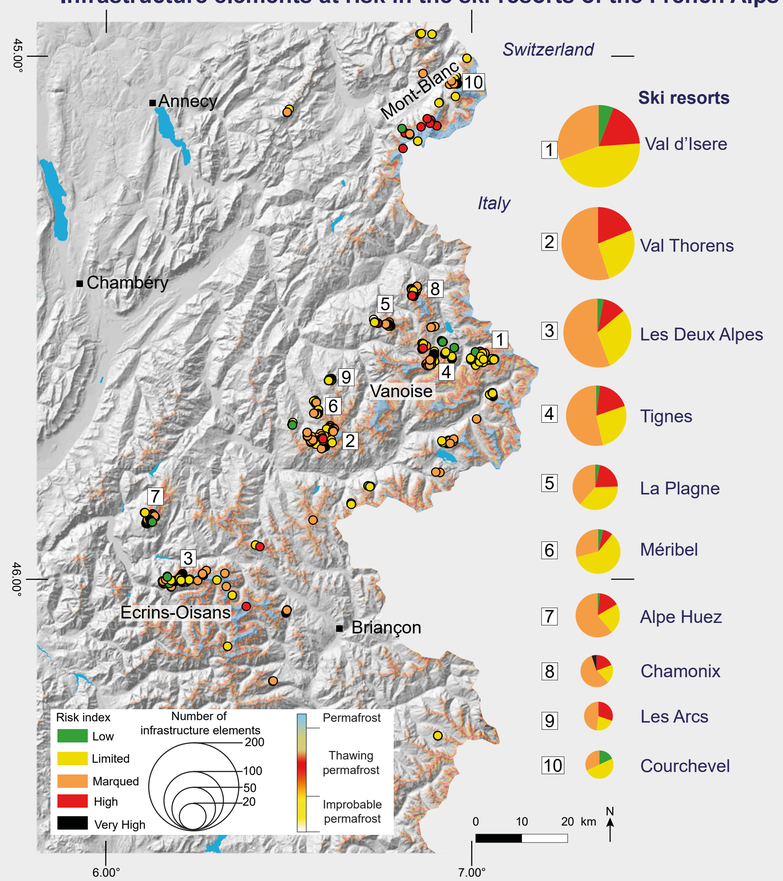
Thawing permafrost ⟶ Pa = 0.8

Cable car arrival station ⟶ D = 0.8

Stakes ⟶ V = 0.9

Rs = [(0.64 (0.8 × 0.9)]
= 0.46
= Very high

Infrastructure elements at risk in the ski-resorts of the French Alps



Possible feedback

⟵ Positive feedback

Infrastructure built with geotechnical solutions adapting to the presence of permafrost

⟵ Negative feedback

Rebuilding or maintenance could locally accelerate the permafrost degradation due to heat input from the work

References

Duvillard P.-A., Ravanel L., Deline P. (2015). Risk assessment of infrastructure destabilisation due to global warming in the high French Alps. *Journal of Alpine Research*. 103 (2). https://doi.org/10.4000/rga.2896

Duvillard P.-A., Ravanel L., Marcer M., Schoeneich P. (2019). Recent evolution of damage to infrastructure on permafrost in the French Alps. *Reg. Environ. Change*. https://doi.org/10.1007/s10113-019-01465-z

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