A crumbling giant

Seismic constraints on rock damaging and stick-slip motion at the Hochvogel, Alps

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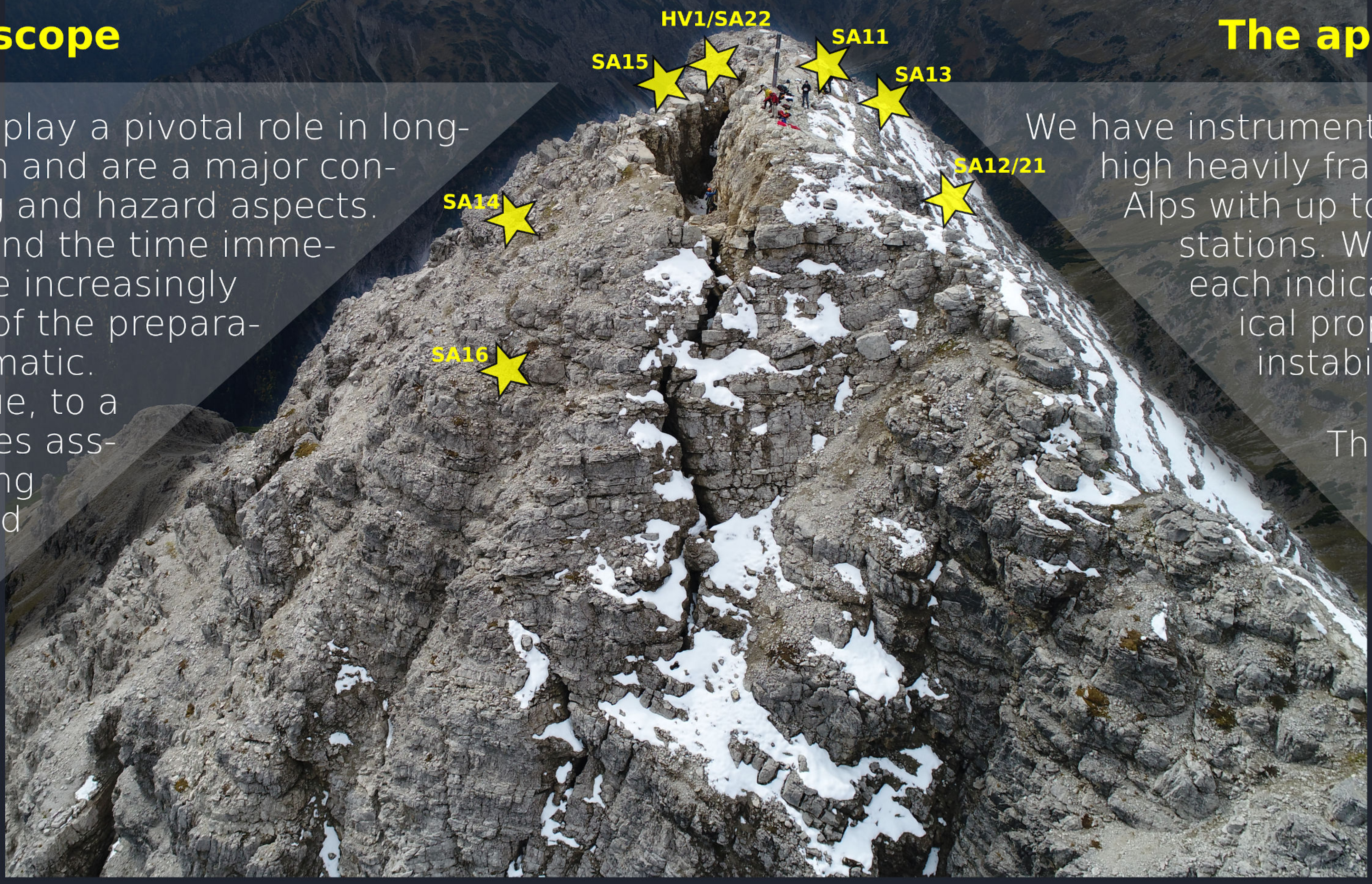
Why bother? – The scope

Large rock slope failures play a pivotal role in long-term landscape evolution and are a major concern in land use planning and hazard aspects. While the failure phase and the time immediately prior to failure are increasingly well studied, the nature of the preparation phase remains enigmatic. This knowledge gap is due, to a large degree, to difficulties associated with instrumenting high mountain terrain and the local nature of classic monitoring methods[1-3], which does now allow for an integral observation of large rock volumes, or results in limited temporal resolution.



The approach and study site

We have instrumented the Hochvogel, a 2600 m high heavily fractured limestone peak in the Alps with up to seven telemetric geophone stations. We analyse different products, each indicative of another rock mechanical property of the 260000 m³ large instability, which prepares to fail[4,5].

The seismic approach allows to continuously sense rock properties at high temporal resolution. In addition, we detect discrete signals of rock cracking, indicative of rock bridge failures.

We relate the rock state proxy data to supposed external drivers.

In a nutshell

Seismic data allows a continuous and spatially integrated survey of an entire instable mountain peak.

The mass shows a stick-slip cyclicity with 5–7 days of stress building up and 1–2 days of motion and stress release.

At the diurnal scale, subcritical processes result in opening and closing of fissures that control rock mass coupling efficiency.

At the seasonal scale, water is the dominant driver, acting as lubricant, with clear activity in spring, ceasing in late summer.

The methods

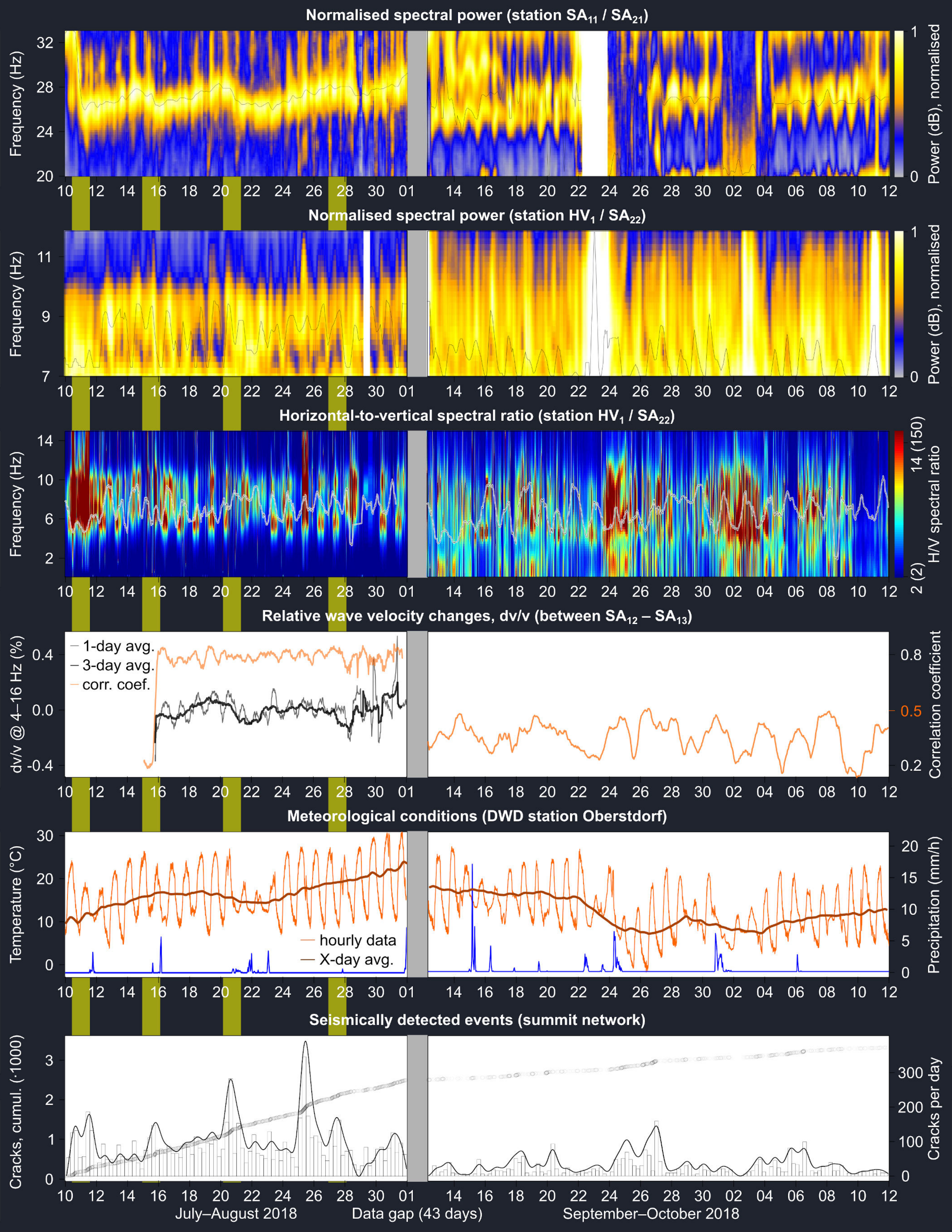
Fundamental frequency analysis (vertical) senses the "stamping hum" of the peak and is controlled by temperature and stress[6].

Fundamental frequency analysis (horizontal) represents the tilting and bending modes of the rock mass.

HVSR is a proxy for the stiffness of the rock mass and/or the coupling efficiancy between bedrock and detaching towers[7,8].

dv/v, seismic wave velocity change is a proxy for stress, water content and structural integrity of the rock mass[9,10].

Meteorological conditions are supposed to be first order drivers of failures. Seismic crack signals allow to resolve breaking of rock bridges and sudden slip on a progressively developing failure plane[10].



Results & Discussion

Gradual frequency rise is due to continuous stress building up, which is released during brief slip events that lower the frequency by 2–4 Hz, again.

Bending & twisting is dominant at the diurnal scale, only. It shows no relation to the longer cycle periodicities.

Diurnally forced temperature change opens and closes fractures that weaken and enforce the coupling of blocks to the intact rockmass (6 vs. 11 Hz).

Wave velocity (dv/v) is not a superiour proxy. The short correlation lengths indicate severe fracturing of the rock between the seismic sensors.

Temperature drives the subcritical diurnal effects, rain does not play an effective short scale role, but sets the seasonal stick-slip activity. Crack signals indicate slip phases, coinsiding with stres release.

References: 1 – Collins B, Stock GM, Eppes MC, Lewis SW, Corbett SC, Smit JB. 2018. Thermal influences on spontaneous rock dome exfoliation. Nature Communications 9:762: 1–12. https://doi.org/10.1038/s41467-017-02728-1 | 2 – Di Maio C, Vassallo R, Vallario M, Pascale S, Sdao F. 2010. Structure and kinematics of a landslide in a complex clayey formation of the italian southern apennines. Engineering Geology 116(3): 311–322. https://doi.org/10.1016/j.enggeo.2010.09.012 | 3 – Dixon N, Smith A, Flint JA, Khanna R, Clark B, Andjelkovich M. 2018. An acoustic emission landslide early warning system for communities in low-income and middle-income countries. Lanslides 15: 1631–1644. | 4 – Krautblatter M, Mayer C, Münzer U, Siegert F, Stilla U, Wunderlich T, Kraushaar S, Keuschnig M, Leinauer J, Friedrich B, Jacobs B, Scandroglio R, Wittmann M, Emmert A, Hoegner L, Raffl L, Reith C, Van der Laan L, Hermle D, Pläsken R. 2019. The alpsense-project: Alpine remote sensing of climate-induced natural hazards. Geophysical Research Abstracts 21: 17541 | 5 – Leinauer JM, Jacobs B, Krautblatter M. 2020. Anticipating an imminent large rock slope failure at the hochvogel (allgäu alps). Geomechanics and Tunneling.

References: 6 – Bottelin P, Lévy C, Baillet L, Jongmans D, Guéguen P. 2013. Modal and thermal analysis of les arches unstable rock column (vercors massif, french alps). Geophysical Journal International 194: 849–858. https://doi.org/10.1093/gji/ggt046 | 7 – Overduin PP, Haberland C, Ryberg T, Kneier F, Jacobi T, Grigoriev MN, Ohrnberger M. 2015. Submarine permafrost depth from ambient seismic noise. Geophysical Research Letters 42(18): 7581–7588. https://doi.org/10.1002/2015GL065409 | 8 – Lévy C, Baillet L, Jongmans D, Mourot P, Hantz D. 2010. Dynamic response of the chamousset rock column (western alps, france). Journal of Geophysical Research: Earth Surface 115(F4): F04043. https://doi.org/10.1029/2009JF001606 | 9 – Hobiger M, Wegler U, Shiomi K, Nakahara H. 2014. Single-station cross-correlation analysis of ambient seismic noise: application to stations in the surroundings of the 2008 iwate-miyagi nairiku earthquake. Geophysical Journal International 198(1): 90–109. 10 – Dietze M, Cook KL, Illien L, Rach O, Puffpaff S, Stodian I, Hovius N. 2020. Impact of nested moisture cycles on coastal chalk cliff failure revealed by multiseasonal seismic and topographic surveys. Journal of Geophysical Research: Earth Surface 125(8): e2019JF005487. https://doi.org/10.1029/2019JF005487