THE EARTH SURFACE PLAYGROUND

Investigating the processes that shape the Earth – from the past and from the modern perspective

ENVIRONMENTAL SEISMOLOGY

GRAIN-SIZE DATA MODELLING

LUMINESCENCE FRAMEWORK

SUBITOP PROJECT MANAGEMENT

GFZ
Helmholtz Centre
POTSDAM

The melody of a failing peak

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

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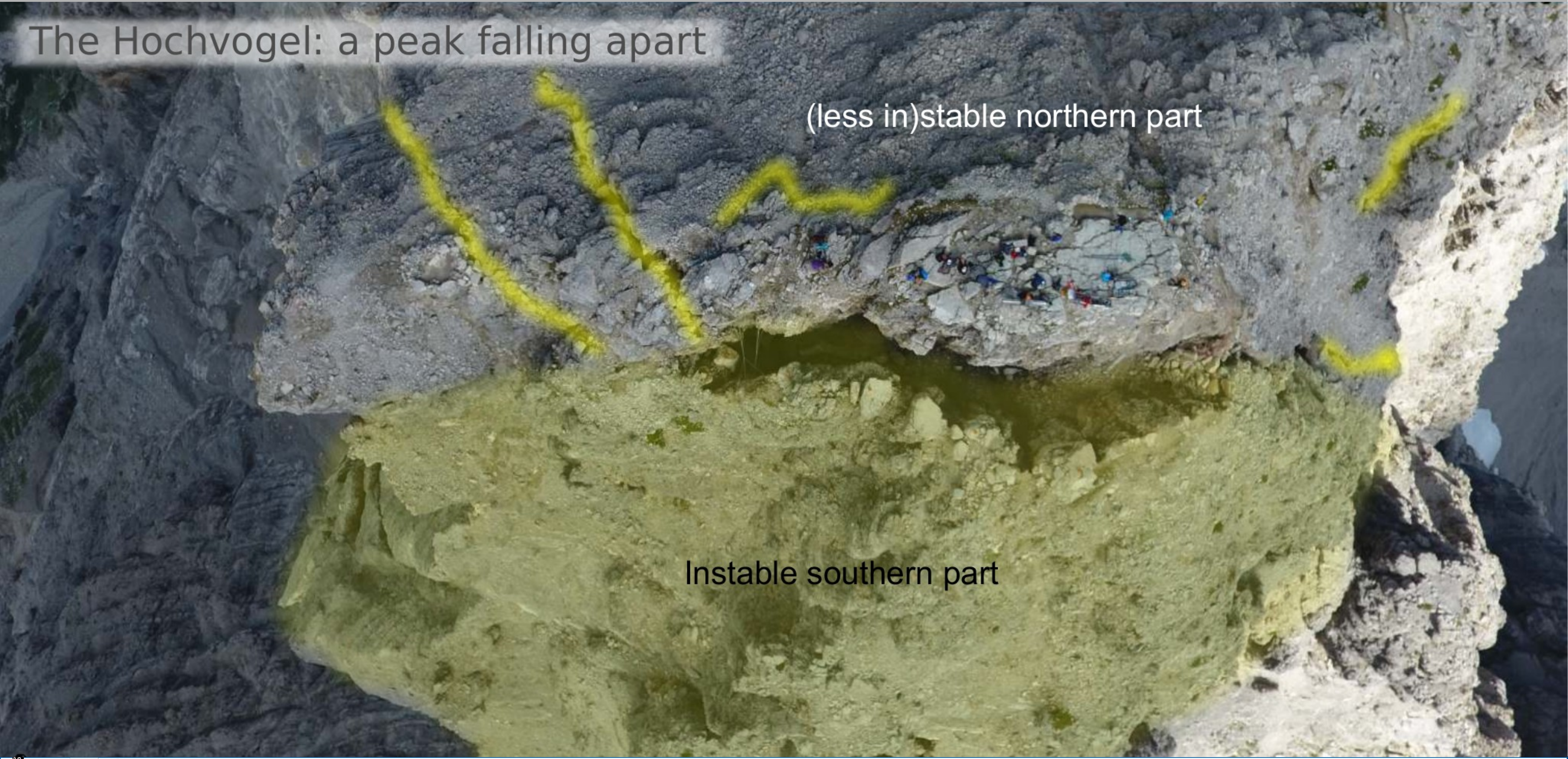
The Hochvogel: a peak falling apart

A 2600 m high, heavily fractured peak with abundant failure planes developing

The Hochvogel: a peak falling apart



The southern (Austrian) side will release 260,000 m³ of material into the Hornbachtal

BUT STOP, WHY ARE WE THERE FIRST OF ALL?

Mass wasting life time	Preconditioning	Preparation	Critical phase	Failure phase	Relaxation
Survey tech-niques	(✓)	?	✓	✓	✓

The preparation phase is the least well constrained phase in the lifetime of a major mass wasting event.

But why? What are the unknowns?

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Survey tech-niques	(✓)	?	✓	✓	✓

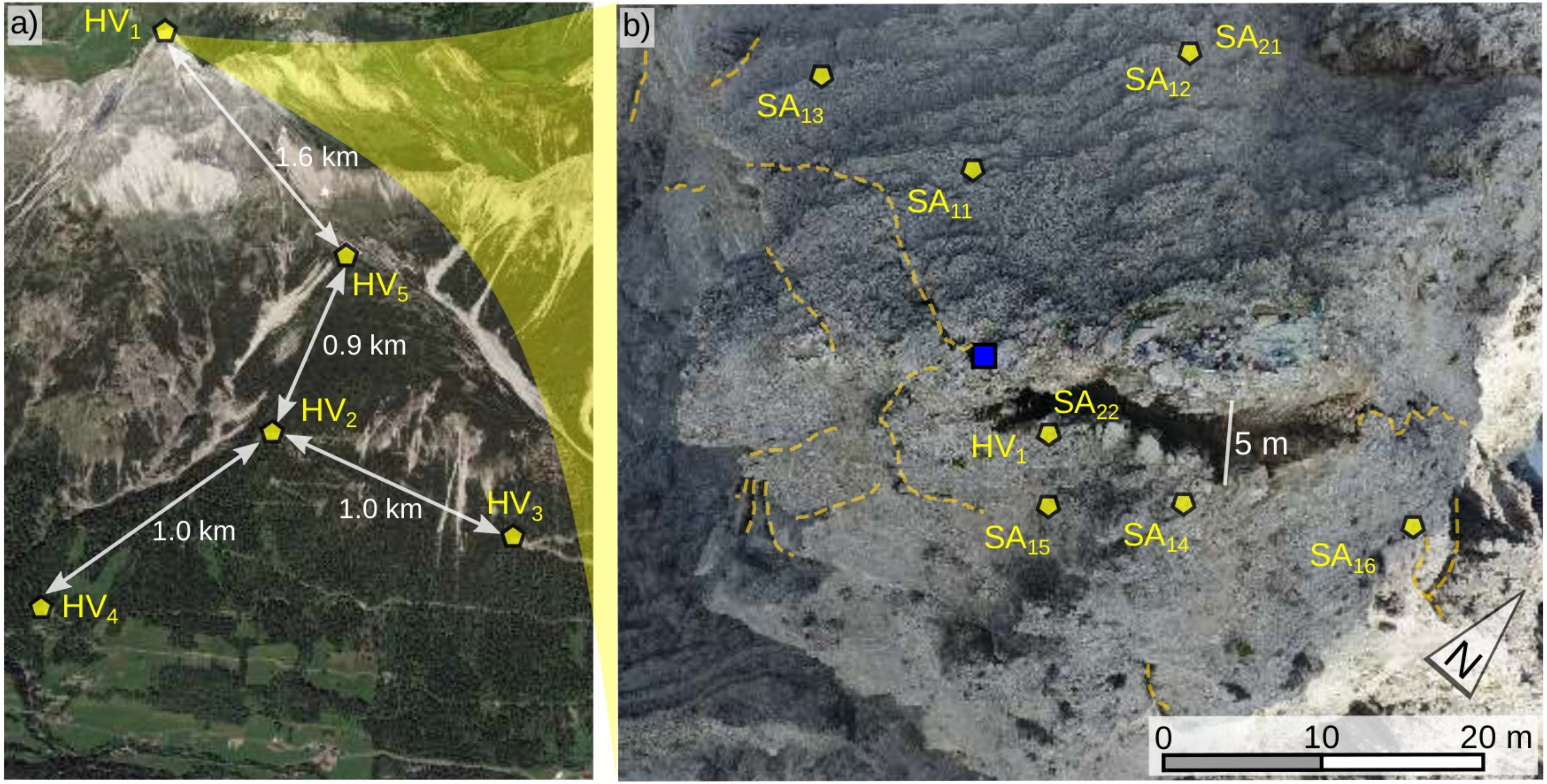
Issues with the topic

- Mechanisms and their interplay?
- Where on the trajectory are we?
- What are the signal expressions?
- Brief episodic (stochastic) events

- What should we look for?
- How can we look for this?
- How to interprete what we sense?
- When does random become systematic?

Hence: Classic survey techniques reach a limit because they are either spatially narrow (point/line meansurement) or temporally discrete (scan surveys).

SO WHY NOT USING SENSOR NETWORKS WITH A WIDE DETECTION RANGE OF PHYSICAL PROCESSES?



Installation of seismic sensors on the peak and down slope

SO WHY NOT USING SENSOR NETWORKS WITH A WIDE DETECTION RANGE OF PHYSICAL PROCESSES?

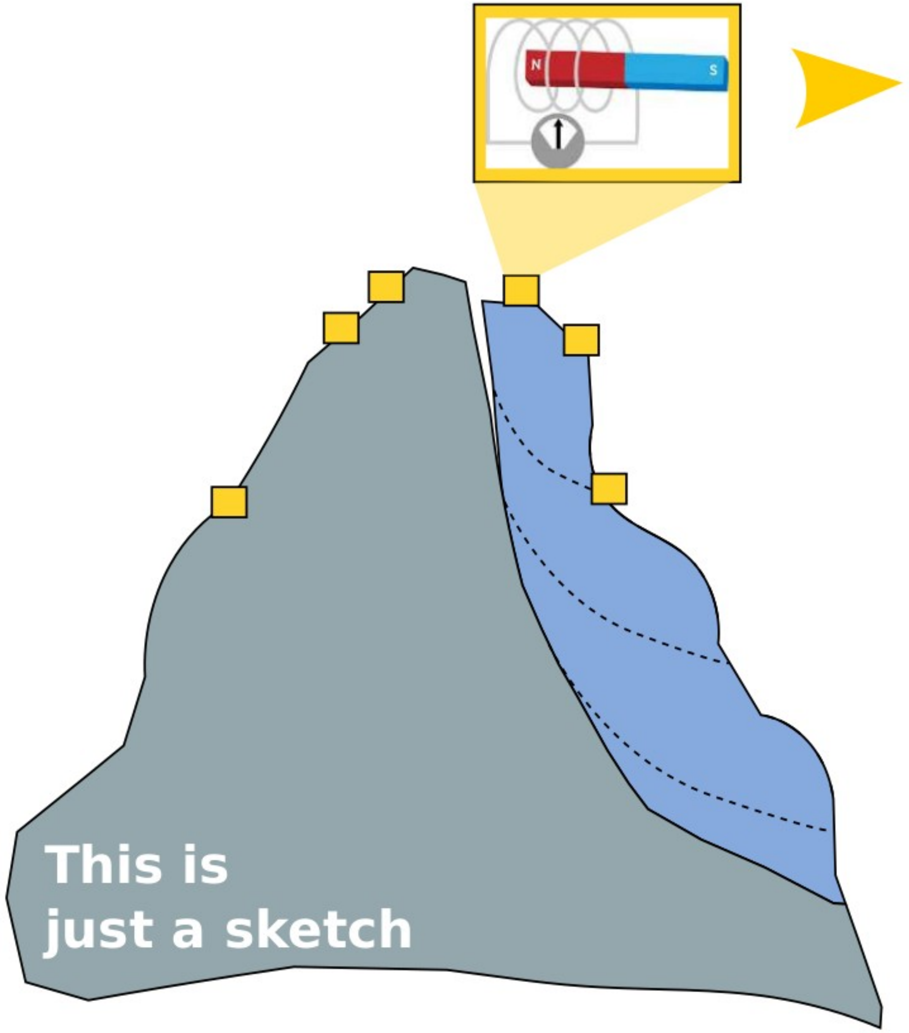
A shiny installation

A lightning strike (15k€)

Lesson learned (Faraday)

Installation of seismic sensors on the Hochvogel peak, early summer 2019

SO WHY NOT USING SENSOR NETWORKS WITH A WIDE DETECTION RANGE OF PHYSICAL PROCESSES?



Evolution of properties

Characteristic **frequency**

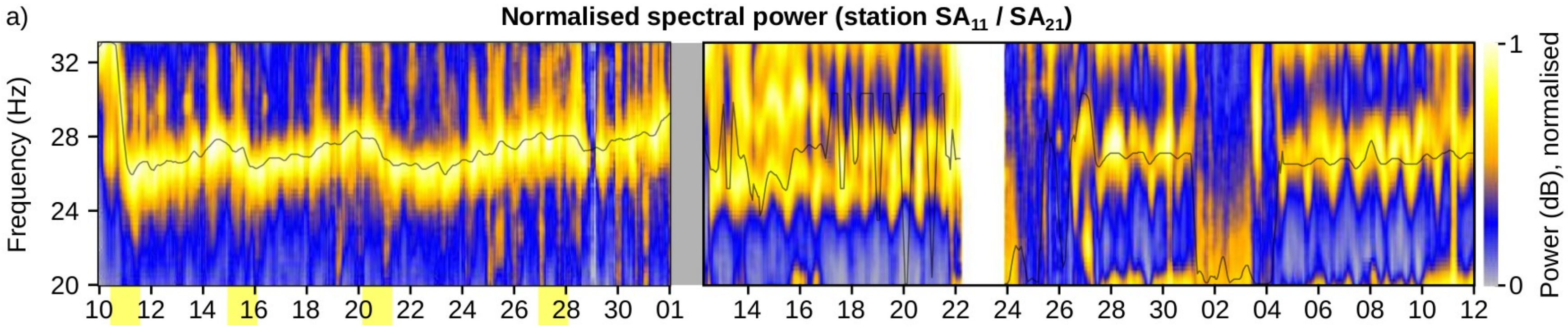
H/V **spectral** ratios

Relative wave **velocity** changes (dv/v)

Discrete features

Rate of rock fracture **signals**

FUNDAMENTAL FREQUENCY ANALYSIS (NORMALISED SPECTRA CLEANED FROM DISCRETE EVENTS)



The peak's fundamental frequency (it's “hum”) in vertical direction shows cyclic increase and de-crease patterns

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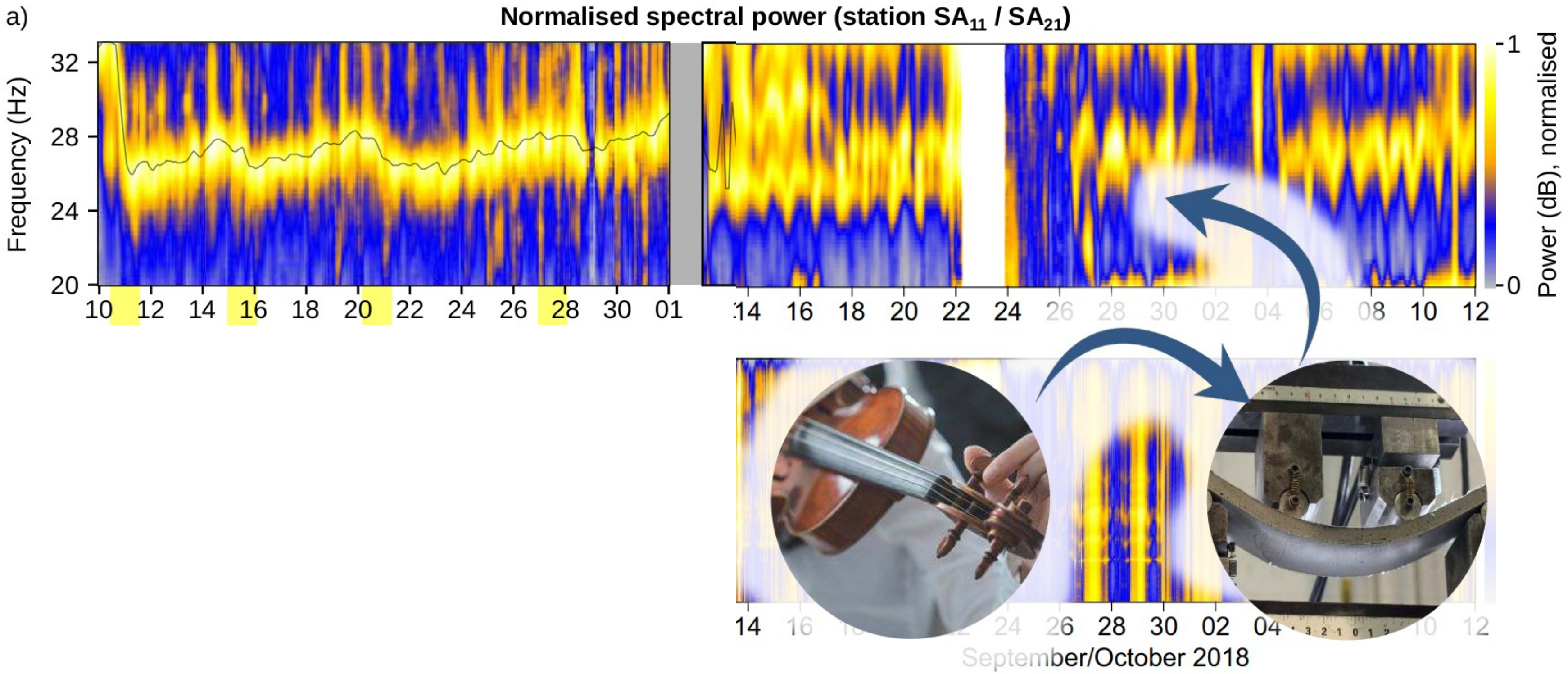
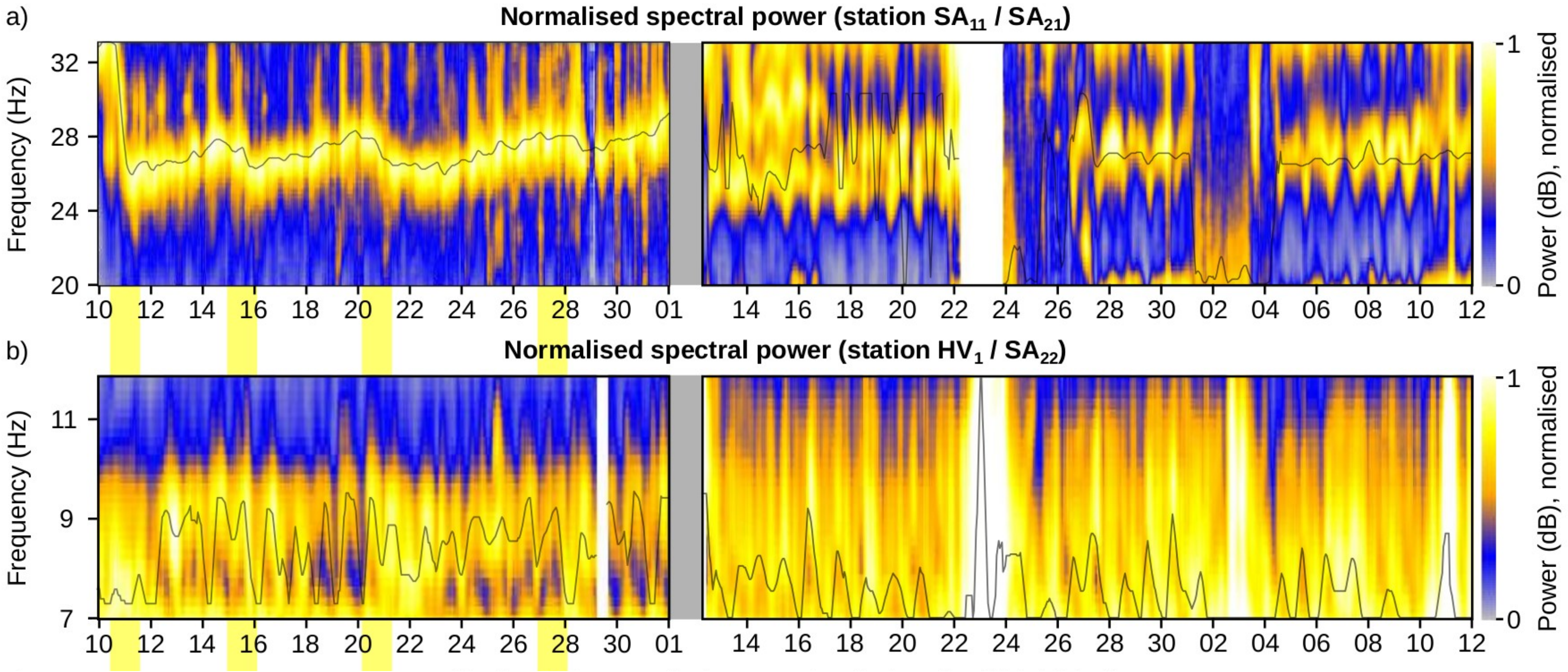


The peak's fundamental frequency (it's "hum") in vertical direction shows cyclic increase and decrease patterns

Like tuning a violin, with increasing internal stress the fundamental frequency goes up.

Note that superimposed on the multi day pattern, there is also a diurnal pattern, which dominates the late summer season.

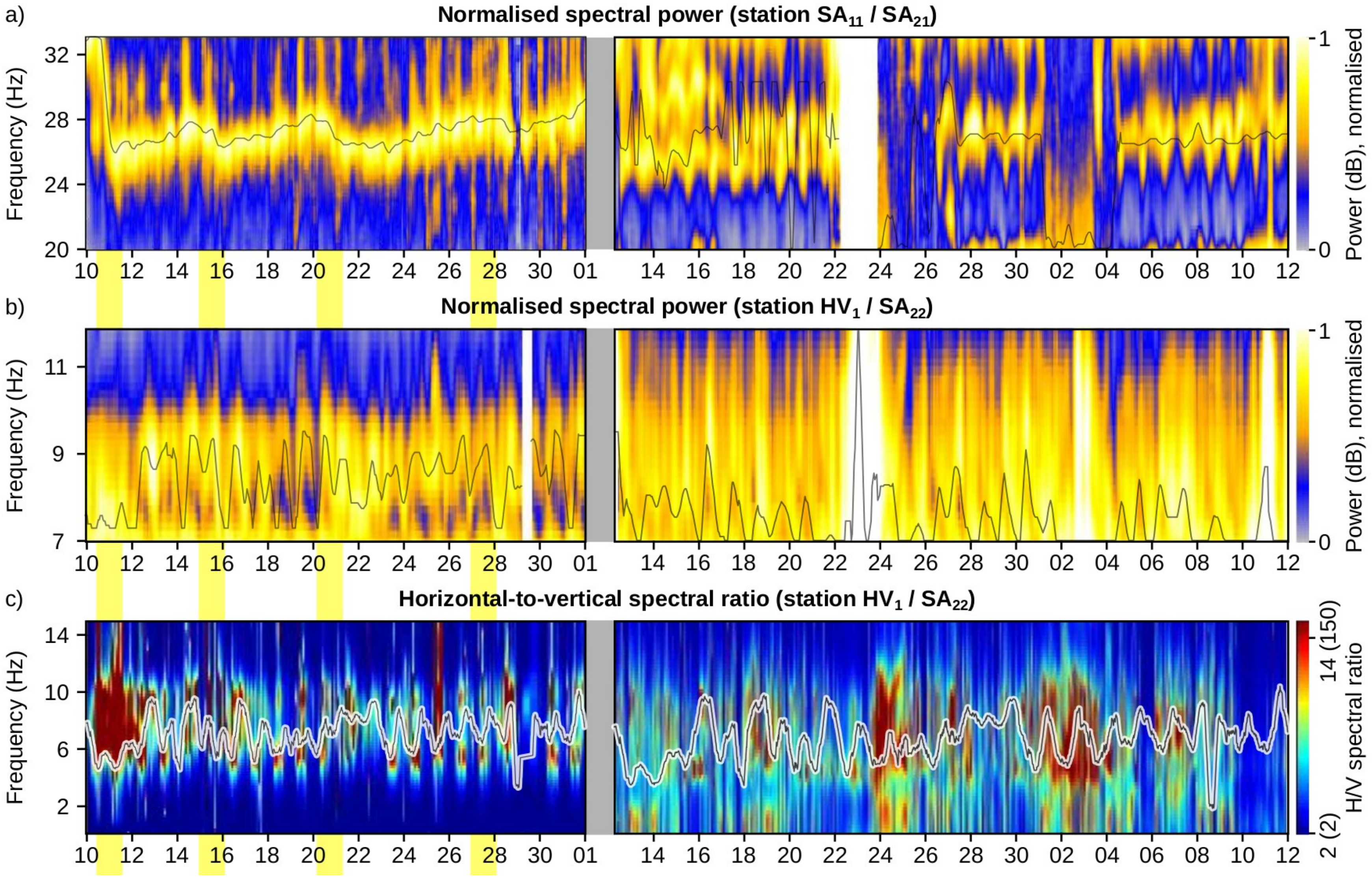
FUNDAMENTAL FREQUENCY ANALYSIS (NORMALISED SPECTRA CLEANED FROM DISCRETE EVENTS)



The peak's fundamental frequency (it's "hum") in vertical direction shows cyclic increase and de-crease patterns

In the horizontal direction, only the diurnal pattern is visible in the data.

CALCULATING RATIOS BETWEEN HORIZONTAL AND VERTICAL FREQUENCY SPECTRA (HVSR)

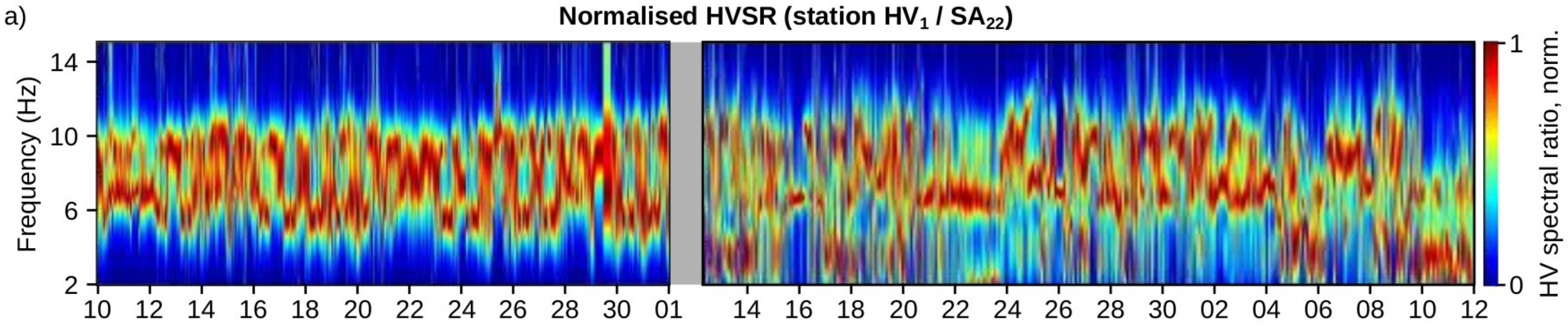


The peak's fundamental frequency (it's "hum") in vertical direction shows cyclic increase and de-crease patterns

In the horizontal direction, only the diurnal pattern is visible in the data.

Explicitly plotting the horizontal-to-vertical spec-tral ratios (HVSR) shows a clear diurnal pattern.

INCREASING RESOLUTION & QUANTIFYING VISUAL IMPRESSIONS: SPECTRAL END-MEMBER MODELLING



The HVSR data set seems to swing between two distinct end-members. Such end-members can be quantified by an explicit modelling approach (EMMA).

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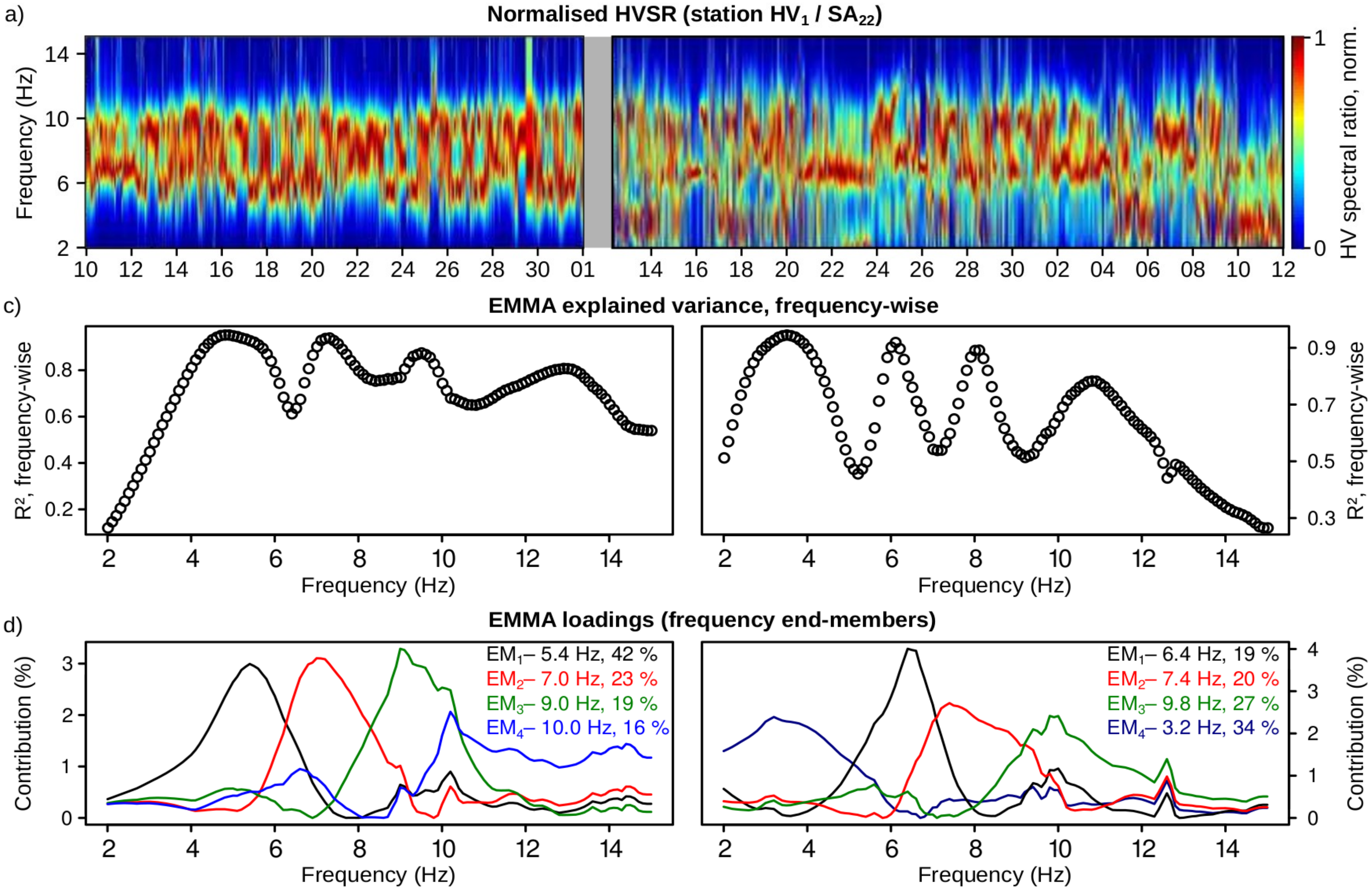
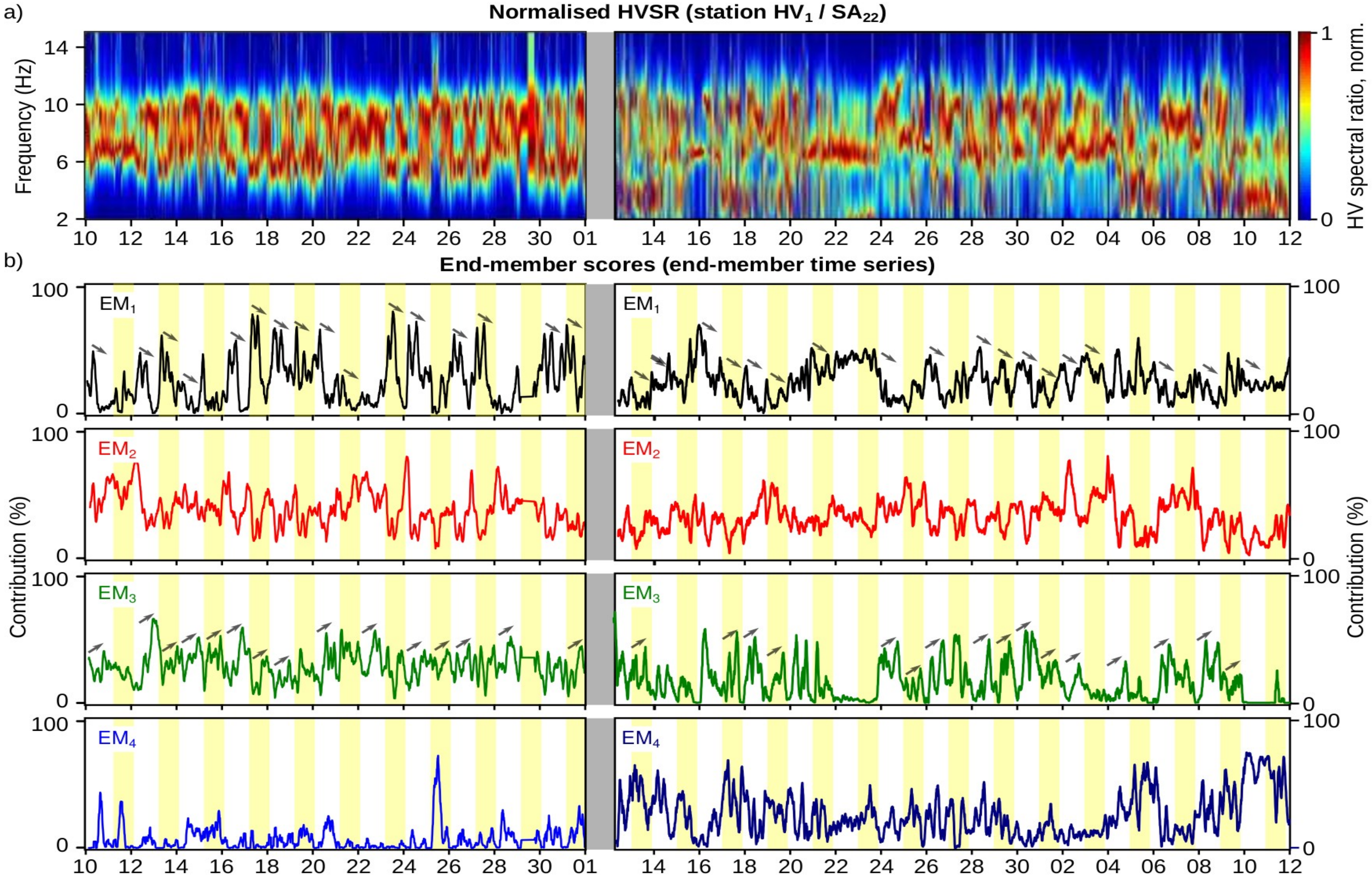


The HVSR data set seems to swing between two distinct end-members. Such end-members can be quantified by an explicit modelling approach (EMMA).

EMMA (Dietze & Dietze, 2019) decomposes multimodal data sets into inherent populations, i.e. frequency distributions or loadings and their relative contributions to each spectrum, i.e., scores (see next slide).
The Hochvogel HVSR data consist of four populations: EM1–EM4.

INCREASING RESOLUTION & QUANTIFYING VISUAL IMPRESSIONS: SPECTRAL END-MEMBER MODELLING

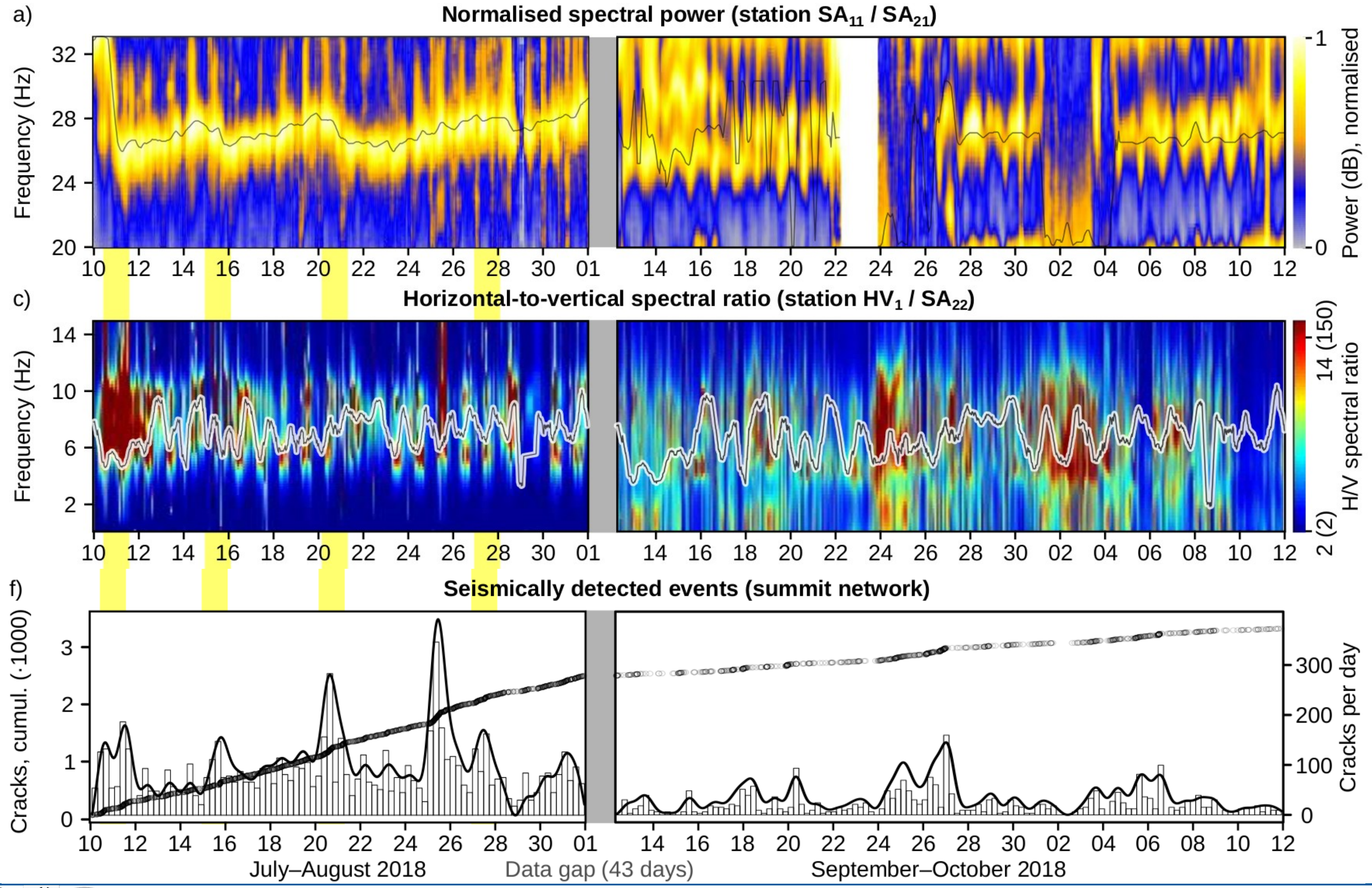


EM1 (5.4 Hz) is highest during the cold, early hours of the day.
EM3 (9.0 Hz) is highest towards the warm, late hours of the day.
EM2 mediates EM1 and EM3 and EM4 represents noise.

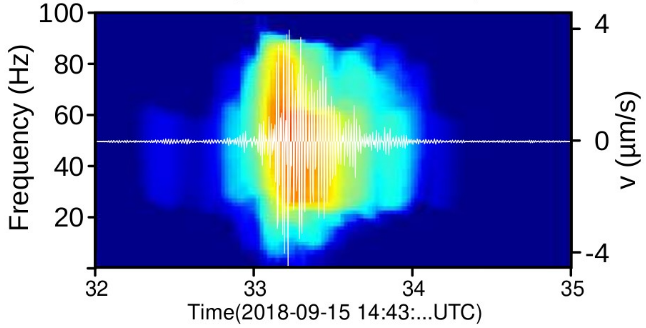
Throughout the year, EM frequencies gradually rise.

Hence, EMMA quantifies diurnal, subcritical stiffening and weakening of the rock mass contacts (sensu Lévy et al., 2010).

SWITCHING FROM GRADUAL CHANGE TO DISCRETE SIGNAL PATTERNS: CRACK SIGNAL ANALYSIS



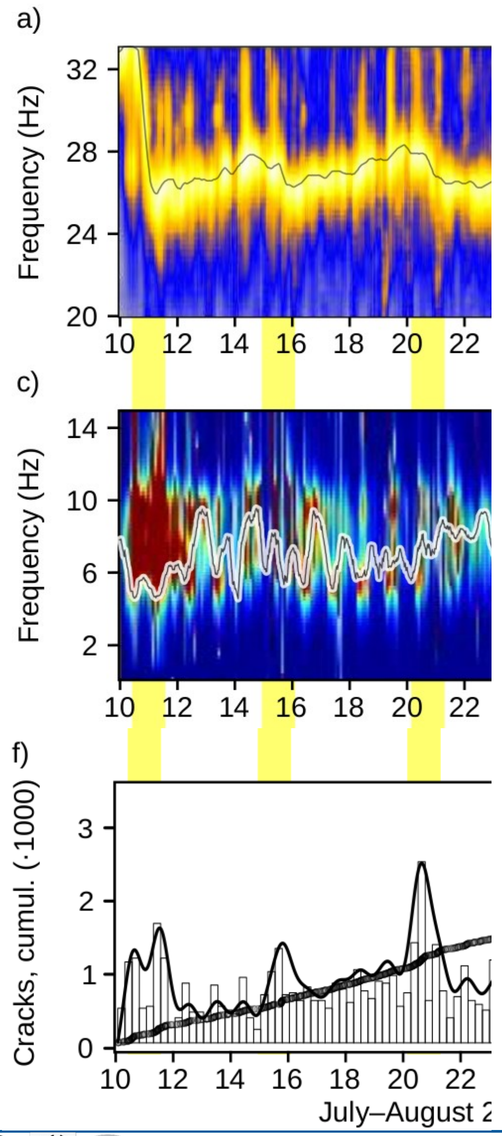
We can add a third line of argument by plotting a time series of seismically detected rock crack signals.



Brief pulses of 20–80 Hz signals, located within the summit area are indicative failing rock bridges.

Note how fundamental frequency drops coincide with increased crack activity.

PUTTING THE EVIDENCE TOGETHER – A SYNTHESIS



Fundamental frequency as proxy for rock internal stress evolution shows a cyclic pattern with multi-day length.
During 1–2 days of stress release, there is an enhanced occurrence of rock crack signals (up to factor 6).

→ We see an early stage of stick-slip motion

Different dominant fundamental frequency windows (horizonal and vertical components) are visible in the data.

→ Expression of different rock mass bending modes, next: model inversion

There is a diurnal swing between high and low HVSR peak frequencies

→ Thermally driven, non-progressive rock mass coupling increase/decrease

Activity and signal amplitudes petered out during late summer

→ A system running out of lubricant (water) is less active?

Thanks!

See the full study and report at https://onlinelibrary.wiley.com/doi/epdf/10.1002/esp.5034