ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ASSESSMENT OF THE COMPLEX SEISMIC RESPONSE OF GEOLOGICAL STRUCTURES

Donat Fäh
Jan Burjánek, Manuel Hobiger, Clotaire Michel, Stefano Maranò, Valerio Poggi, Marco Pilz, Ulrike Kleinbrod, Ben Edwards, Walter Imperatori, Daniel Roten

Swiss Seismological Service
ETH Zürich

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Local seismic hazard assessment requires our understanding of site-specific ground motion (before a strong earthquake):

1) Interpretation of earthquake recordings using site-amplification from spectral modelling of ground motion:

- Issue of 1D, 2D or 3D resonances ?
- Presence of edge-generated surface waves ?
- Presence of focusing/defocusing effects ?
- Possibility of non-linear soil effects ?

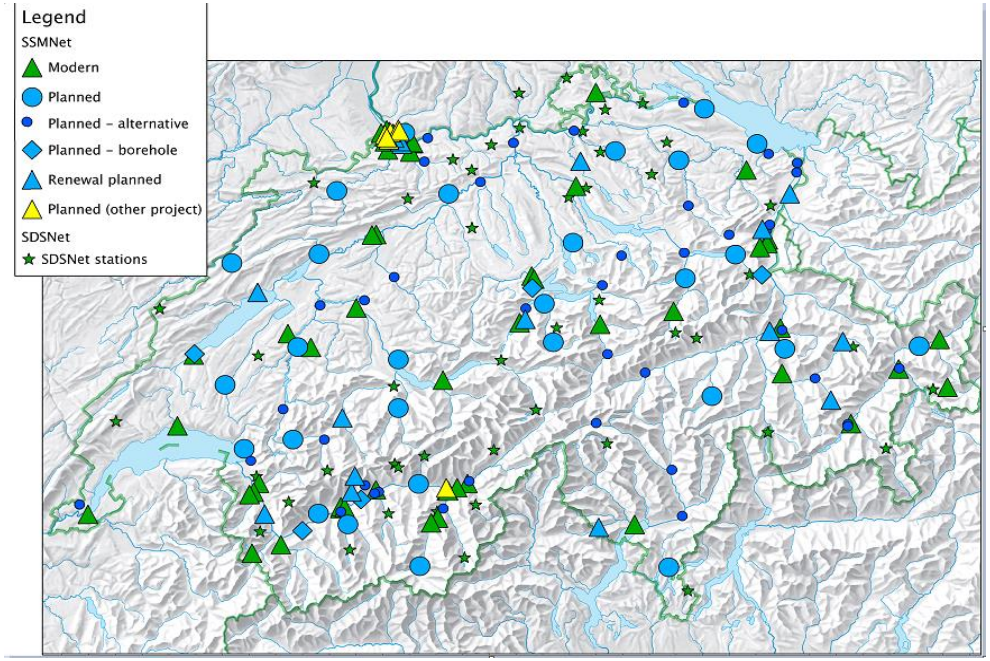
2) Characterization of the sites of seismic stations is key

- Geology, topography, rock interface at depth, fracturing, ..
- Geophysical measurements (f_0 from H/V, S-wave profiles, ...)
- Geotechnical measurements (SPT, CPT, ….)

Site Characterization

Evolving procedures at the Swiss Seismological Service for new permanent seismic stations since 2009

2009: 27 sites (mostly rock sites) in the Pegasos Refinement Project
2013: 30 sites of the Swiss strong-motion network renewal – Phase 1
2014: 16 sites from NagraNet project and Basel mitigation project
2019: 70 sites of the Swiss strong motion network renewal – Phase 2
(For the procedures see Poster by Hobiger et al.)



Ground motion analysis

Site-amplification from spectral modelling of ground motion using the Swiss stochastic ground-motion prediction model for reference rock in the Swiss network (Edwards et al., 2013)

$$\Omega_{ij}(f,r) = \omega \cdot \Omega_i \cdot f_c^{\gamma} / (f_c^{\gamma} + f^{\gamma}) \cdot S_{ij}(r) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot t_{ij}^{*}) \cdot A_j(f) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot K_j)$$

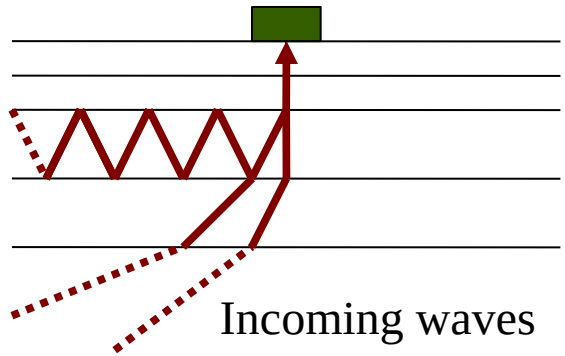
Source Spectrum | Path Effects | Site Effects

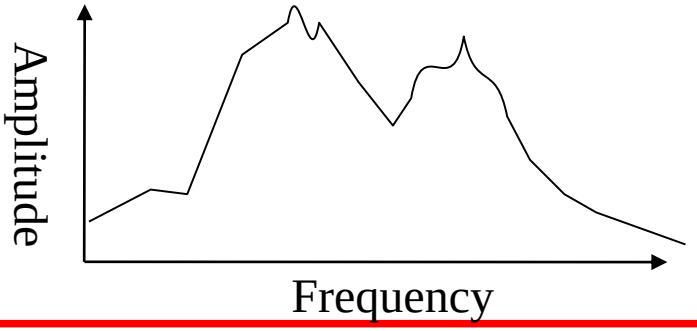
Effect of the upper layers:

Amplification $A_j(f)$

Damping (Kappa K_j)

for a fixed rock-reference measured by using all seismic stations j and all earthquakes i.

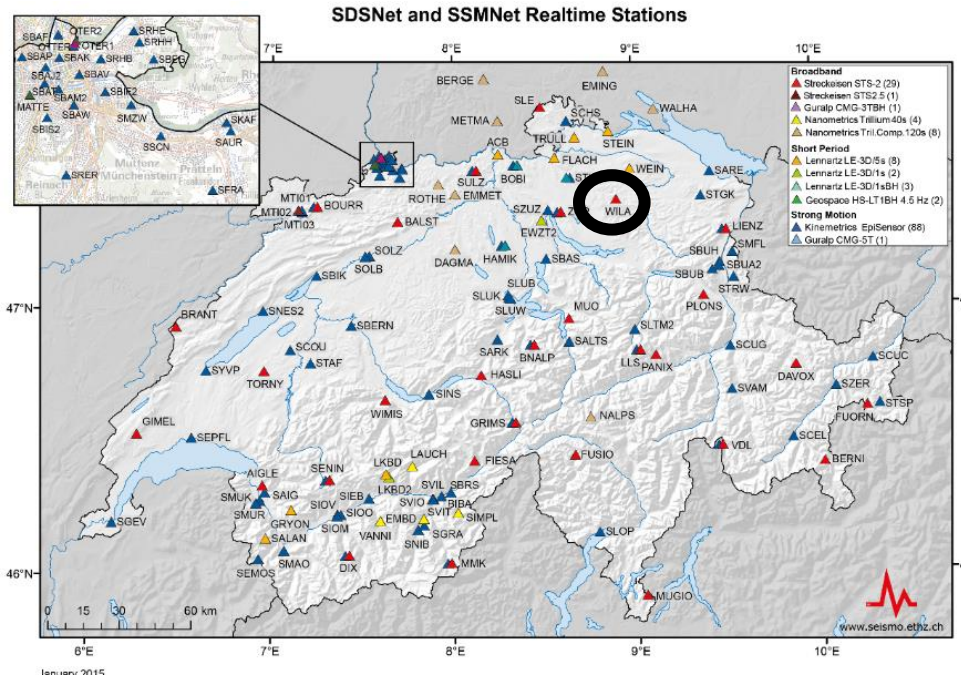


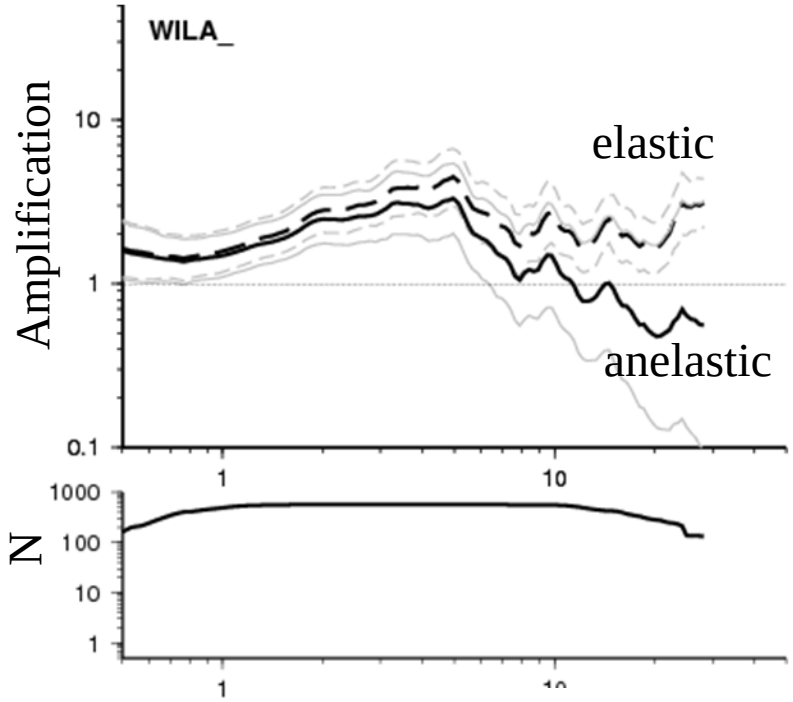


Ground motion analysis

Site-amplification from spectral modelling of ground motion using the Swiss stochastic ground-motion prediction model for reference rock in the Swiss network (Edwards et al., 2013)

Automatic determination of **site-specific empirical amplification** for all stations relative to a fixed reference-bedrock profile.

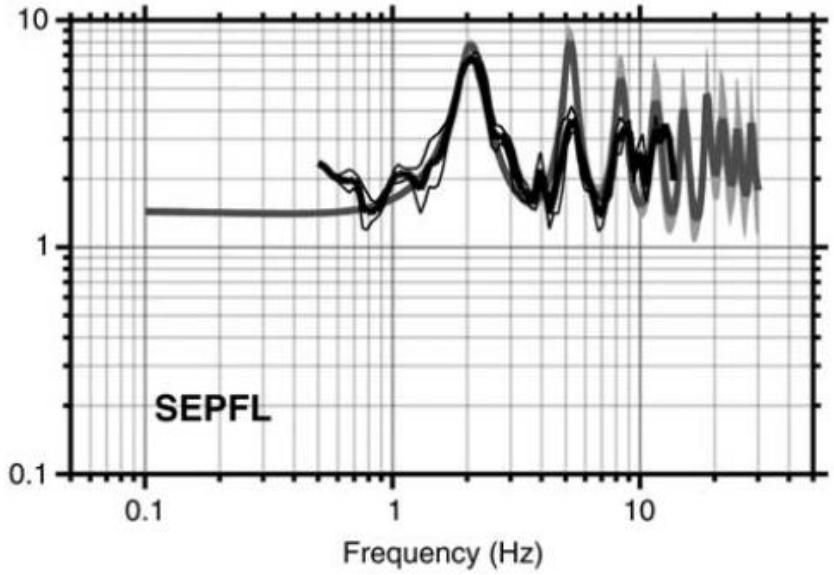




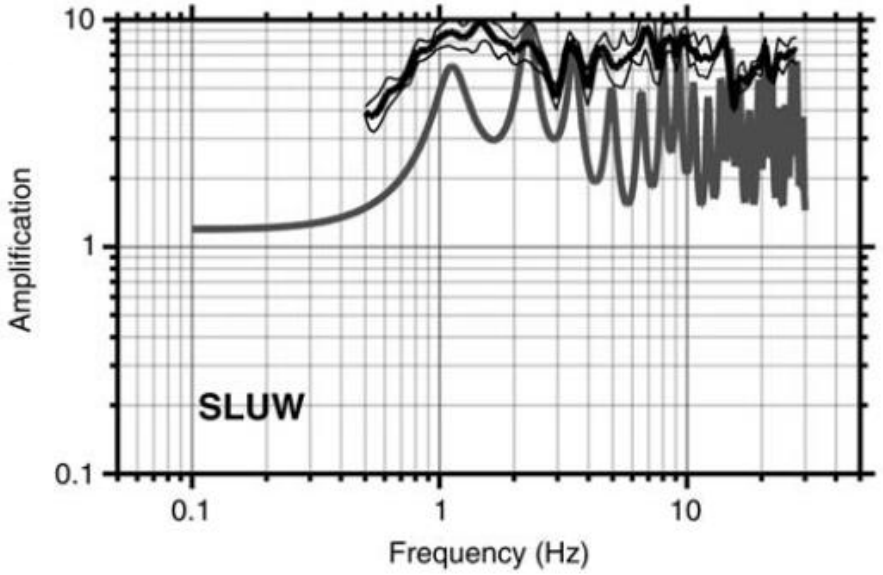
Ground motion analysis

1) **Derive features of the site response** by comparison with computed 1D SH-amplification from the measured velocity profiles.
2) **Tool for the verification of measured velocity profiles.**

Simple 1D response at Lausanne EPFL site



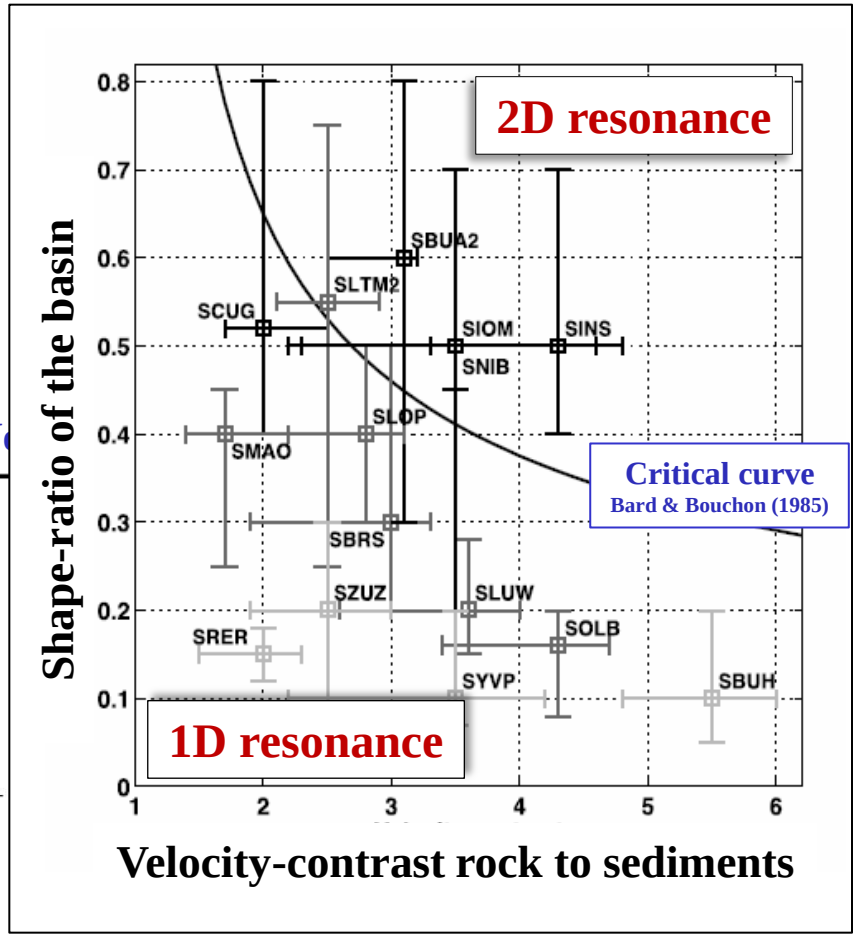
Edge-generated surface waves at Lucerne site

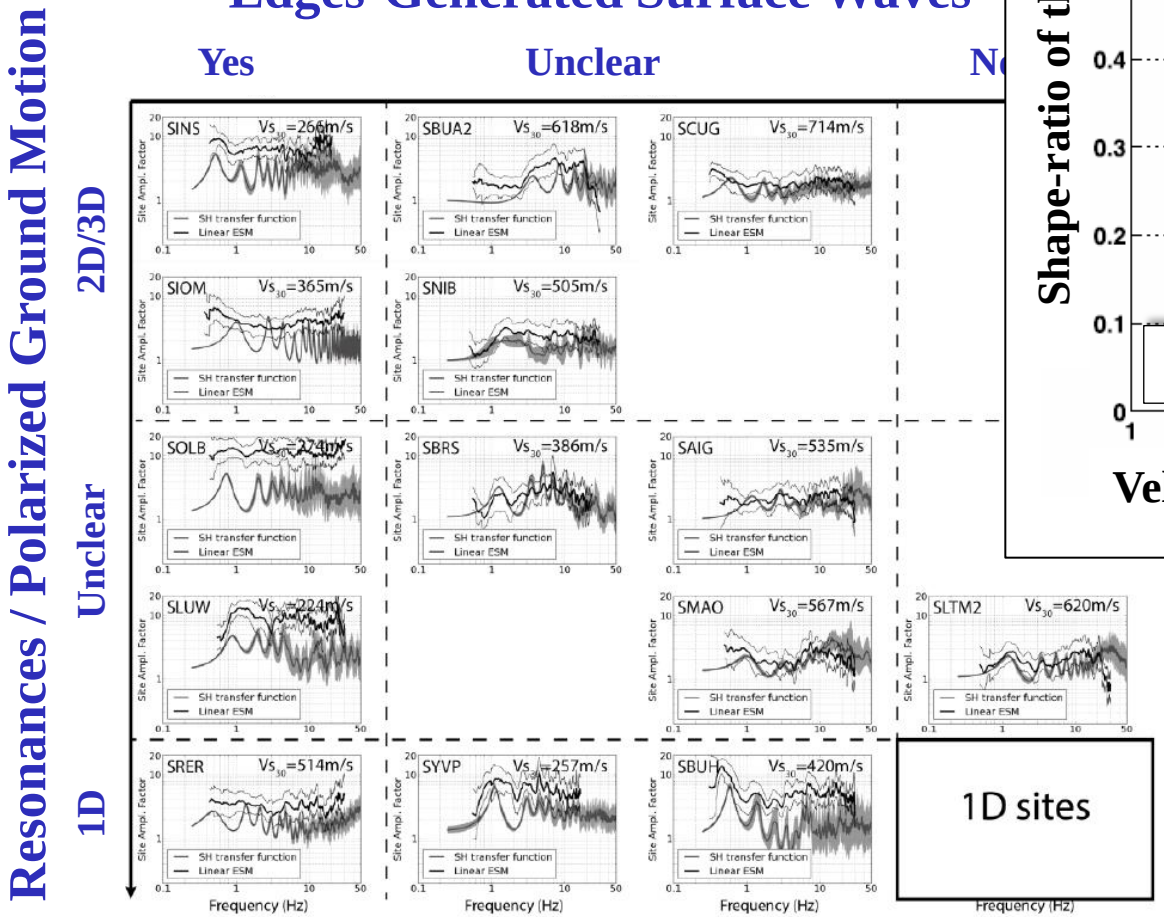


Vs30~200 m/s

Classification of seismic stations

Using site amplification from spectral modelling





Michel et al. (2014)

Characterization of sites

Target from 3C array measurements:

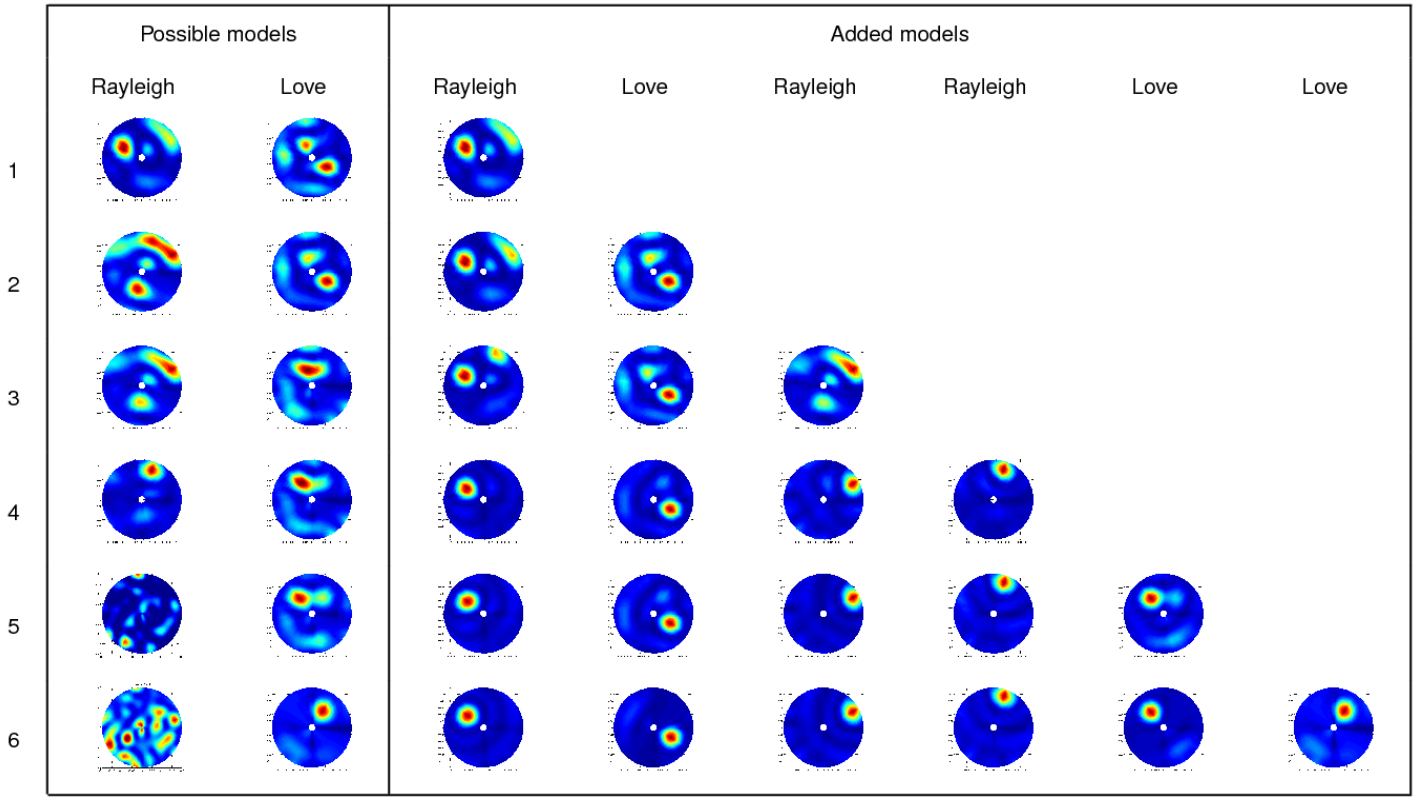
- Rayleigh waves dispersion curves
- Rayleigh waves ellipticity and f_0
- Love waves dispersion curves
- Identification of 2D resonances and polarization features

Methods:

- HRBF: Including interpretation of the horizontal components with directional decomposition
- **Rayleigh wave ellipticity** combining vertical and horizontal information from dispersion curves
- Maximum likelihood method and waveform decomposition
- **Ground-motion polarisation analysis**
- Frequency-domain decomposition to analyse **2D resonances**
- Combination of the ambient vibration methods with active methods
- Verification of inverted profiles with measured amplification

Maximum Likelihood Method

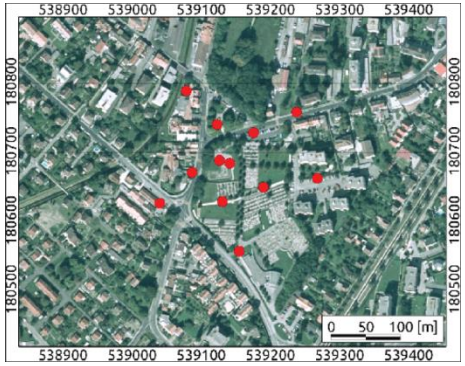
- Treat all stations and all components in the same framework
- Full decomposition of the wavefields
- Detect and characterize small signals in ambient vibrations
- **Ellipticity is obtained at high resolution with sense of rotation**



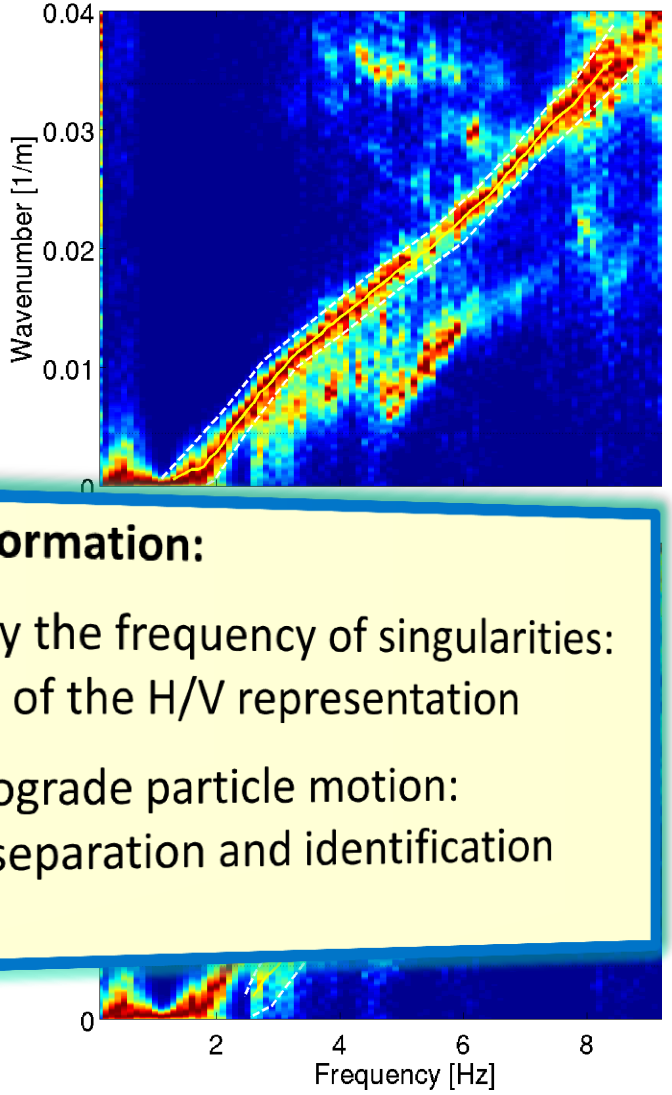
Marano et al. (2012)

Rayleigh wave ellipticity

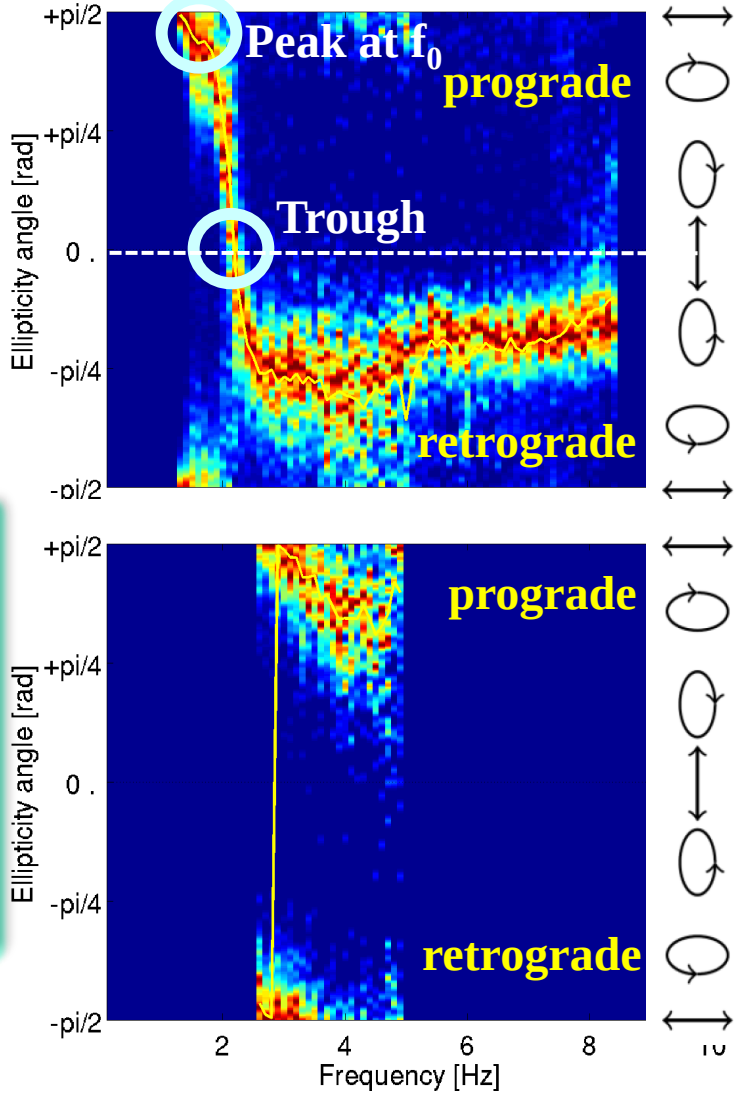
Site Yverdon



Rayleigh wave dispersion curves



Rayleigh wave ellipticity angle



Use of ellipiticty information:

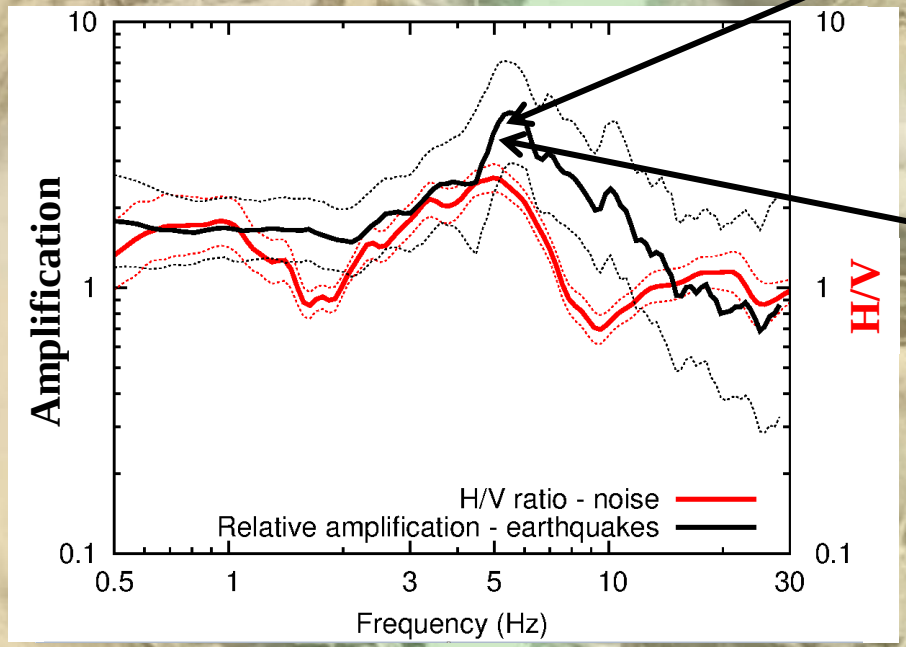
+ pinpoint accurately the frequency of singularities: peaks and troughs of the H/V representation

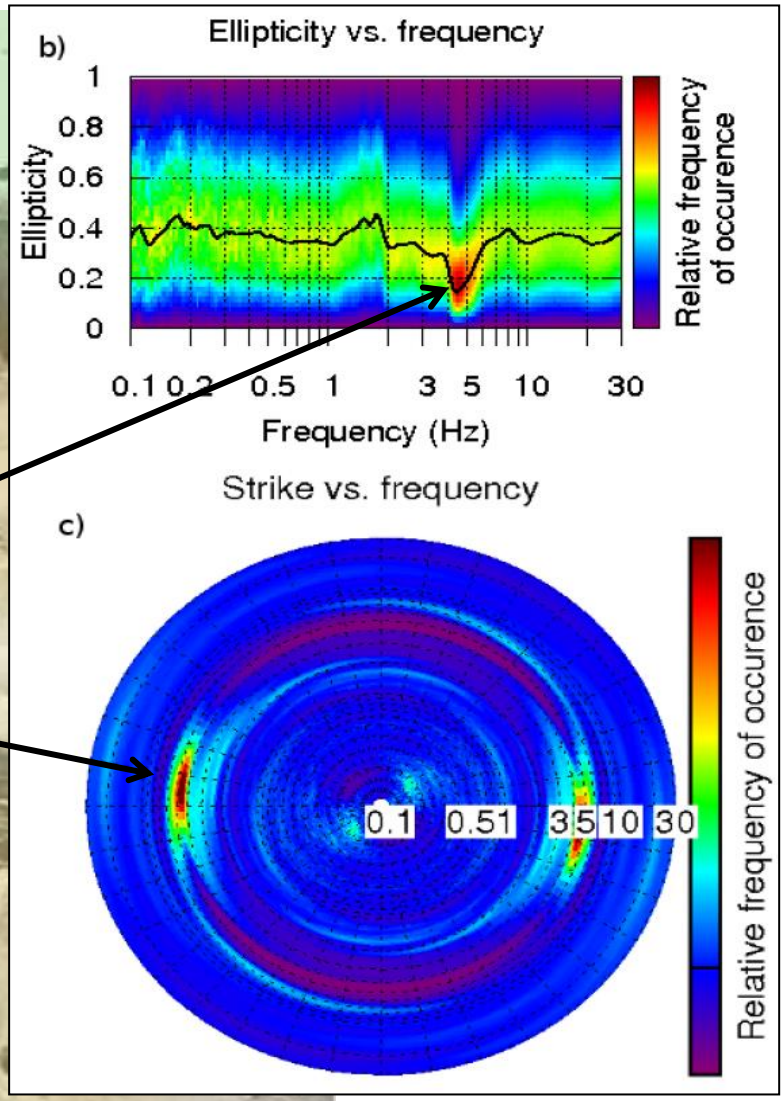
+ Prograde and retrograde particle motion: valuable in mode separation and identification

Marano et al. (2012, 2016)

Polarisation of ground motion

Identification of unstable rock-slopes



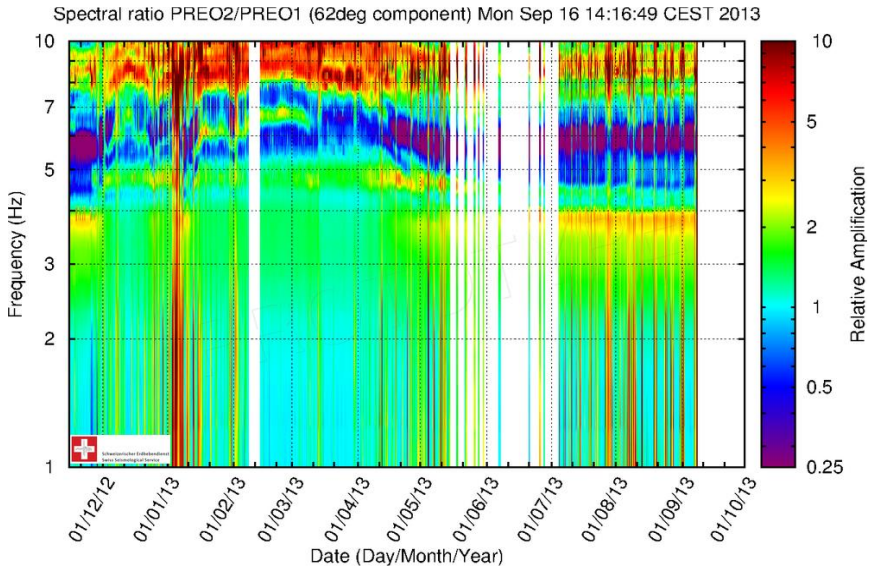


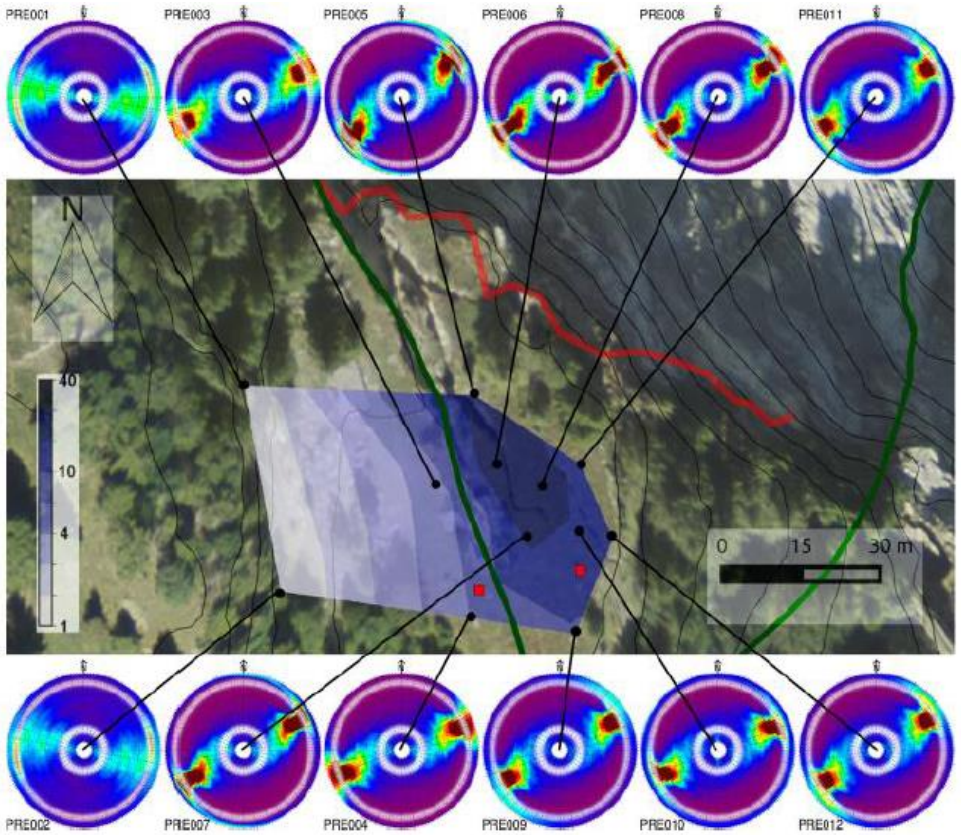
Burjanek et al. (2013)

„Topographic Site-Effects“

Characterization of unstable rock-slopes

Seasonal variation of the seismic response



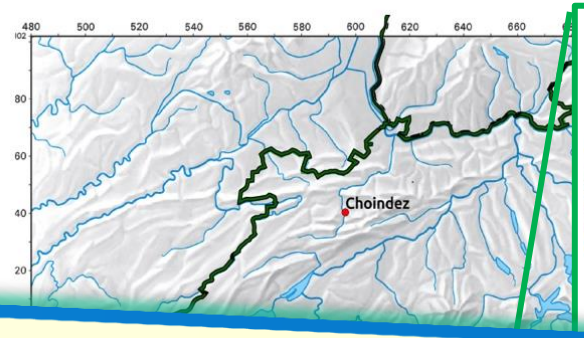


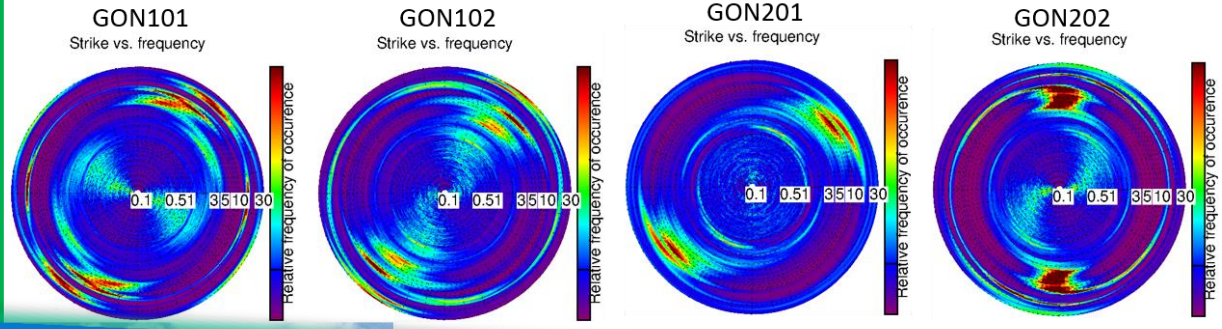
Alpe di Roscioro (Switzerland)

Burjanek et al. (2013,2016)

„Topographic Site-Effects“

Characterization of unstable rock-slopes



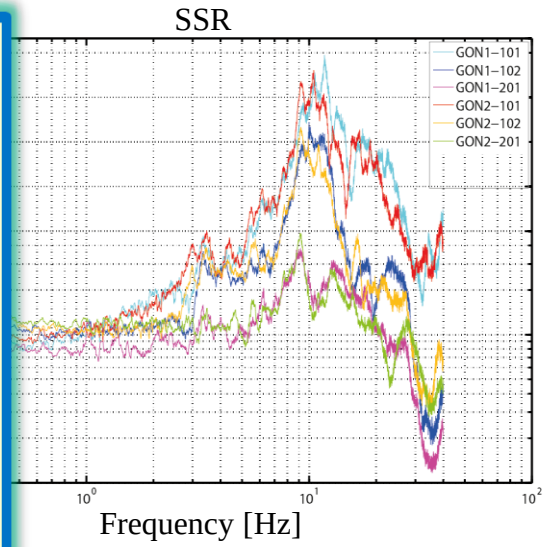


From observations on a large number of slopes:

+ Variety of site-effects associated with large local amplification levels (Kleinbrod et al., 2016):
  . Polarized ground motion is related to fracturing.
  . Normal mode behavior ←→ propagating surface waves

+ Shape of topography does not play a major role, internal structure of the instability is of primary importance (Burjanek et al., 2014).

+ Hard-rock sites on topography show de-amplification to reference rock.

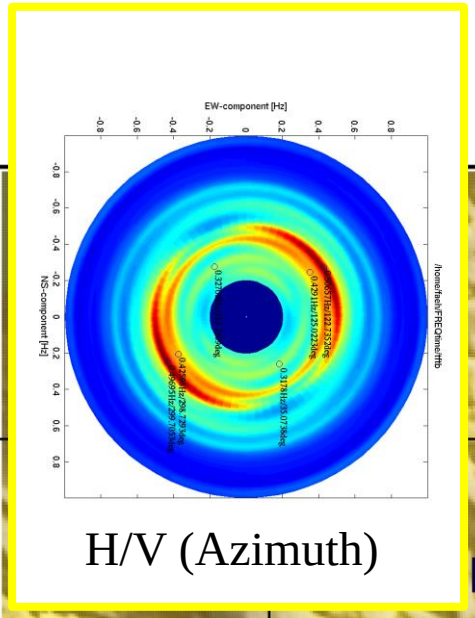


Gondo(Switzerland)

(See poster by Kleinbrod et al.)

Polarisation of ground motion

Identification of 2D resonances in alpine valleys



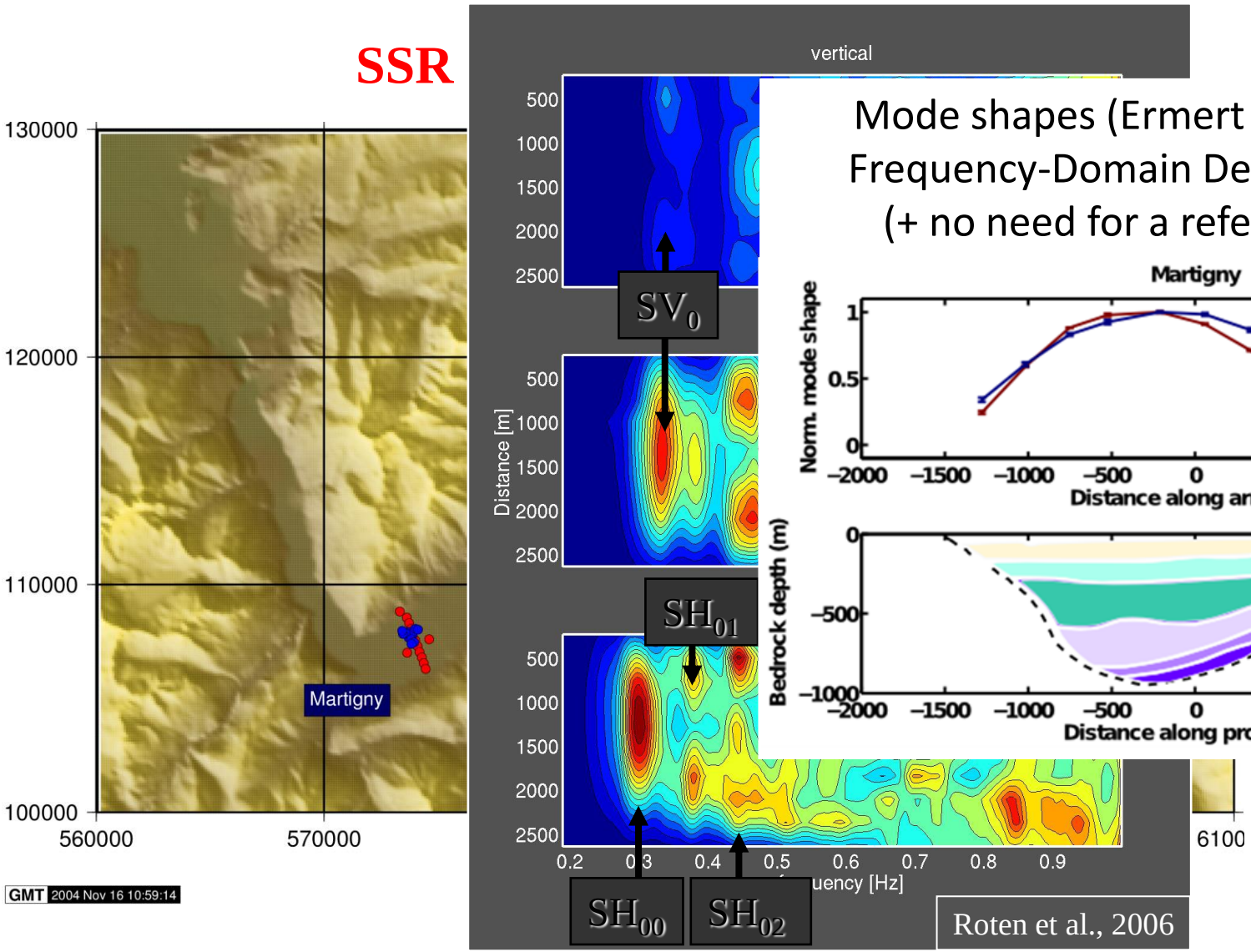
H/V (Azimuth)

Rhone Valley (Switzerland)

All stations have similar polarization of H/V at f_0

Polarisation of ground motion

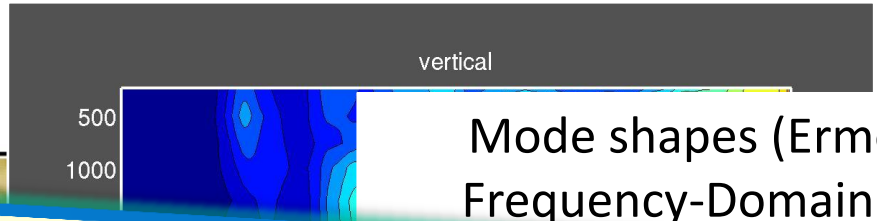
Identification of 2D resonances in alpine valleys



Polarisation of ground motion

Identification of 2D resonances in alpine valleys

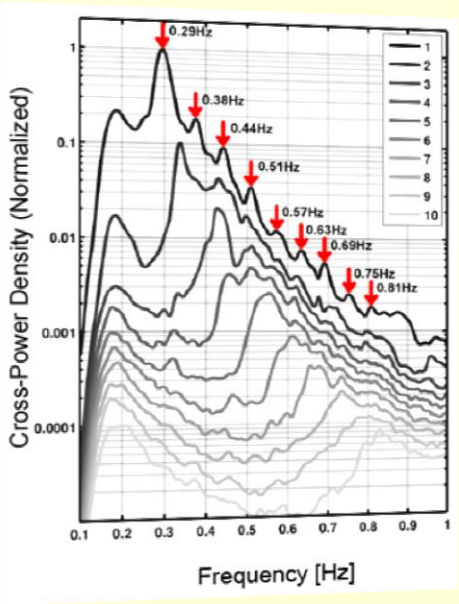
SSR



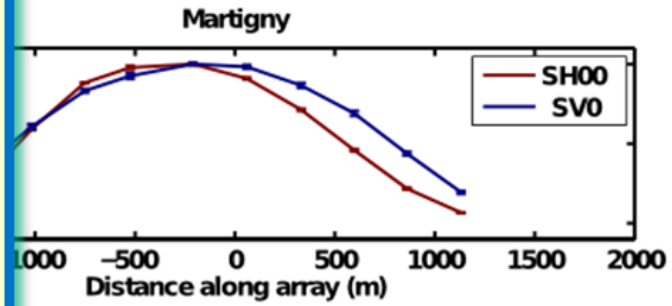
Mode shapes (Ermert et al., 2013)
Frequency-Domain Decomposition
eed for a reference site)

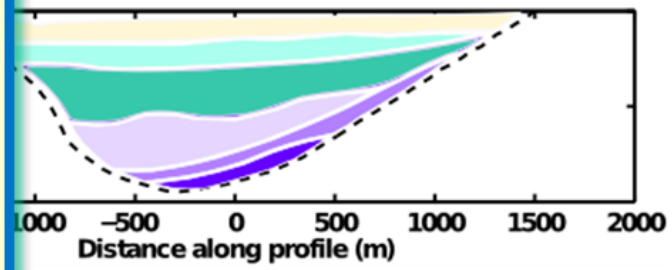
2D resonances:

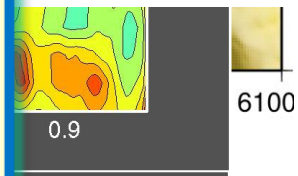
+ Mode shapes and eigen-frequencies contain information that is presently not used to define:



. Shape and depth of the basin
. Layering of the sediments
. Asymmetry of properties
. Deviation from 2D







n et al., 2006

Conclusions

1) Detailed site characterization is highly recommended for all (new) seismic stations: The first step to improve future seismic-hazard products.

2) Amplification can be referenced to the same rock profile, using a regional stochastic ground-motion model. This will decrease epistemic uncertainties in seismic-hazard products.

3) Systematic and detailed site-characterization allows:

   - Site-classification beyond Vs30, including 2D and 3D effects, quarter-wavelength representation, non-linear site behavior, etc.
   - Site properties can be combined with site amplification, a starting point to derive new seismic-hazard products : GMPEs and empirical amplification models for specific site classes (e.g. Alpine valleys) decreasing epistemic uncertainties in ground-motion estimation.