Schweizerischer Erdbebendienst
Service Sismologique Suisse
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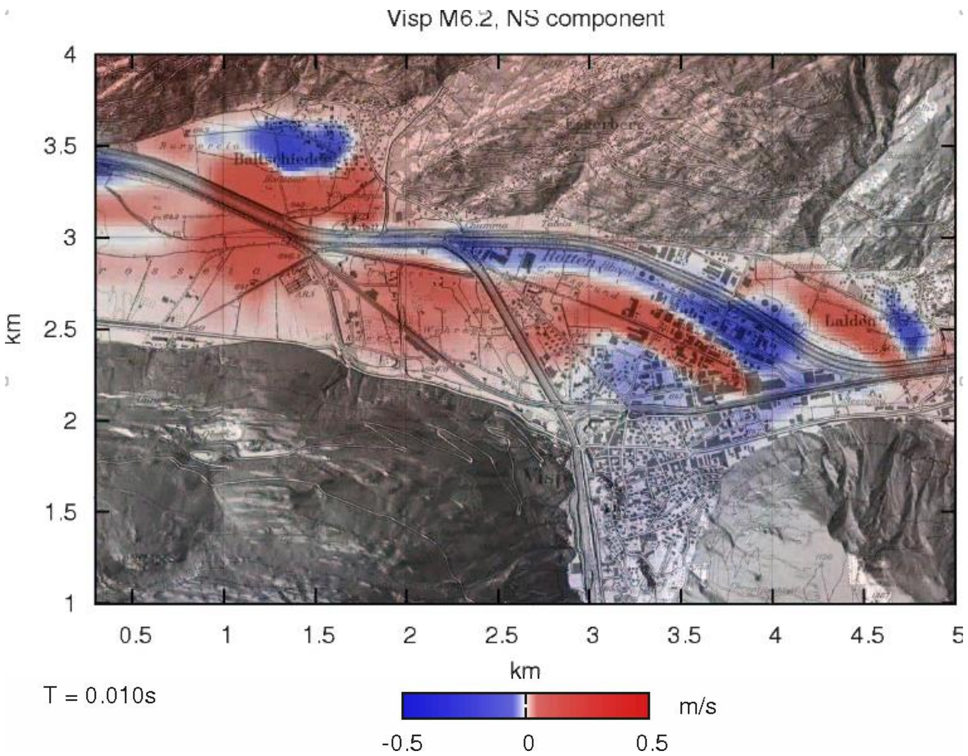
Swiss Seismological Service

ETH zürich

"Just add a factor"

Considerations about (in)correct treatment of site-effects in seismic hazard and risk assessment

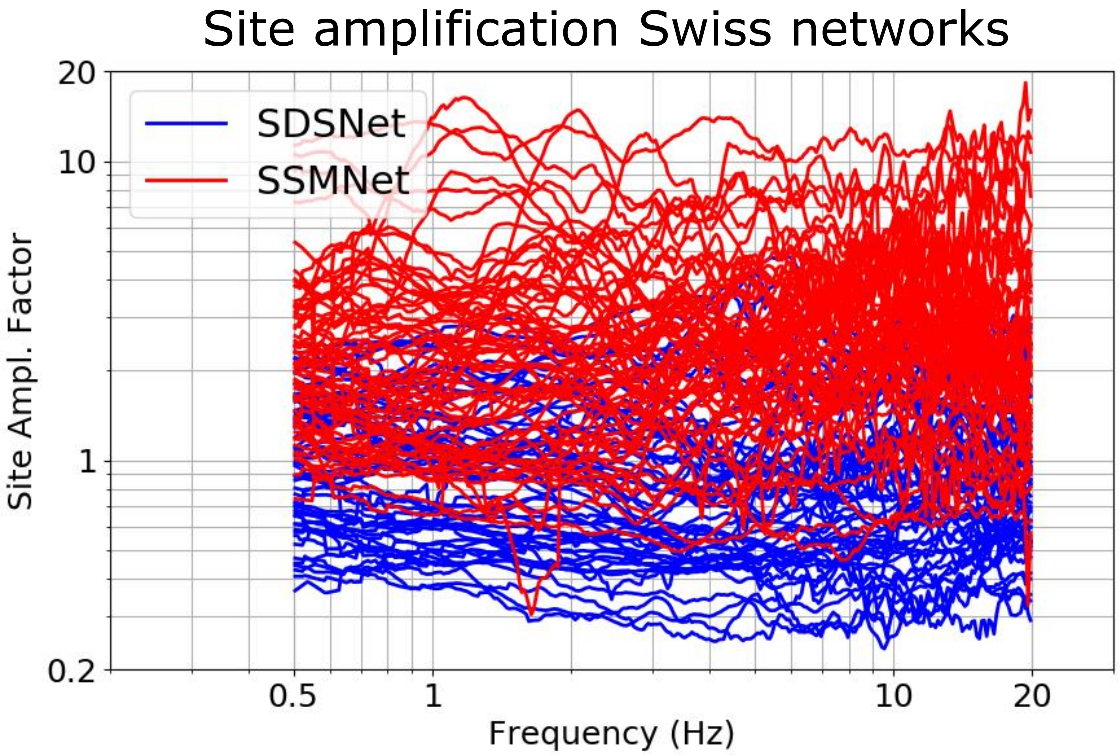


Donat Fäh &
Engineering Seismology Group
Swiss Seismological Service
ETH Zürich

PSHA Workshop Lenzburg 2017

Site amplification

The quality of many products in seismology and engineering seismology depends on a correct treatment of the site-response:
Magnitude, source inversions, GMPEs, seismic hazard and risk products, etc.

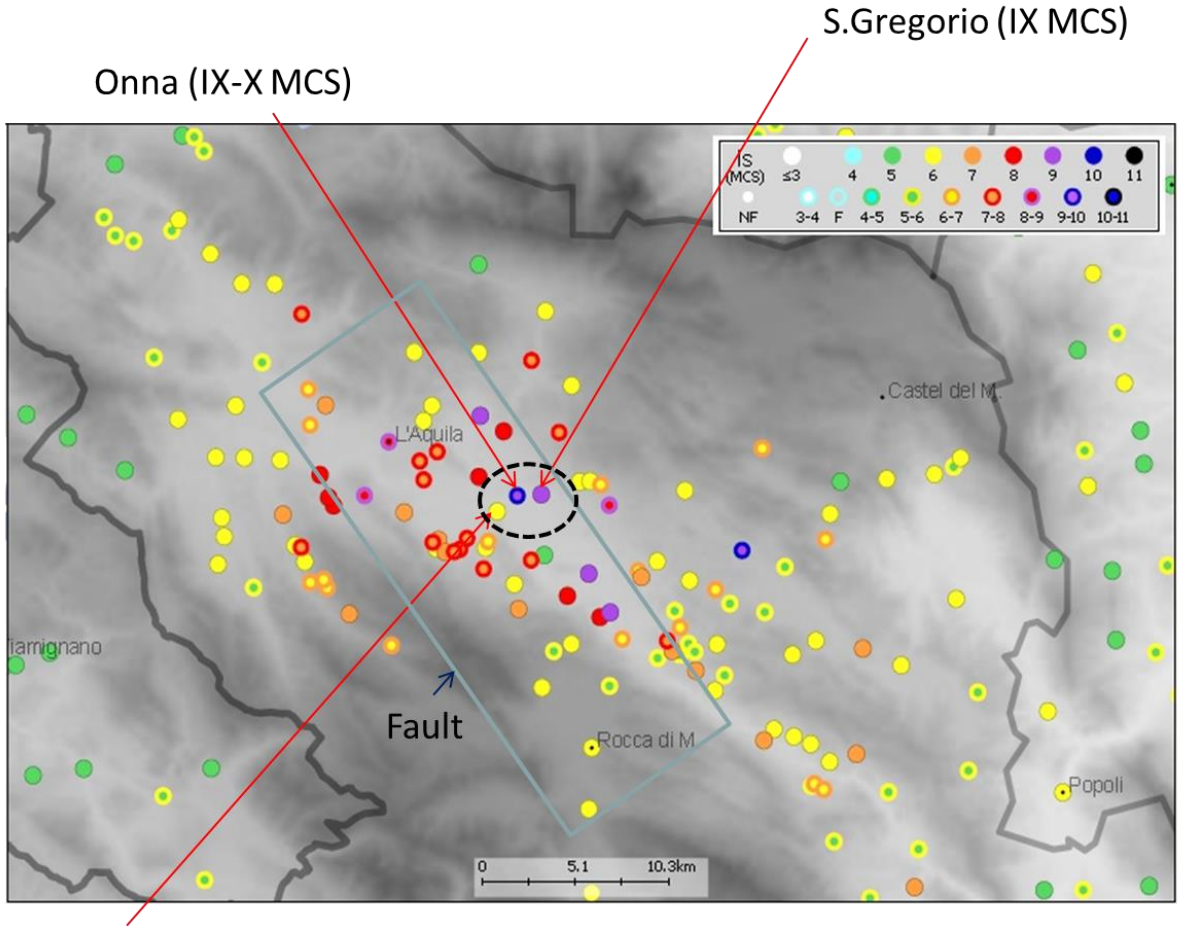


Variation in Intensity

- ← **+III** «Extreme» sites
- ← **+II** Soft sediments
- ← **+I** Sediments
- ← Reference rock
- ← **-I** Hard rock

Site amplification

Seismic hazard is mostly driven by local site-effects.



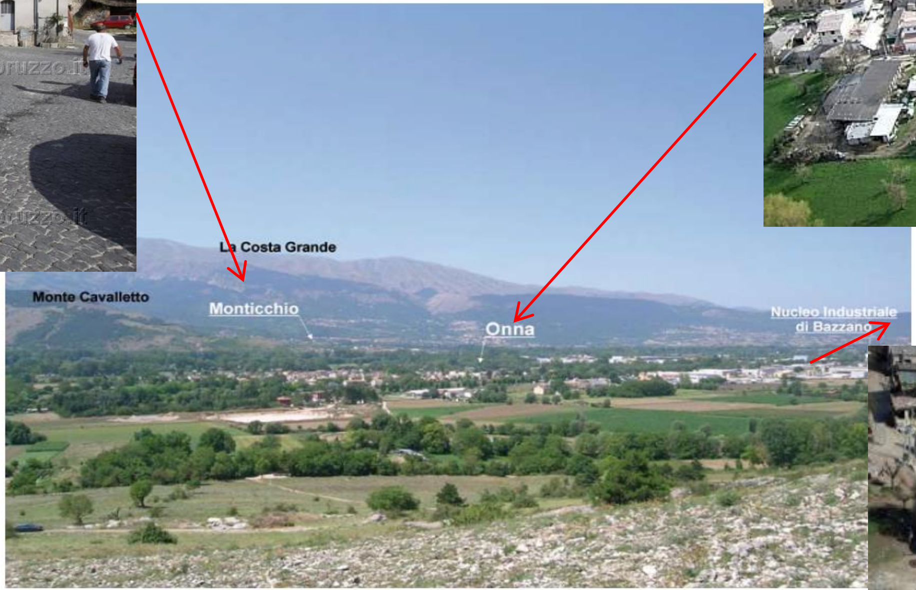
Courtesy D. Albarello

Macroseismic Map L'Aquila earthquake of April 9, 2009

Site amplification

Onna (IX-X MCS)

Monticchio (V-VI MCS)



S.Gregorio (IX MCS)

L'Aquila earthquake 2009

Similar buildings but different damage

Courtesy D. Albarello

A long dream: Easy ways to classify site-amplification

- Using «relevant» site-properties (Proxies) to predict measured amplification (Geophysical, geotechnical, geological, geometrical site properties)

Today's practice:

- Use Vs30 as a proxy to define site-amplification (maybe combined with f_0)
- In some cases: Vs30 proxy is derived from other proxies (topography, geology)

Does this practice introduce flaws in seismic hazard and risk products?

A long dream: Easy ways to classify site-amplification

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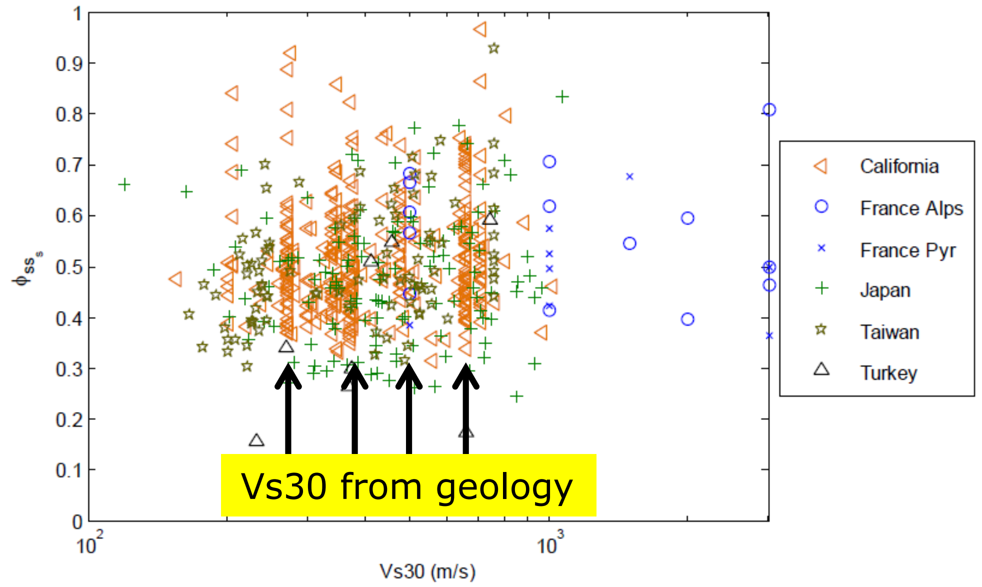
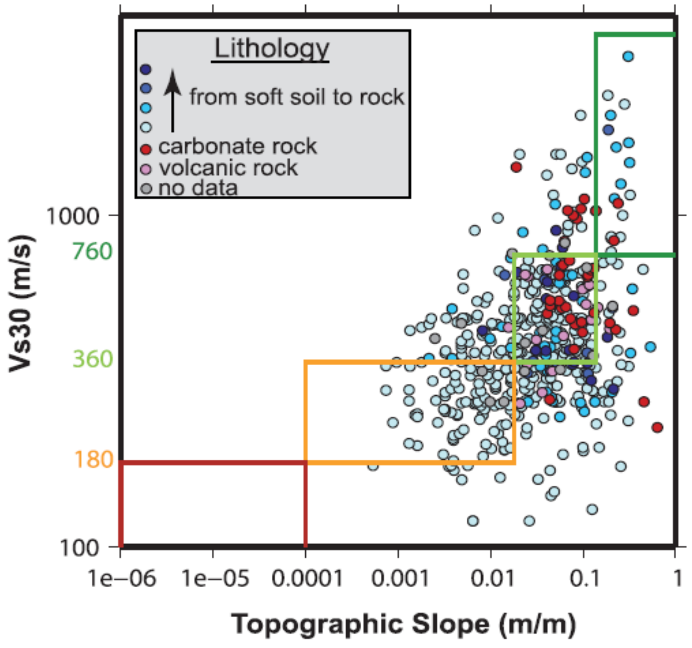
Today's practice:

- Use Vs30 as a proxy to define site-amplification (maybe combined with f_0)
- In some cases: **Vs30 proxy is derived from other proxies (topography, geology)**



Single-station standard deviation for PGA (PRP EXT-TB-1058)



Lemoine et al. (2012)

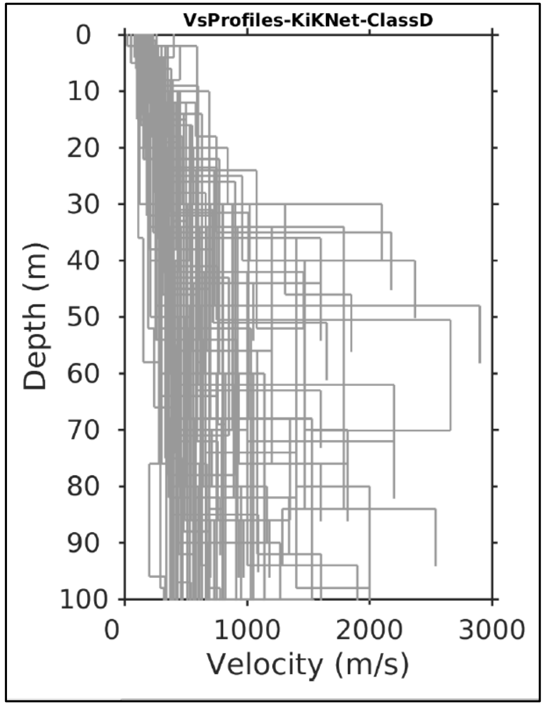
Issues

- One Vs30 value corresponds to many models (reliability of Vs30 often unknown)
- Smoothing over broad Vs30 or f_0 ranges destroys information on site-specific amplification:

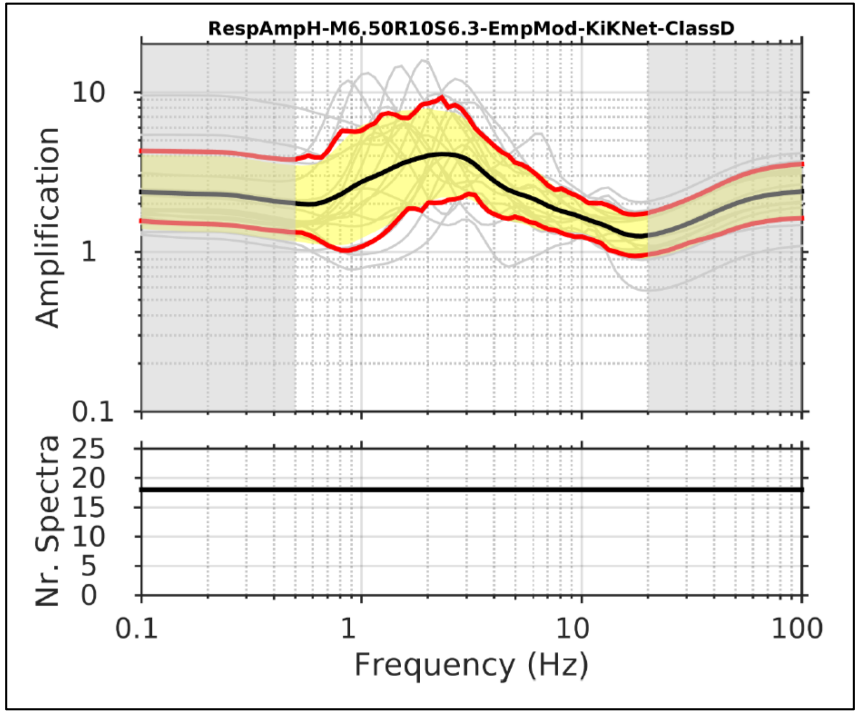
→ ***Large range in site properties reduces average amplification,***

(1) soil classes in building codes

KIKNet Sites (Class D)



Observed amplification

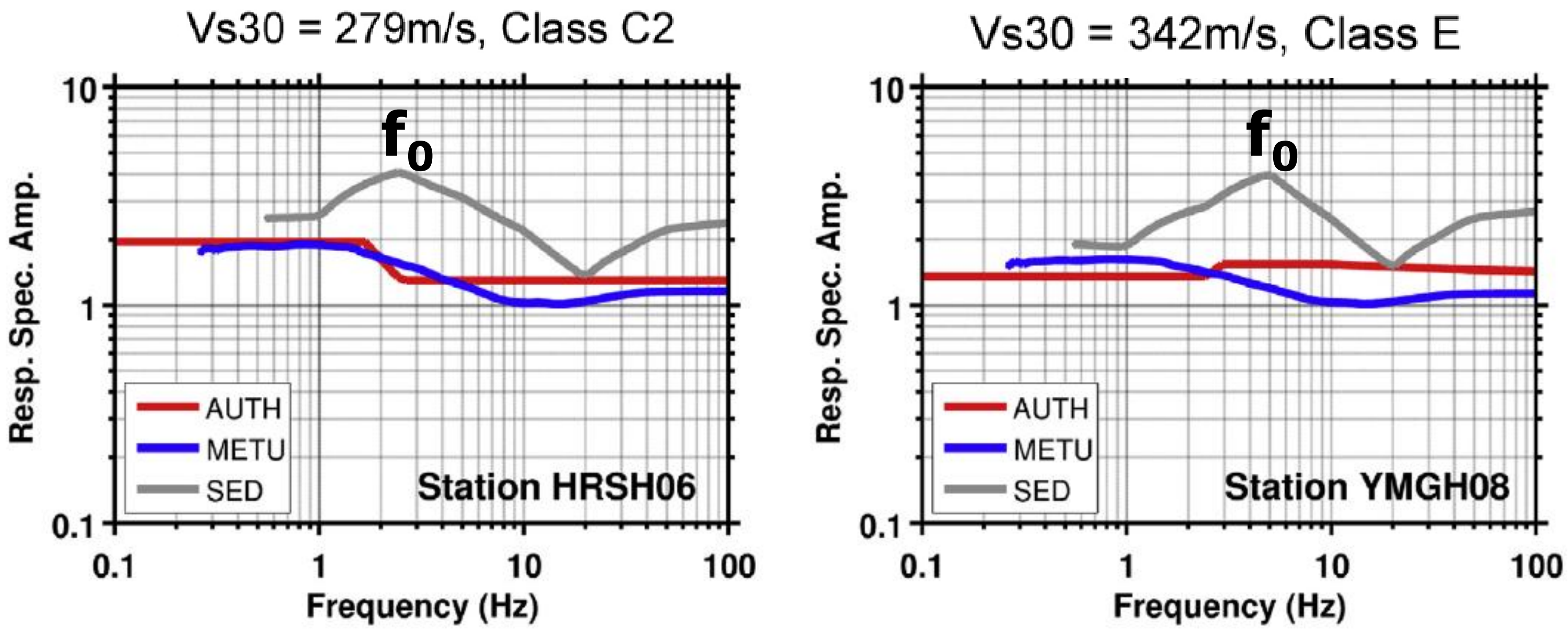


from Poggi et al. (2015)

Issues

- ***(2) Vs30 based GMPEs:***
  Empirical models for amplification derived from GMPEs (blue and red) are generally too smooth due to averaging over many sites when compared to empirical models derived from spectral modeling (gray).

  → ***Vs30 does not contain information about resonances***



from Poggi et al. (2016)

How can we address the problem?

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

1) **Interpretation of earthquake recordings using methods as site-amplification from spectral modelling of ground motion:**
    - What means «free-field» condition for a seismic stations?
    - Issue of 1D, 2D or 3D resonances ?
    - Presence of edge-generated surface waves ?
    - Presence of focusing/defocusing effects ?
    - Possibility of non-linear soil effects ?

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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

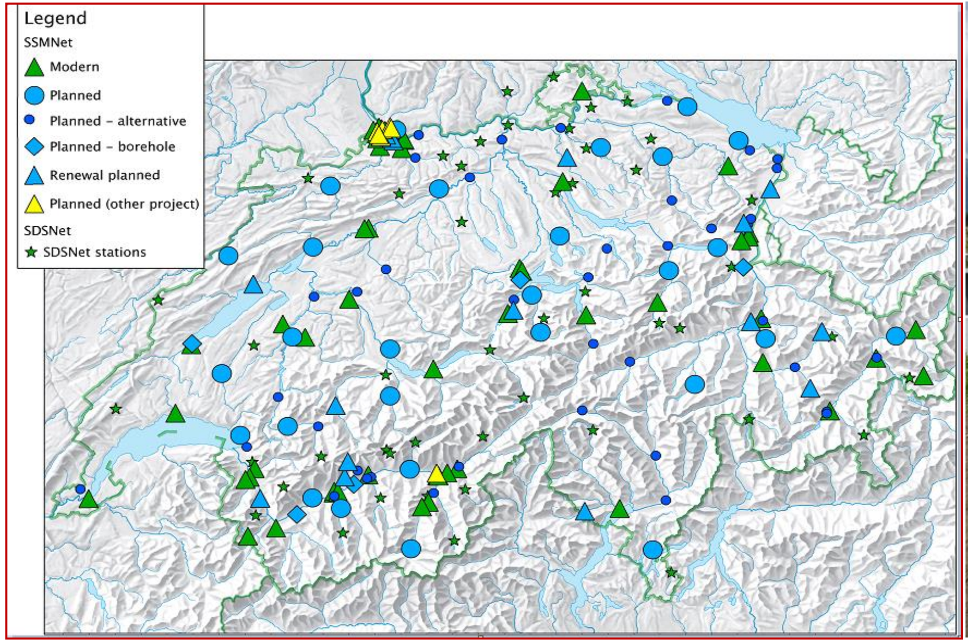
Evolving procedures at the Swiss Seismological Service for new permanent seismic stations since 2009 (Access: http://stations.seismo.ethz.ch)

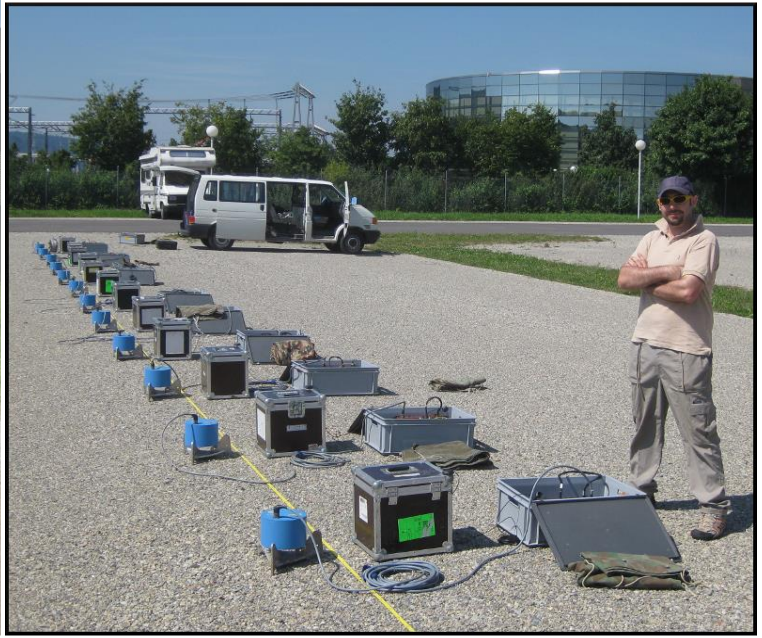
2009: 27 sites (mostly rock sites) in the Pegasos Refinement Project

2013: 30 sites of the Swiss strong-motion network renewal – Phase 1

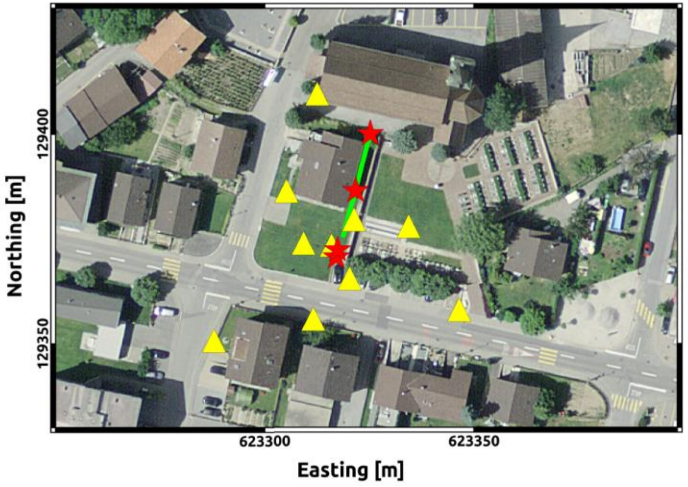
2014: 16 sites from NagraNet project and Basel mitigation project

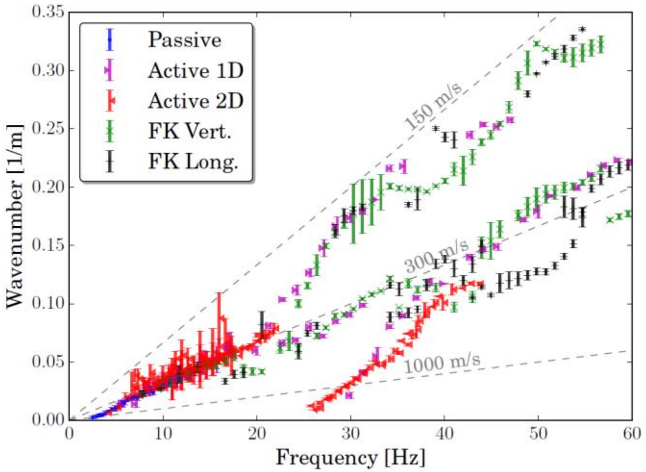
2020: 70 sites of the Swiss strong motion network renewal – Phase 2





Site Characterization
(see poster by Paolo Bergamo et al.)





Marano et al. (2017)

Target from measurements:

- Rayleigh waves dispersion curves
- Rayleigh waves ellipticity , f_0 and shape of H/V curves
- Love waves dispersion curves
- Identification of 2D resonances and polarization features
- Derivation of velocity profiles including their uncertainties

Methods:

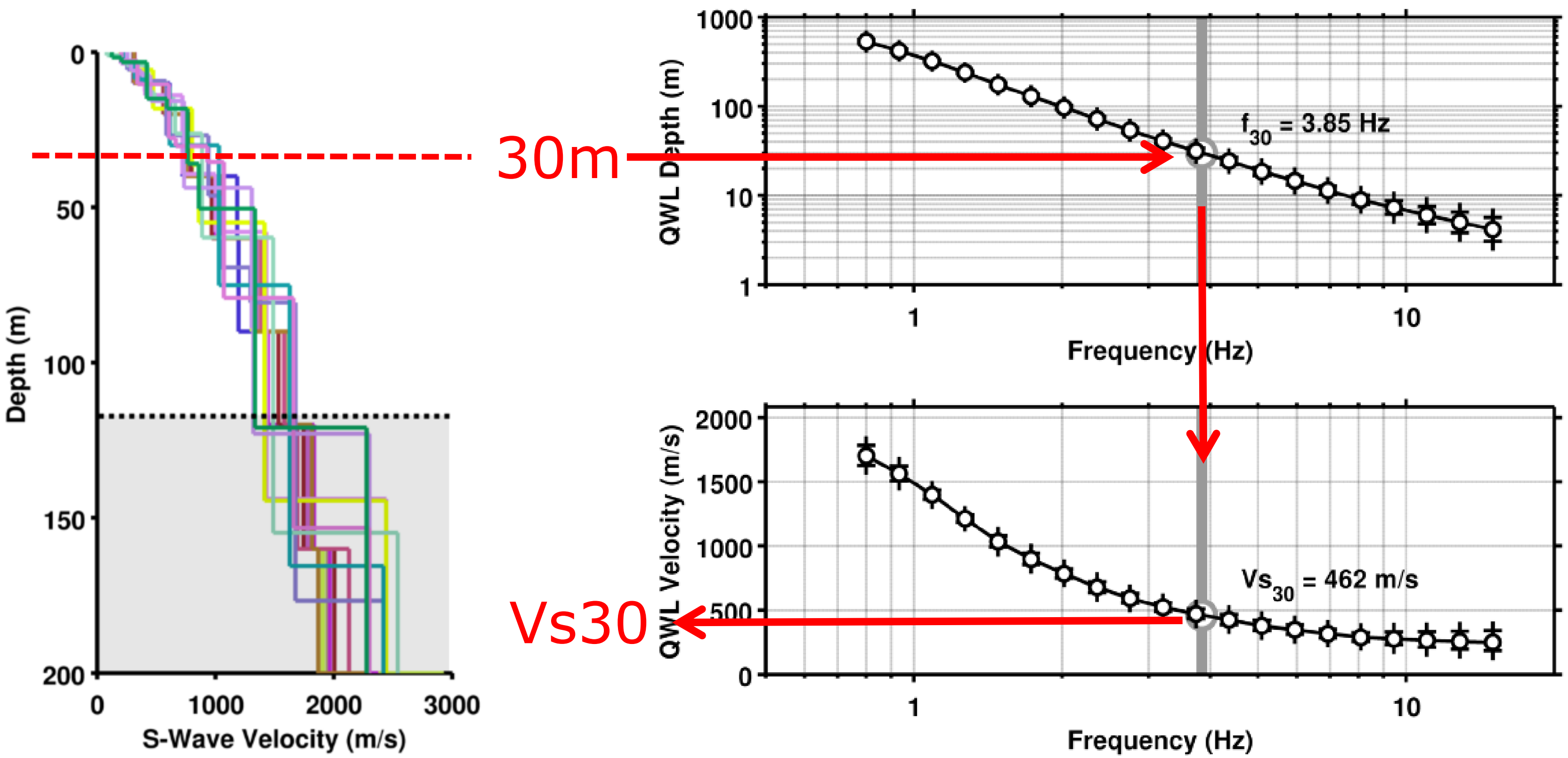
- Ambient vibrations: H/V, HRBF, SPAC, WaveDec, RayDec,….
- Combination of the ambient vibration with active methods
- Ground-motion polarisation analysis
- Frequency-domain decomposition to analyse 2D resonances
- …………………..

The long-term goal: New ways to classify sites

S-Wave Velocity Profiles

- Vs30 is a wavelength measure → Hazard is defined in the frequency space
- Vs30 is just a point in the quarter-wavelength representation of a site:

Quarter-wavelength (QWL) representation of velocity profiles



Ground motion analysis

Site-amplification from spectral modelling of ground motion:

Stochastic ground-motion prediction model for **reference rock** in a regional network (e.g. Edwards et al. (2013) for the Swiss Networks)

$$\Omega_{ij}(f,r) = \underbrace{\omega \cdot \Omega_i \cdot f_c^{\gamma}/(f_c^{\gamma} + f^{\gamma})}_{\text{Source Spectrum}} \cdot \underbrace{S_{ij}(r) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot t_{ij}^{*})}_{\text{Path Effects}} \cdot \underbrace{A_j(f) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot K_j)}_{\text{Site Effects}}$$

Ground motion at reference rock

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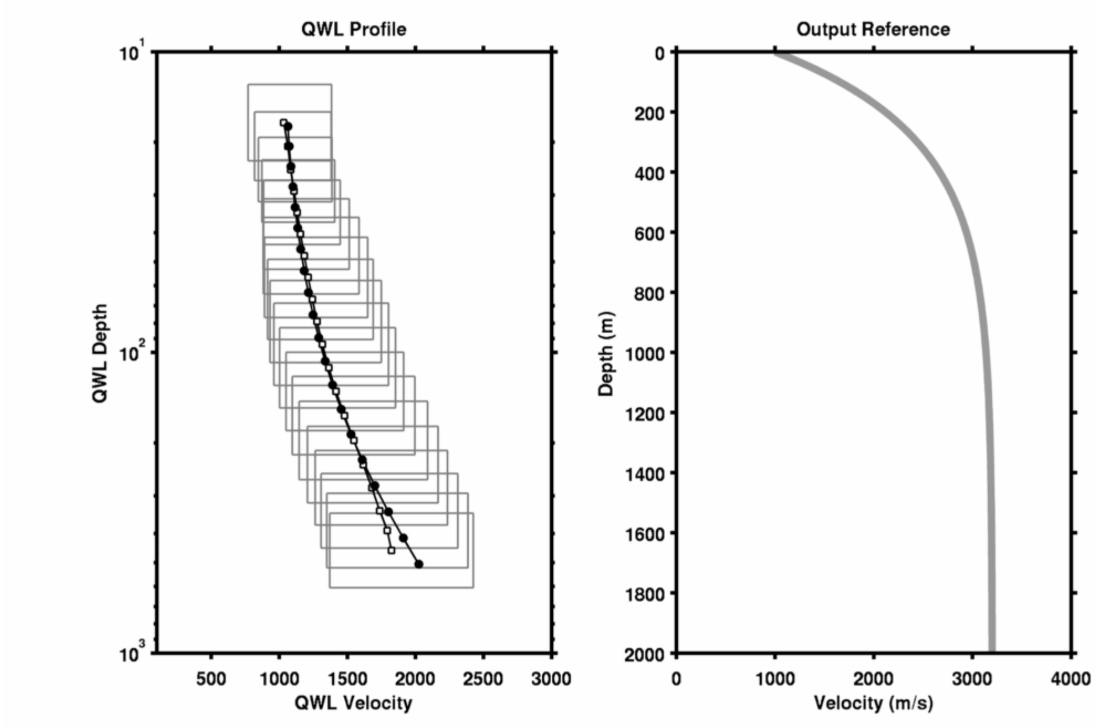

Ground motion at reference rock

Generic rock profile from network
average amplification = 1
(Poggi et al., 2011)

Reference rock profile for the
2015 Swiss seismic hazard

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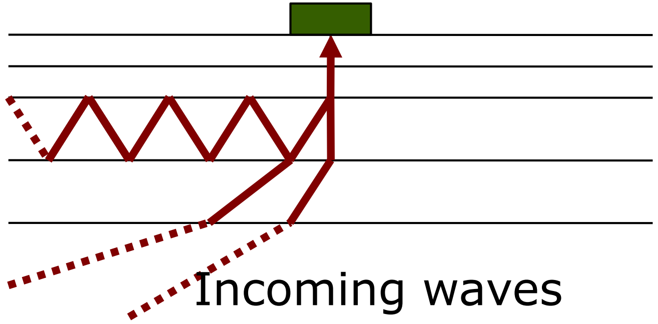
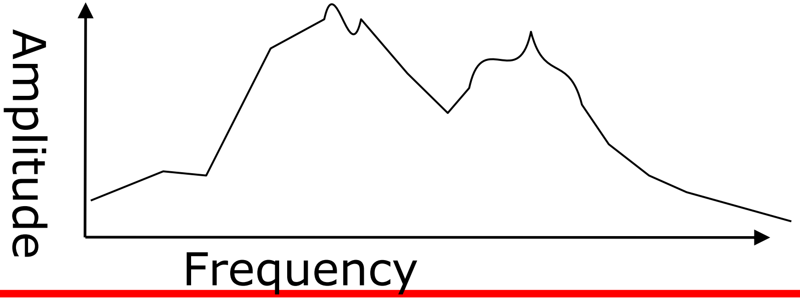
Effect of the upper layers:

Amplification $A_j(f)$
Damping (Kappa K_j)
Duration

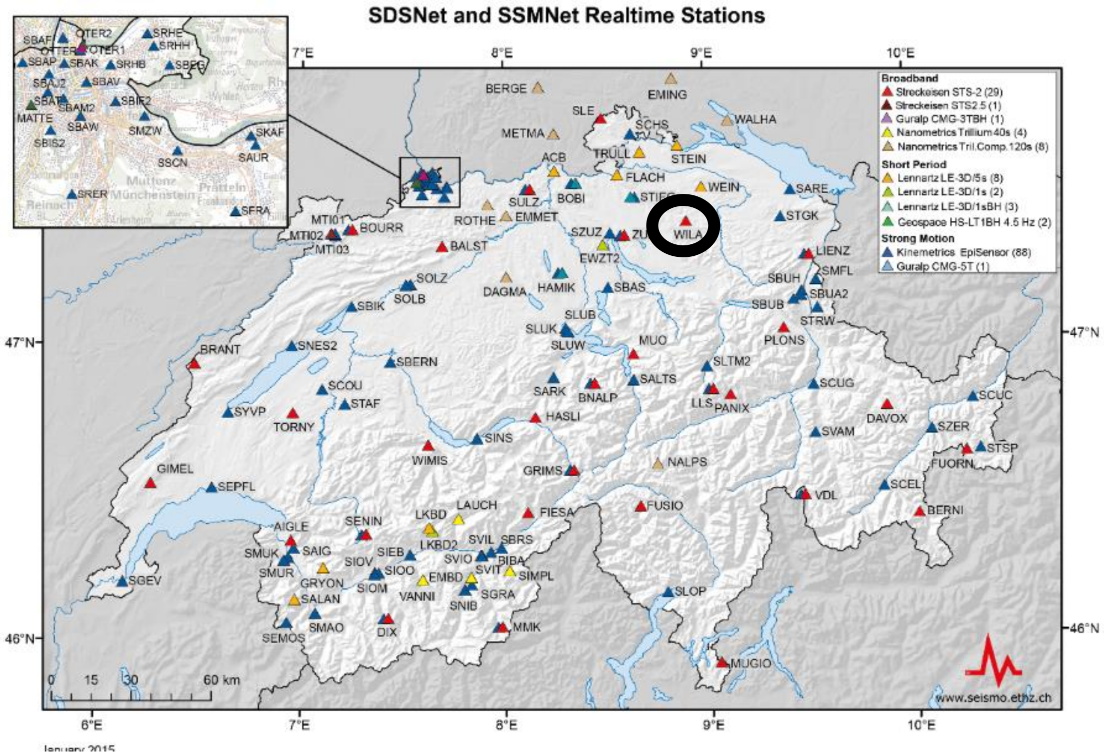
for the fixed rock-reference measured by using all seismic stations j and all earthquakes i.

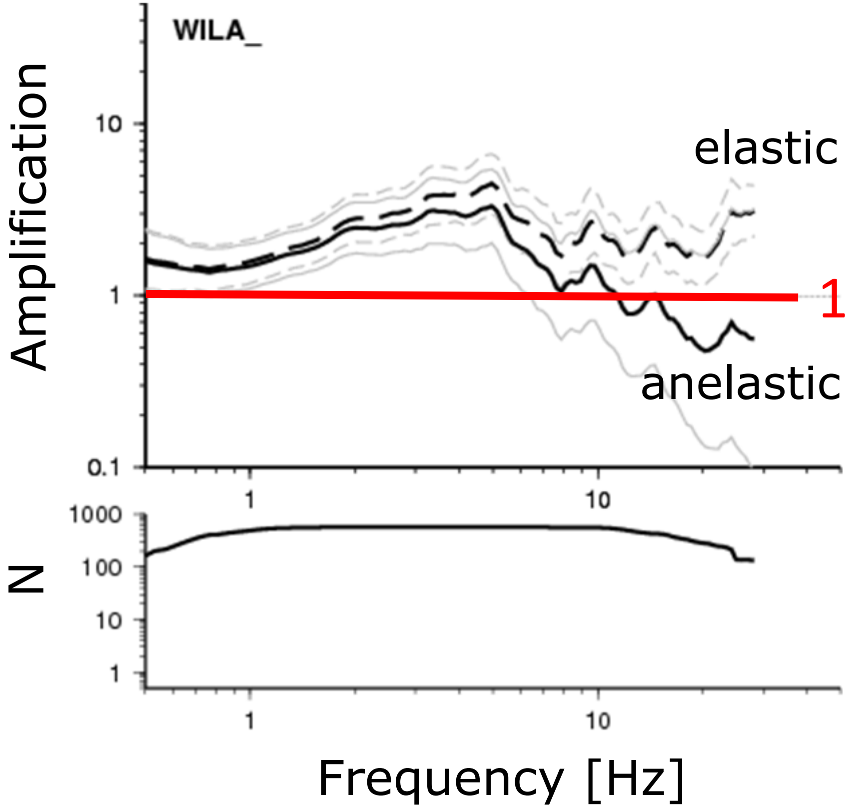




Ground motion analysis

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

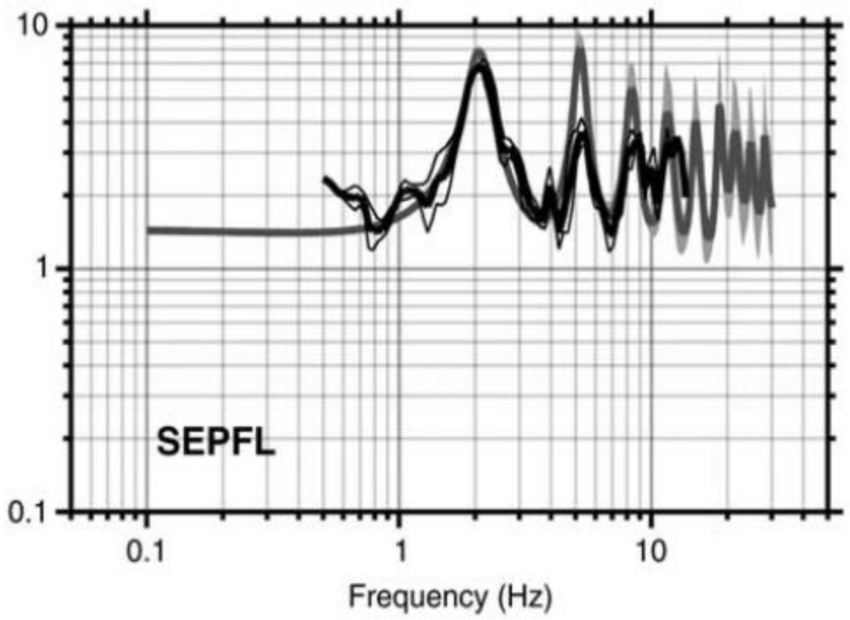




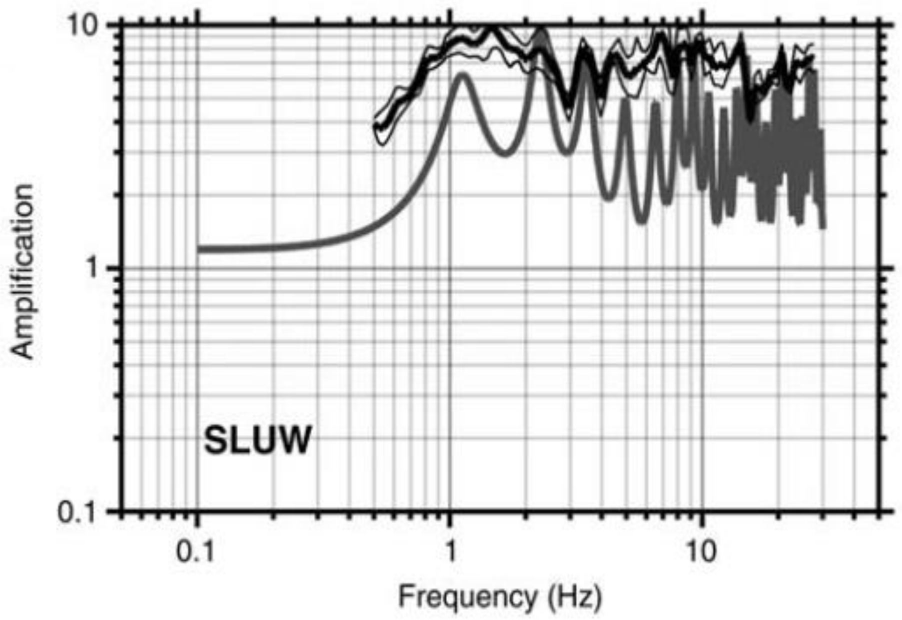
Ground motion analysis

1) Derive features of the site response by comparison with computed 1D SH-amplification from the measured velocity profiles:

Simple 1D response at Lausanne EPFL site



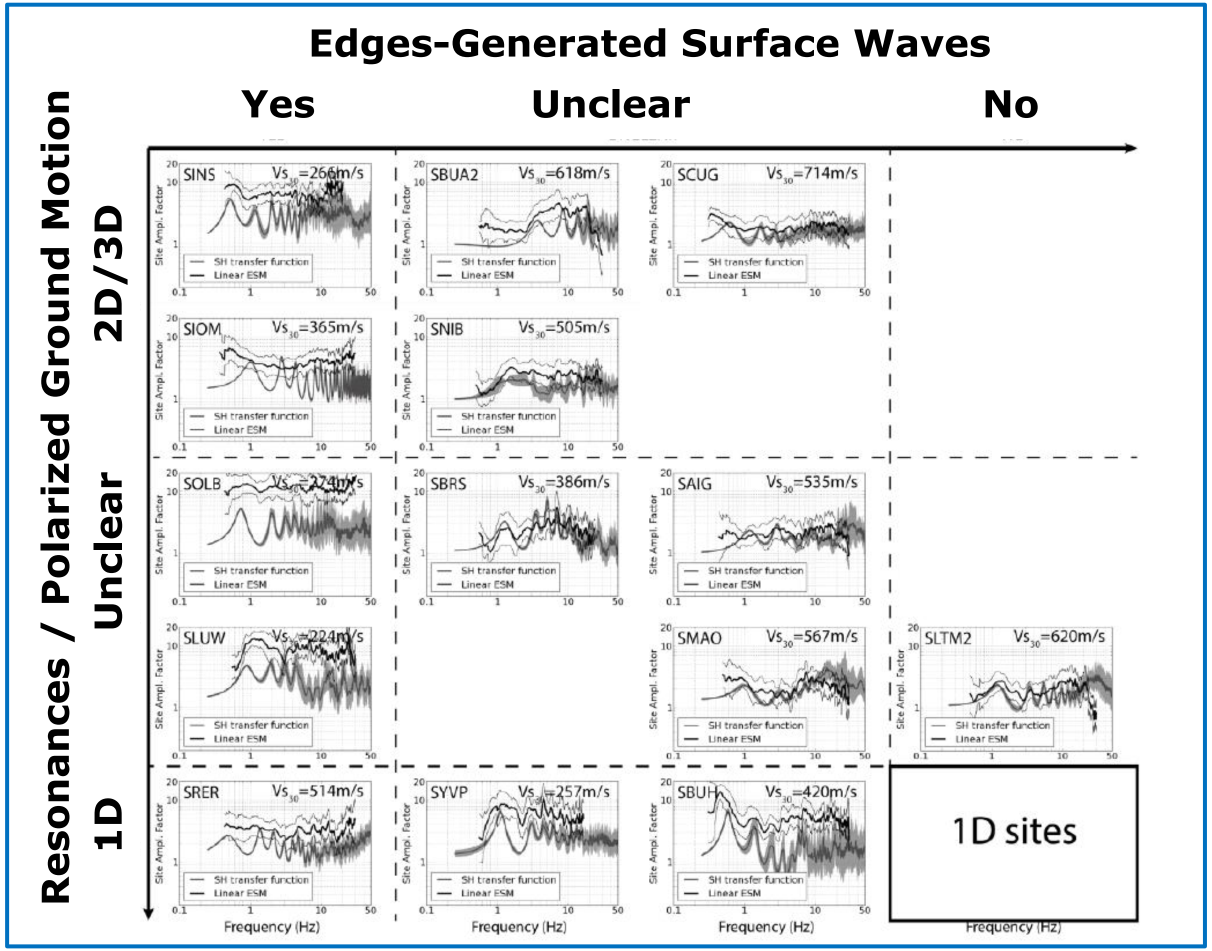
Edge-generated surface waves at Lucerne site

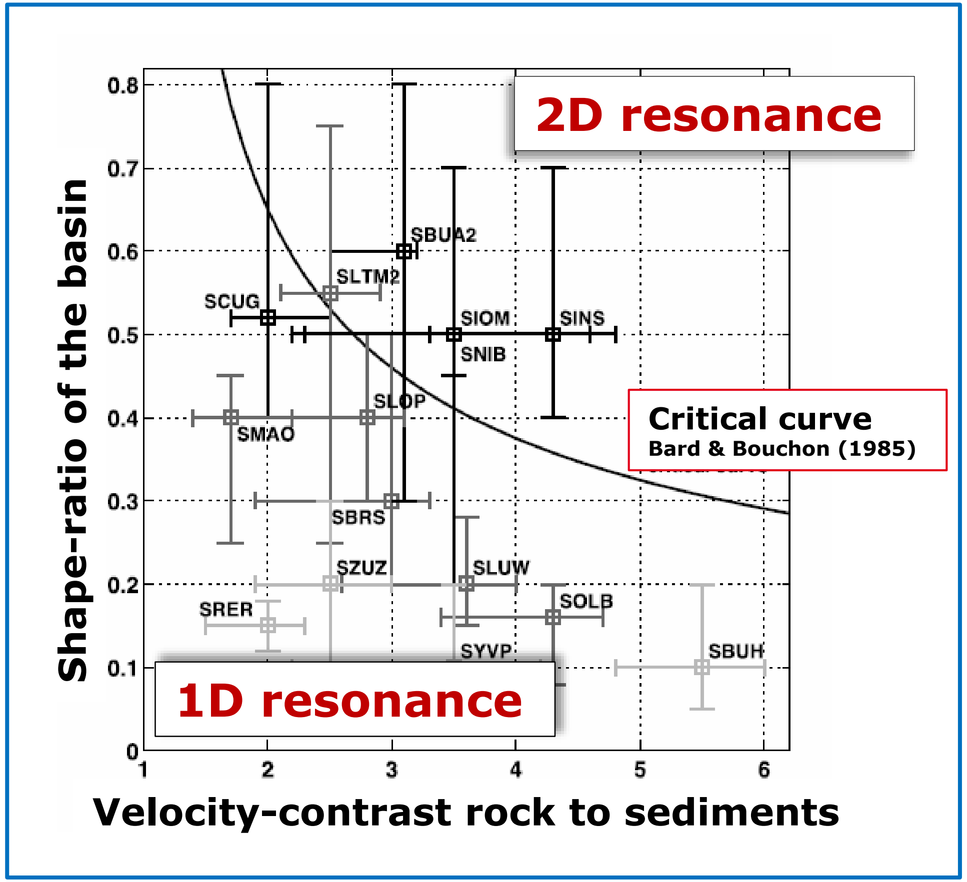


Vs30~200 m/s

Ground motion analysis

2) Use site amplification from spectral modelling for site classification





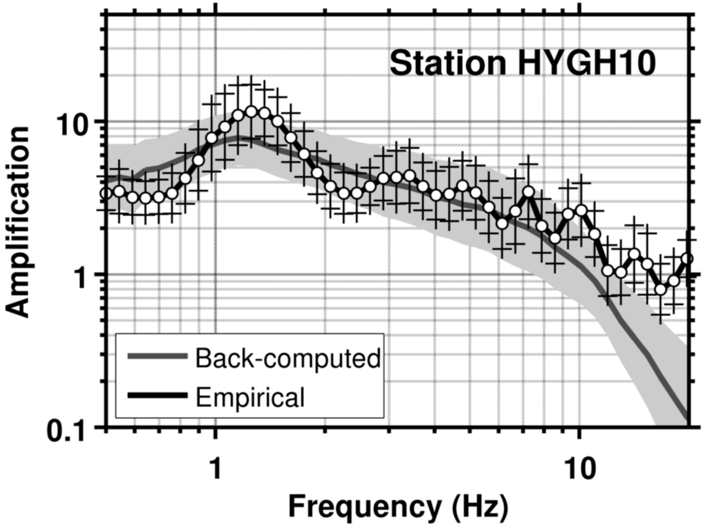
Michel et al. (2014)

Ground motion analysis

Empirical relations for site-amplification based on quarter-wavelength velocity and contrast generally do a rather good job:

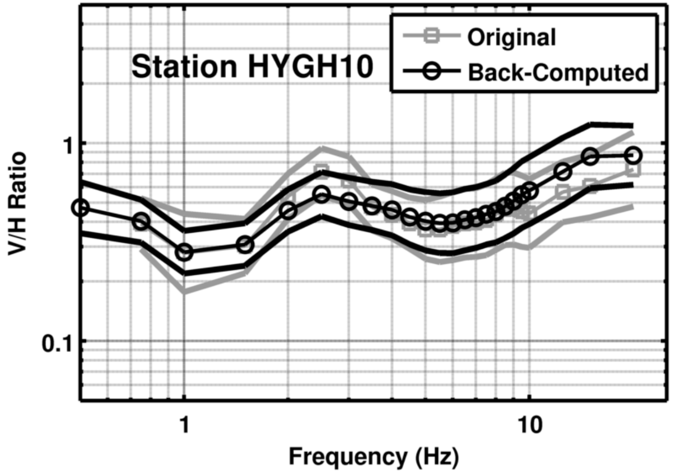
Amplification from velocity profiles

- Based on stochastic ground-motion prediction model for Switzerland and Japan
- Referenced to the same rock velocity-profile
- Model using Qwl and Qwl-contrast (Poggi et al., 2013)



V/H ratios from velocity profiles

- Rock model using Qwl-representation (Edwards et al, 2011)
- Soil model using Qwl and Qwl-contrast (Poggi et al., 2012)



Fundamental frequency f_0

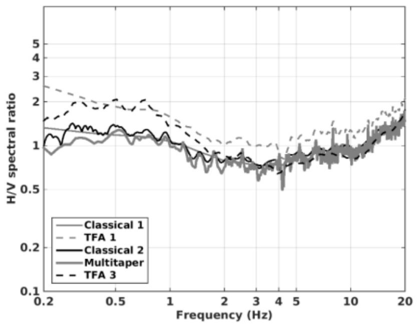
- One Vs30 value corresponds to many models (reliability of Vs30 often unknown)

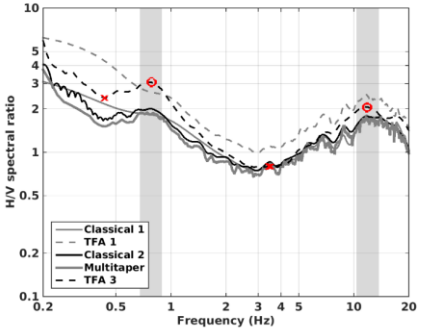
  → Adding f_0 information reduces the model space
  → H/V measurements is a cheap tool to determine f_0

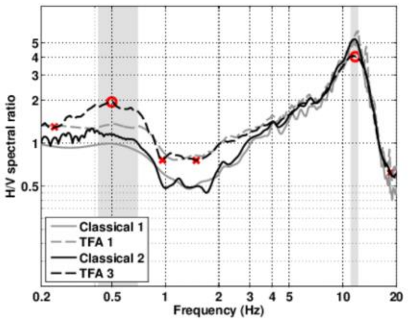
However:

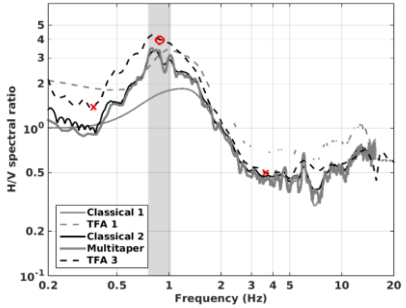
- f_0 might be related to different interfaces or 2D resonances:
  rock-rock, rock-sediment, sediment-sediment
- There might be several peaks in H/V, maybe not related to resonances
- In structures with only velocity-gradients and no Vs-contrast,
  we cannot identify f_0 from H/V curves

Advanced methods: H/V Inversion, H/V classification, arrays for 2D structures



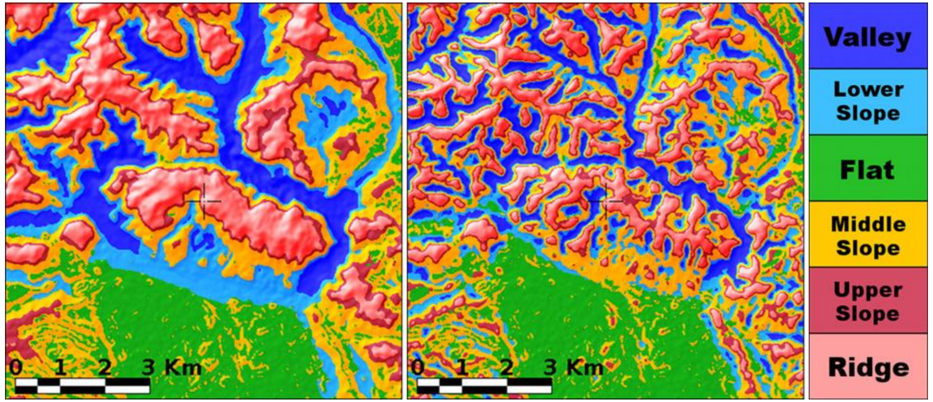






2D/3D Geometrical Effects

- **Surface topography** (NERA-JRA1 report doi:10.3929/ethz-a-010222426)
  - Influence of geometry on amplification is small (maximum ~ factor 2)
  - Rock/soil properties are more important than geometry
  - Scattering by topography might be important but is not only a local property
  - **Needs classification related to length scales** in high-resolution digital maps



Burjanek et al. (2014)

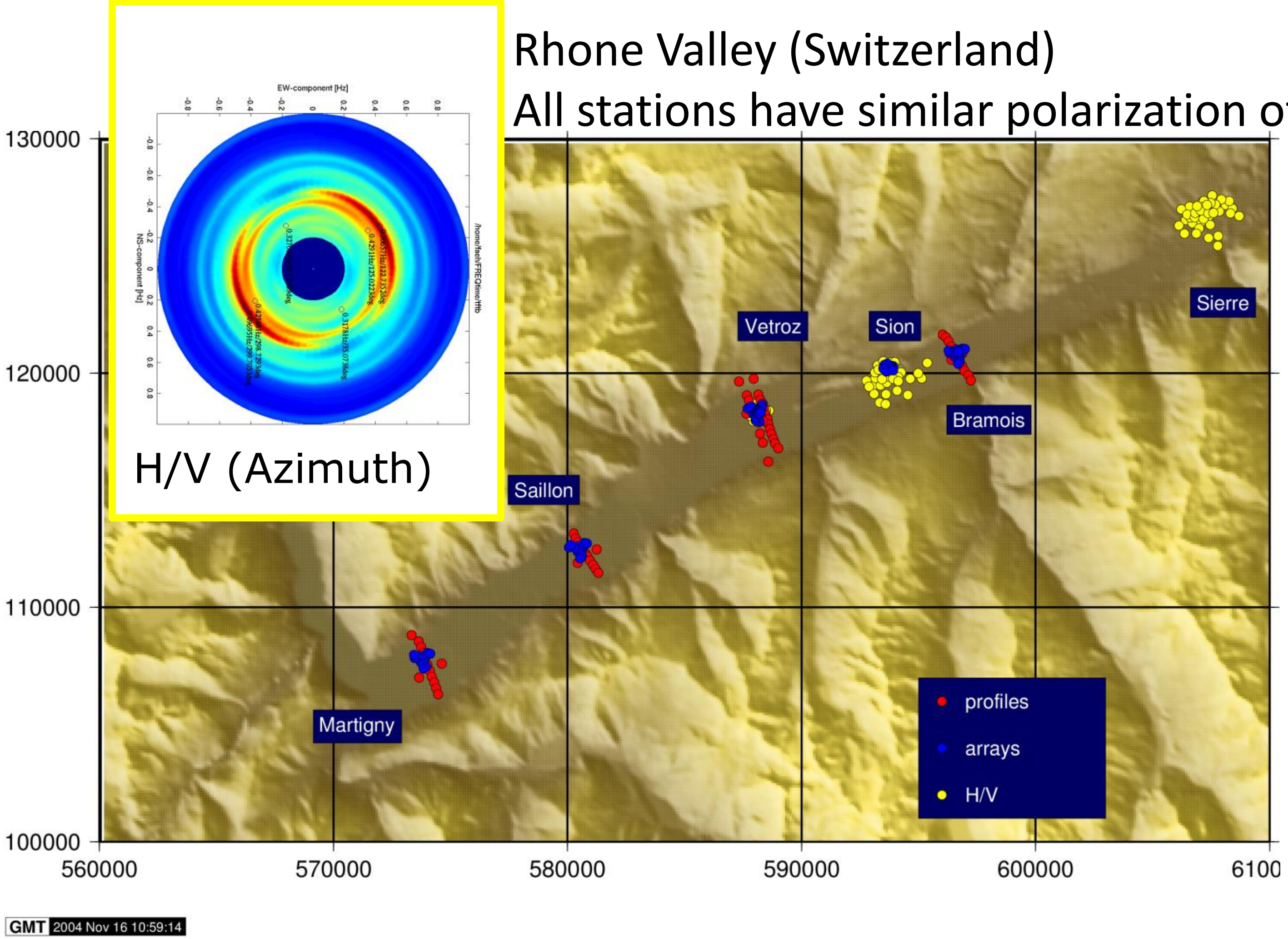
- **Subsurface topography**:
  - Dipping layers (identified from H/V in array measurements)
  - 2D/3D resonances (polarization, shape of eigenmodes from arrays)
  - Edge-generated surface waves (e.g. identified from amplification function):
  - **Needs classification related to length scales** of basin geometry

2D Resonances in Alpine valleys

Identification of 2D resonances in alpine valleys

Rhone Valley (Switzerland)

All stations have similar polarization of H/V at f_0



2D Resonances in Alpine valleys

www.seismo.ethz.ch

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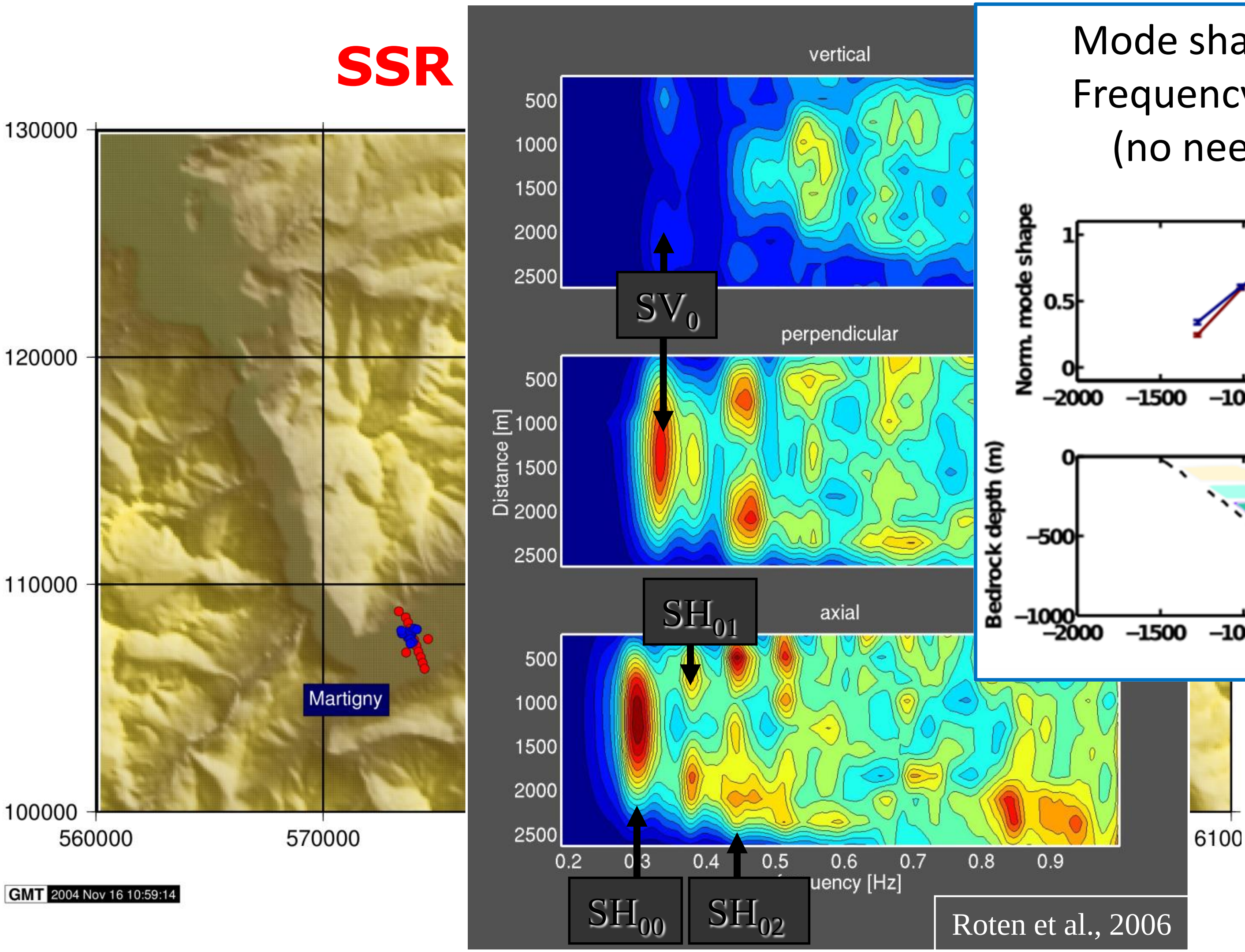
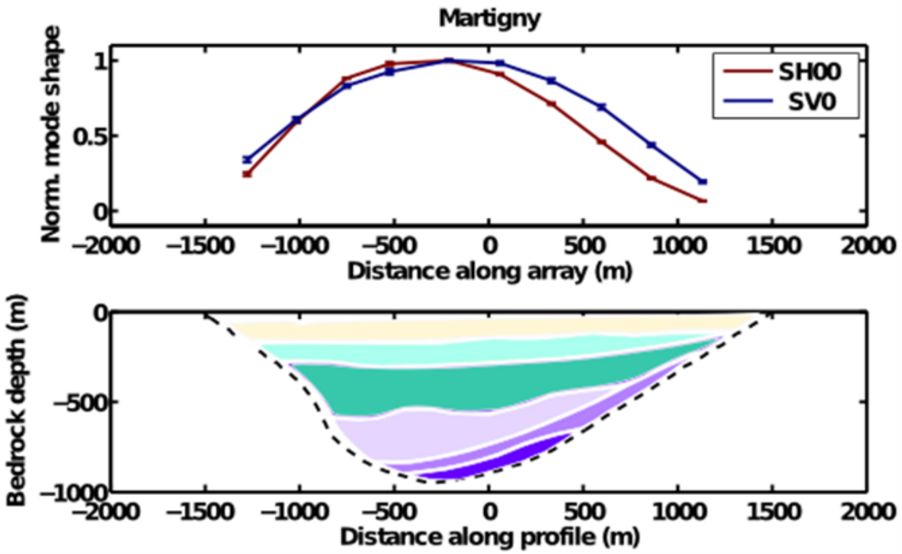


Mode shapes (Ermert et al., 2013)
Frequency-Domain Decomposition
(no need for a reference site)



Some recommendations

For networks operators and developers of GMPEs:

Systematic and detailed site-characterization is required for seismic stations

- Site-classification beyond Vs30 and f_0, including quarter-wavelength representation, 2D and 3D effects, geometrical and geological properties, non-linear site behavior, station installation, etc.
- Combine site properties with observed site amplification for classification of sites.

For seismic-hazard and -risk modelers:

There is yet no simple proxy to define site-amplification A(f)

- This needs complete and transparent treatment of epistemic uncertainties.
- There are tools to map A(f): Microzonation (DOI:10.3929/ethz-a-010735479).

For decision makers and users:

- Be aware of the issues related to the correct treatment of site-amplification.
- Large investments are required to achieve reliable estimates of site-response.