Site characterization: Example from SED network

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Orfeus Meeting Bucharest 2015

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

1) Interpretation of earthquake recordings :

- Housing information and installation details (free-field!)
- Site-specific amplification / deamplification
- Issue of 1D, 2D or 3D resonances
- Presence of edge-generated surface waves
- Presence of focusing/defocusing effects
- Possibility of non-linear (soil-) effects

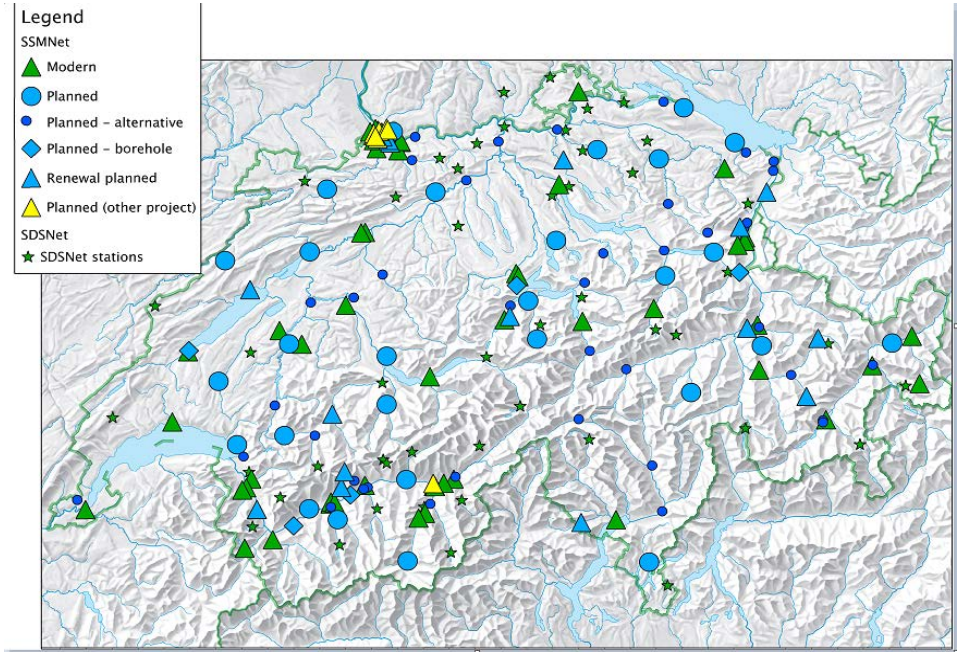
2) Characterization of sites of the seismic stations

- Geology, topography, rock interface at depth,..
- Geophysical measurements (fo from H/V, S-wave profiles, ...)
- Site-amplification from spectral modelling of ground motion
- Geotechnical measurements (SPT, CPT, ….)

Site Characterization

Evolving procedures at the Swiss Seismological Service done for most of the 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



Array methods

Target from 3C array measurements:

- Rayleigh waves dispersion curves
- Rayleigh waves ellipticity and fo
- Love waves dispersion curves
- Identification of 2D resonances from related polarization features

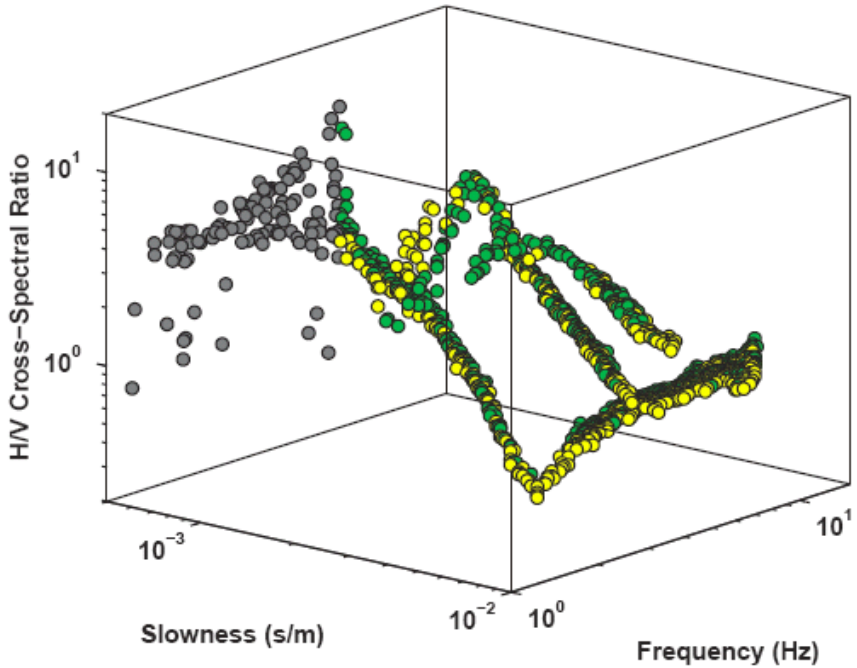
Methods and their improvement: no method works in all situations

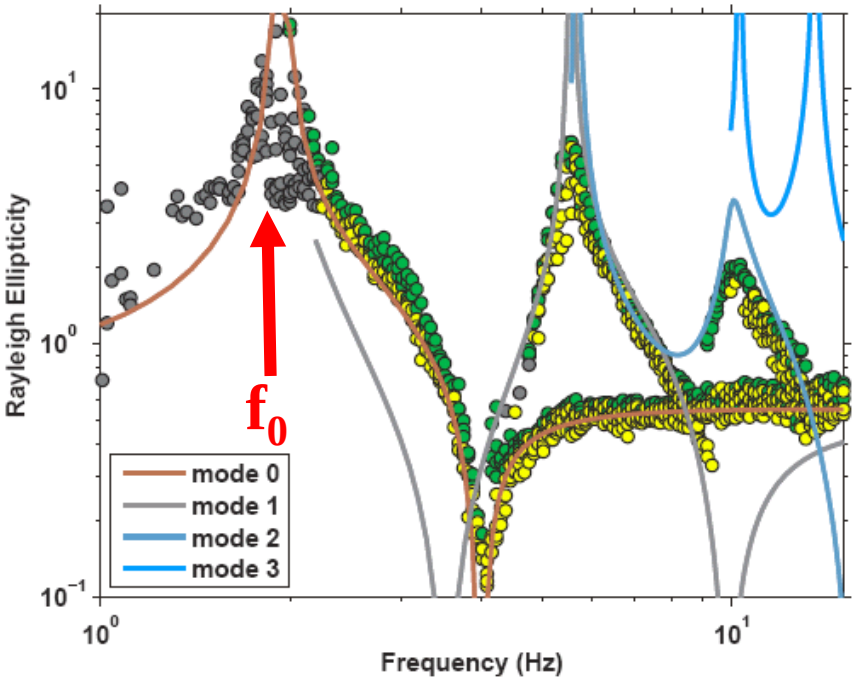
- HRBF: Including interpretation of the horizontal components with directional decomposition √
- Rayleigh wave ellipticity combining vertical and horizontal information from dispersion curves √
- SPAC (SPatial Auto-Correlation) and M-SPAC √
- Probabilistic graphical models and waveform decomposition √
- Directional polarisation analysis √
- Frequency domain decomposition to analyse 2D resonances √
- Combination of the ambient vibration methods with active methods √
- Borehole measurements performed exceptionally √
- Verification of inverted Vs profiles with measured amplification √

3C HRBF

High-Resolution Beam Forming

- Ambient vibration array tool (1D interpretation):
  Rayleigh waves and Love waves dispersion curves, ellipticity
- Retrieving f_0 and ellipticity from 3-C analysis

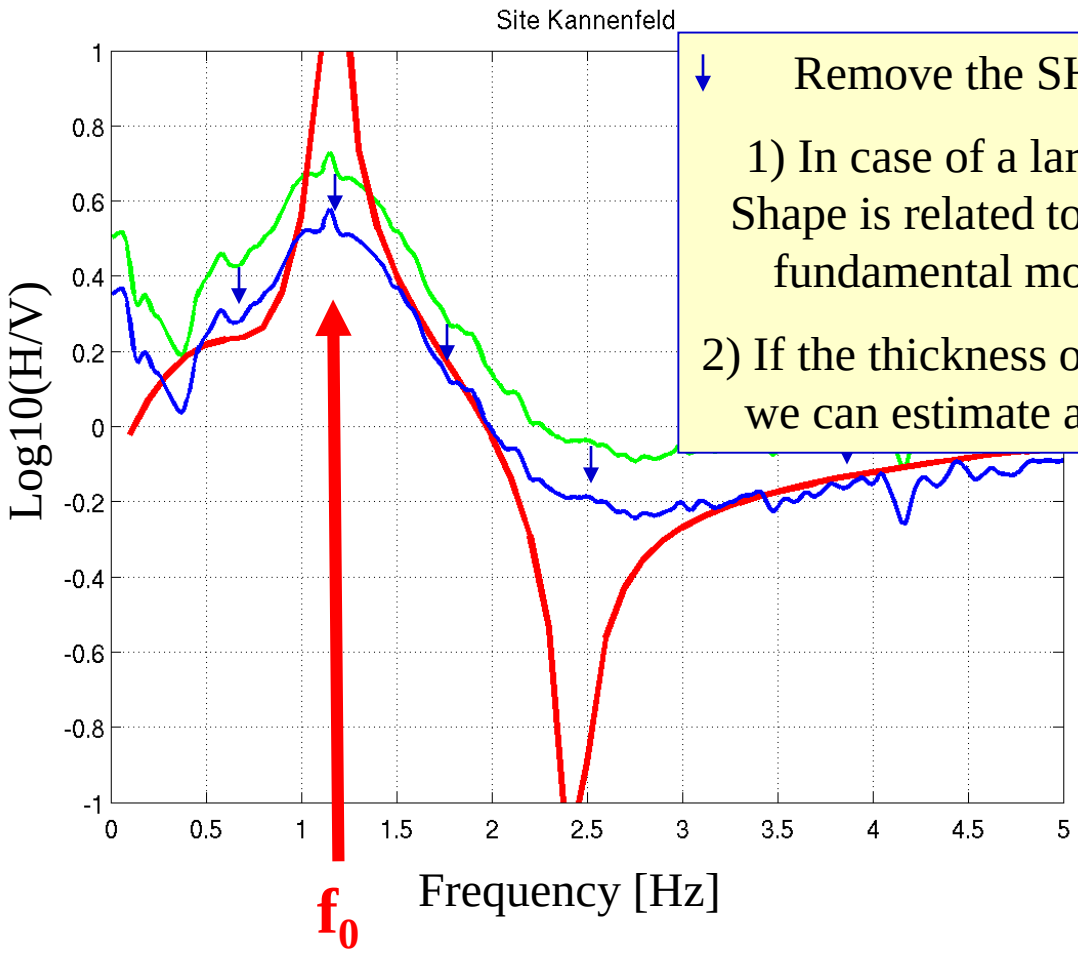




Poggi and Fäh (2010)

Ambient vibration H/V ratio

Anatomy



↓ Remove the SH-wave part.....

1) In case of a large velocity contrast: Shape is related to the ellipticity of the fundamental mode Rayleigh wave.

2) If the thickness of sediments is known, we can estimate an S-velocity profile.

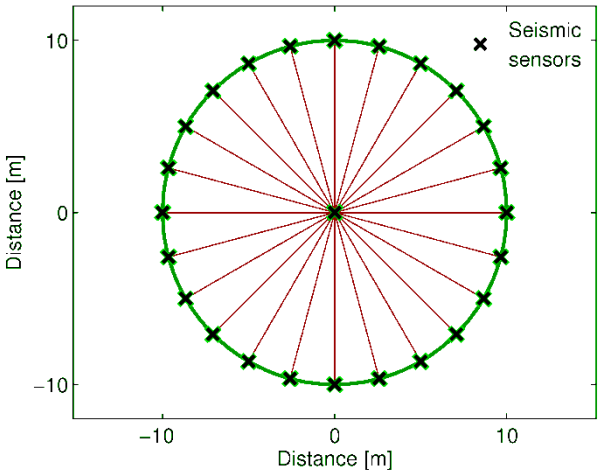
Peak is at fundamental frequency $f_0=v_s/4h$

of the sediments (Considerable Uncertainty)

SPAC and M-SPAC

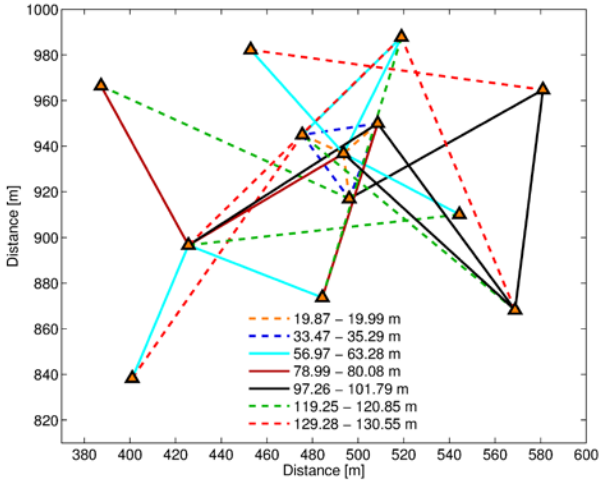
SPAC Layout:

- Large number of stations on ring around central station (Aki, 1957)
- Calculation of the correlation function between central station and all ring stations results in a Bessel function.



M-SPAC Layout:

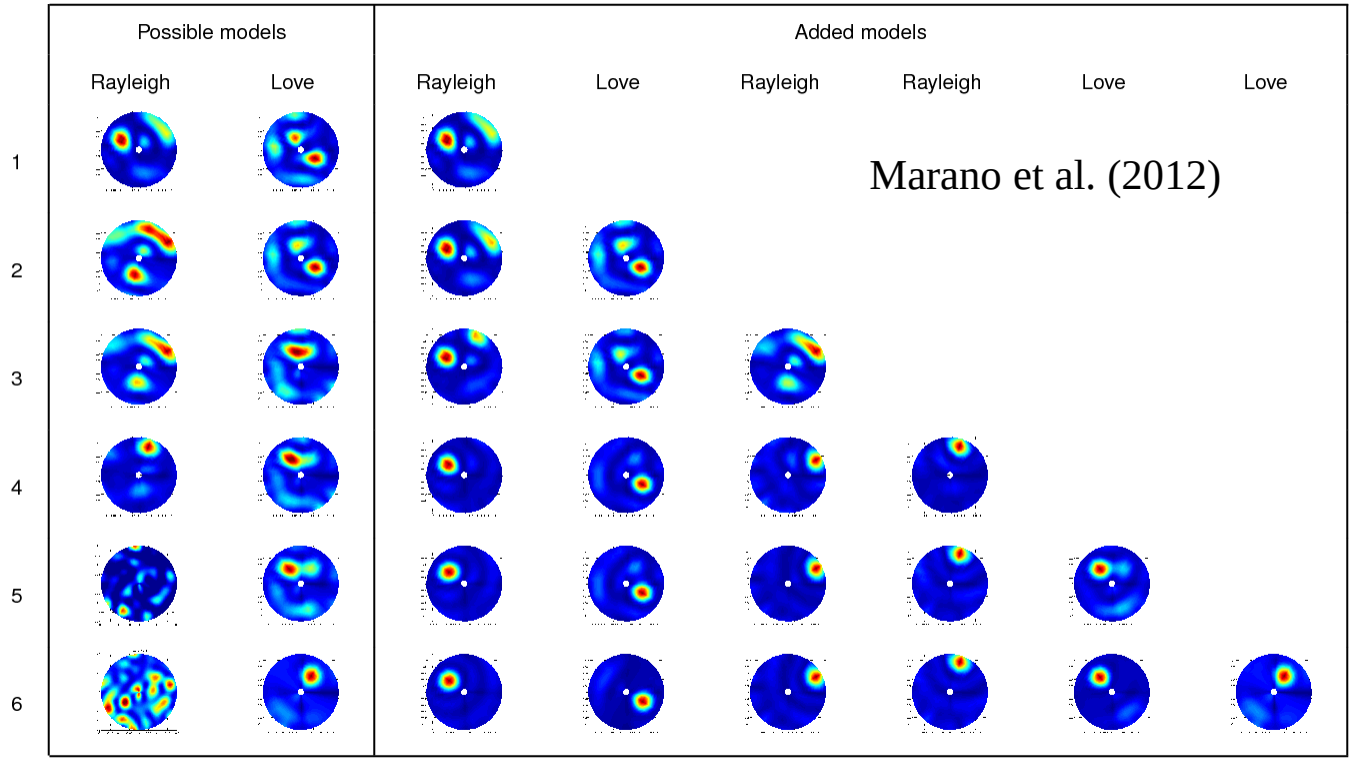
- Station pairs with similar distances are grouped on rings (Bettig et al., 2001).
- Can also analyse horizontal components (Köhler et al., 2007)



Hobiger et al. (2015)

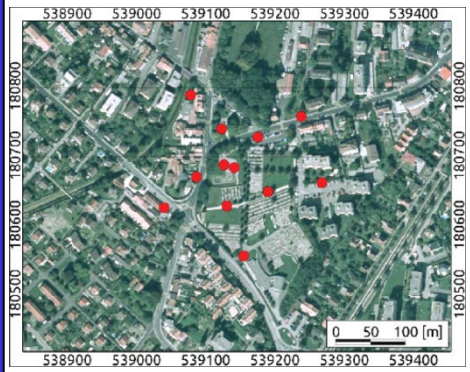
Probabilistic graphical models

- 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



Probabilistic graphical models

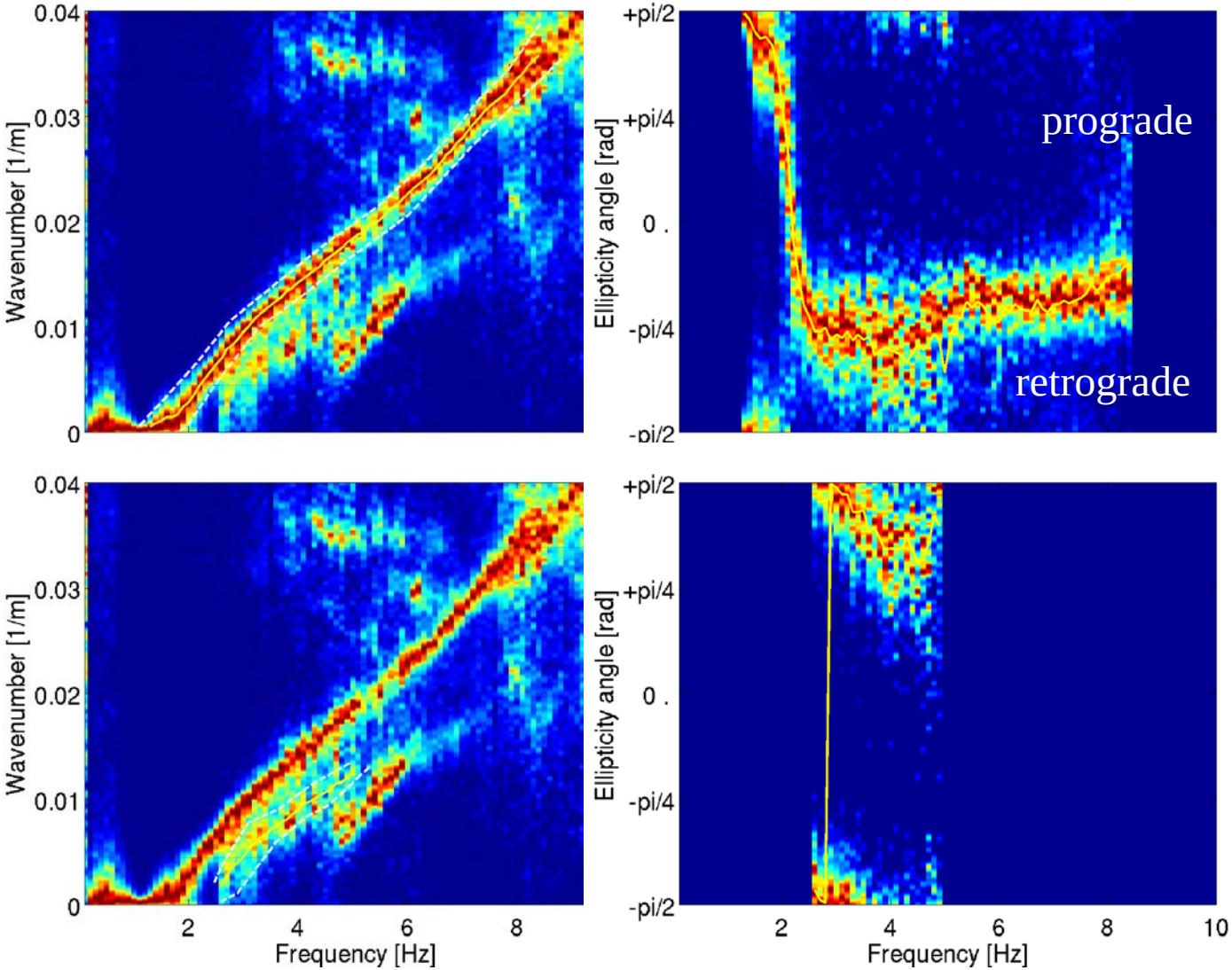
Site Yverdon



Marano et al. (2012)

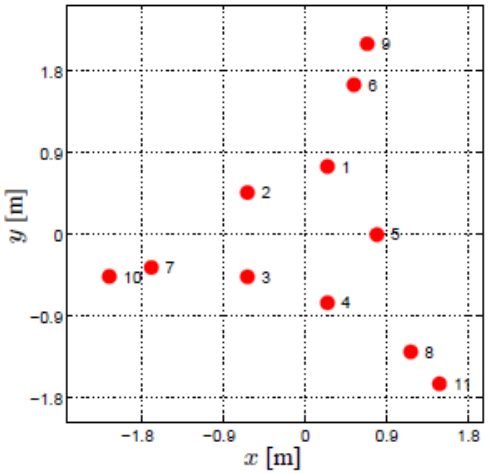
Rayleigh wave dispersion curves

Rayleigh wave ellipticity angle

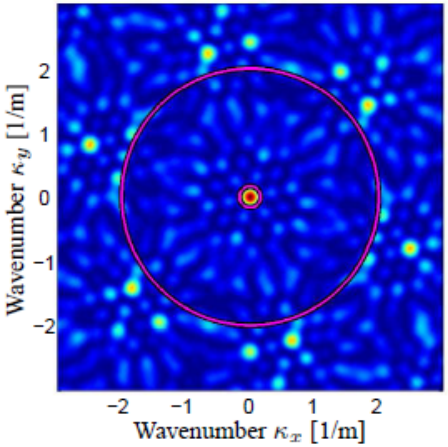


Probabilistic graphical models

- What is the minimum number of sensors and the optimum configuration?
- How to optimize array configuration in urban environment.

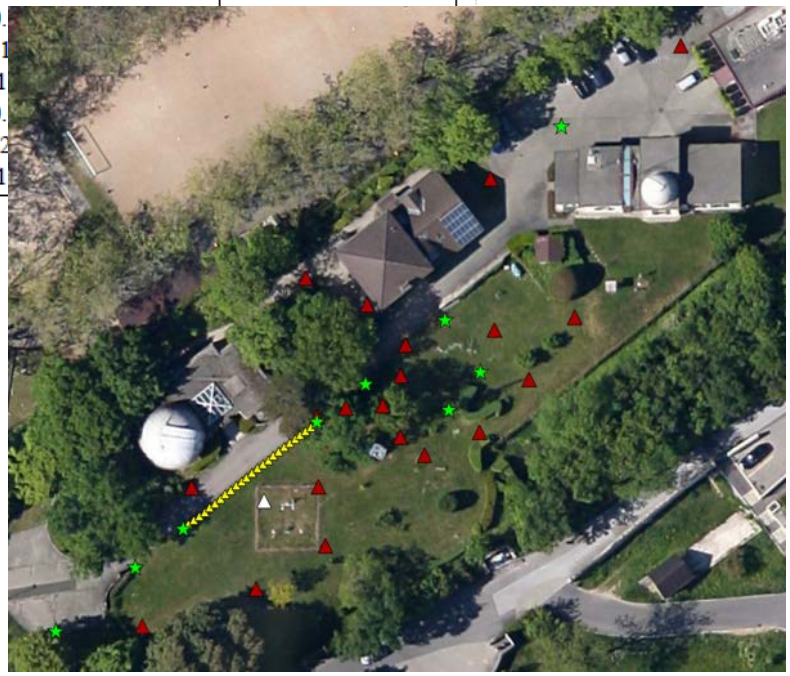


(a) $h(x, y)$



(b) $|H(\kappa_x, \kappa_y)|^2$

n	x_n [m]	y_n [m]	r_n [m]	ψ_n [°]
1	0.24396	0.75083	0.78947	72
2	-0.6387	0.46404	0.78947	144
3	-0.6387	-0.46404	0.78947	216
4	0.24396	-0.75083	0.78947	288
5	0.78947	0	0.78947	0
6	0.			
7	-1			
8	1			
9	0.			
10	-2			
11	1			



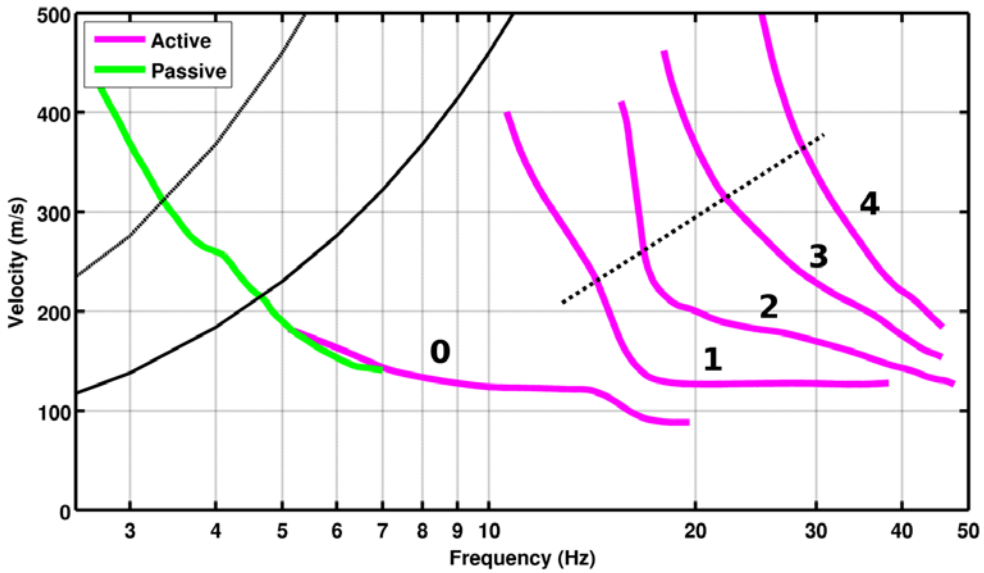
Marano et al. (2013)

Active methods

- Application of active methods (MASW, S-seismic) in complex topography;
- However, passive methods resolve larger depths than active methods;
- Body-wave methods can resolve more details than surface wave methods;
- However, we prefer average velocity profiles (surface wave techniques);
- Combination of active and passive methods allows to

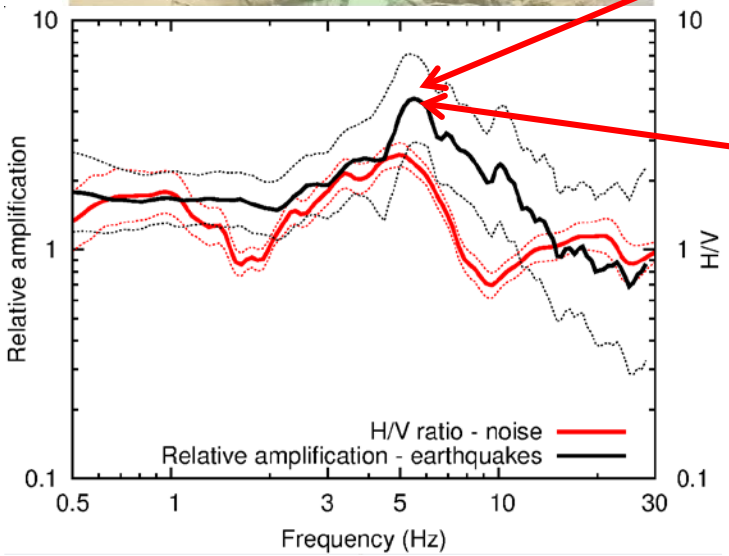
  → extend dispersion curves to high frequencies and

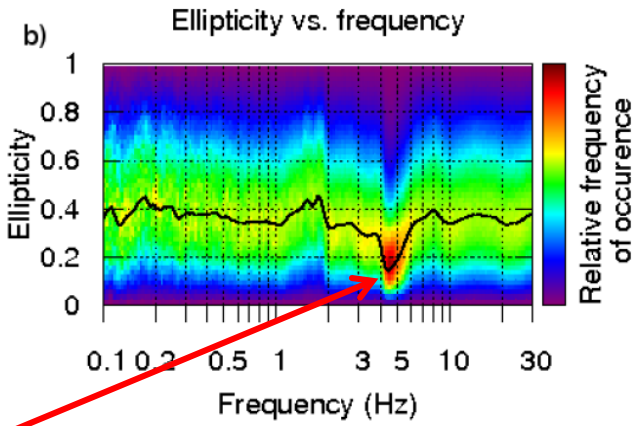
  → to constrain Vs at the surface.

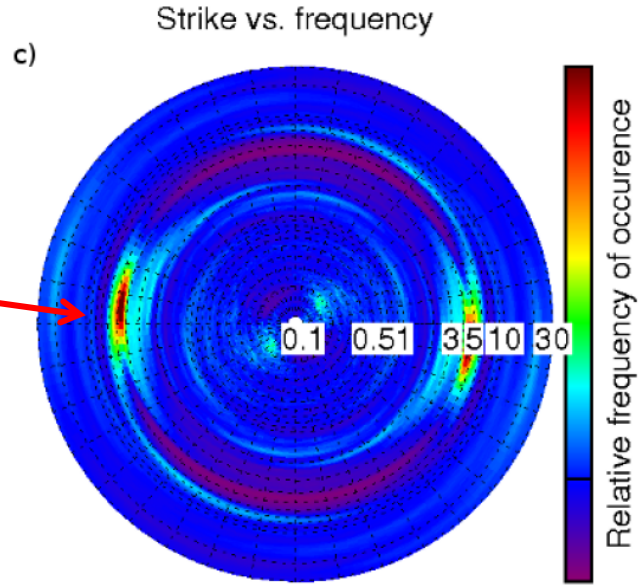


Directional polarisation

Identification of instable rock-slopes



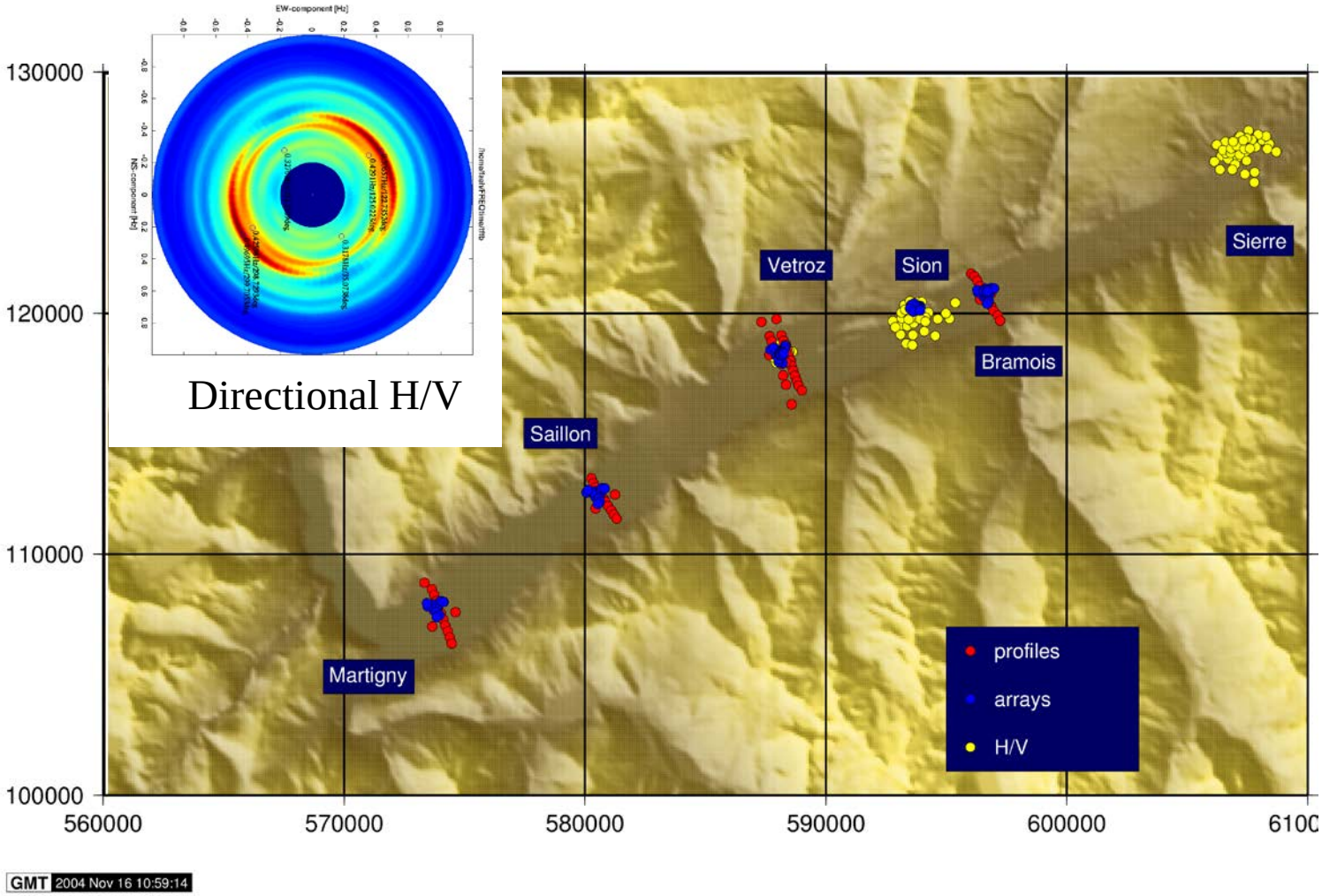




Burjanek et al. (2013)

Directional polarisation

Identification of 2D resonances in alpine valleys



Directional polarisation

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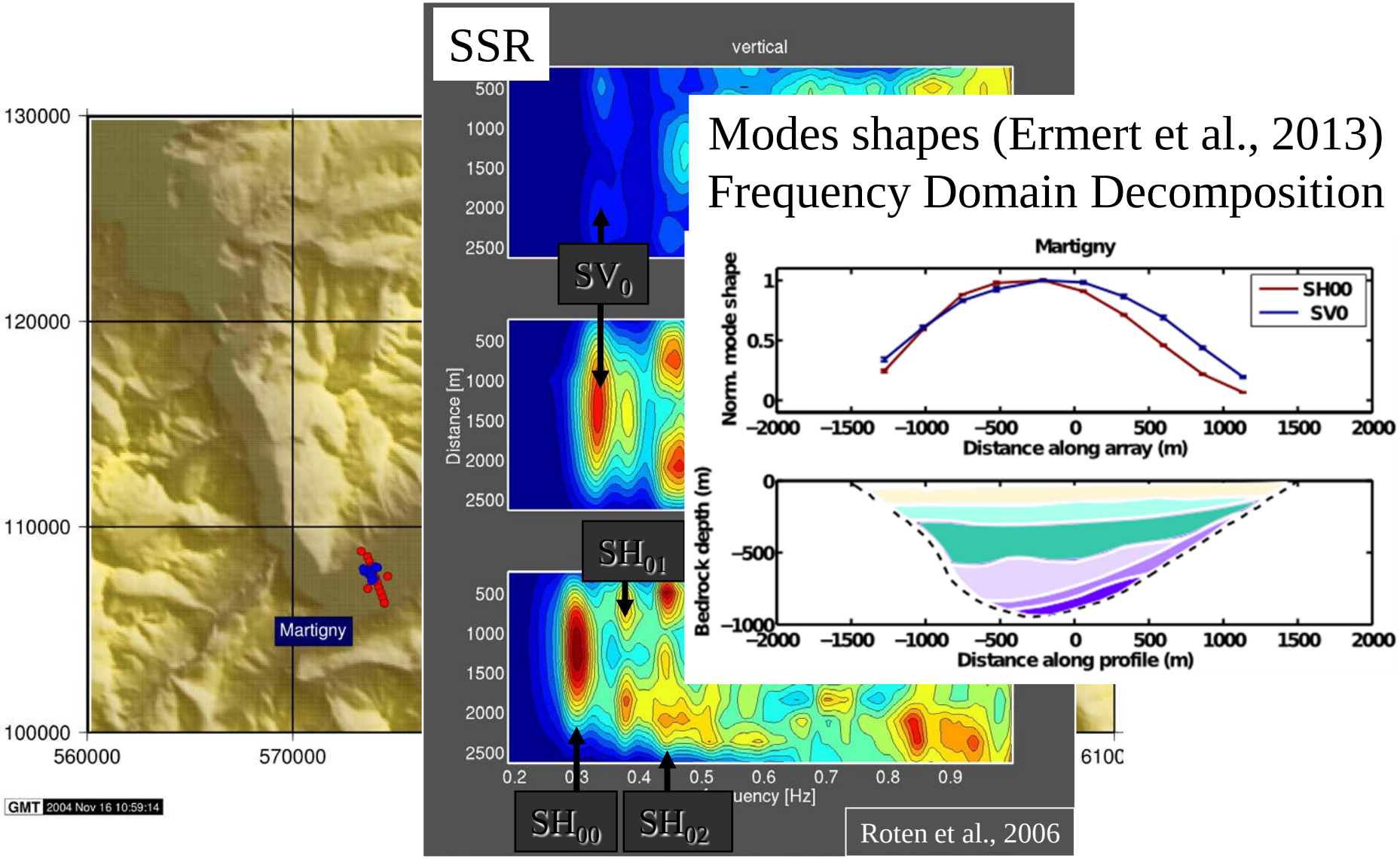


Ground motion analysis

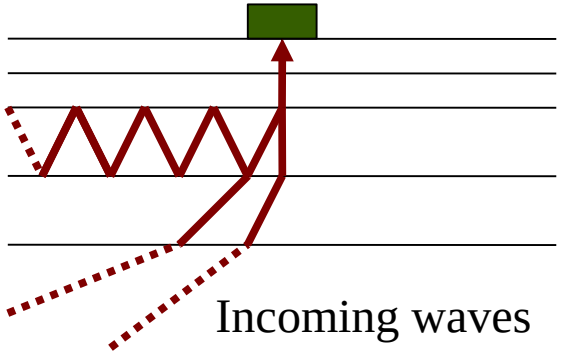
Using the Swiss stochastic ground motion prediction model for the reference rock in the Swiss network (Edwards et., 2013)

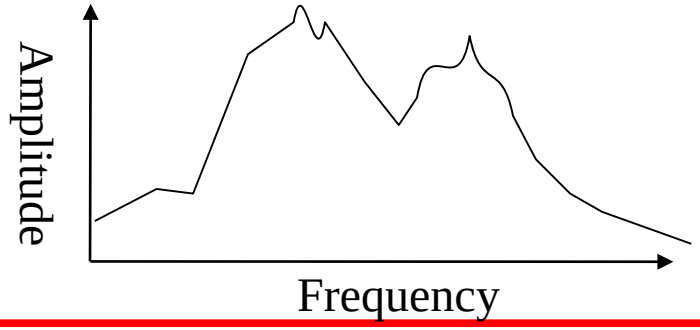
$$\Omega_{ij}(f,r) = \omega \cdot \Omega_i \cdot f_c^{\gamma} / (f_c^{\gamma} + f^{\gamma}) \cdot S_{ij}(r) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot t_{ij}^{*}) \cdot A_j(f) \cdot \exp(-\pi \cdot f^{1-\alpha} \cdot K_j)$$

Source Spectrum | Path Effects | Site Effects

Soil/rock in the upper layers:

- Amplification A(f)
- Damping (Kappa)

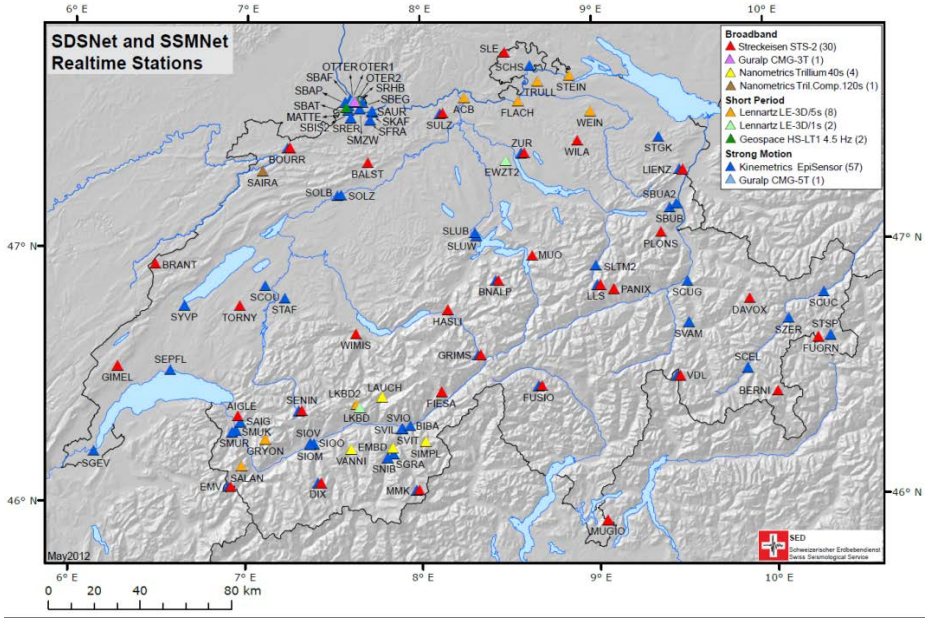


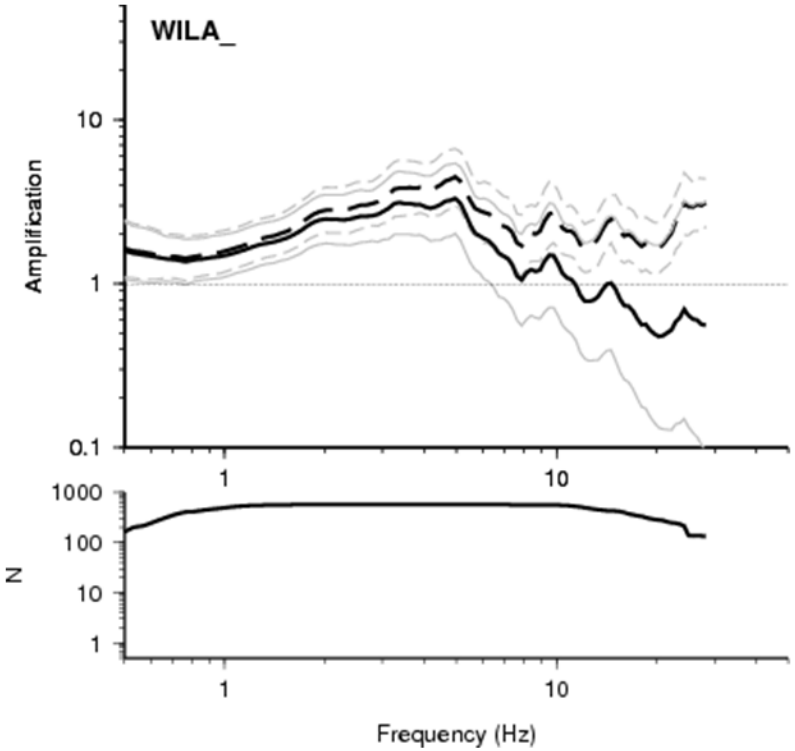


Ground motion analysis

Using the Swiss stochastic ground motion prediction model for the reference rock in the Swiss network (Edwards et., 2013)

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

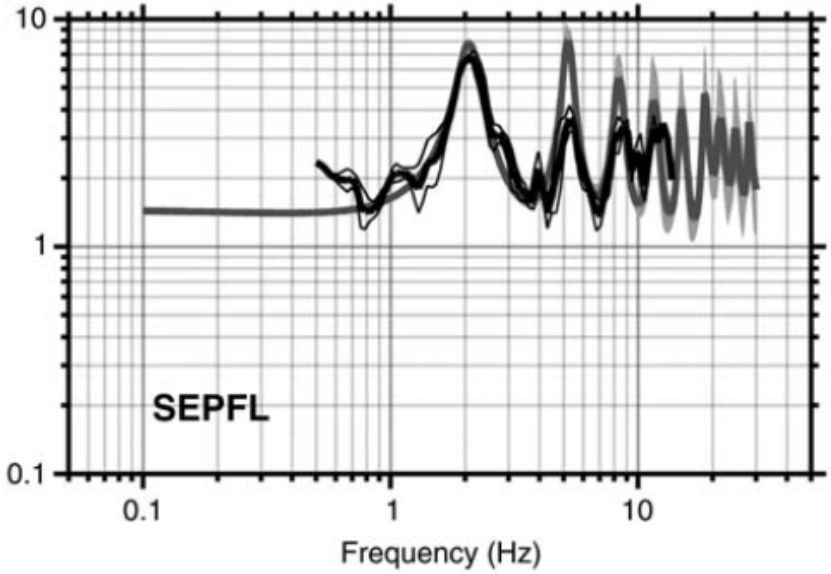




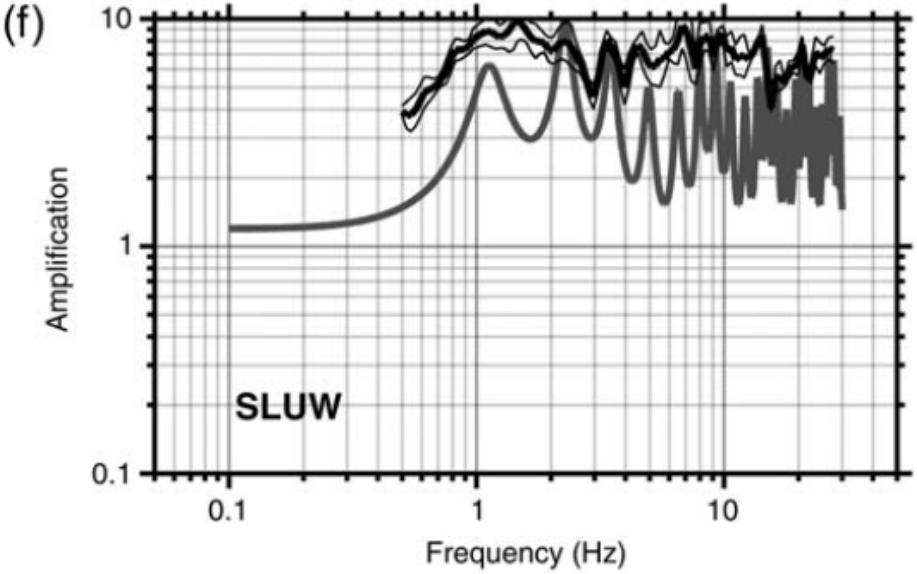
Ground motion analysis

1) **Verification of the measured velocity profiles**
2) **Derive features of the stations** by comparison with computed 1D SH-amplification from measured velocity profile

Simple 1D response
at Lausanne EPFL site



Edge-generated surface waves
at Lucerne site

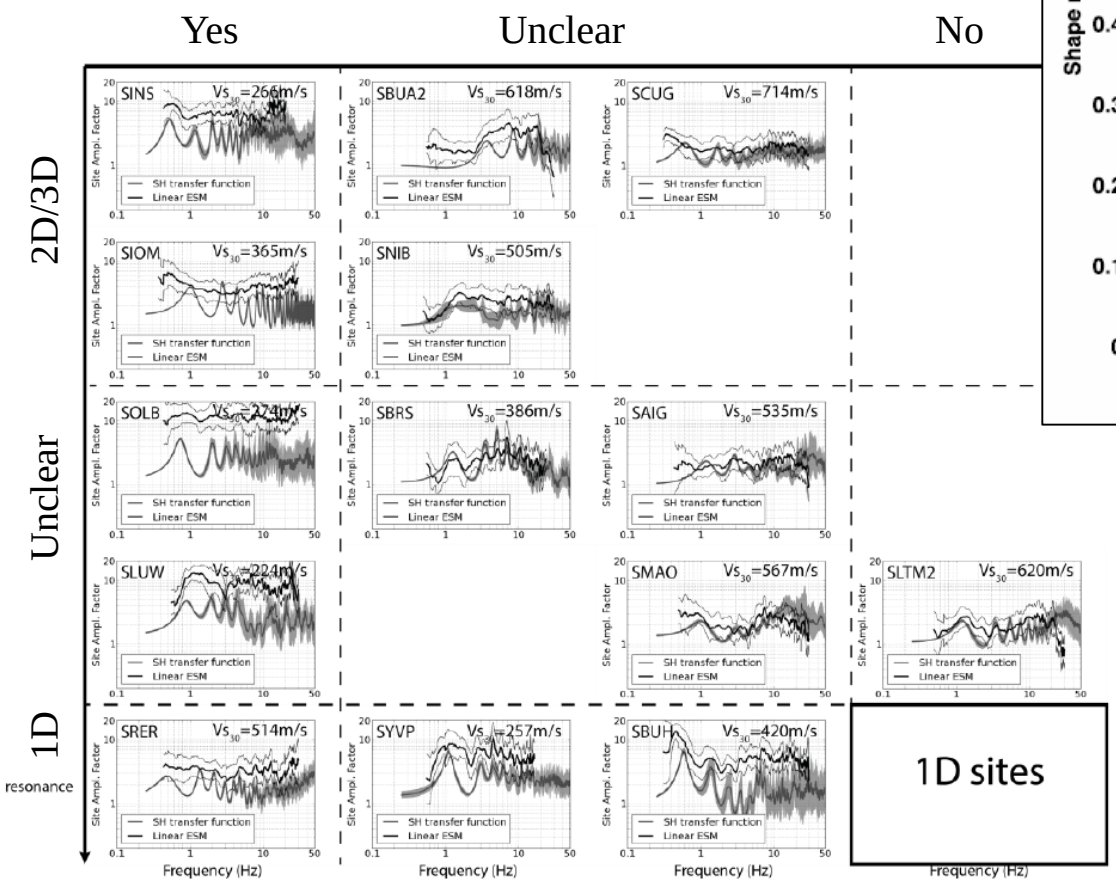


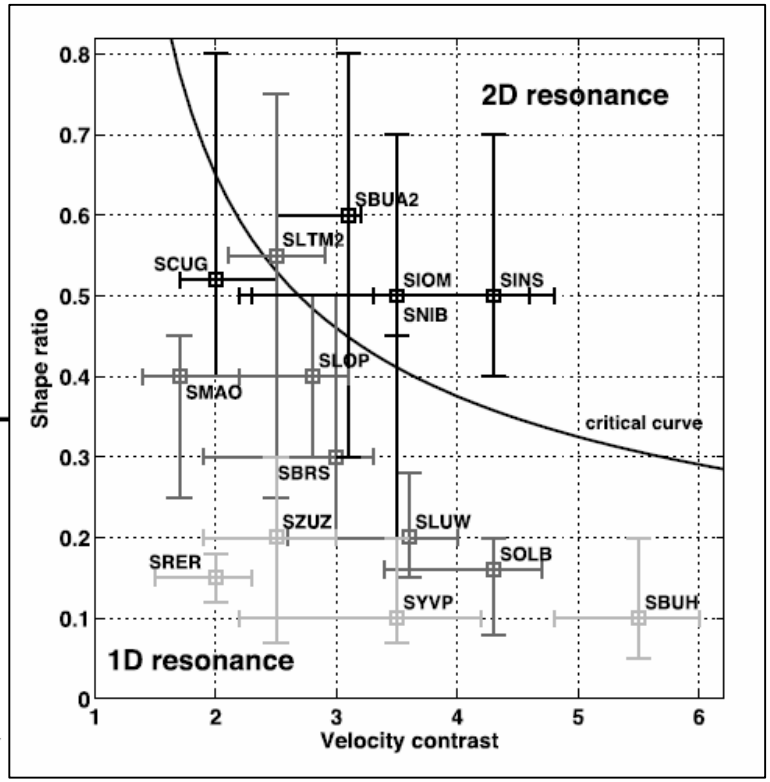
Vs30~200 m/s

Classification of seismic stations

Site amplification from spectral modelling

Edges generated surface waves

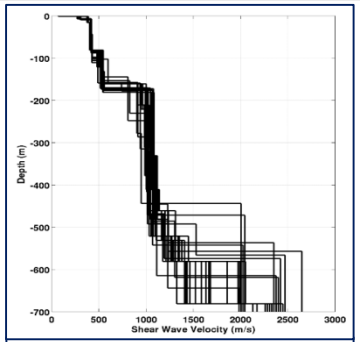


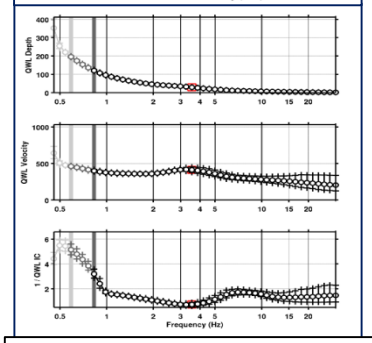


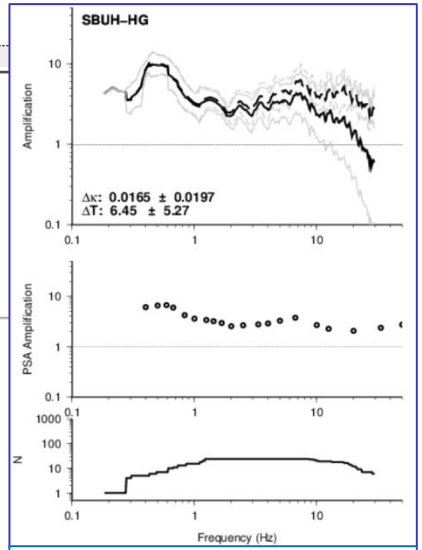
Michel et al. (2014)

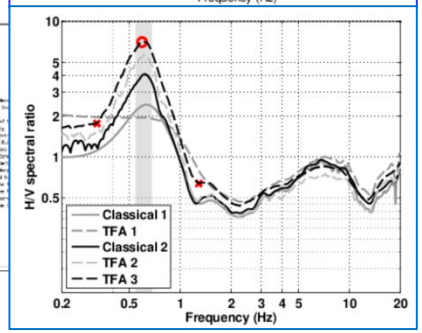
Resources

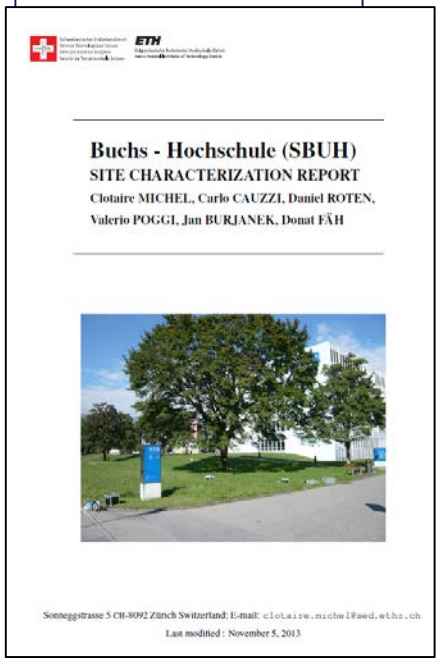
- File structure for all H/V and Vs measurements
- Database including selected information
- Access via specific web-interfaces (e.g. for seismic stations)
- Reports accessible via web









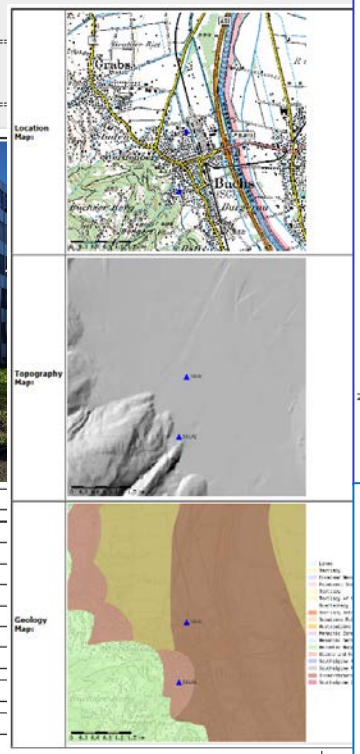


Stations

List of Stations for network: CH

Lines/page: 20

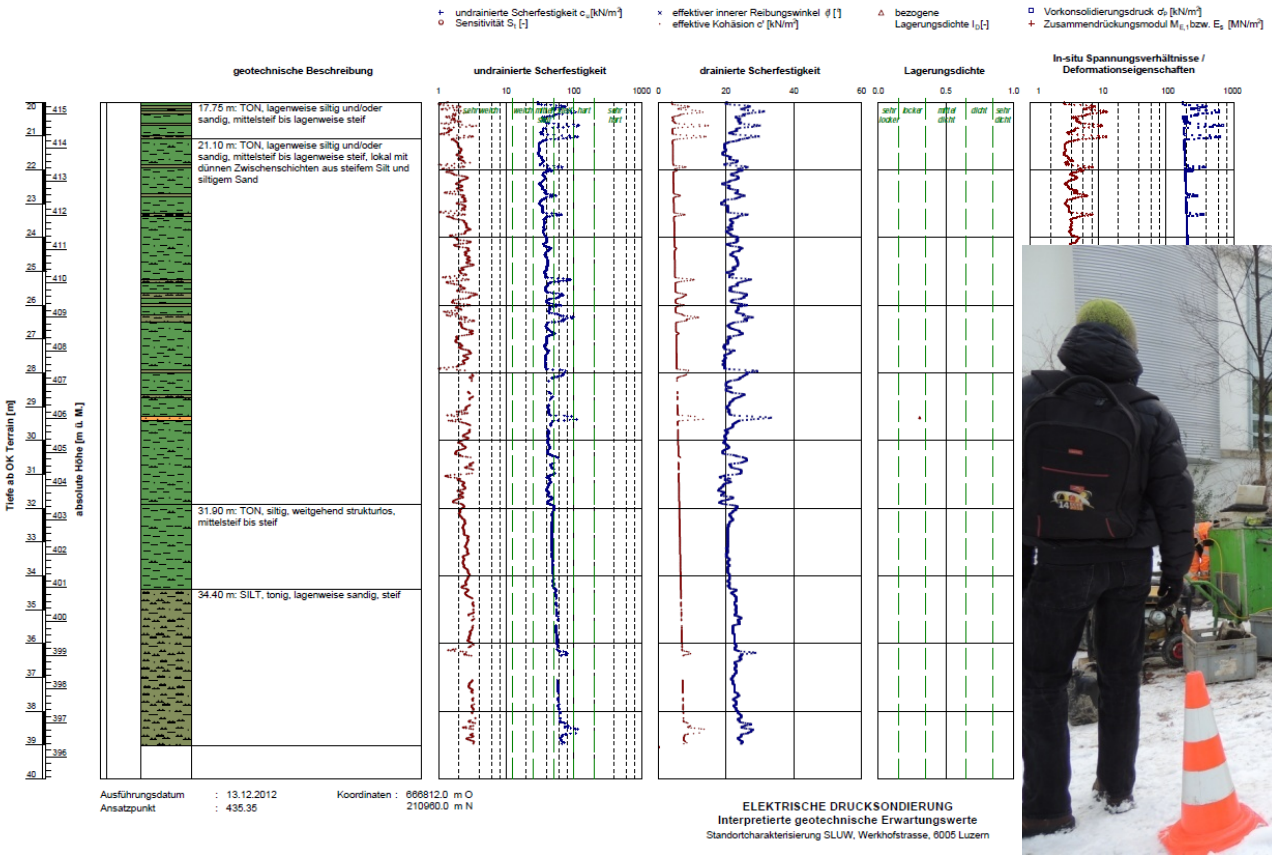
networkcode	network agency	sta coc
CH		SMAR
CH		SMAV
CH		SMTK
CH		SMUK
CH		SMUR
CH		SMZA
CH		SMZW
CH		SNES
CH		SNEW
CH		SNIB
CH		SOLB
CH		SOLZ
CH		SPG1
CH		SPG2
CH		SPG3
CH		SPG4
CH		SPG5
CH		SPG6
CH		SPGF
CH		SRER



Overview Location:	
Picture Gallery:	details...
Network:	CH
Station Code:	SBUH
Latitude (WGS84):	47.17255
Longitude (WGS84):	9.474050
Altitude (CH1903):	444
running from:	2012-10-19
...until:	now
Sensor Types:	Accelerometer
Geological Unit:	Alluvium (Holocene)
Site Morphology Class:	T1
Site Morphology Description:	Centre of the Rhone alluvial plain
Soil Class EC8:	B
Soil Class SIA:	C
Basin Information:	Rhine basin, interface at fundamental frequency at 250 m depth
Reference:	Michel Clotaire, Cauzzi C., Roten D., Poggi V., Burjanek J., Fäh D., "Buchs - Hochschule (SBUH) Site characterization report", Swiss Seismological Service, ETH Zürich, 2013

CPT measurements

- Requires particular expertise – SED is still in a testing phase
- From CPT to modeling of non-linear soil response (under development)
- Comparison with geotechnical laboratory testing (pending)
- Database structure yet undefined



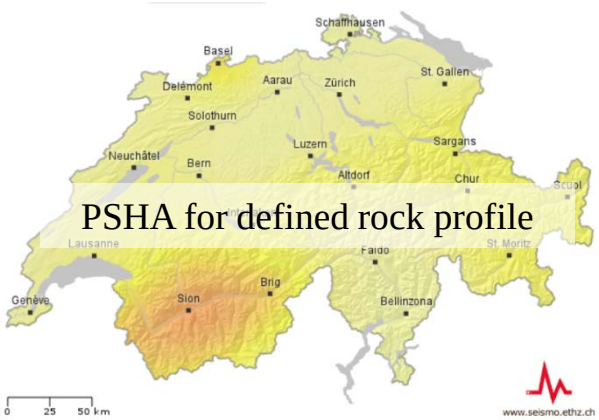
Conclusions

1) Site characterization is highly recommended for all (new) seismic stations:

- The step **needed** for improved seismic hazard products
- Needs specific expertise to perform reliable Vs measurements
- Field techniques are developing and still improving
- Important issue: data storage and access

2) Site characterization will allow that:

- Sites can be systematically classified beyond Vs30
- Site properties can be derived and combined with site amplification: A(f), Kappa
- Ground motion can be referenced to a Vs-profile, decreasing epistemic uncertainties in seismic hazard products



PSHA for defined rock profile