# Overview of recent progresses on the empirical assessment of site response

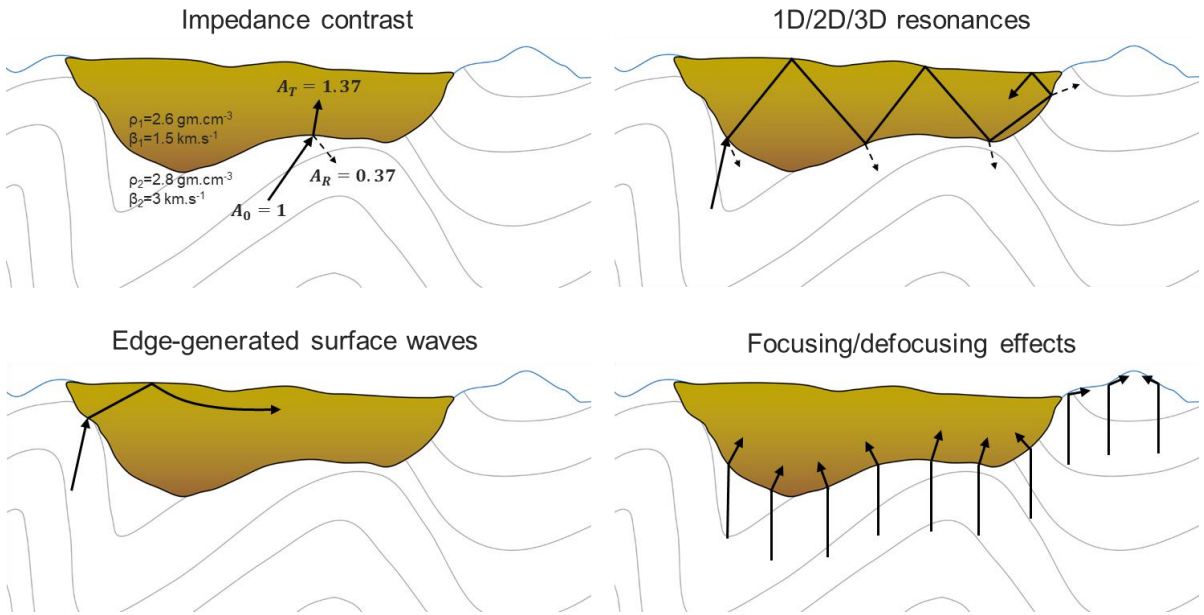
## And how to combine them…

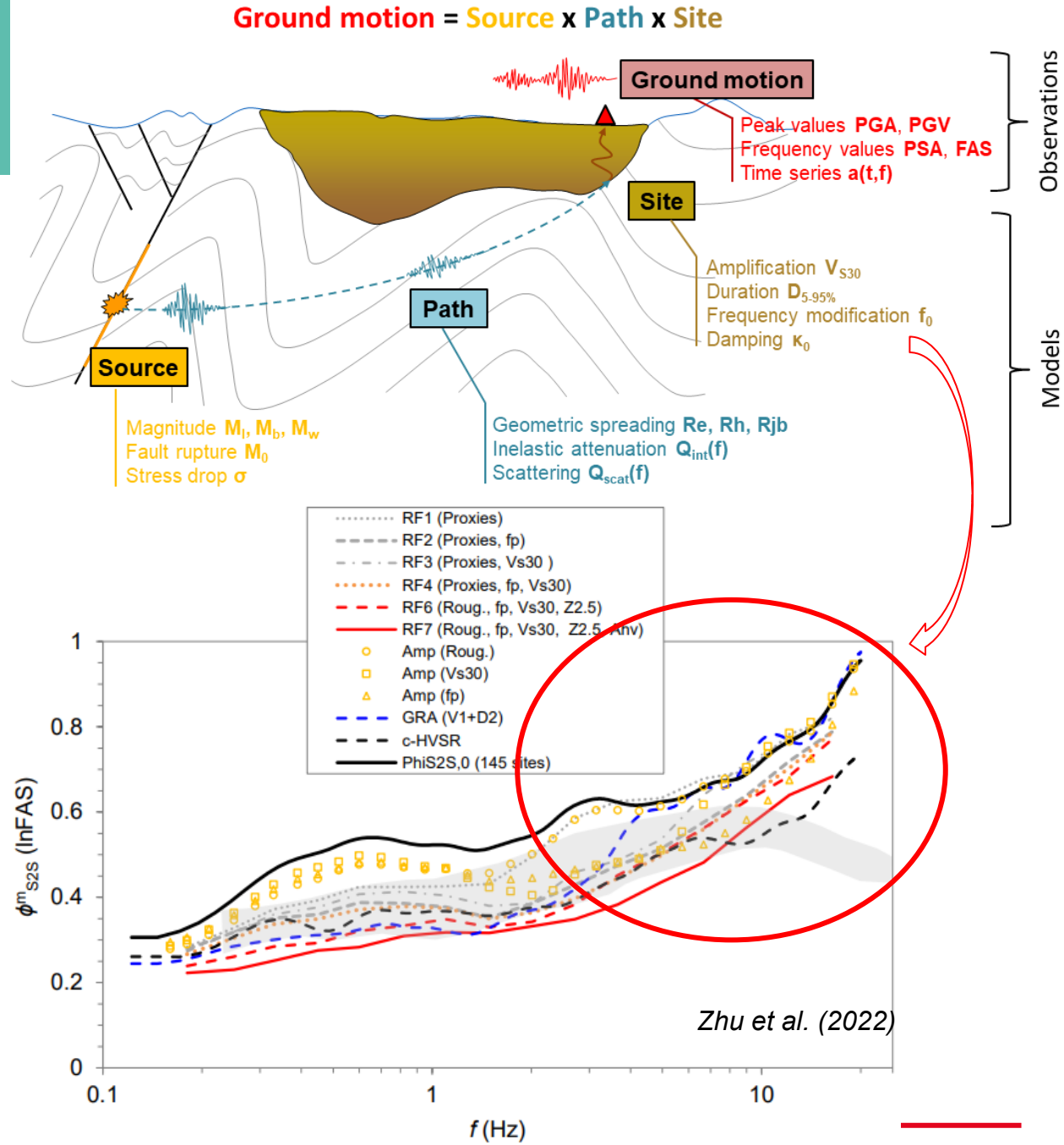
***Vincent PERRON, CEA, vincent.perron@cea.fr***
*Fabrice HOLLENDER, CEA, fabrice.hollender@cea.fr*
*Margaux BUSCETTI, Uppsala Universitet, margaux.buscetti@geo.uu.se*
*Ioannis GRENDAS, ITSAK, grendasioannis@gmail.com*
*Paola TRAVERSA, EDF, paola.traversa@edf.fr*
*The EMISSER partners: Julie REGNIER (CEREMA), Isabelle DOUSTE-BACQUE (ISTerre), Remy BURLOT (ISTerre)*

# Site effects

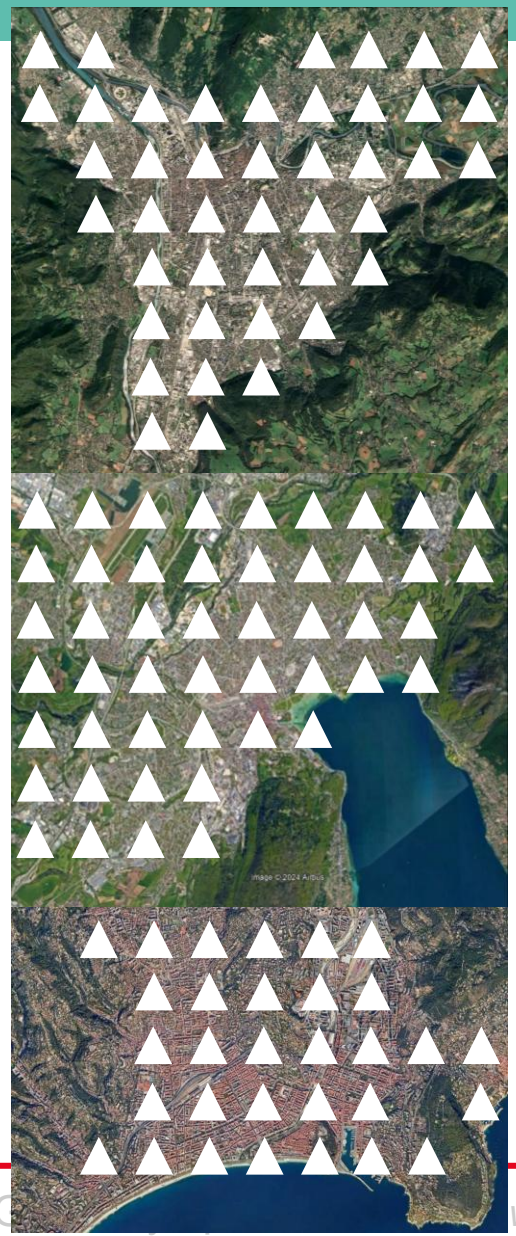
Site effects are:

- Complex phenomena's
- Still challenging to model in GMM
- Lead to high uncertainties at high frequencies (>3 Hz)



# Site-specific SHA in urban and industrial areas



1 Grenoble

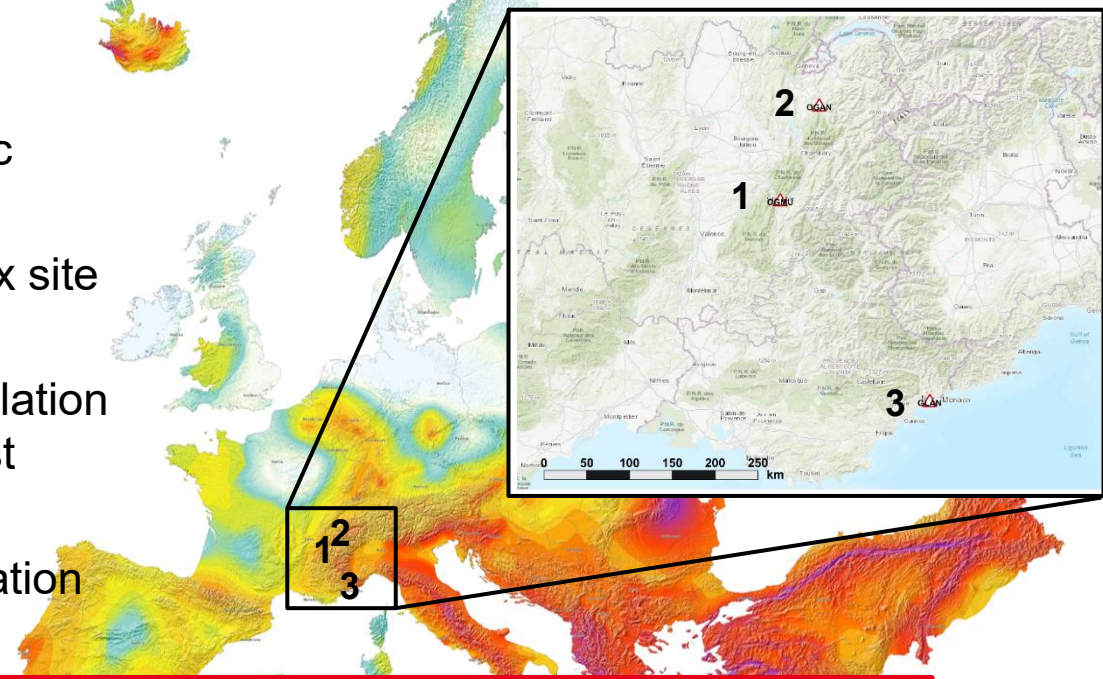
2 Annecy

3 Nice

3 French cities with:

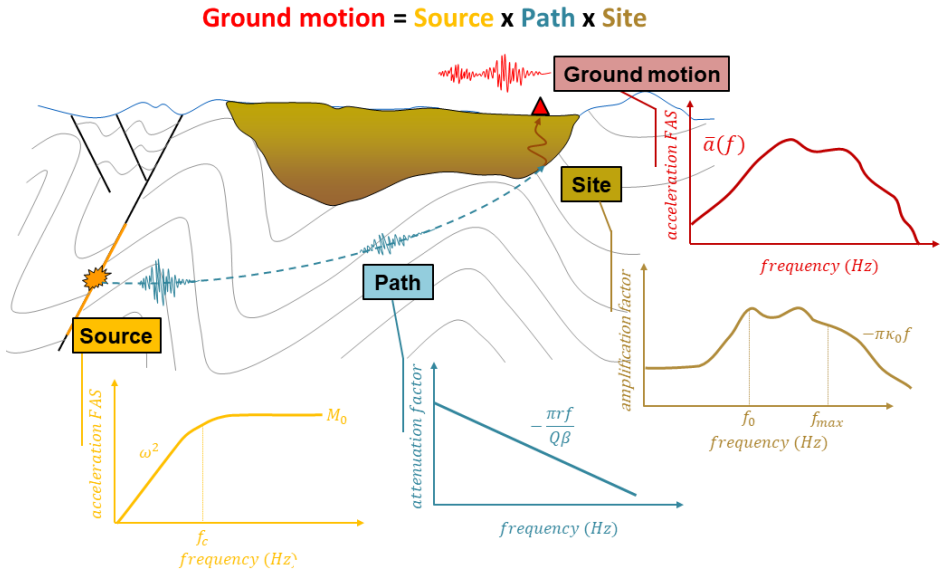
- Relatively high seismic activity (for France)
- Important and complex site effects (2D & 3D)
- Relatively dense population (Nice is the 5th biggest cities in France)
- Long-term instrumentation already available

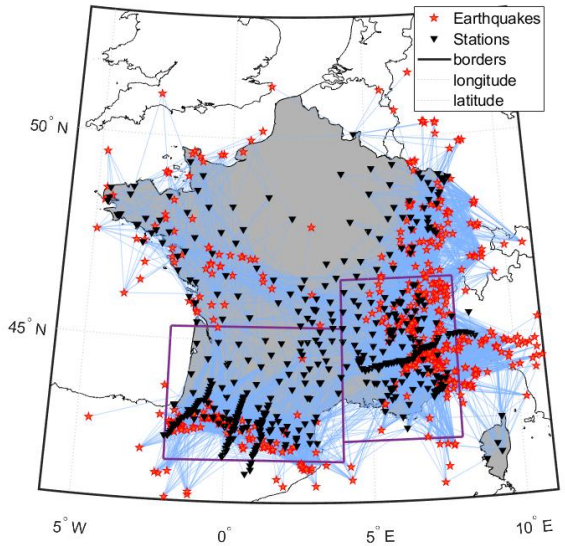
- Current models accuracy and resolution are insufficient (e.g. ESHM20)
- However difficult instrumentation
- High and variable anthropic noise

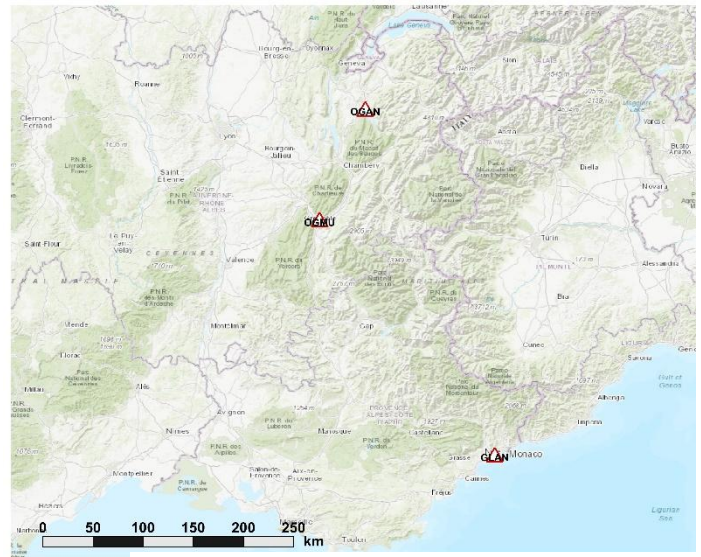



How could SHA be estimated specifically in targeted areas based on empirical approaches?

# Regional and coherent site effects assessment using GITn

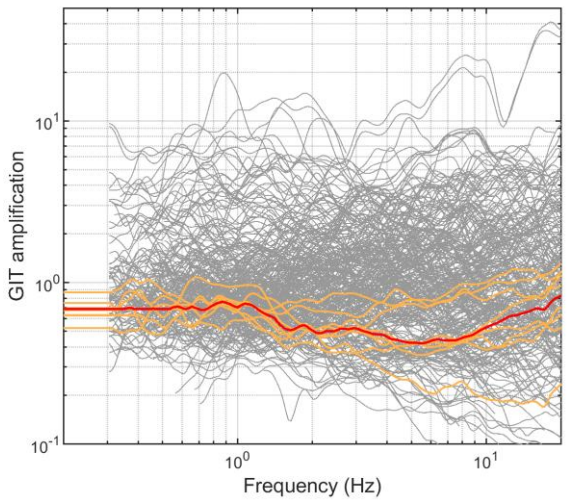


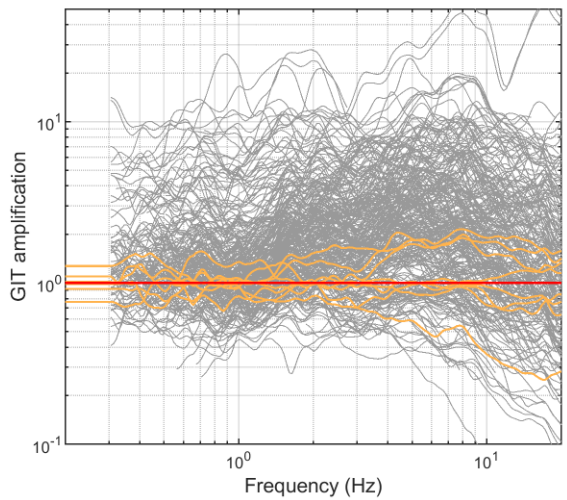



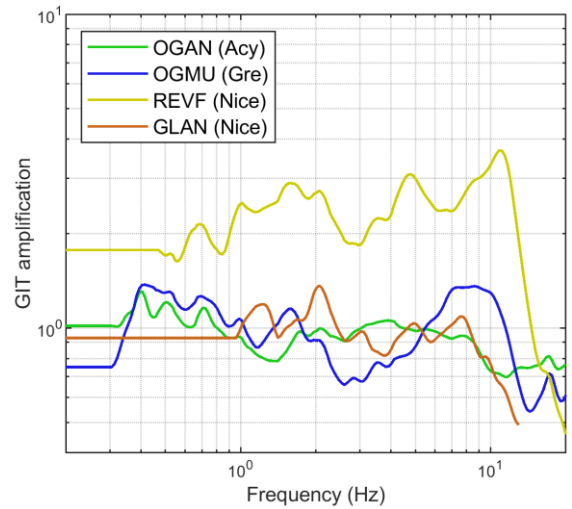




Stations de référence au rocher très dur:

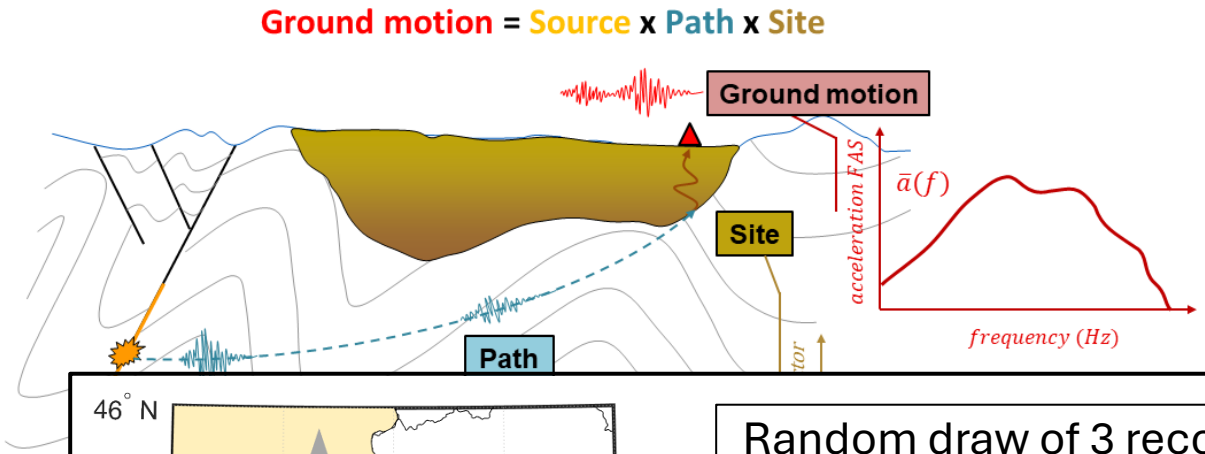
- CA01
- IRVG
- CALF
- OGSM
- OGCH
- OGAN
- OGCA
- OGSA



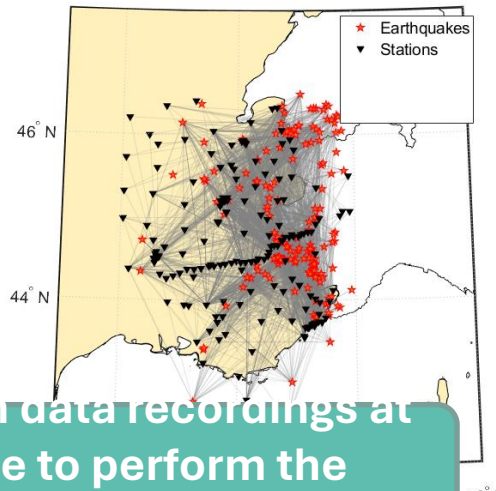



# Regional and coherent site effects assessment using GITn

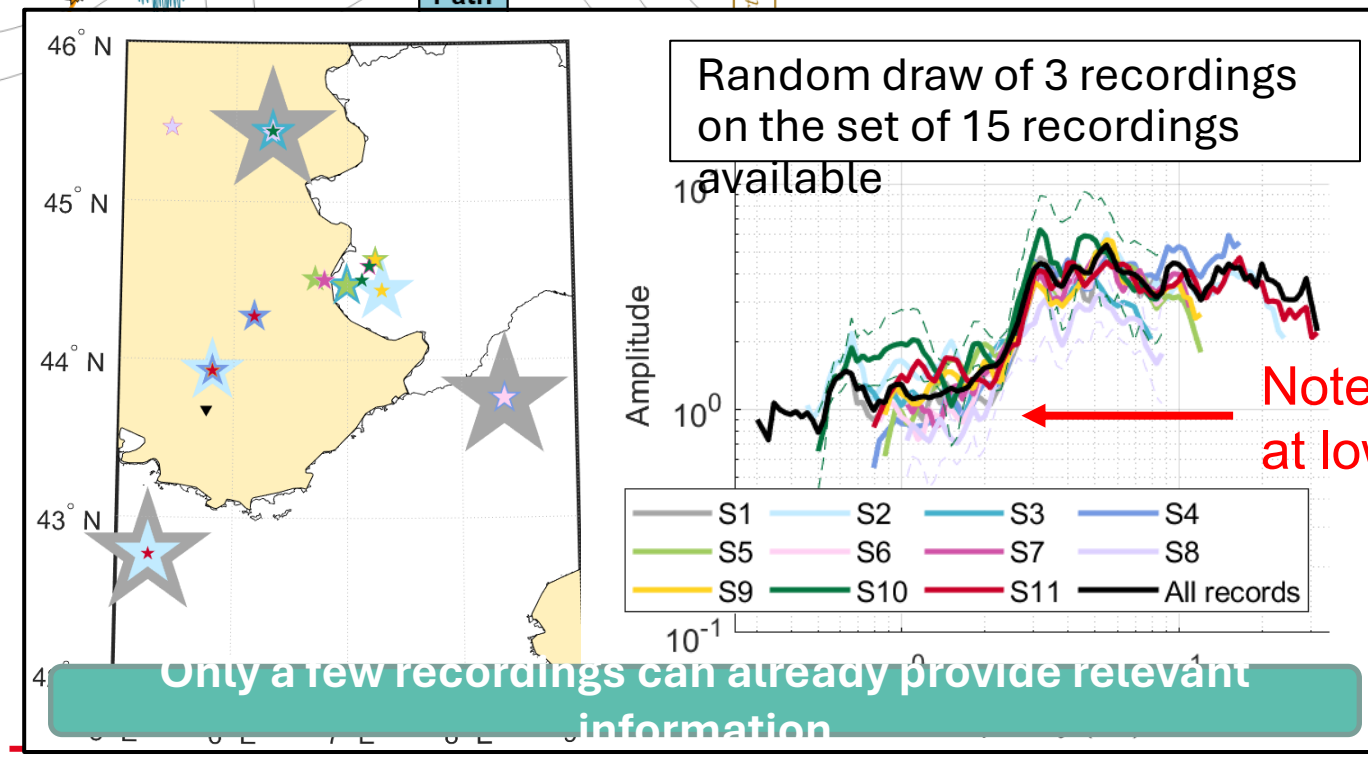



GIT is restricted to:

- ✓ Dense regional network
- ✓ M>2.5
- ✓ Re<150 km

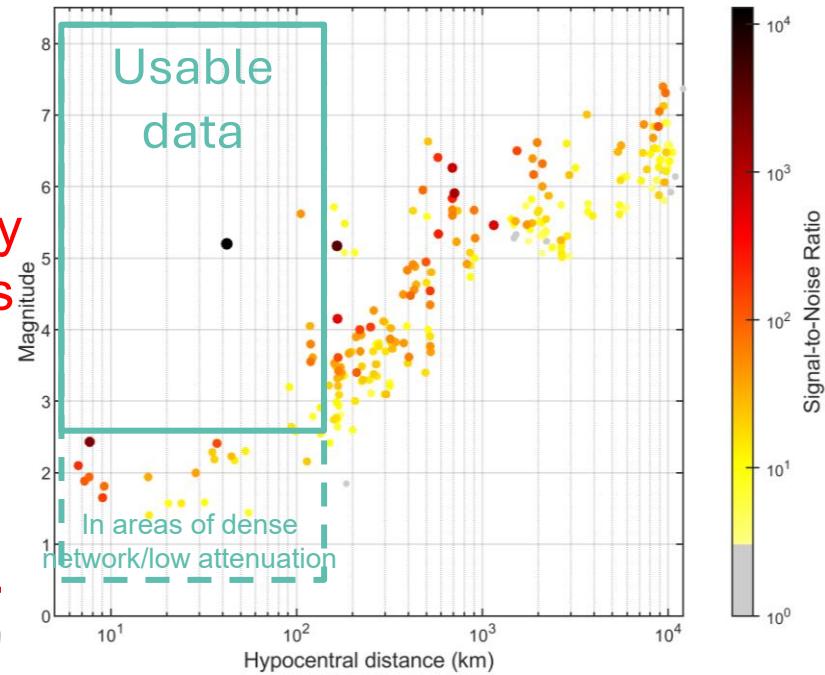



**GITs require enough data recordings at the regional scale to perform the inversion**

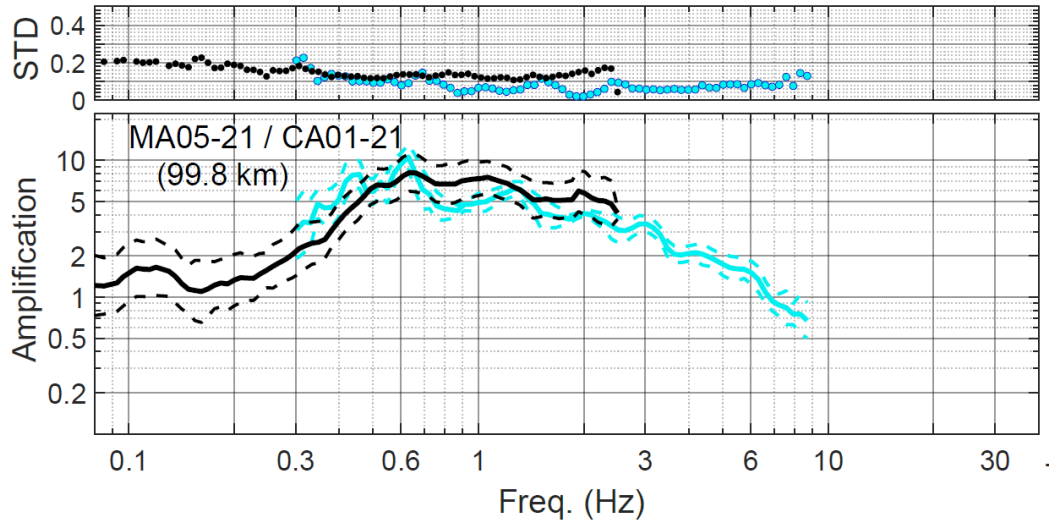


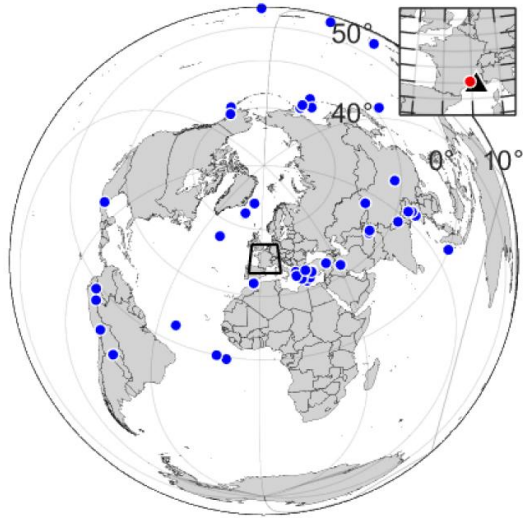

Note the variability at low frequencies

**Only a few recordings can already provide relevant information**



# Spectral ratio on teleseismic P-waves (SSRp)



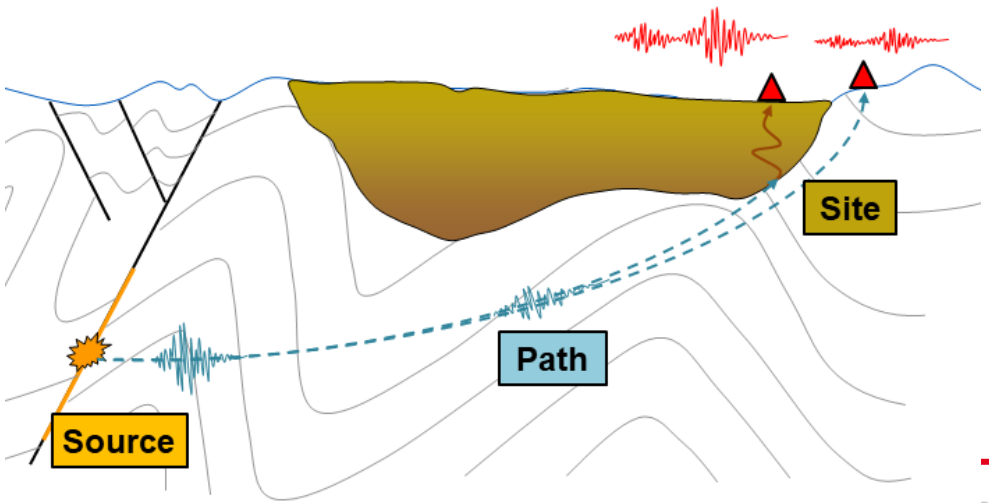




GIT (local to regional EQs)

P-wave SSR (teleseism Re > 1000 km)

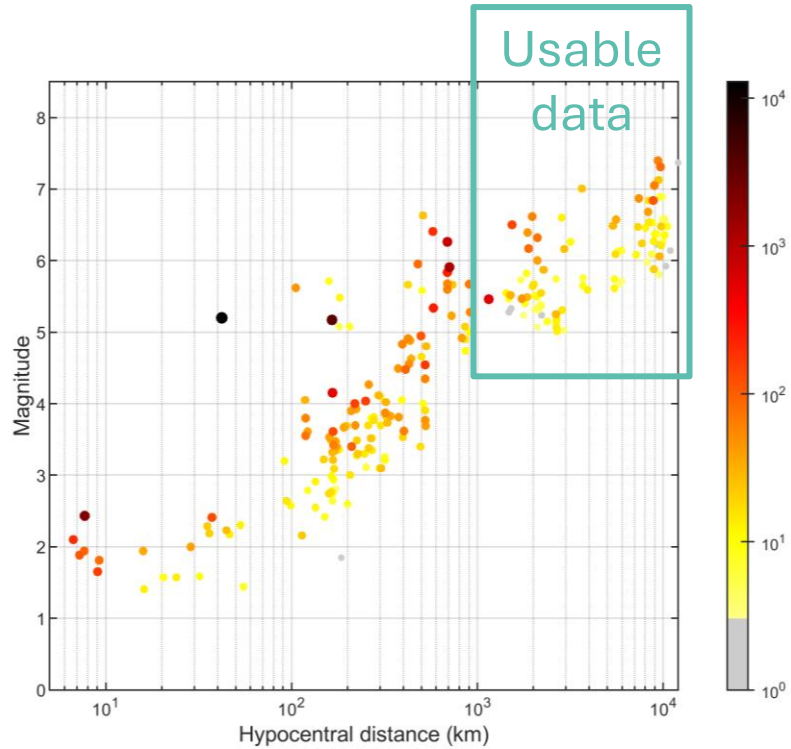
Very distant reference stations!
(~100 km between CA01 and MA05)

**Ground motion = Source x Path x Site**

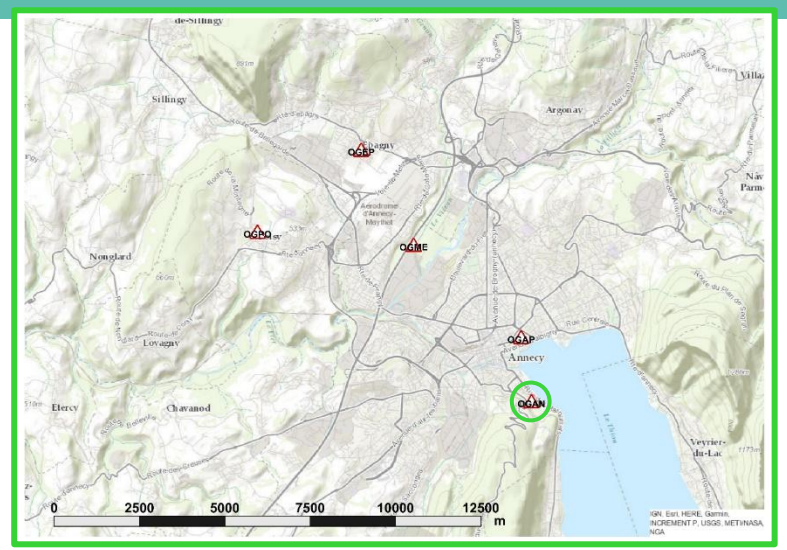


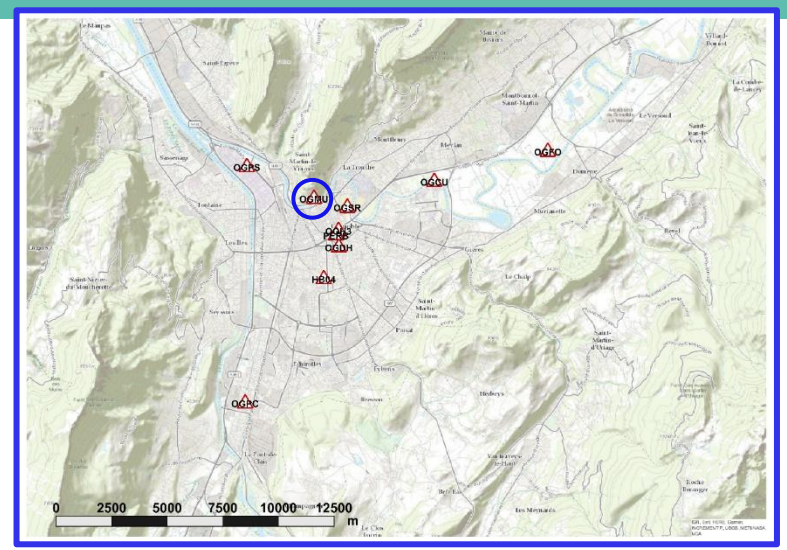

**Extend results of GIT to very low frequencies**

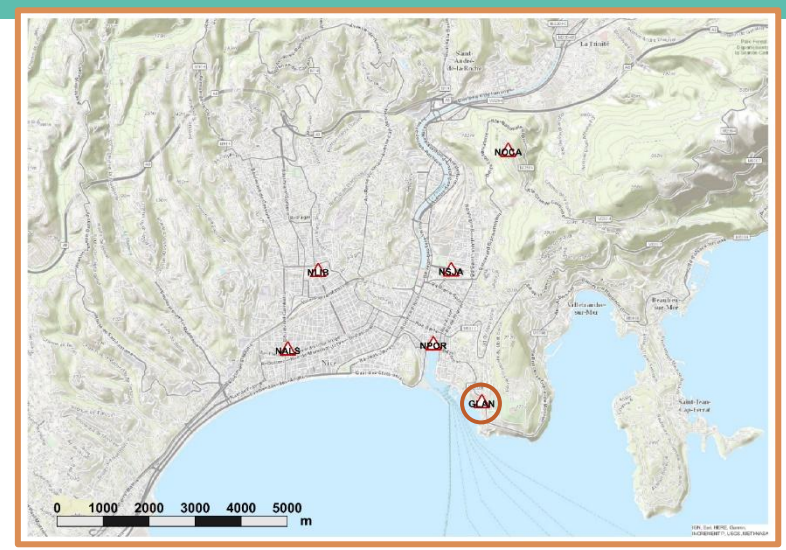
**Applicable even in very low seismicity areas**

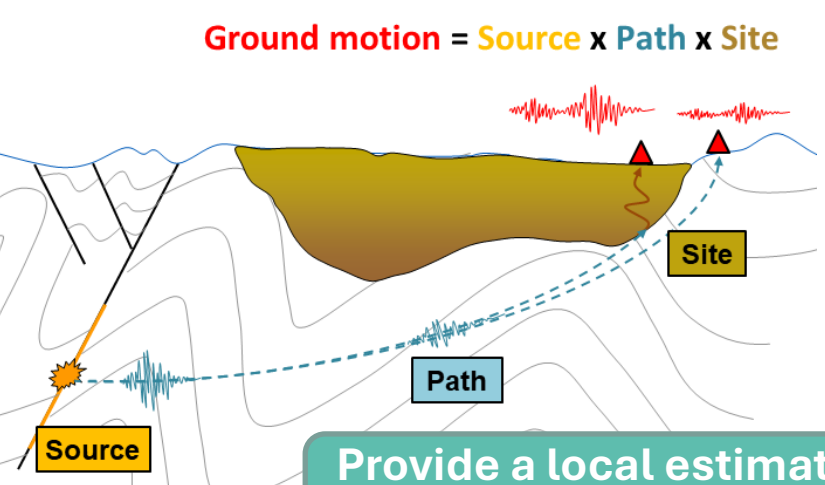


# Standard Spectral ratio (SSR)

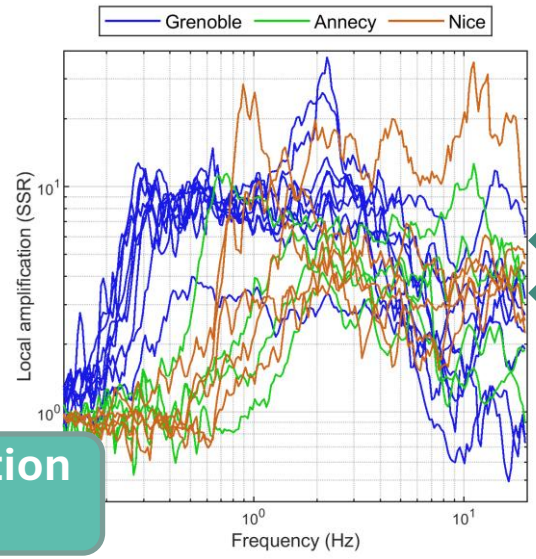


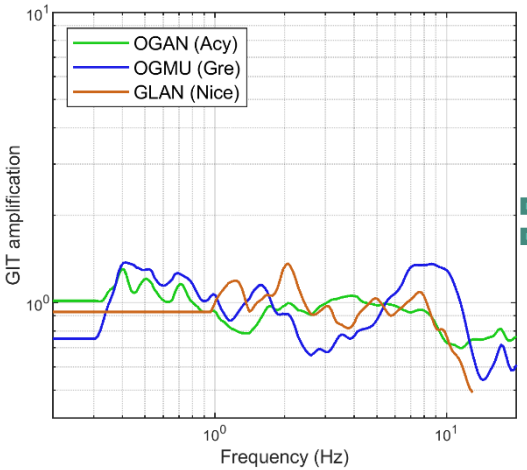



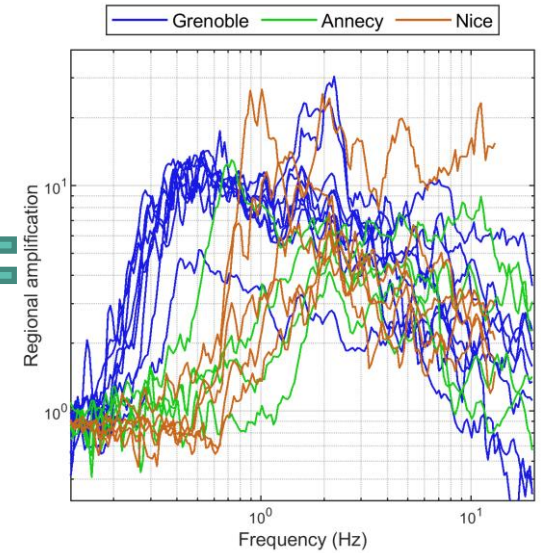




**Provide a local estimation of the site effects**



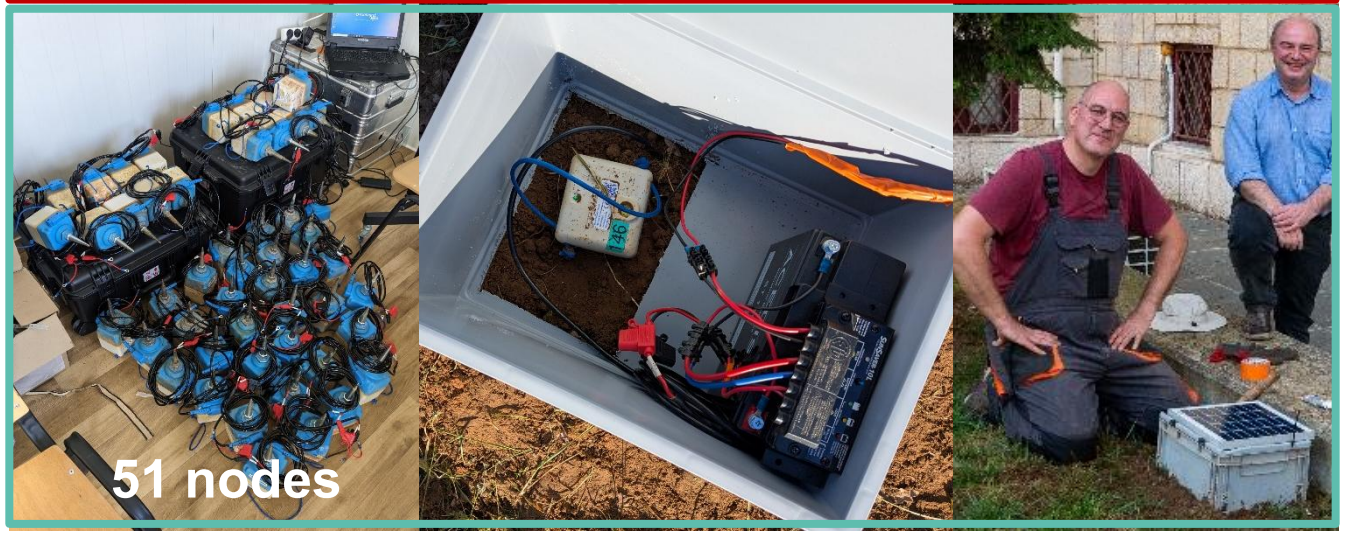



# Station deployments

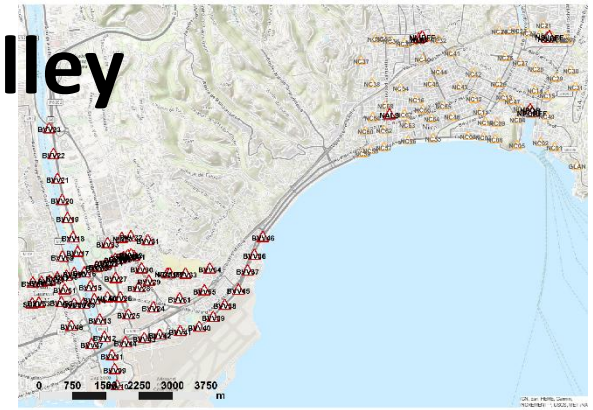
Before


Now

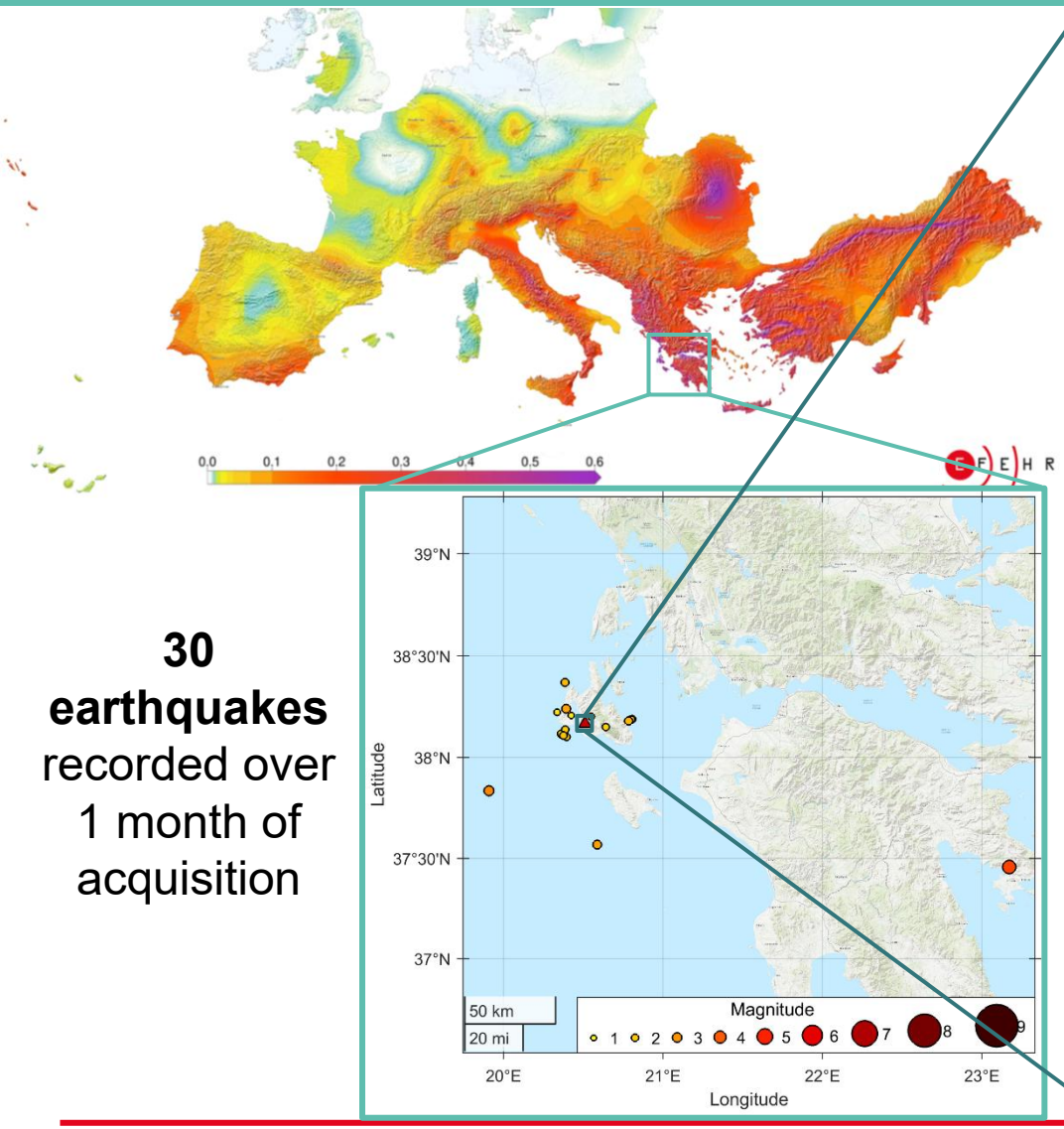



## Nice + Var Valley

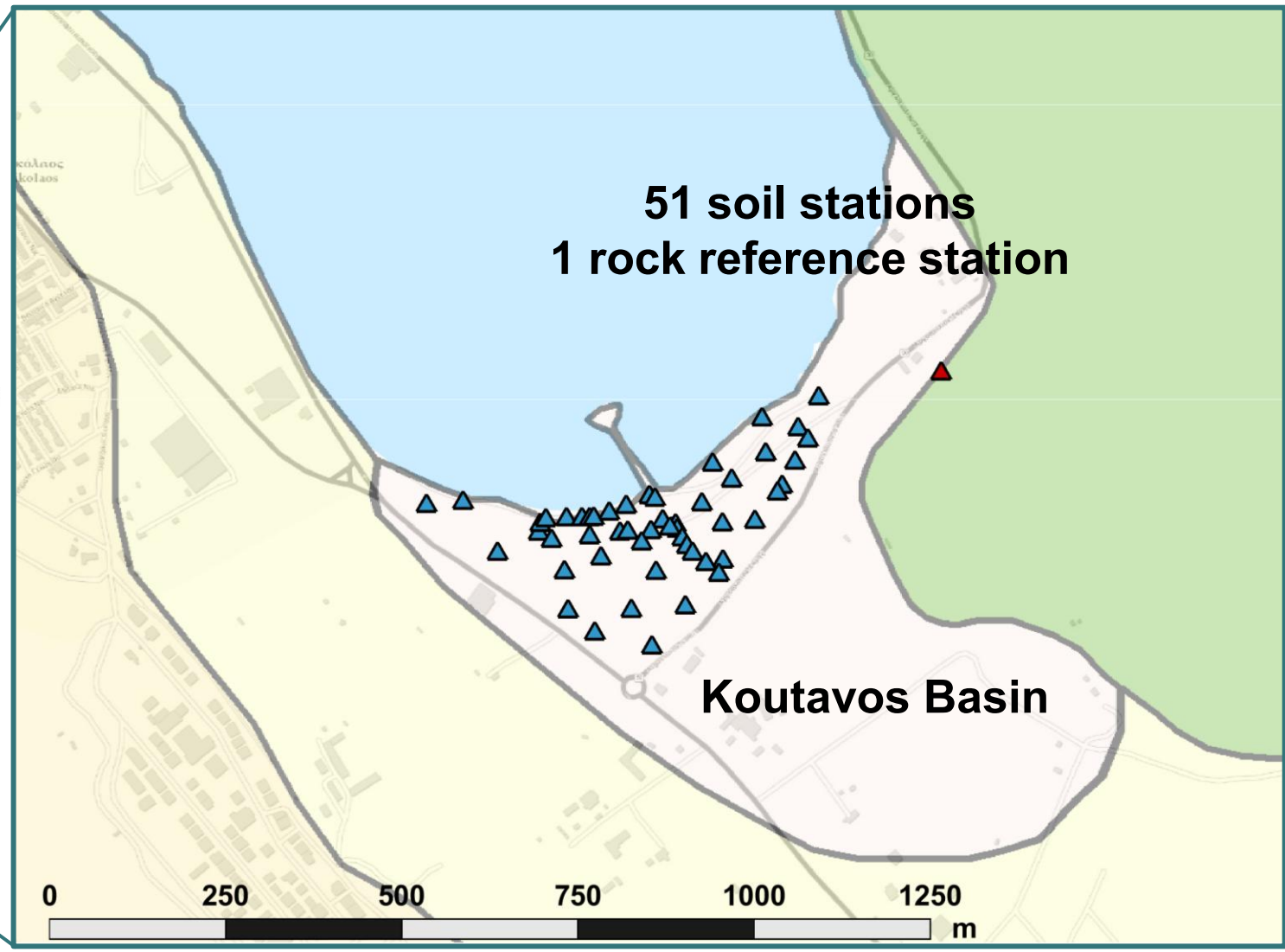
- 160 points
- 4 days in total



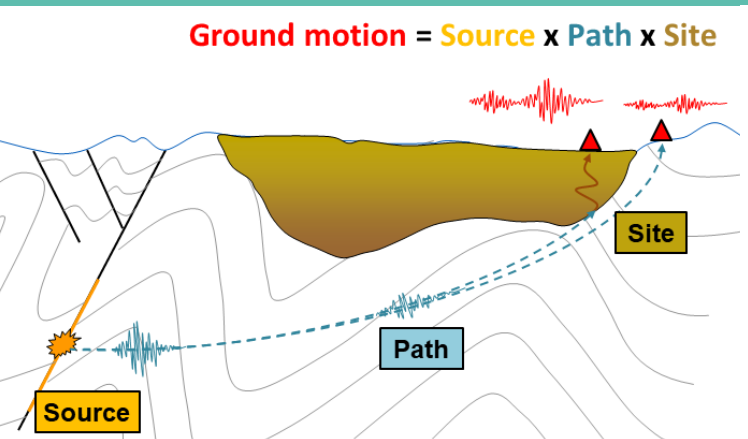
# Site effect assessment at high resolution

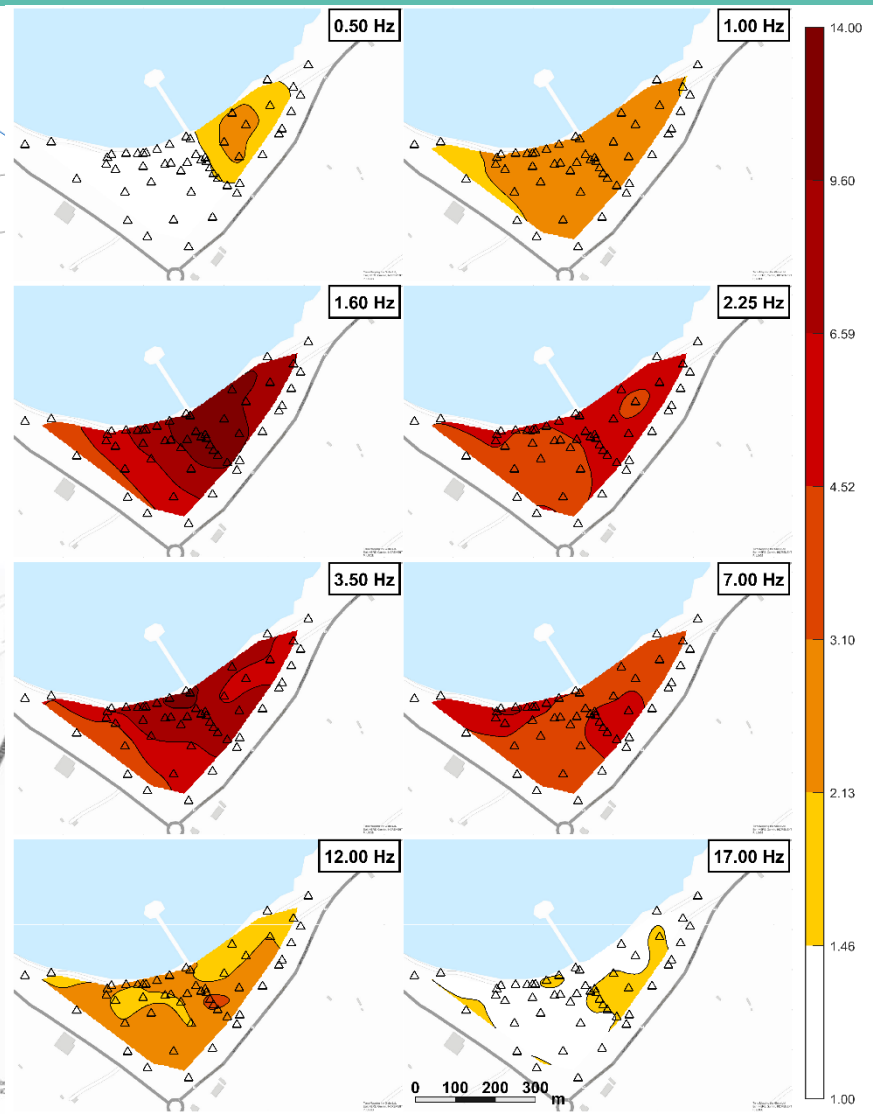


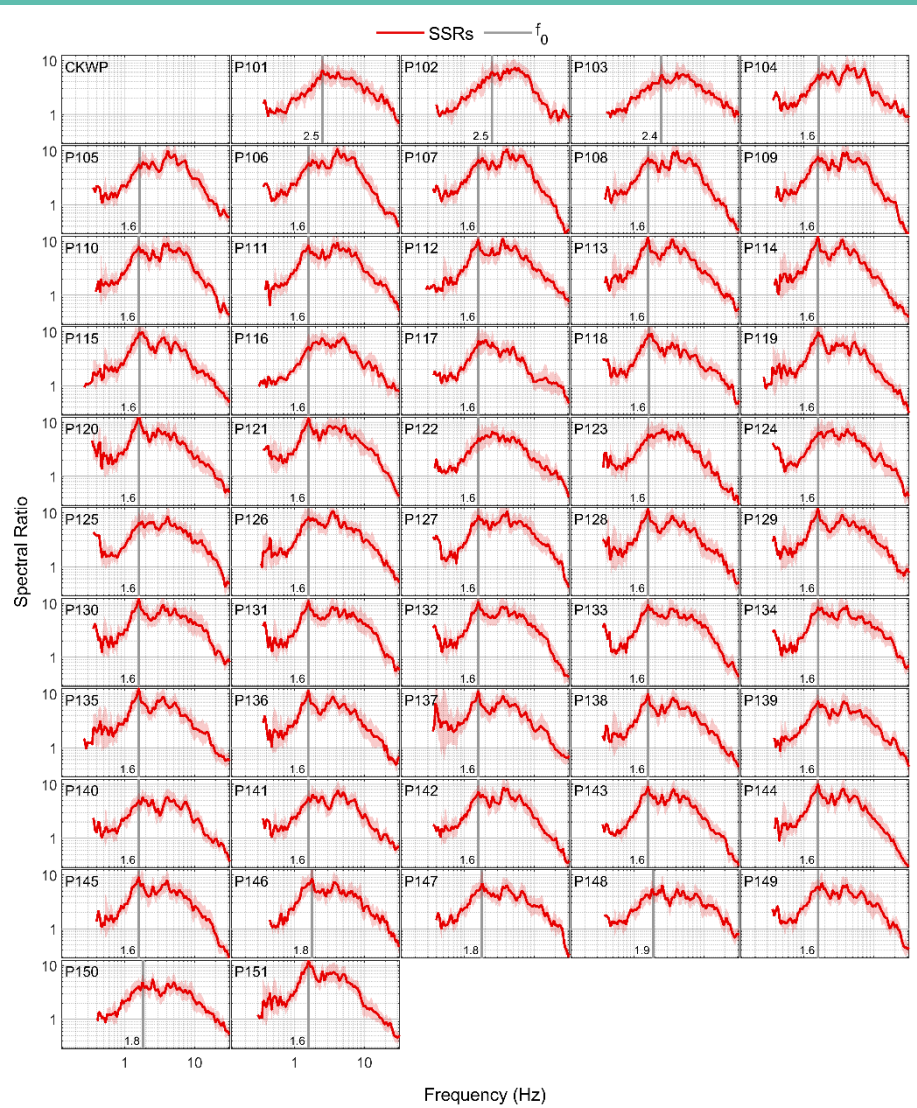

**30 earthquakes** recorded over 1 month of acquisition



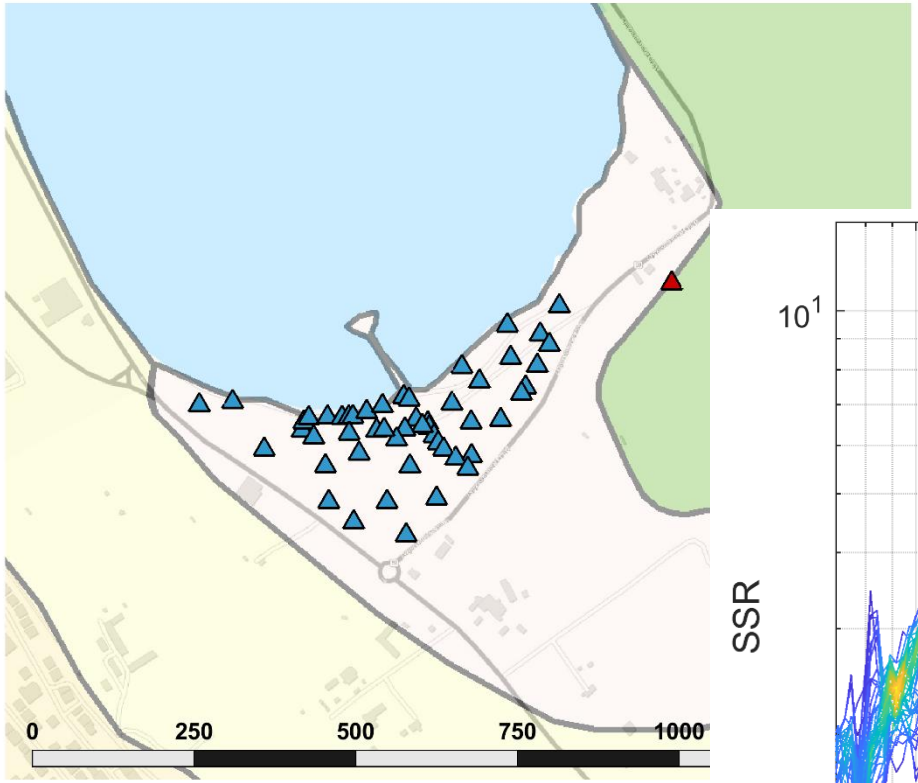
# Site effect assessment at high resolution

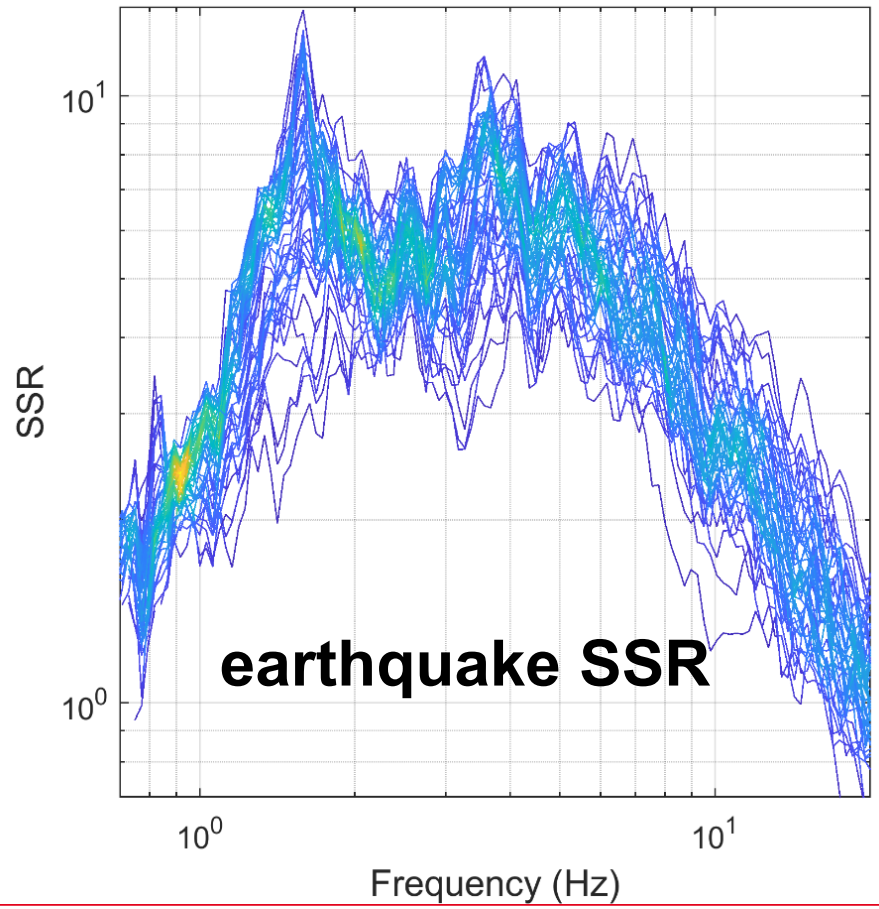


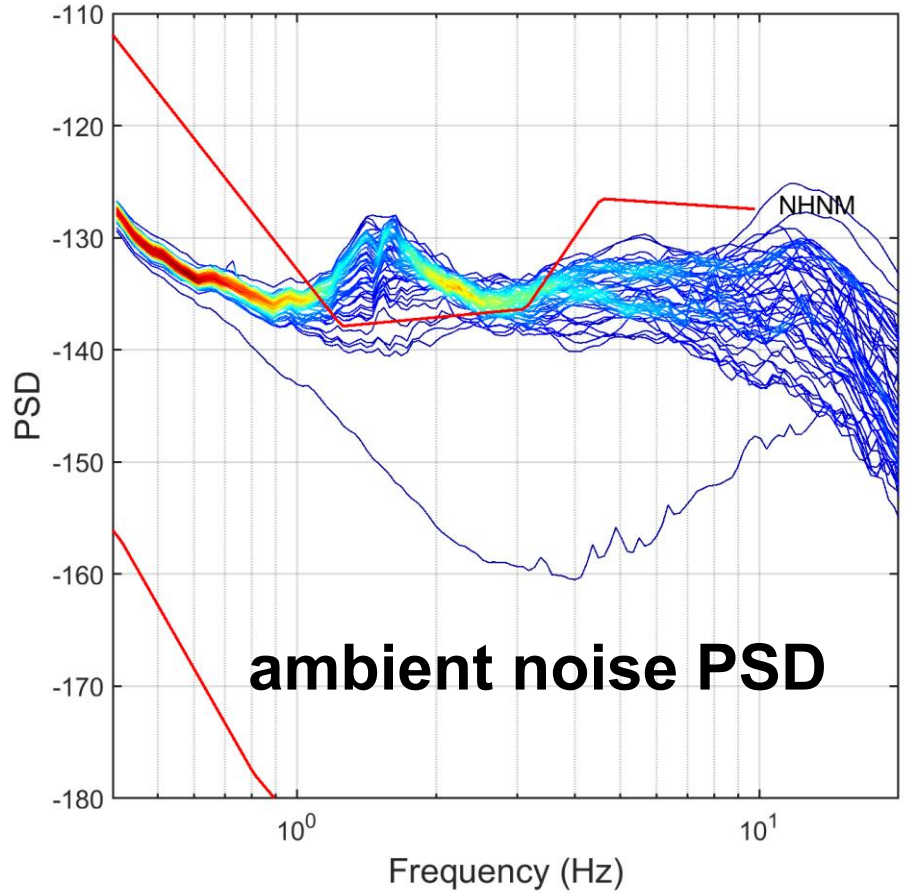



# Site effect assessment at high resolution from ambient noise



# Site effect assessment at high resolution from ambient noise: The HVSRn

The horizontal-to-Vertical Spectral Ratio (HVSRn) on the ambient noise recorded at one single station

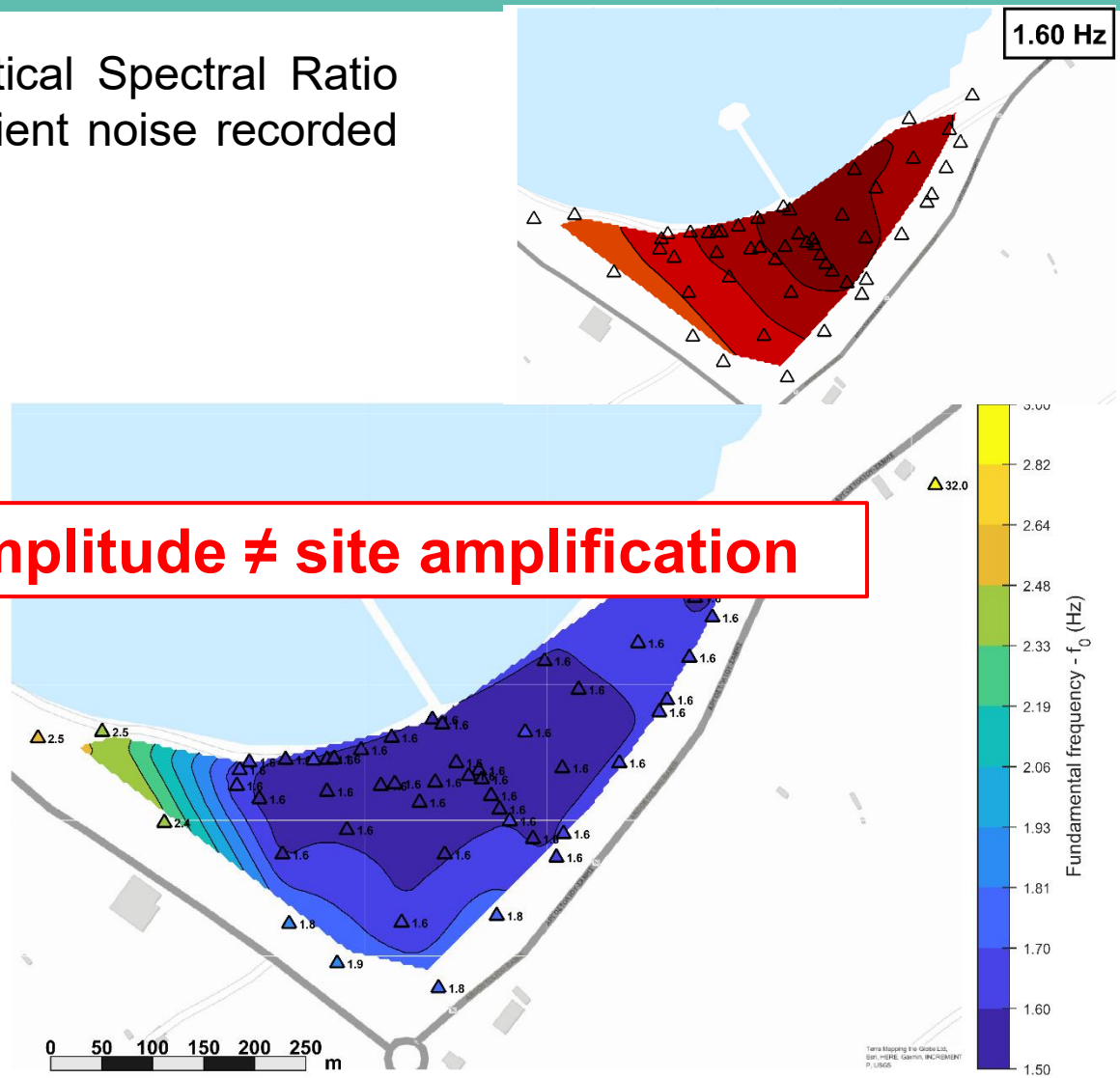
$$HVSR_n = \frac{|\bar{A}_H(f)|}{|\bar{A}_V(f)|}$$

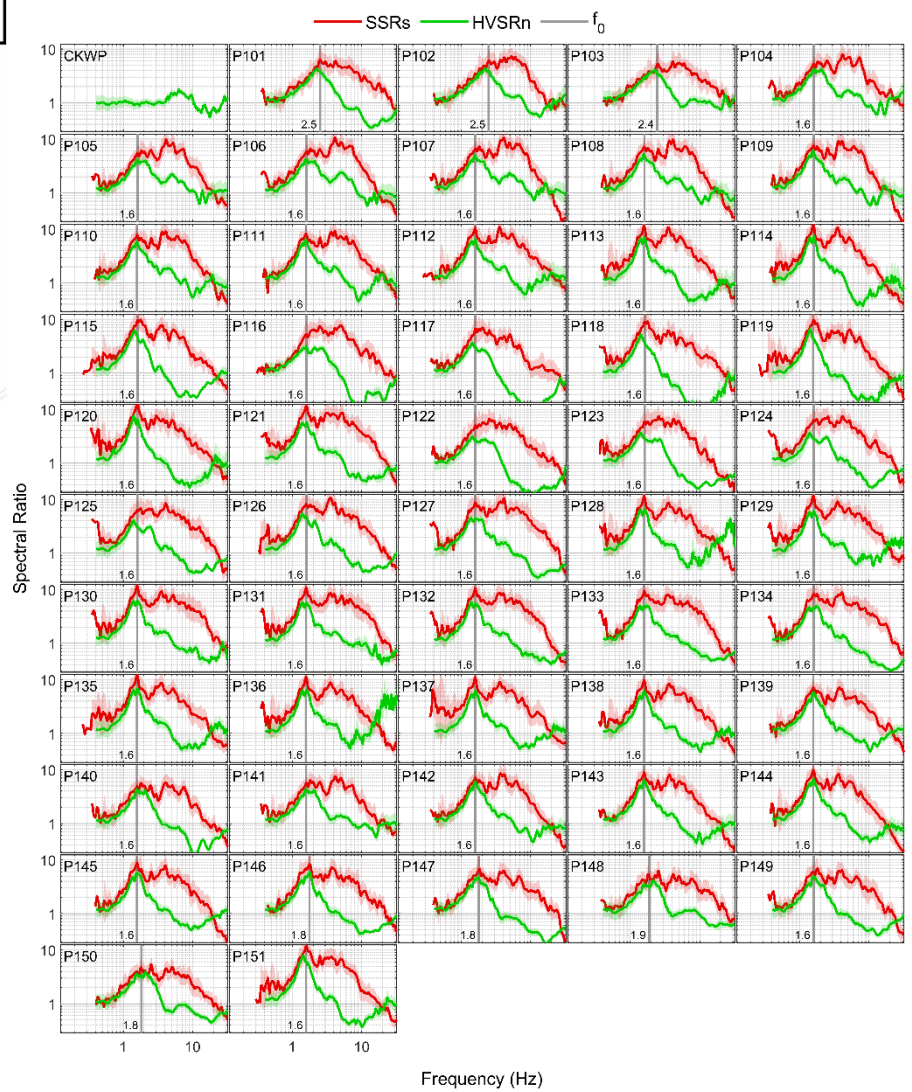
*Nogoshi and Igarashi (1971)*
*Nakamura (1989)*

**HVSRn amplitude ≠ site amplification**

The fundamental frequency ($f_0$) can be identified by the peak of the HVSRn curve:

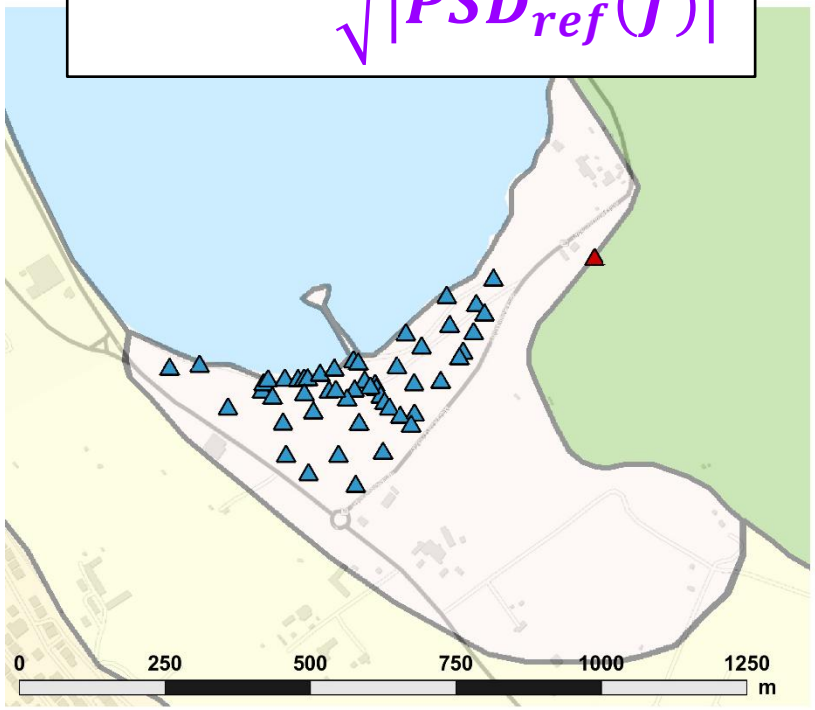
$$f_0 = \frac{Vs}{4H}$$

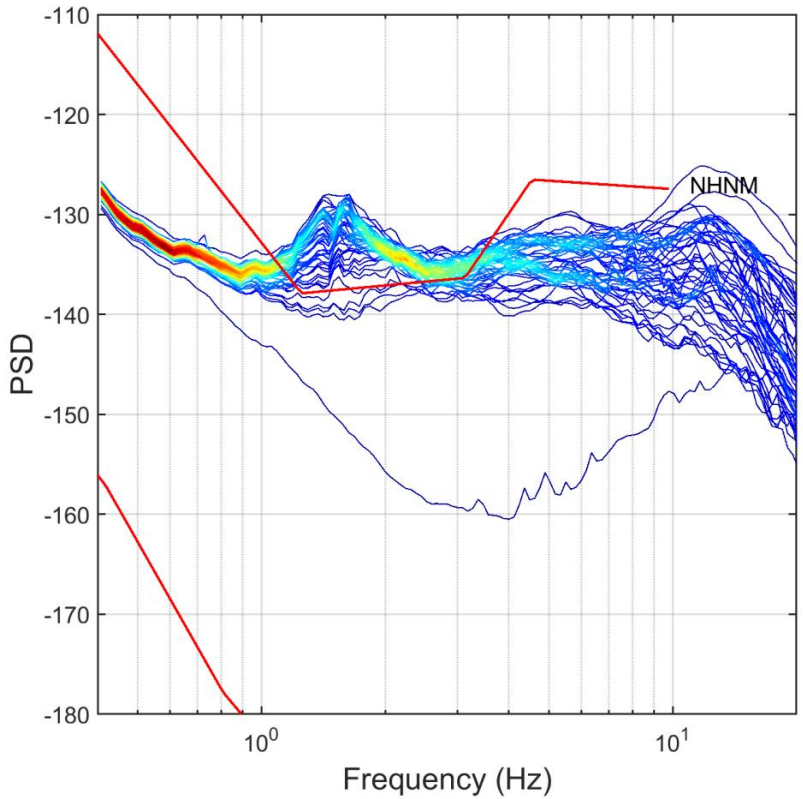


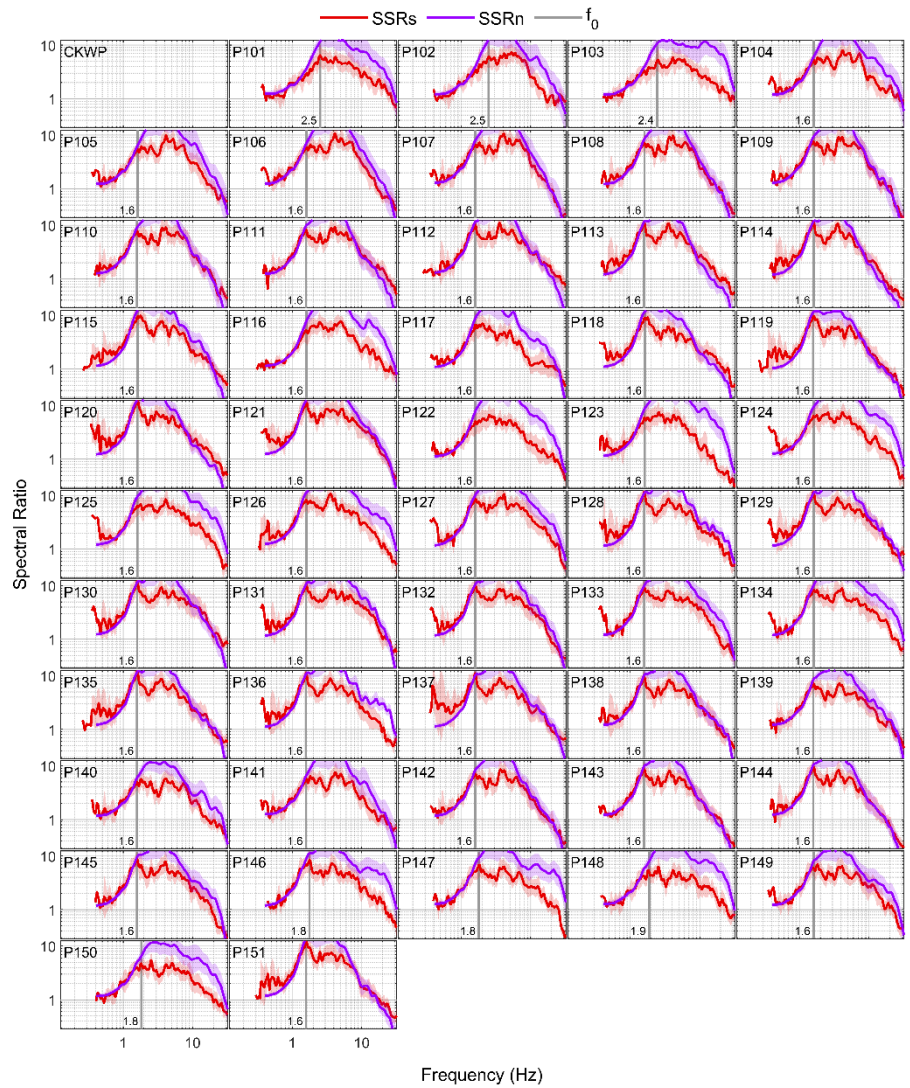



# Site effect assessment at high resolution from ambient noise: The SSRn

$$\mathbf{SSRn} = \sqrt{\frac{|PSD_X(f)|}{|PSD_{ref}(f)|}}$$



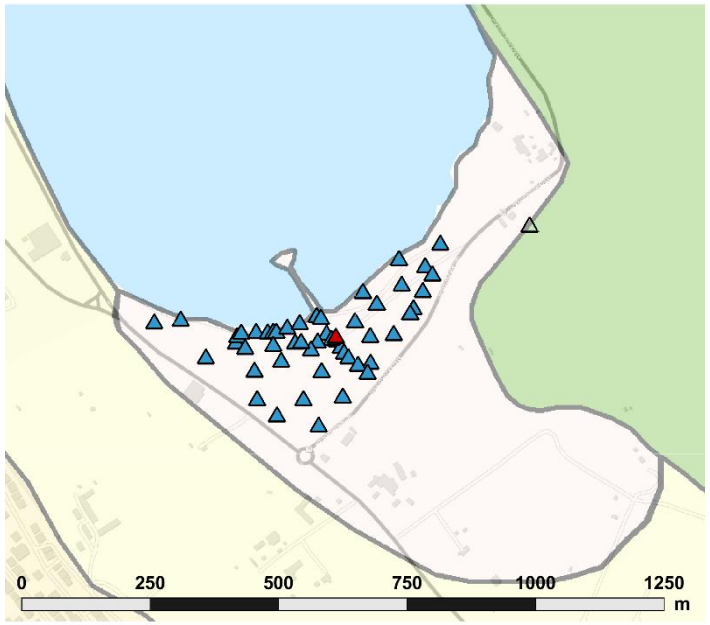
# Site effect assessment at high resolution from ambient noise: The SSRh

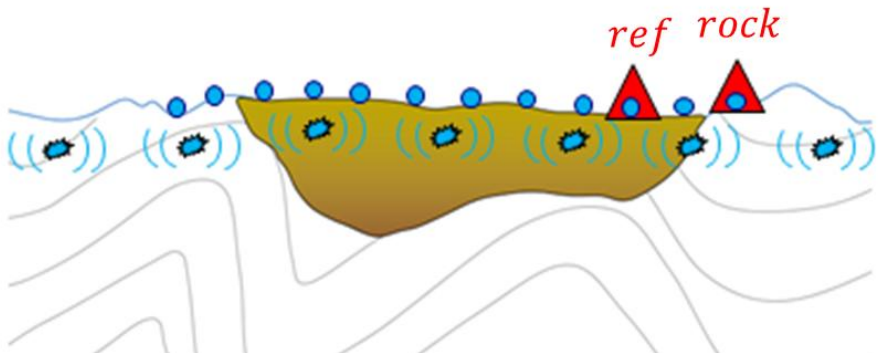
Spectral ratio of ambient noise recordings between stations located inside the basin to estimate the spatial variation of the site amplification

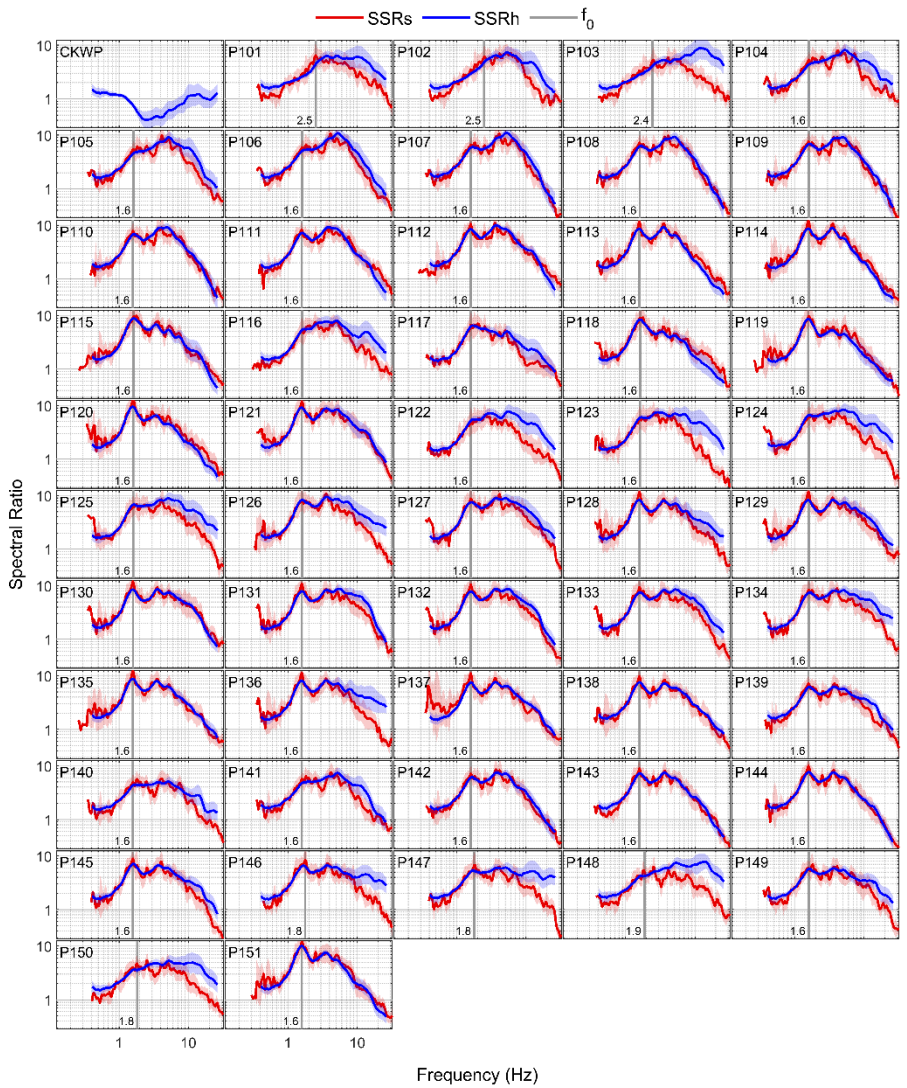
$$\mathbf{SSRh} = \sqrt{\frac{|PSD_X(f)|}{|PSD_{ref}(f)|}} \; x \; \frac{|FAS_{ref}(f)|}{|FAS_{rock}(f)|}$$

*Perron et al. (2018)*

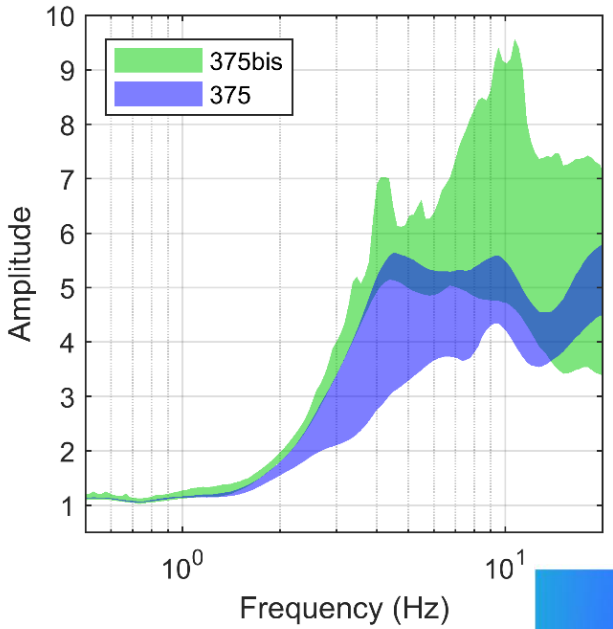
Rock-referencing using the SSR of earthquake recordings at a few stations inside the basin



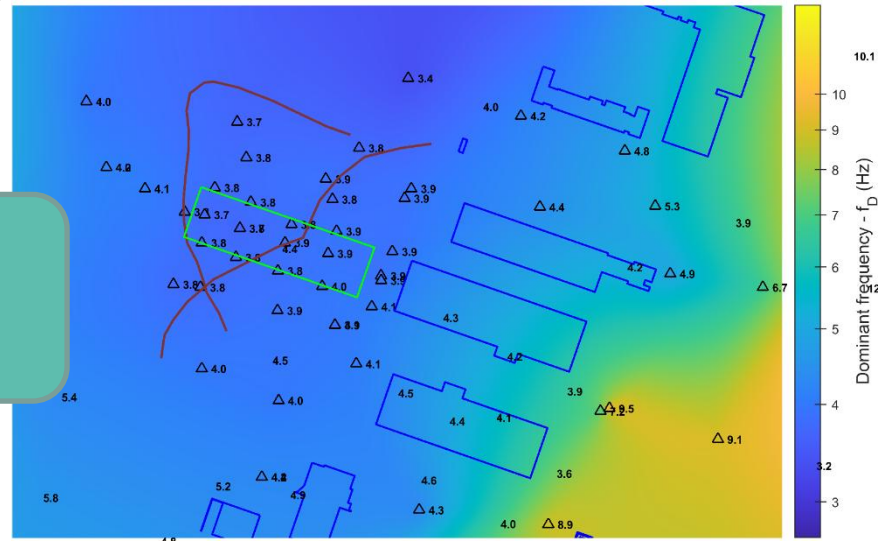



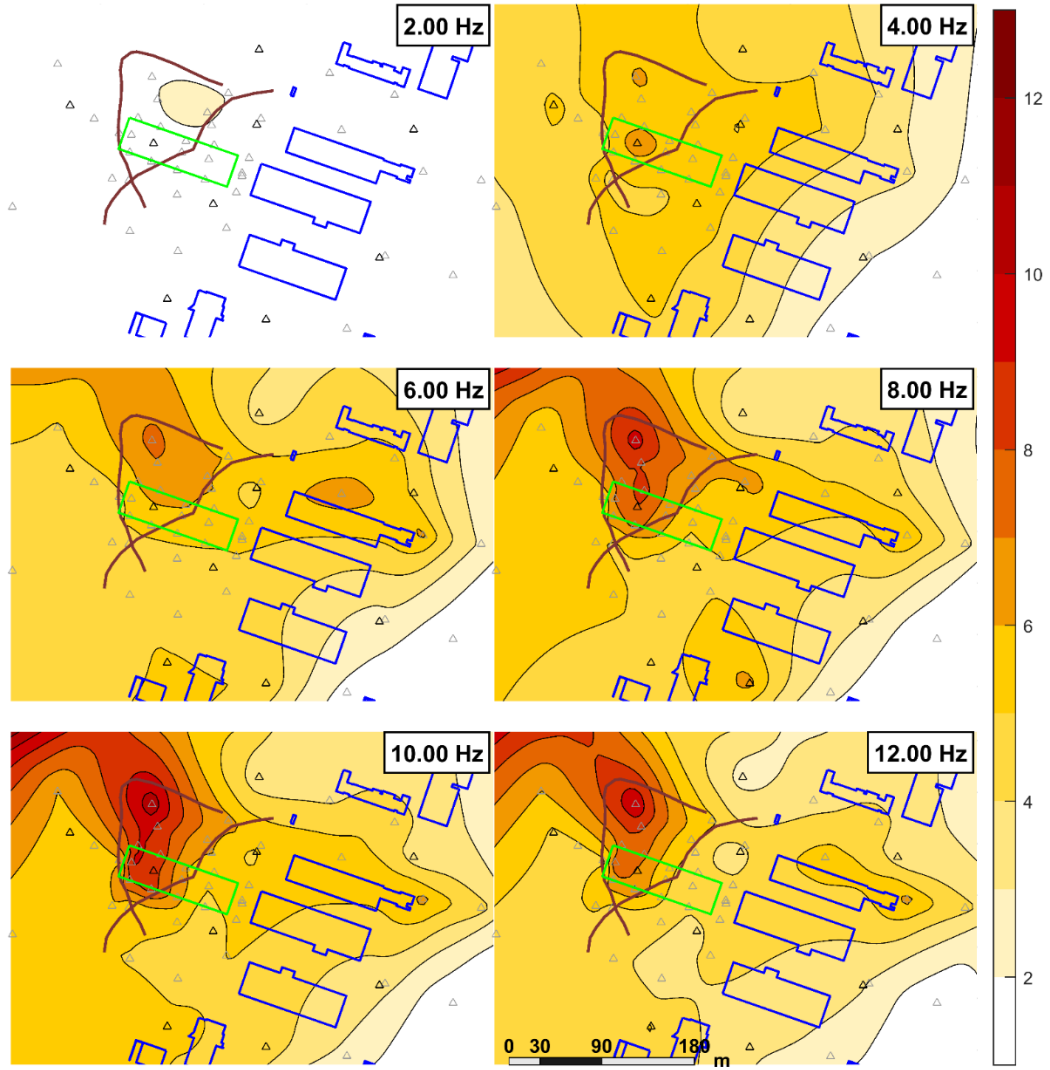
# Site effect assessment at high resolution from ambient noise: The SSRh



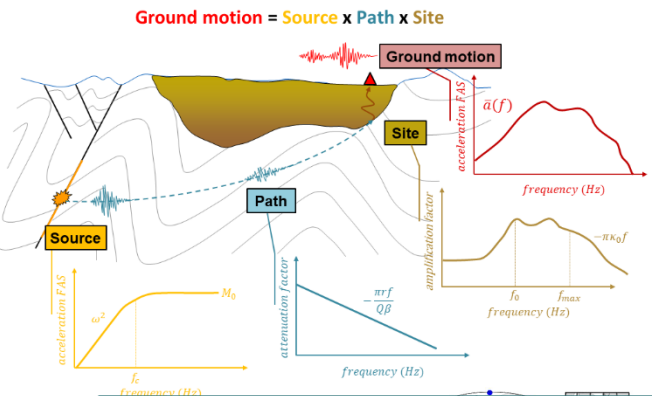


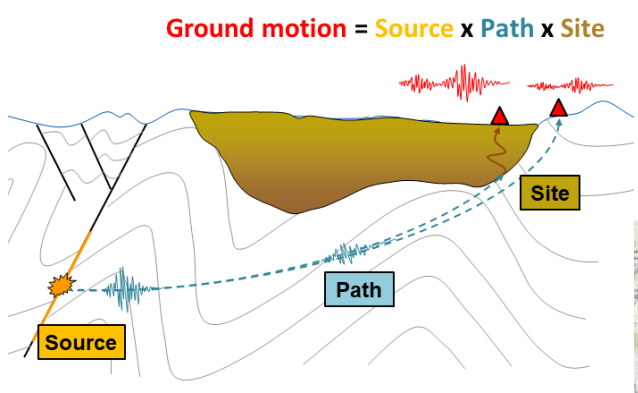



**Ambient noise = practical solution to assess site effects at high resolution**



# Combining empirical approaches to benefit from each method's strengths





- Well define reference
- Limited usable EQ
- Limited spatial resolution

- Applicable to every EQ
- Local referencing only
- Limited spatial resolution

- Good spatial resolution

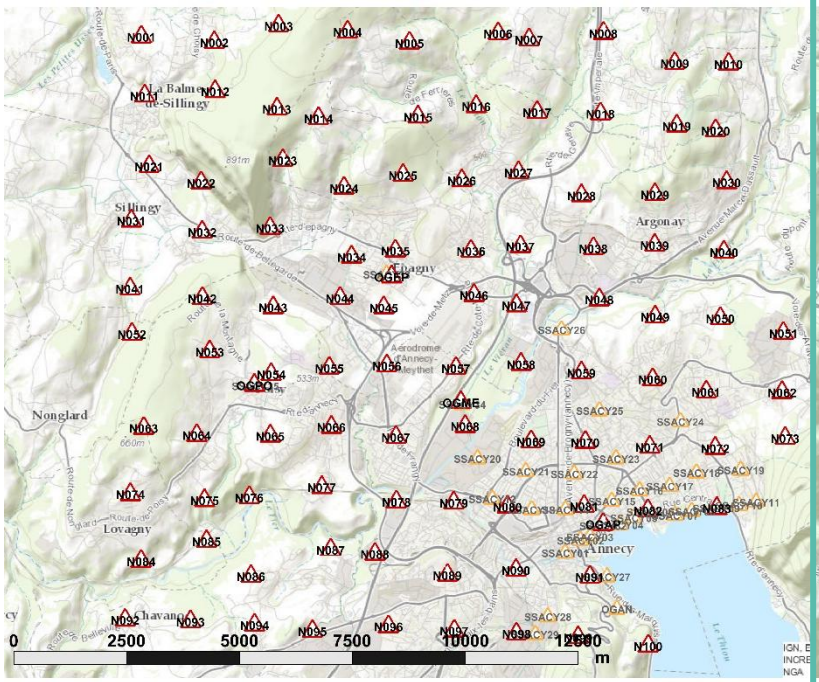
Large scale — **GITn SSRp** — **SSR** — **SSRh** — Small scale

$$\mathbf{EAF}_{\frac{x}{RegionalRef}} = GIT\&SSRp_{\frac{LocalRef}{RegionalRef}} \times SSR_{\frac{SoilRef}{LocalRef}} \times SSRn_{\frac{x}{SoilRef}}$$

- Well define reference
- Good spatial resolution

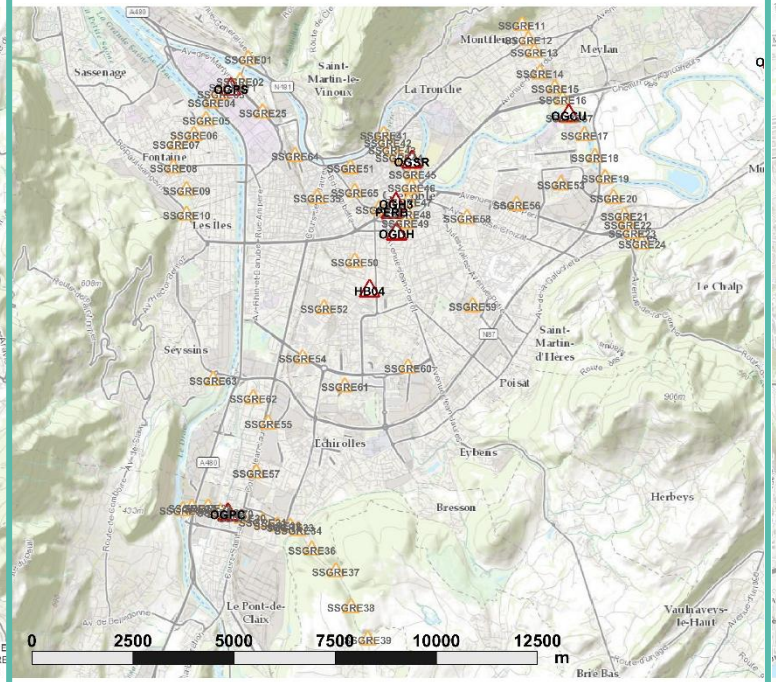
# Combining empirical approaches to benefit from each method's strengths

## Annecy



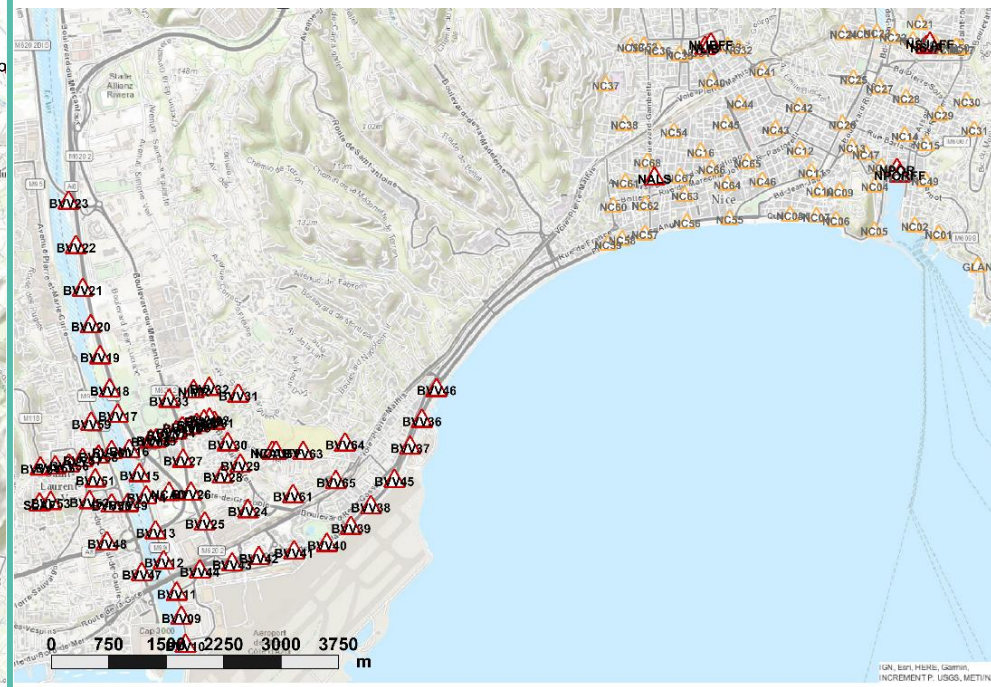

- 100 nodes Zland (1 month)
- 35 nodes SmartSolo (1 day)

## Grenoble




- 71 nodes SmartSolo (1 day)

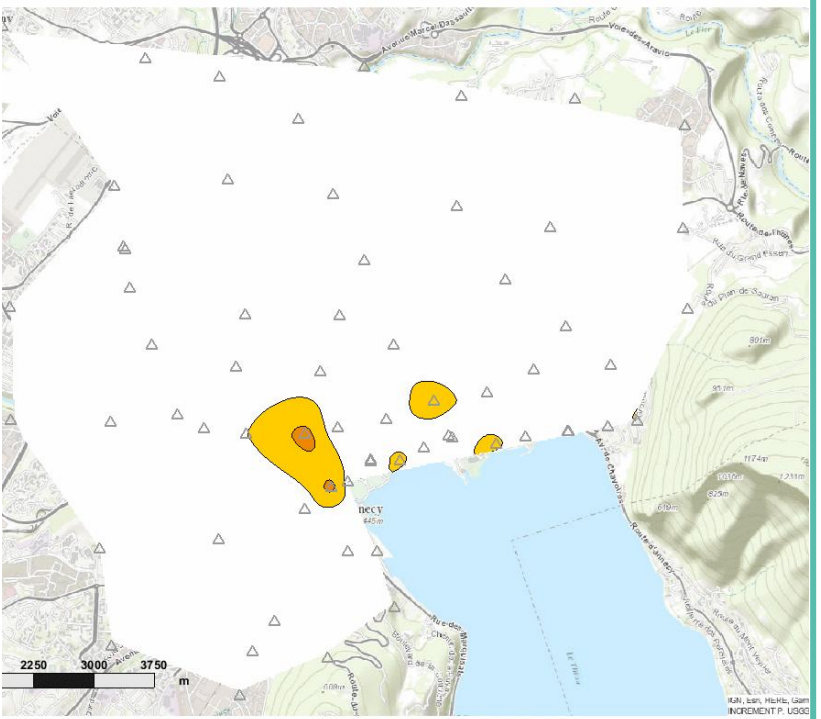
## Nice



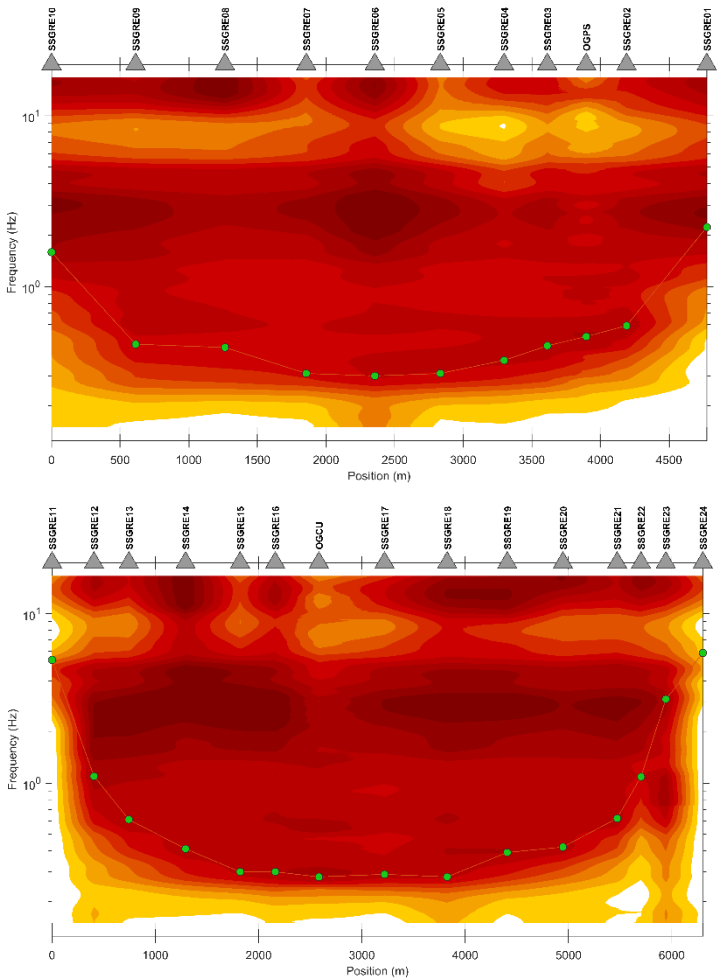

- Nice & Var valley: 80 nodes SmartSolo (1 day each)

# Combining empirical approaches to benefit from each method's strengths

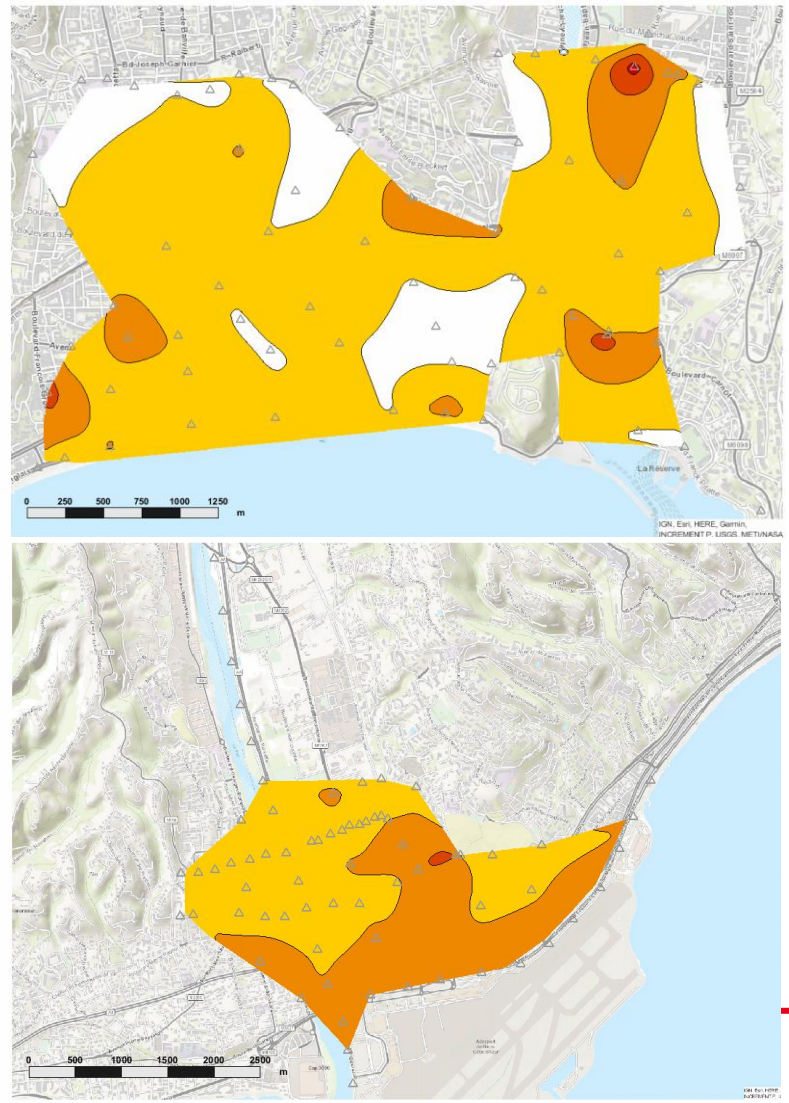
## Annecy




## Grenoble

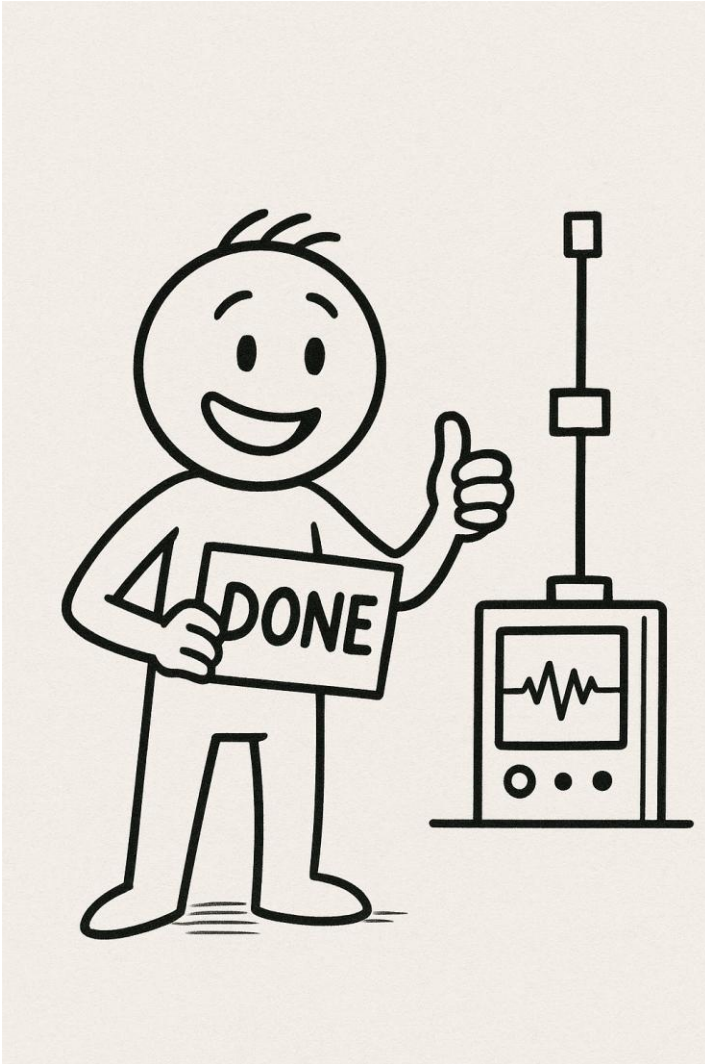



## Nice



# Conclusions

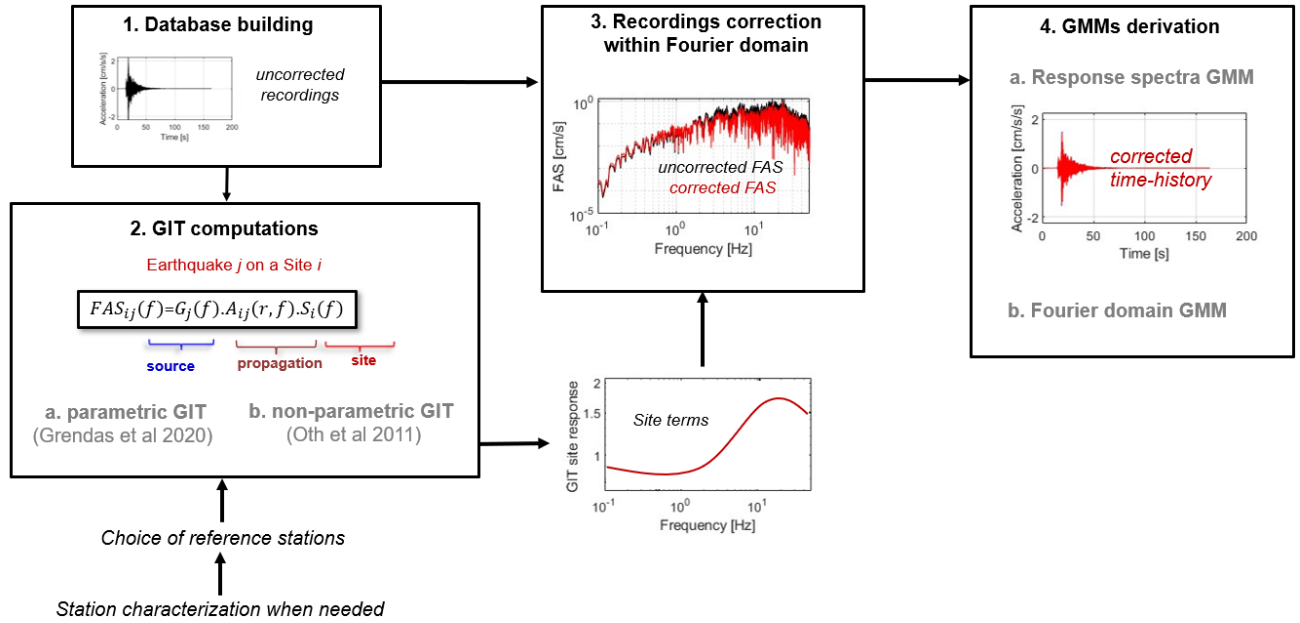
- ✓ The combination of various empirical approaches (GIT, SSR, and SSRh) is promising for performing site-specific SHA at high resolution and with a coherent referencing
- ✓ Dense array of ambient noise measurement can be done inside big cities
- ✓ The SSRh is effective, even in urban areas
- ✓ The SSRh is a very convenient tool to perform micro-SHA



# Perspectives

- The GIT site amplification could be extended at lower frequencies (<0.5 Hz) using the spectral ratio of coda waves (SSRc)
- The referencing could be scaled to Vs30=800m/s to be consistent with the French and European hazard map of the EC8
- The amplification model could be computed in response spectrum to obtain hazard map
- The amplification function could be computed based on previous H/V points using the canonical correlation approach (e.g. in Grenoble)

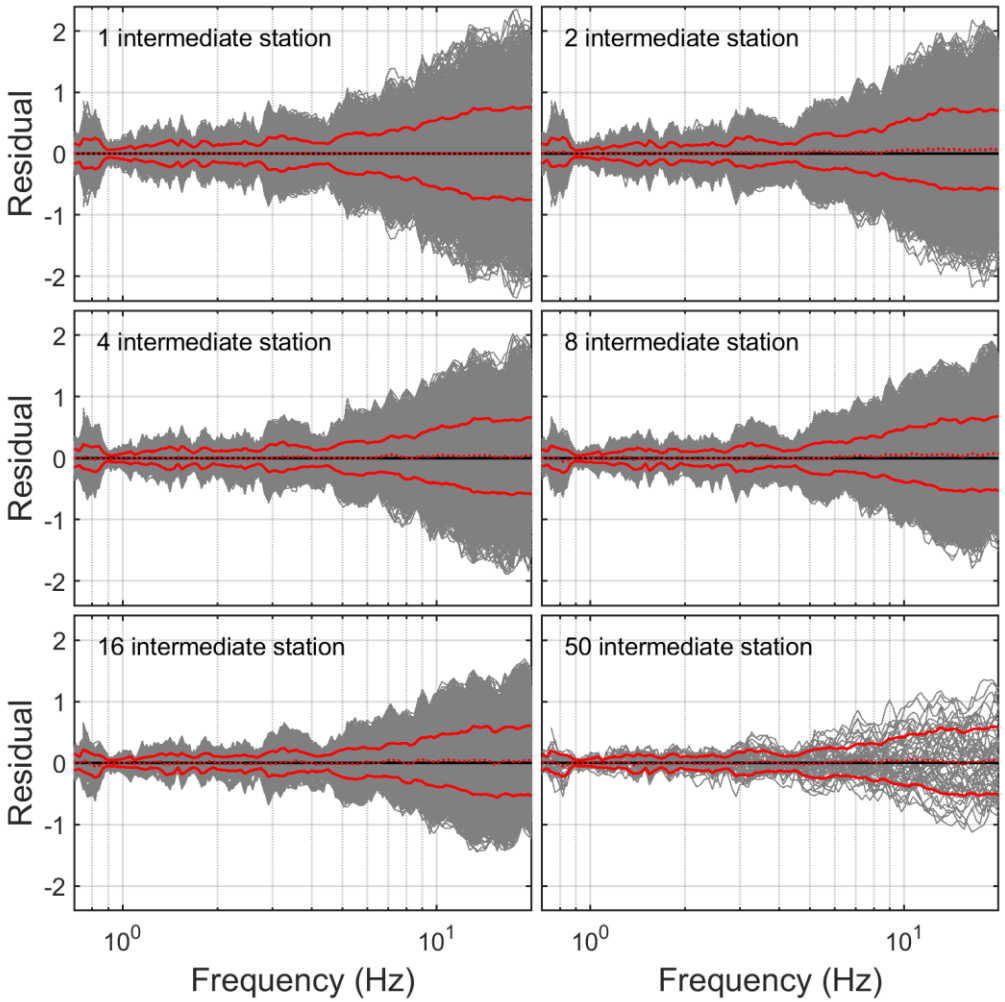
"Deconvolved GMPEs" Shible et al. (Deliverable D2.2.5.1)

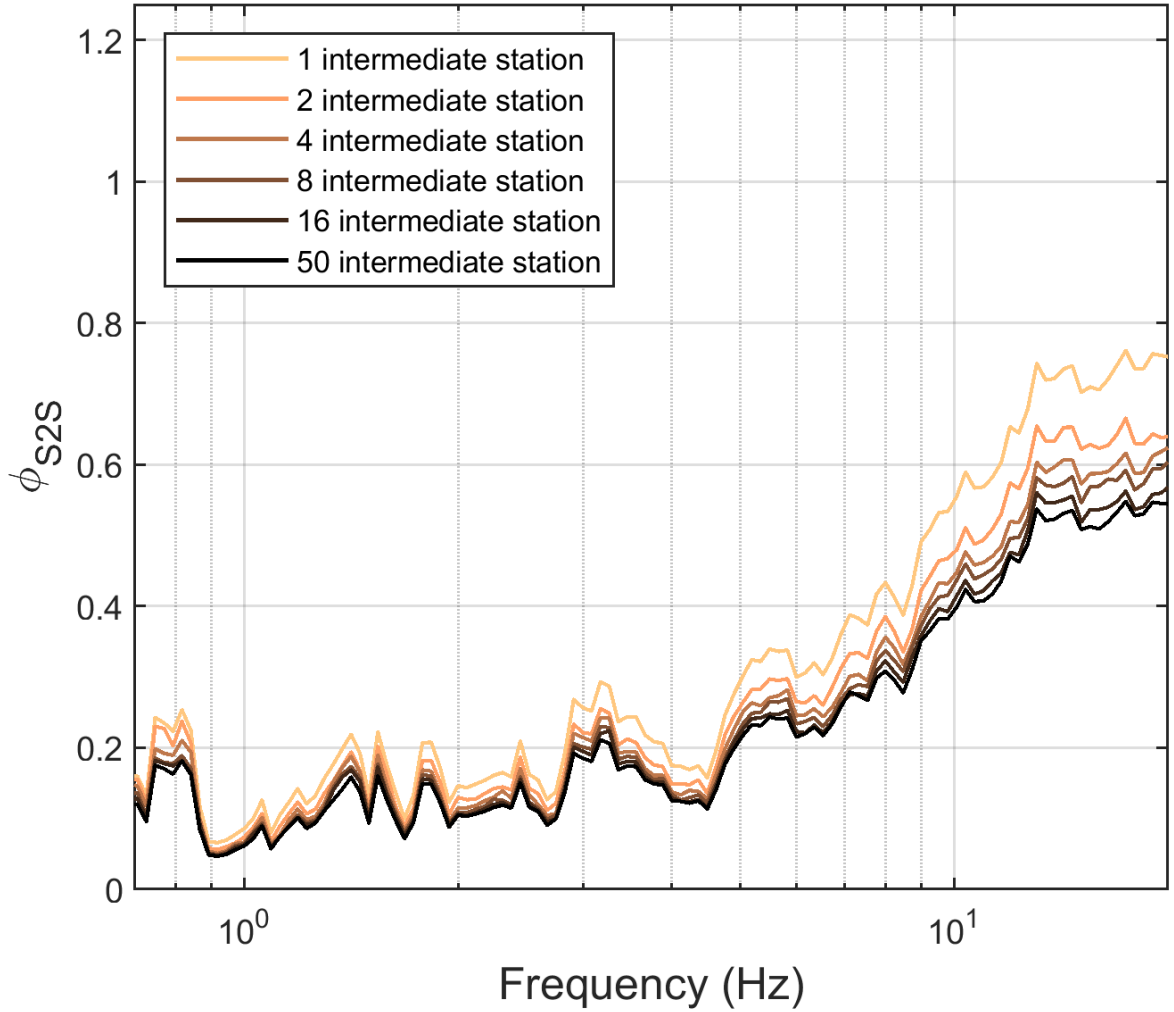



Any questions ?

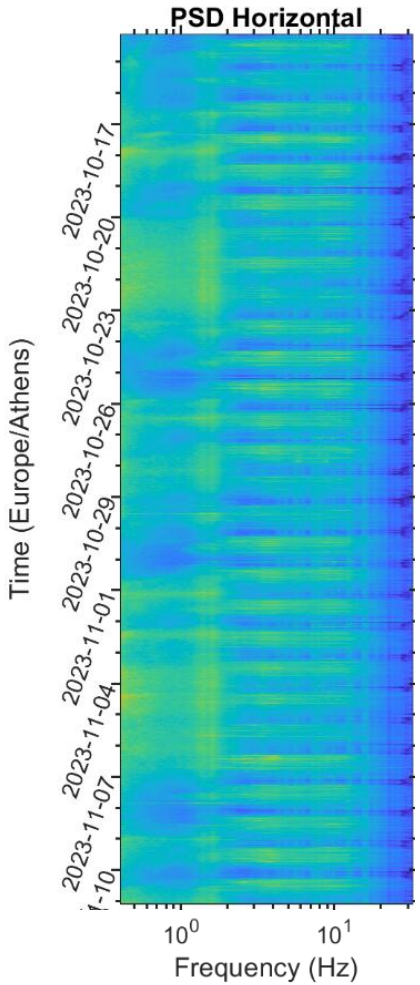
# Can site effects be assessed from ambient noise ? The SSRh

$$\textbf{Residual} = log(SSRh) - log(SSR)$$

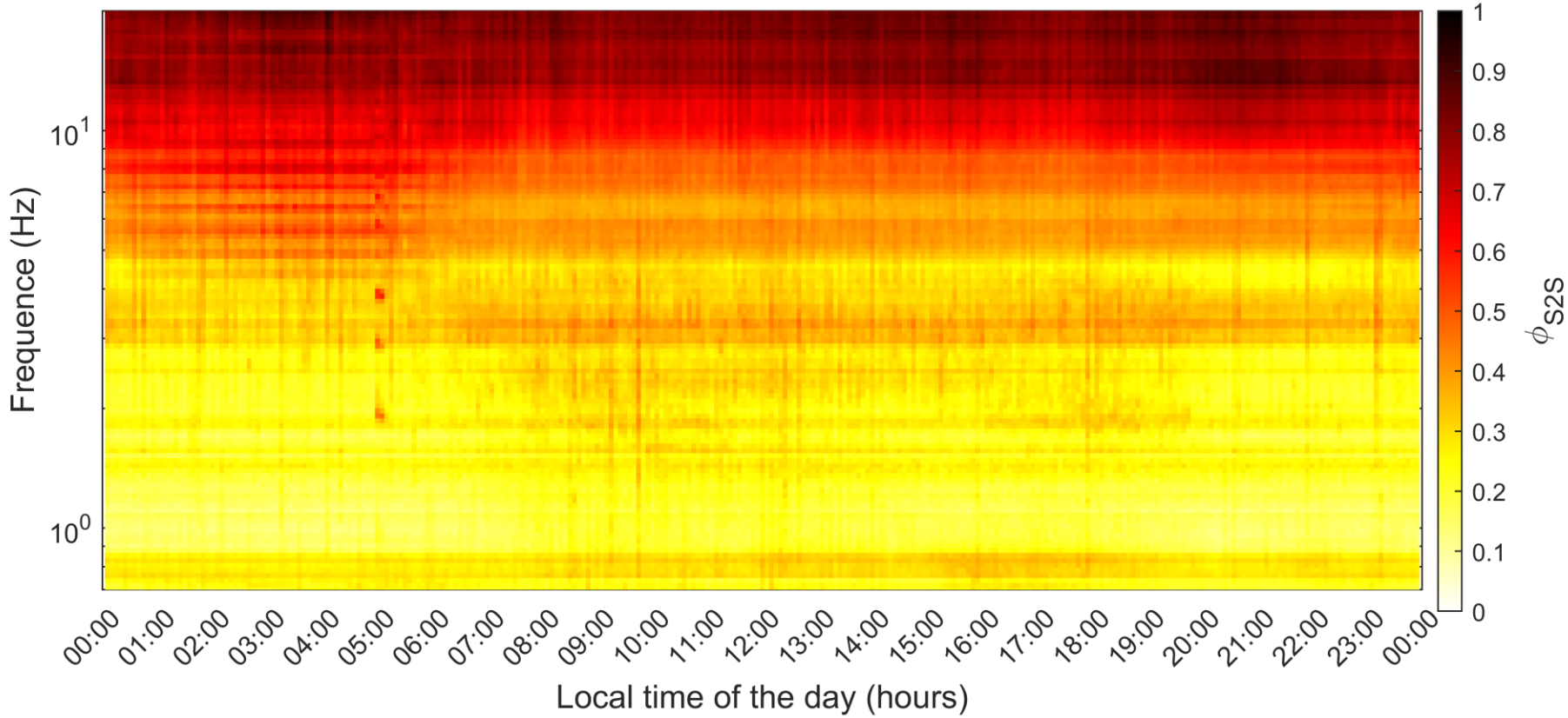


# Can site effects be assessed from ambient noise ? The SSRh

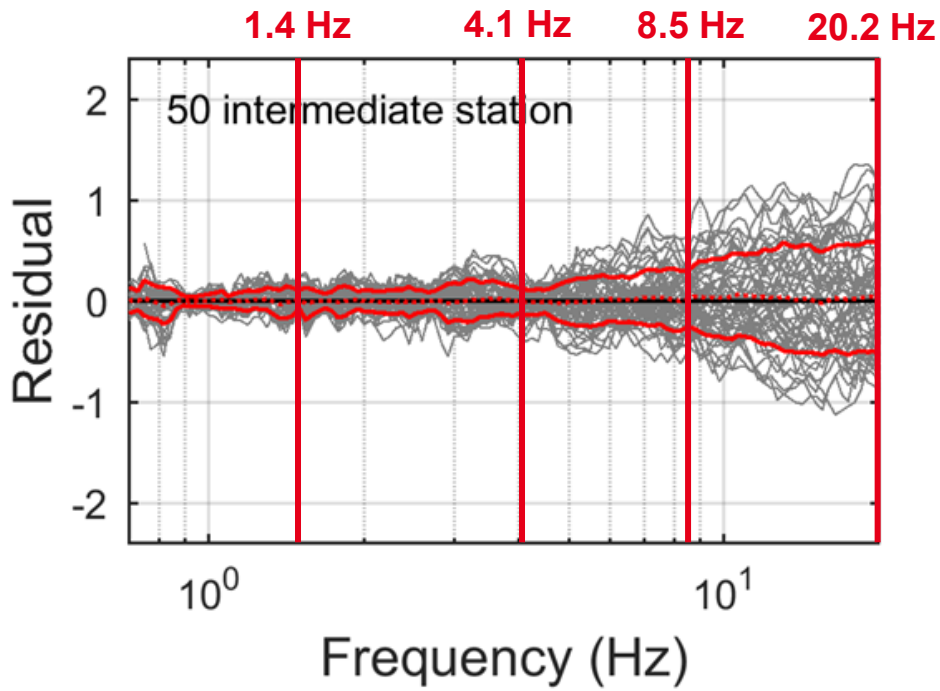


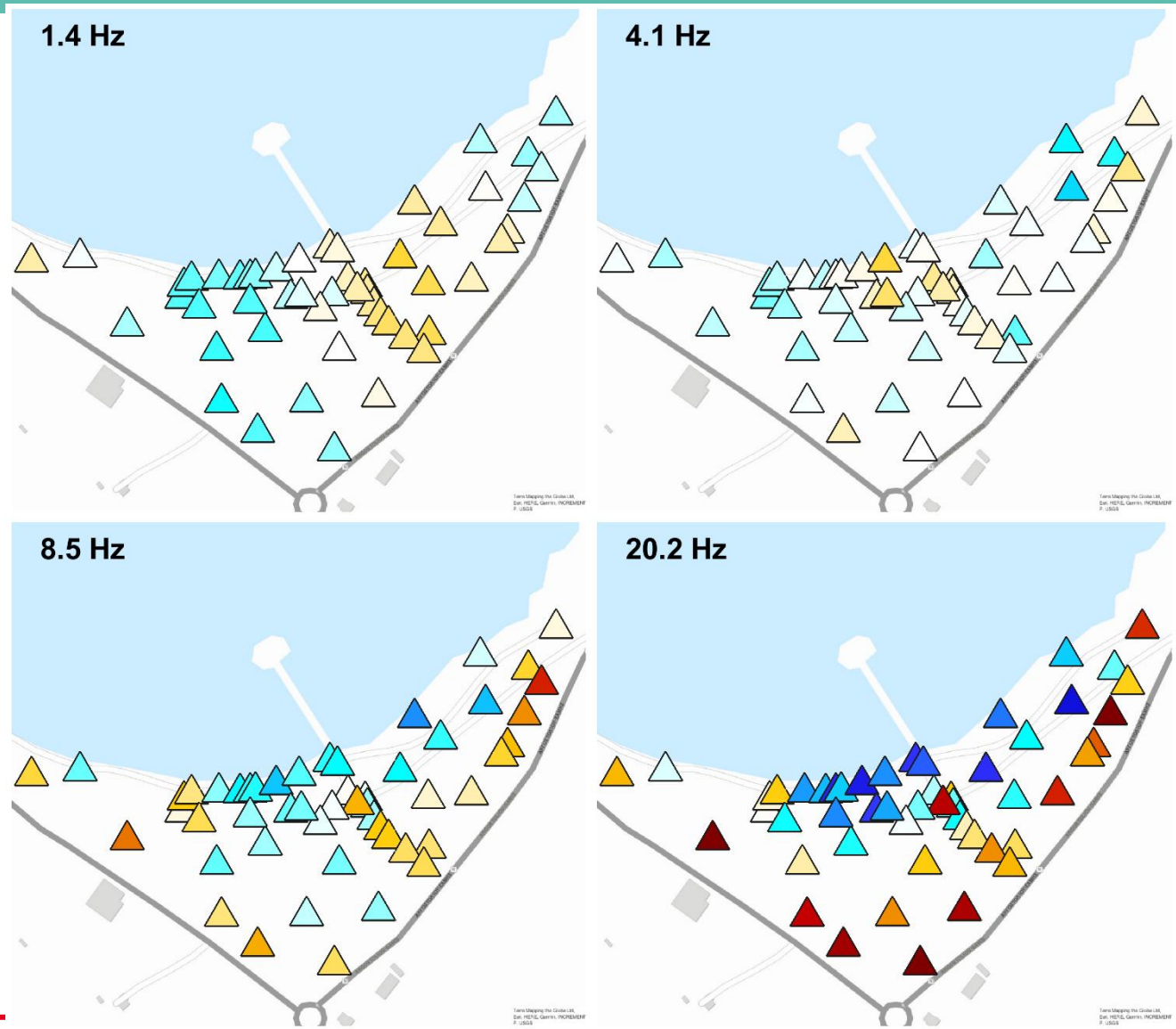

$$\textbf{Residual} = \boldsymbol{log(SSRh) - log(SSR)}$$




**Slight influence of the daily variation. Surprisingly, better performance at daytime than night-time above 3 Hz !**

# Can site effects be assessed from ambient noise ? The SSRh




**Visible spatial dependence of the residual, but varies with frequencies.**