

Seismic Non-linear behavior of soil inferred by analysis of borehole data

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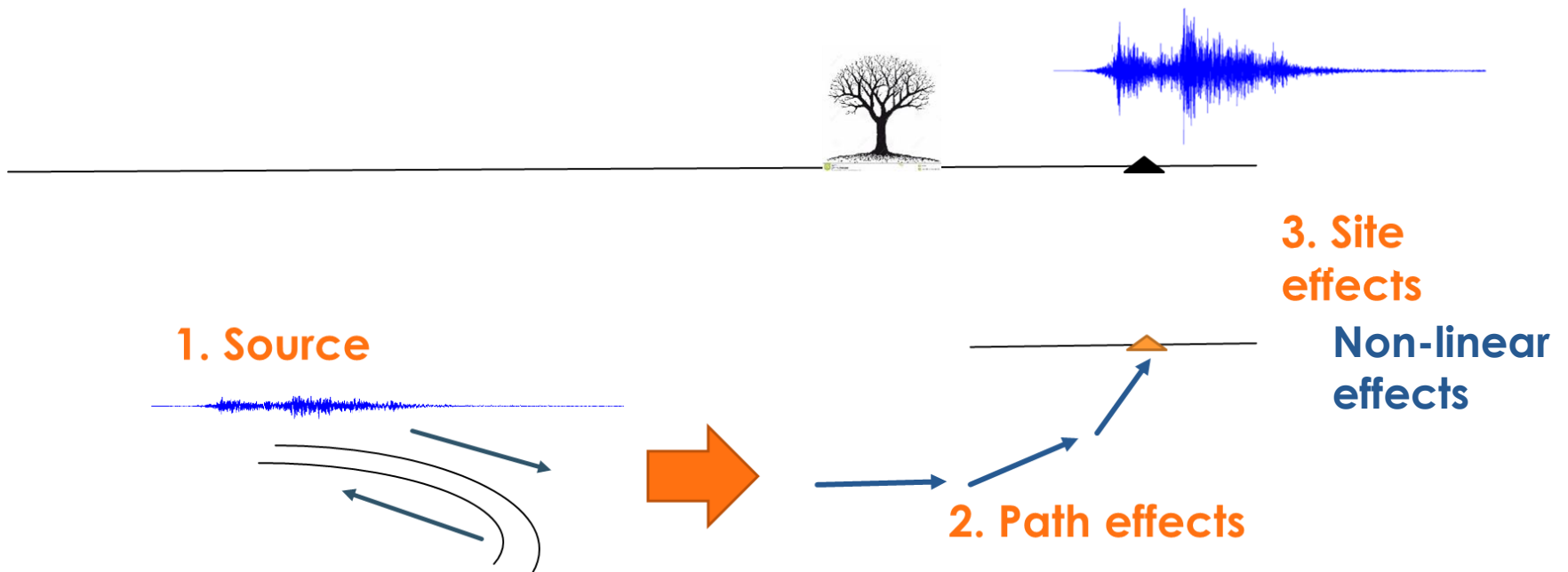
David Alejandro Castro Cruz

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Context

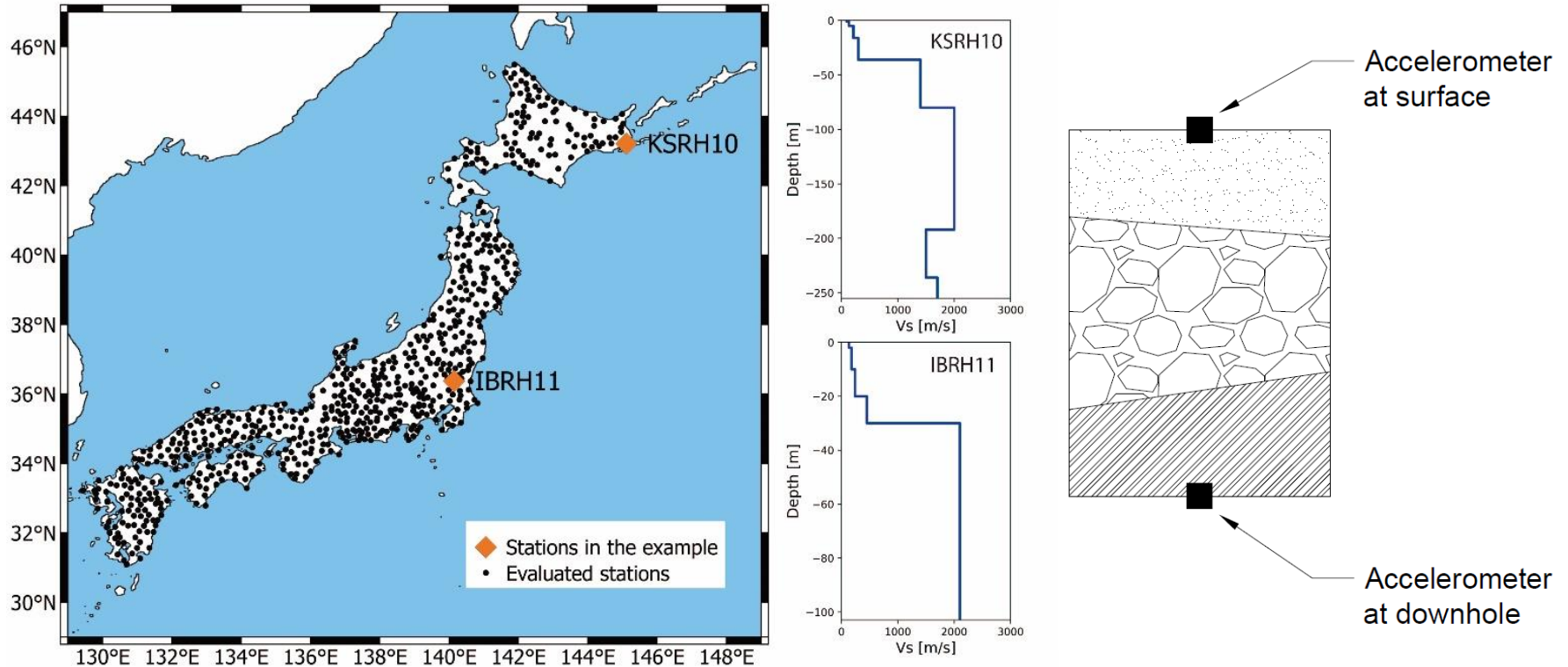
- ▶ How the **non linear behavior** affects a ground motion?



Data network

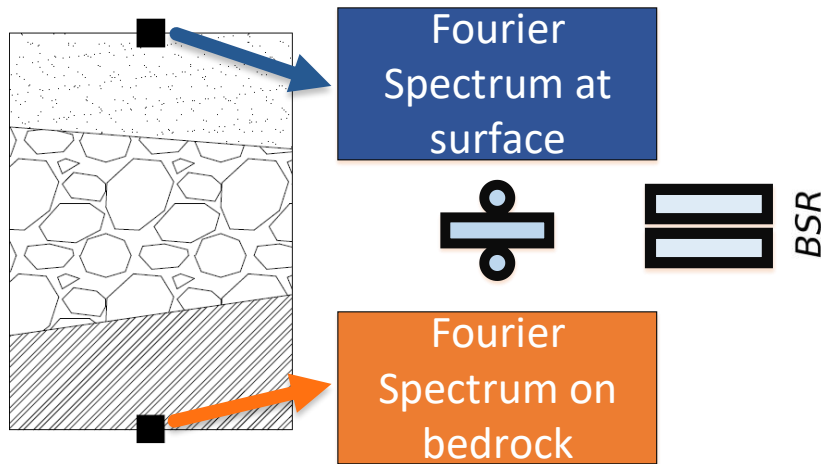
- ▶ The Kik-Net data, Japan (Aoi, et al., 2004) is used in this study. This data set has two stations by site, one at surface and another in downhole.

650 sites



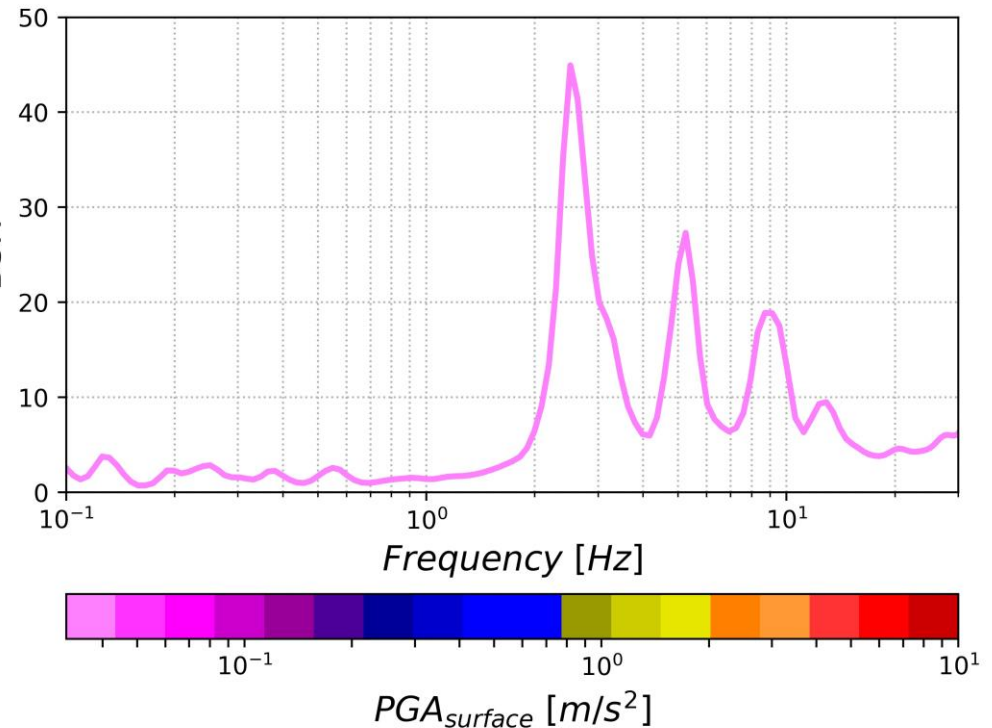
Site effects

- We computed an empirical transfer function (Borehole Spectral Ratio - BSR) to quantify the site effects.



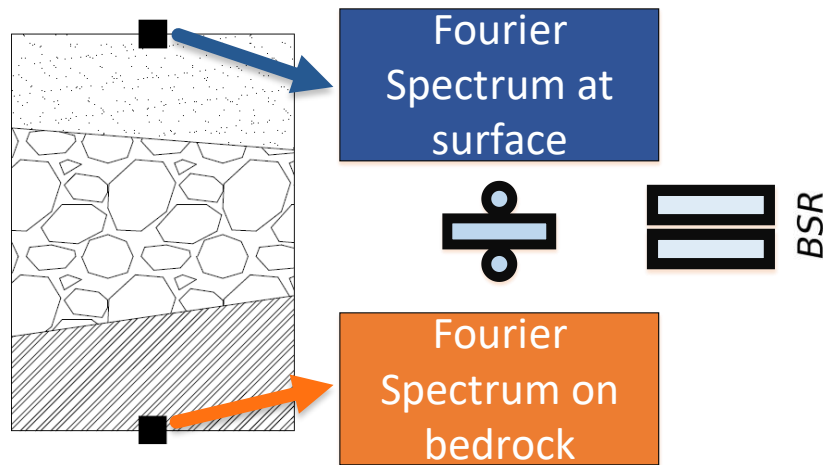
$$BSR(f) = \sqrt{\frac{|EW_{surf}|^2 + |NS_{surf}|^2}{|EW_{depth}|^2 + |NS_{depth}|^2}}$$

Station: IBRH11



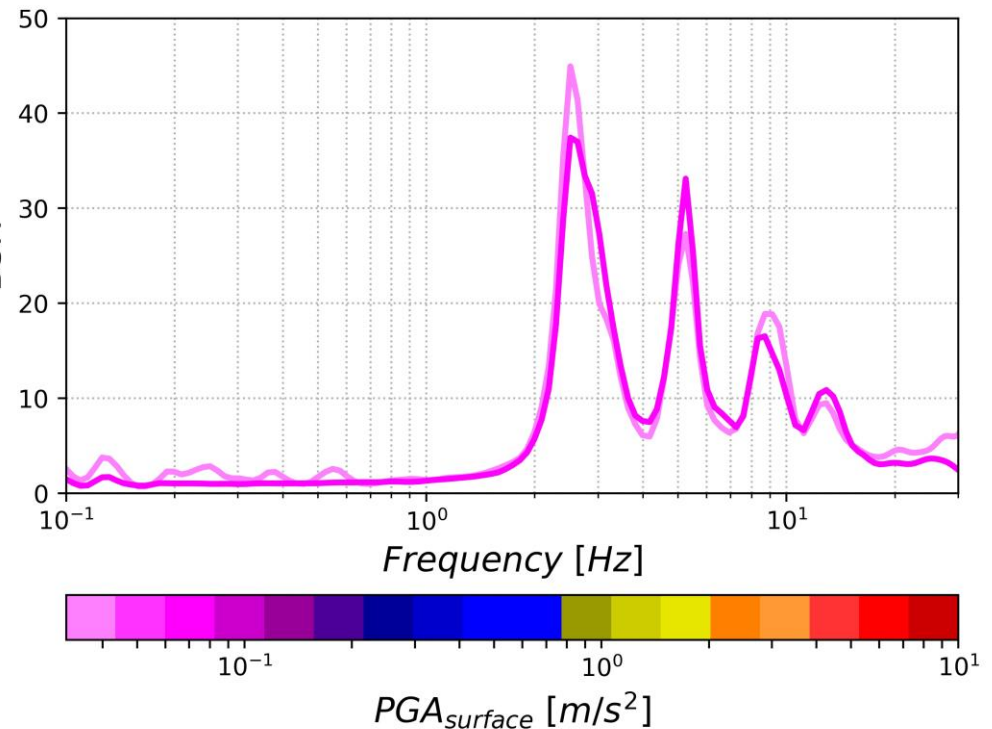
Non-Linear effects

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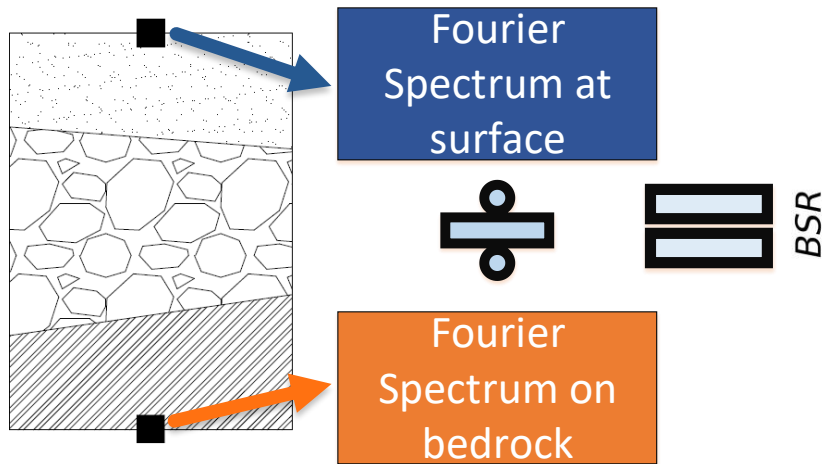
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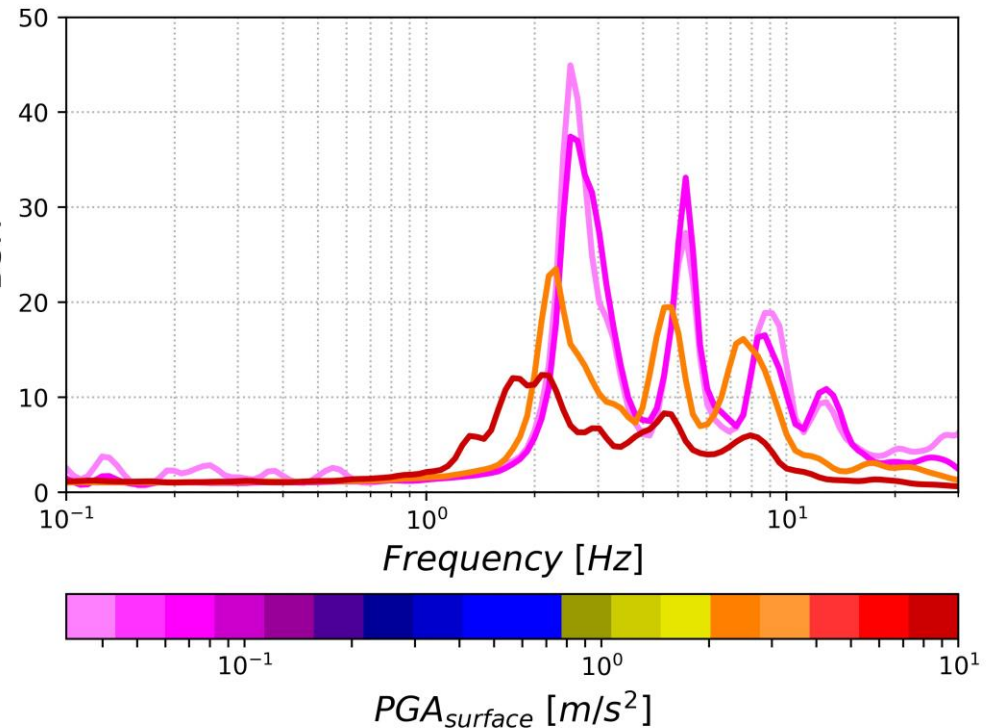
Non-Linear effects

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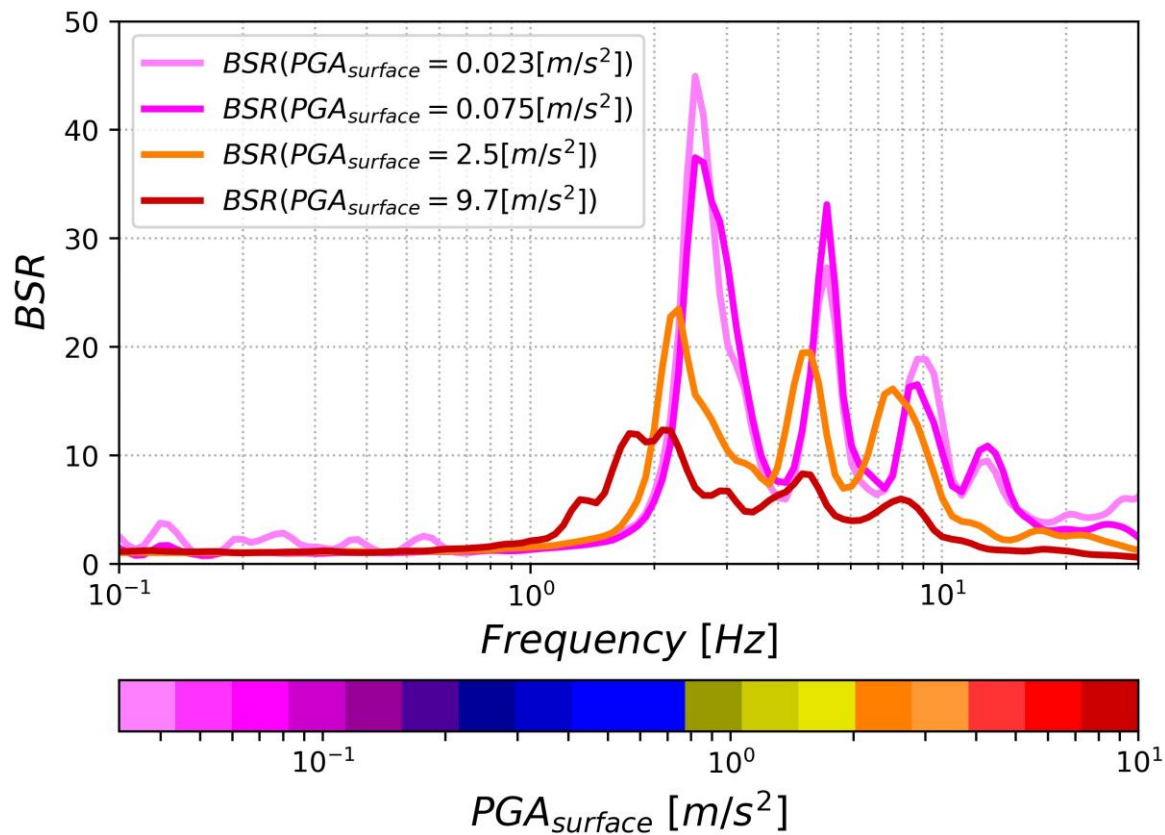
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Non-Linear effects

Station: IBRH11



Shift to lower frequencies on the amplification

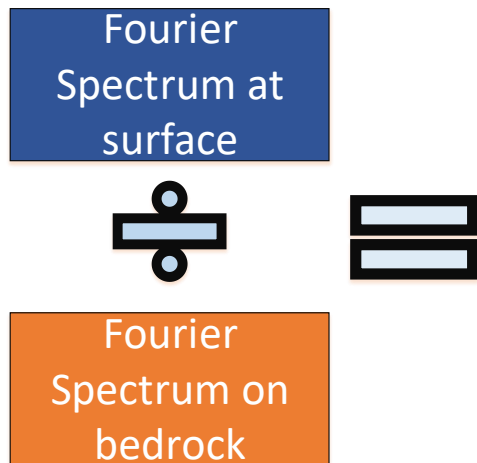


Decrease of the amplification

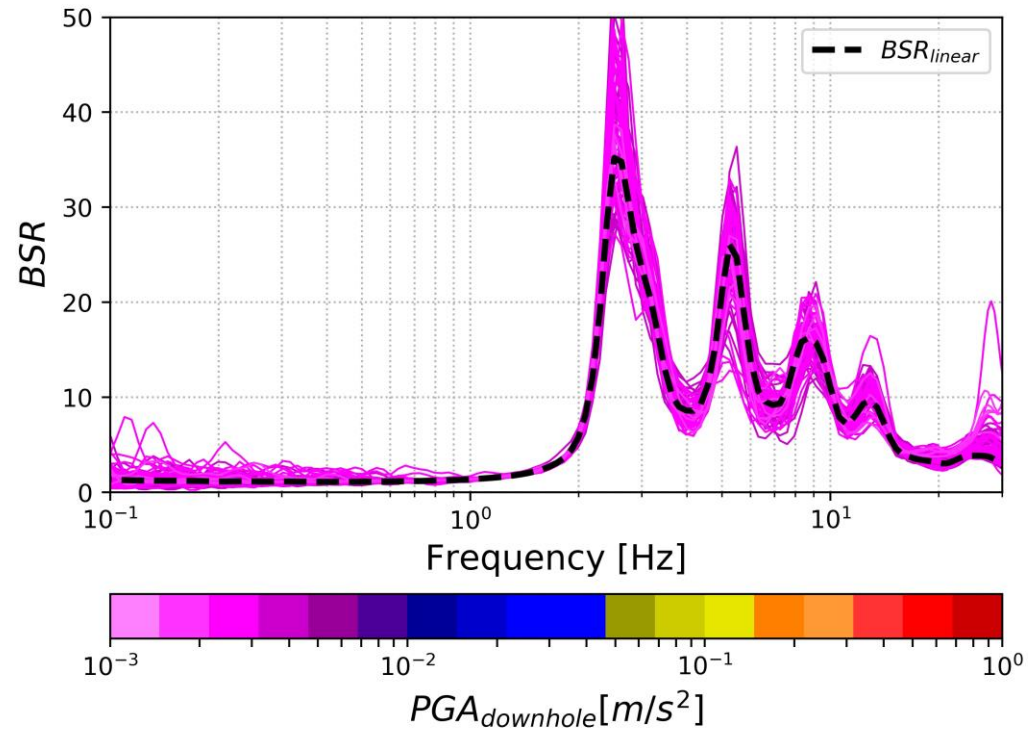
Frequency shift parameter (f_{sp})

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- BSR_{linear} is the average from the $BSRs$ from weak ground motions



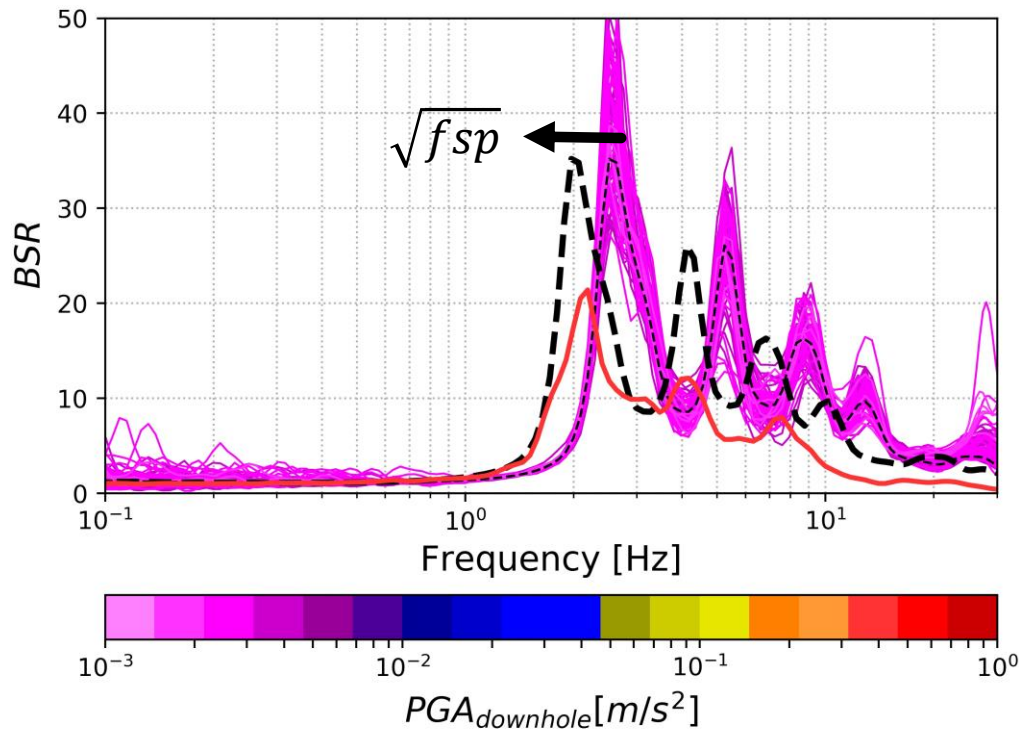
Station: IBRH11



$$BSR_{linear} = \left[\sum_{i=1}^n BSR_{weak(i)}(f) \right] / n$$

Frequency shift parameter (fsp)

- **Frequency Shift Parameter (fsp):** It measures the logarithmic ten frequency lag with respect to BSR_{linear}



$$BSR_{linear}(f\sqrt{fsp}) \rightarrow BSR$$

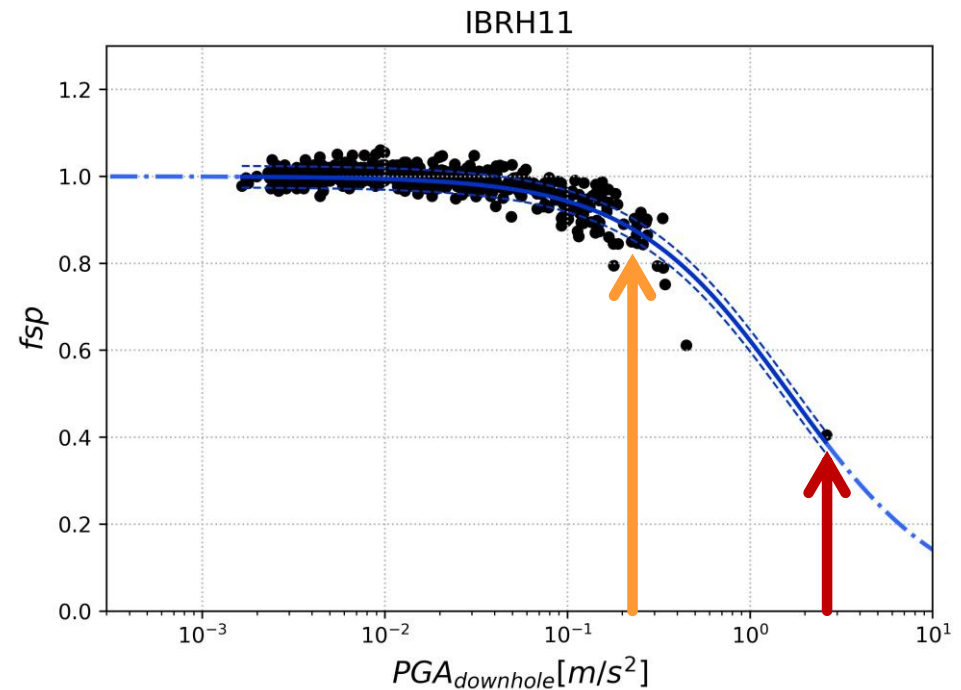
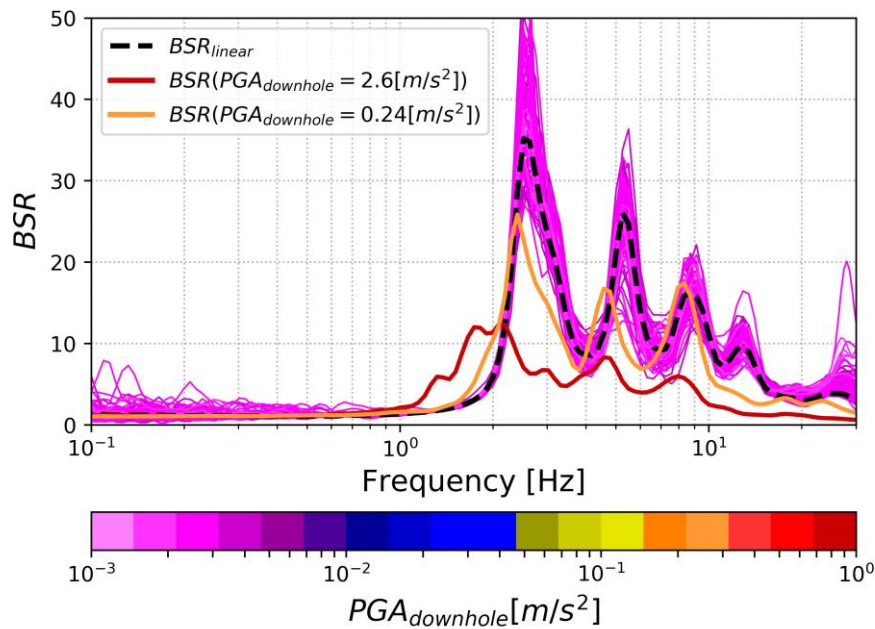
$fsp < 1 \rightarrow$ Shift to lower frequencies

$fsp = 1 \rightarrow$ No shift

$fsp > 1 \rightarrow$ Shift to higher frequencies

Frequency shift parameter (f_{sp})

- ▶ f_{sp} value is related with the intensity of the ground motion.

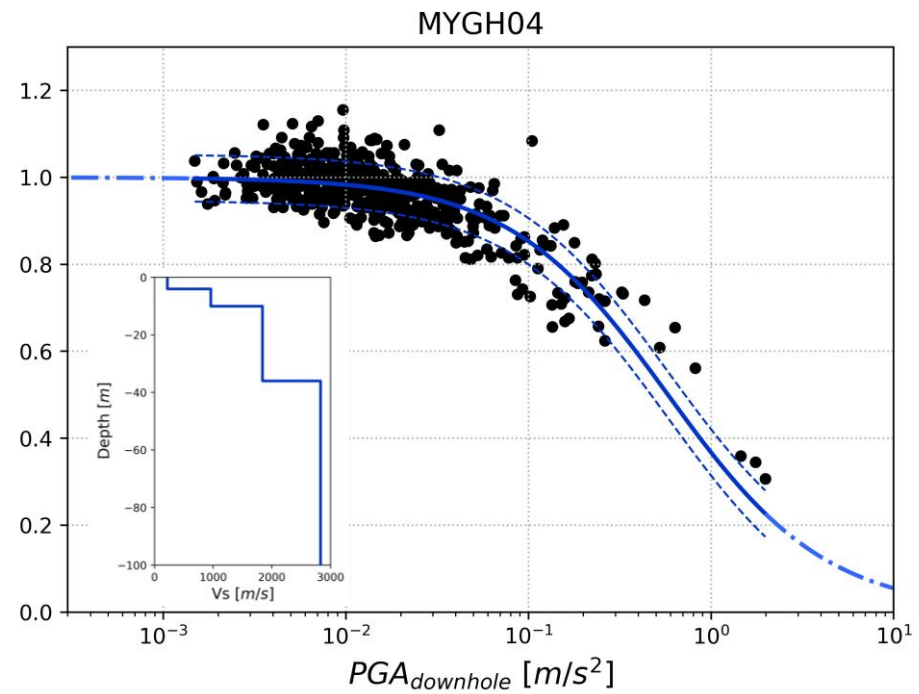
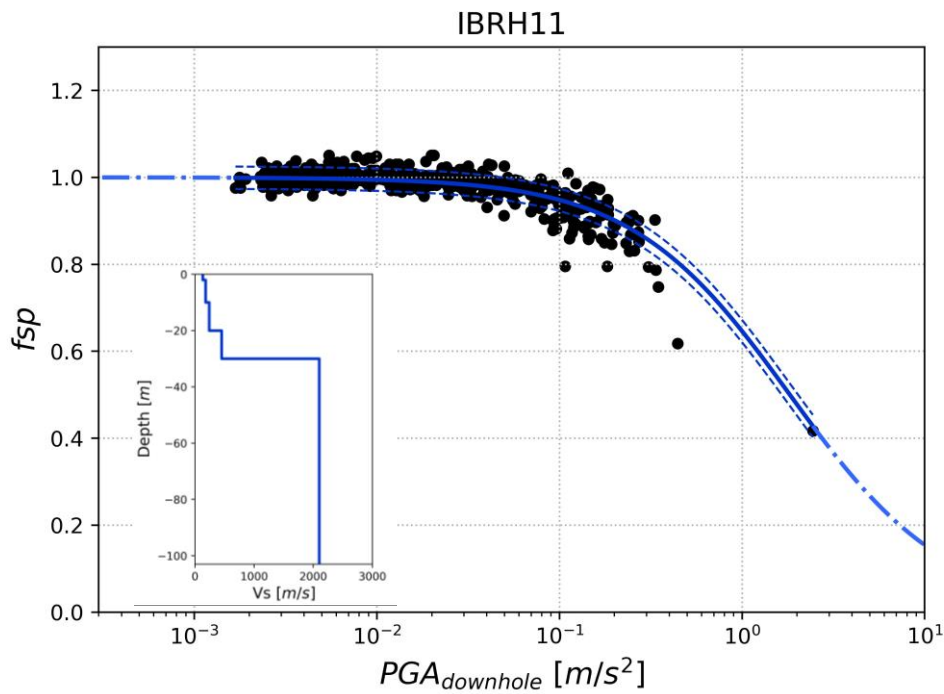


$$BSR_{linear}(f\sqrt{f_{sp}}) \rightarrow BSR$$

$$f_{sp} = \frac{1}{1 + \frac{PGA_{downhole}}{PGA_{ref\ downhole}}}$$

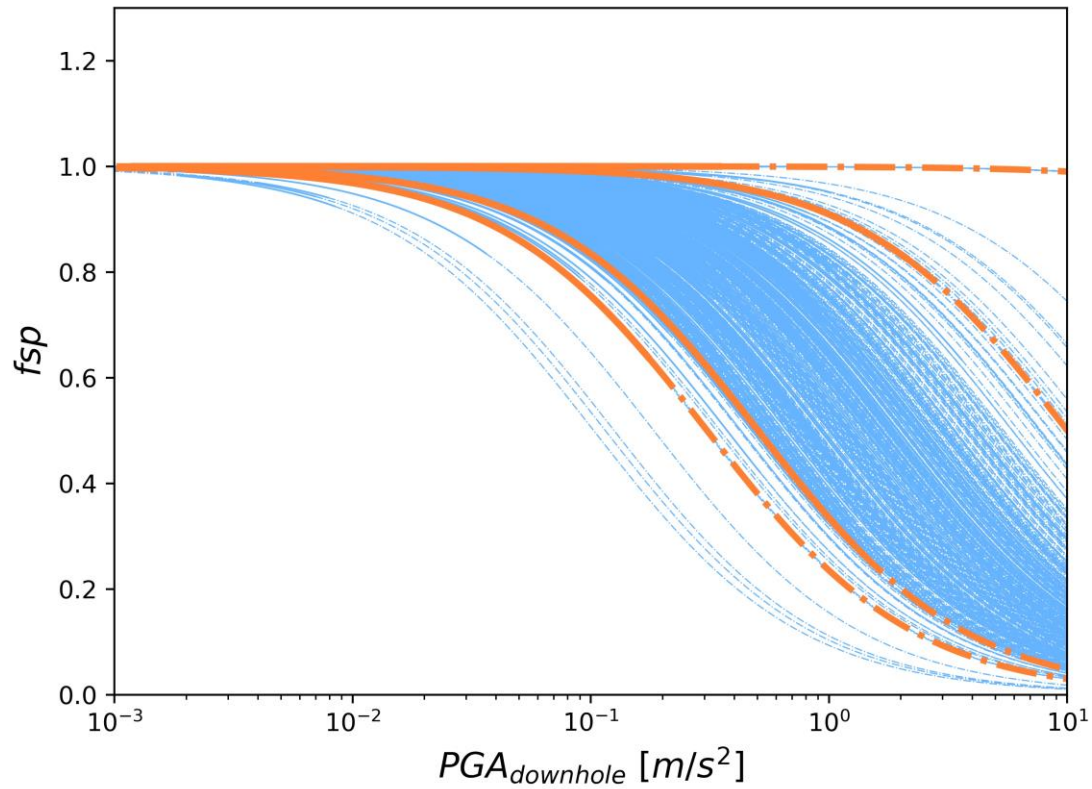
Frequency shift parameter (f_{sp})

► f_{sp} curves are related with the site:



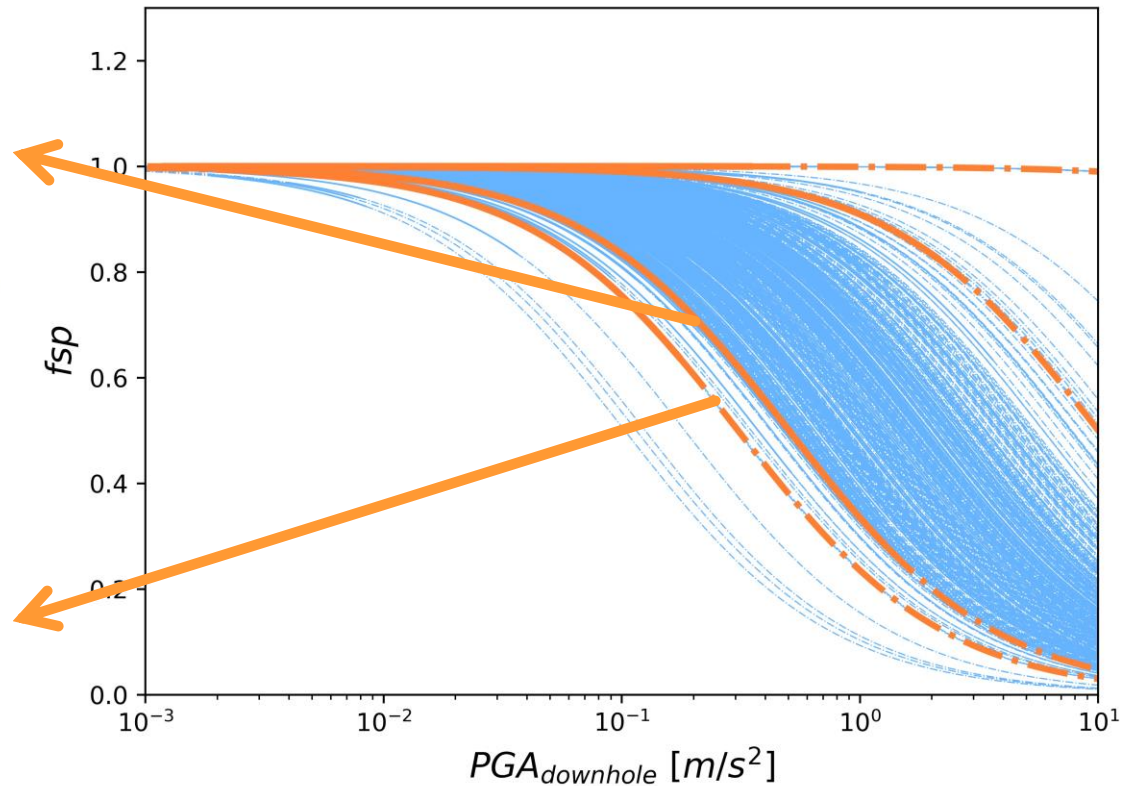
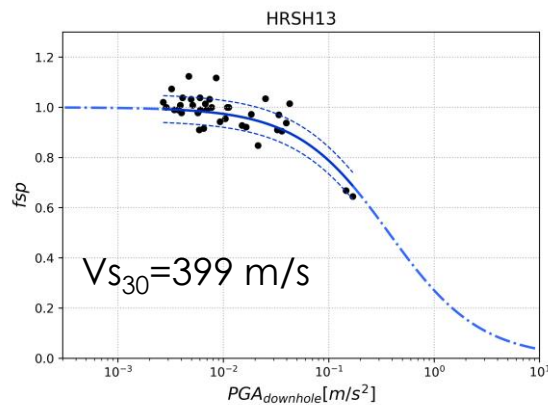
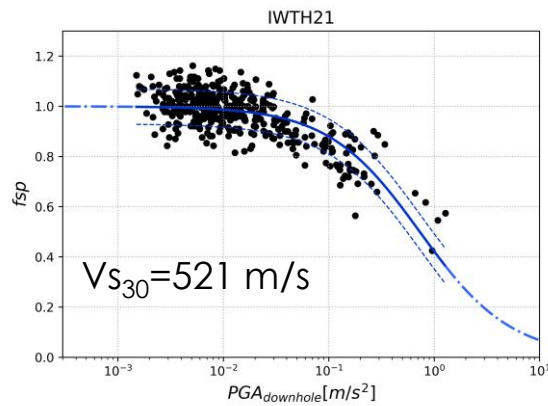
Frequency shift parameter (f_{sp})

- ▶ Comparison between 466 stations



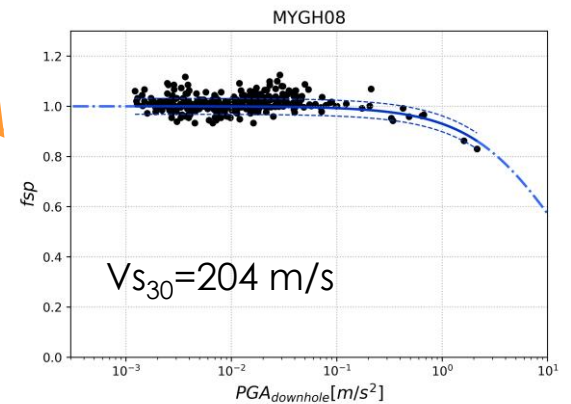
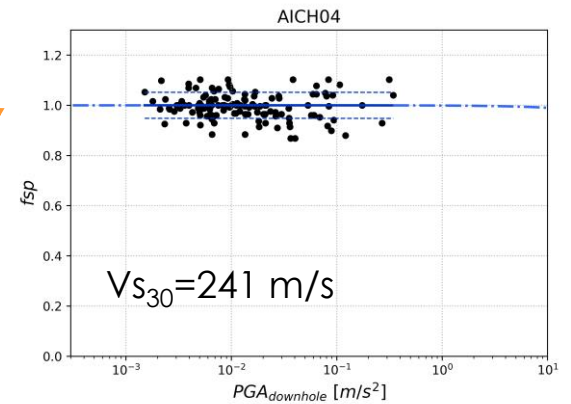
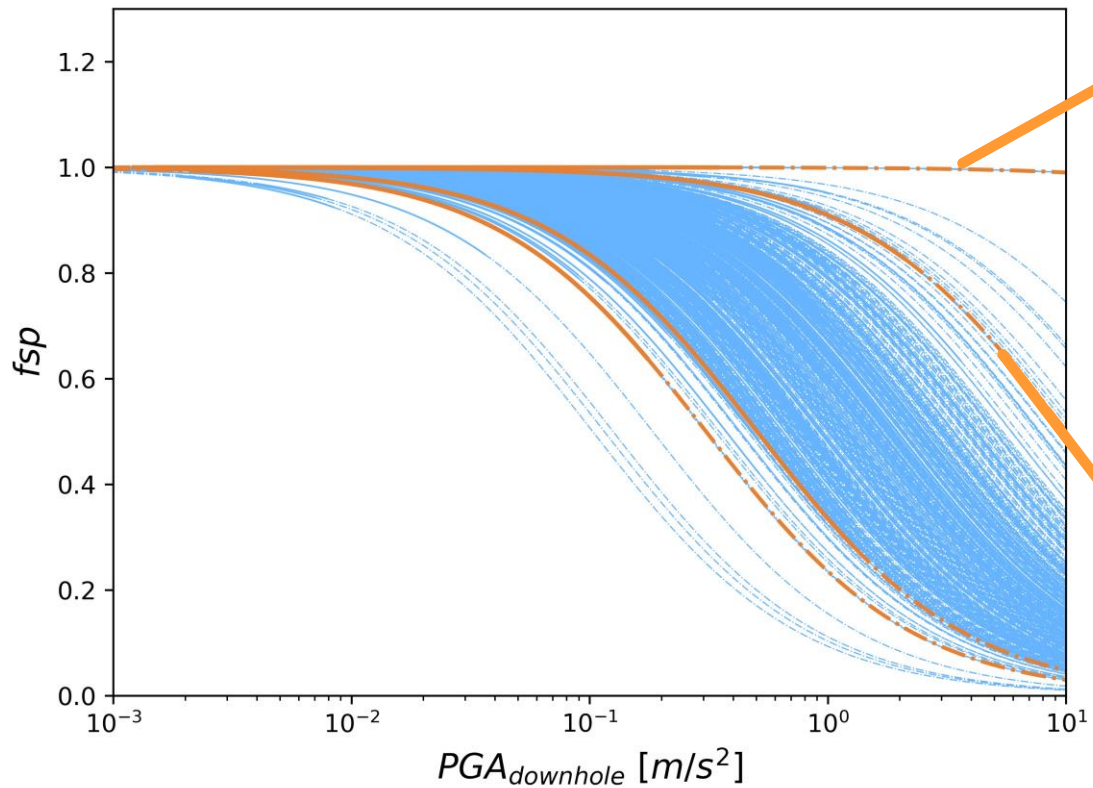
Frequency shift parameter (f_{sp})

Comparison between 466 stations



Frequency shift parameter (f_{sp})

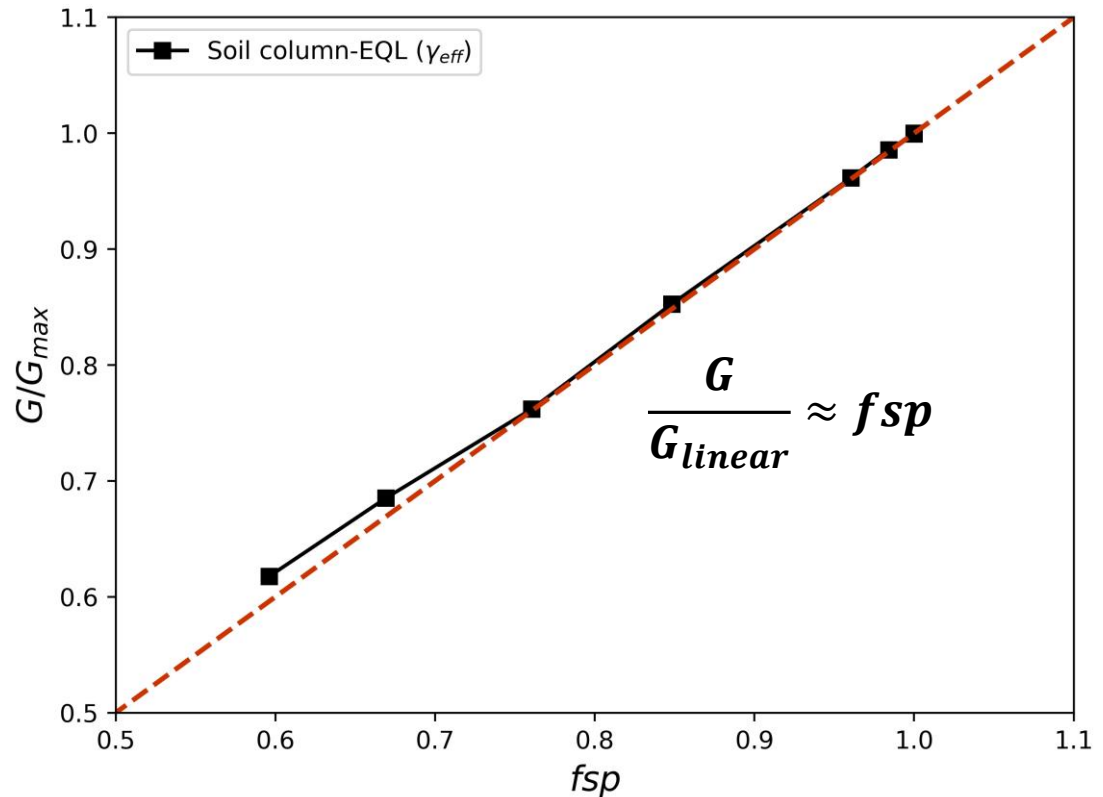
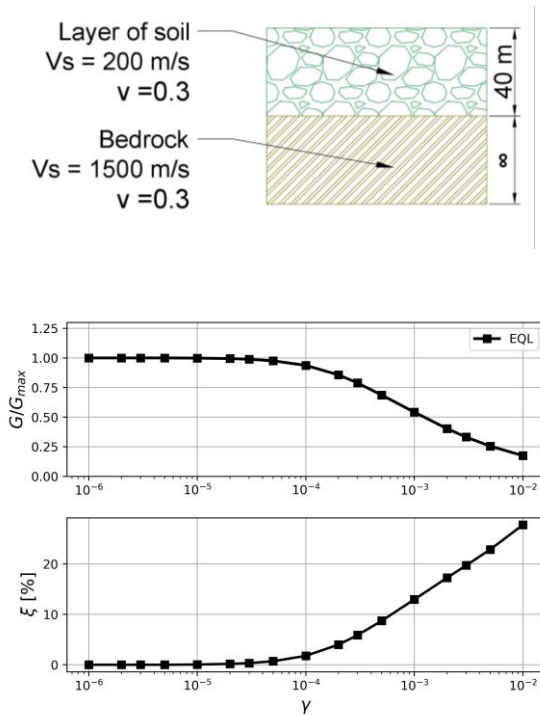
Comparison between 466 stations



fsp relationship with decay of stiffness (G/G_{max})

Frequency shift parameter (f_{sp})

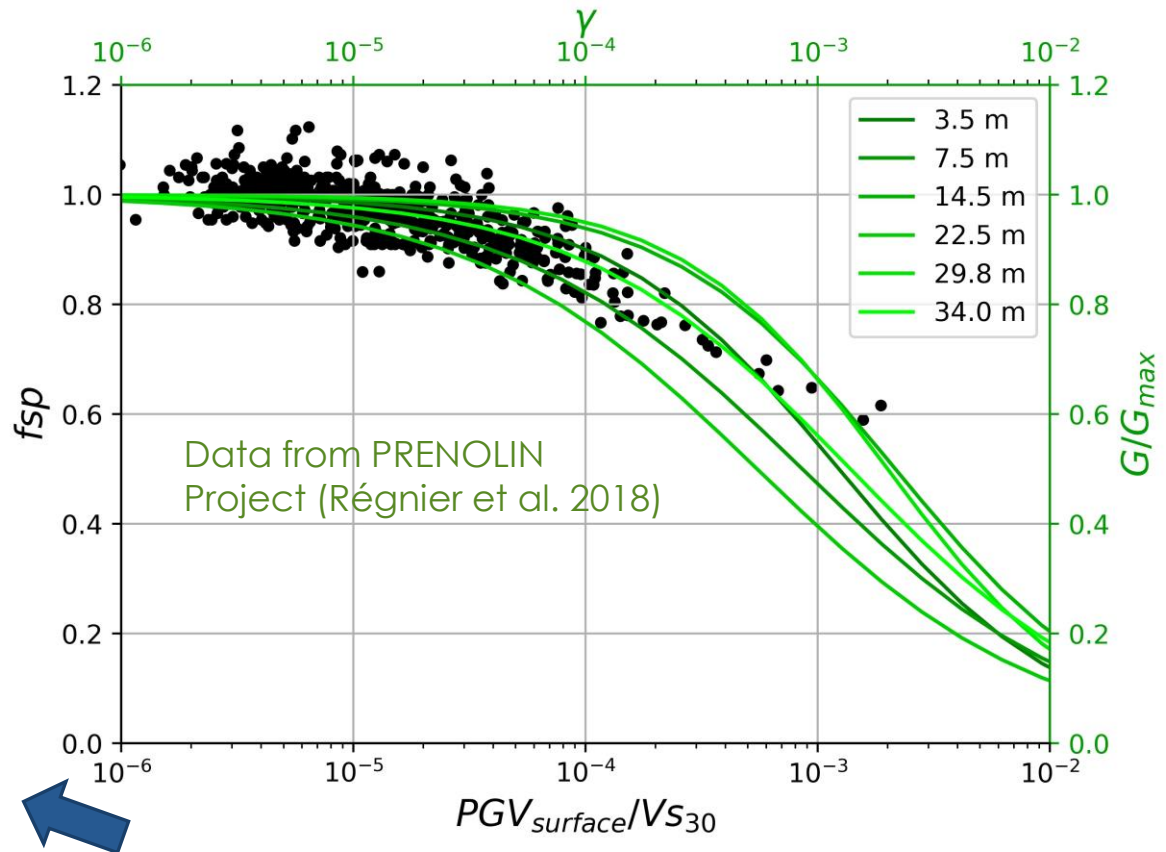
► f_{sp} in equivalent linear analysis



Frequency shift parameter (f_{sp})

- Comparison with laboratory data:

Station: KSRH10



f_{sp} is related with the loss of stiffness



PGV/V_{s30} as proxy of strain (Chandra et al., 2015) (Idriss, 2011)



Conclusions

- ▶ The frequency shift parameter (fsp) can quantify the influence of the non-linearity of the soil in a ground motion.
- ▶ fps curves are linked with the site characteristic.
- ▶ The fsp curves show a similar trend with the shear modulus reduction curves.



ευχαριστώ πολύ

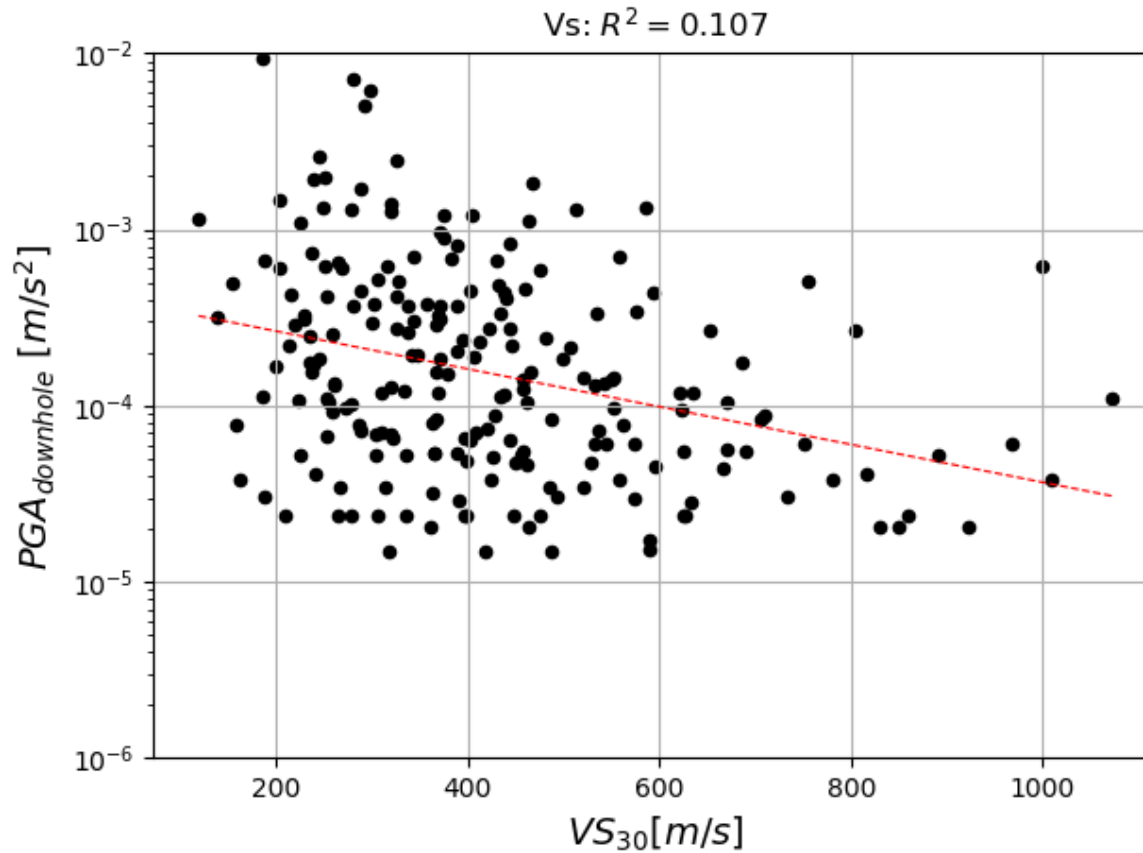
Thank you

I will be attentive to
any question

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Frequency shift parameter (f_{sp})

- ▶ Comparison with different stations



fsp curves

