First results of the (Infrasound-Seismoacoustic) "Ground Coupling Experiment"

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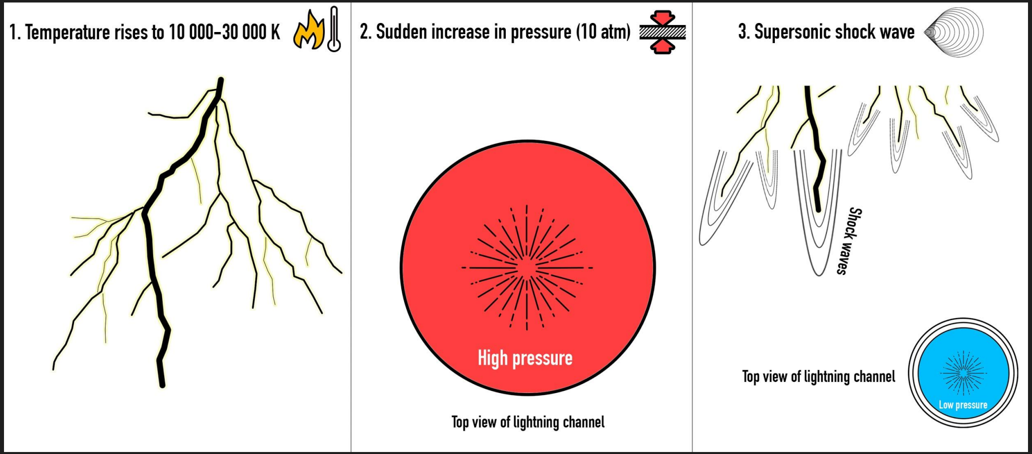
Structure

- Experiment overview
- Sources signatures on collocated stations
- Parameter estimation
- Results
- Conclusions

Experiment Overview

Motivation

Lightning is often accompanied by strong acoustic energy (thunder), both at frequencies of sound (above 20 Hz) and/or in the infrasound frequency band (below 20Hz). It is believed that the thermal expansion due to the sudden heating of the air in the lightning channel leads to the shock wave and is responsible for the audible part of the thunder spectrum.

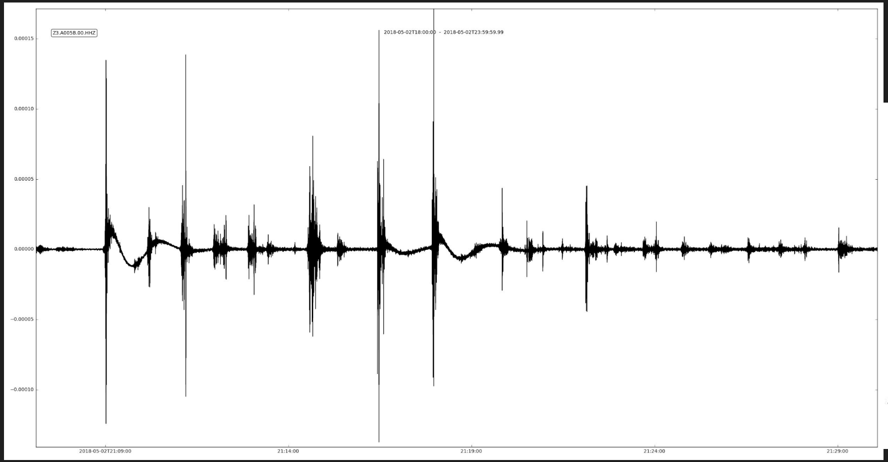


https://weathergeeks.org/what-is-a-red-lightning-and-is-it-real/

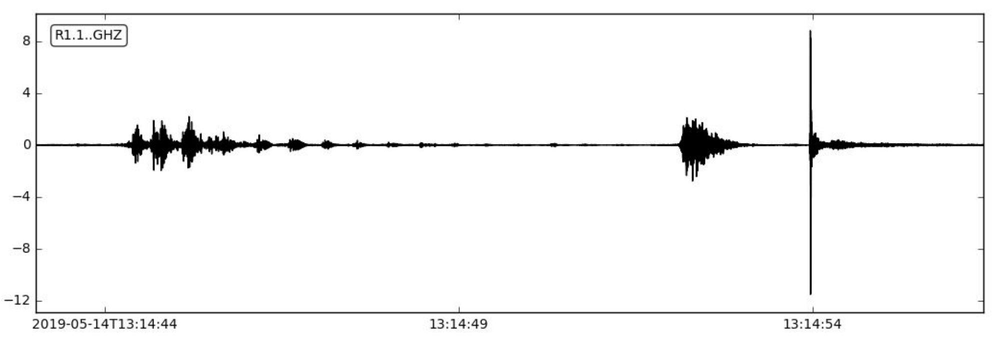
References: A. Few, 1974.Thunder signatures

Motivation

Thunder seismic signals can be “simulated” in a cheap maneer with fireworks

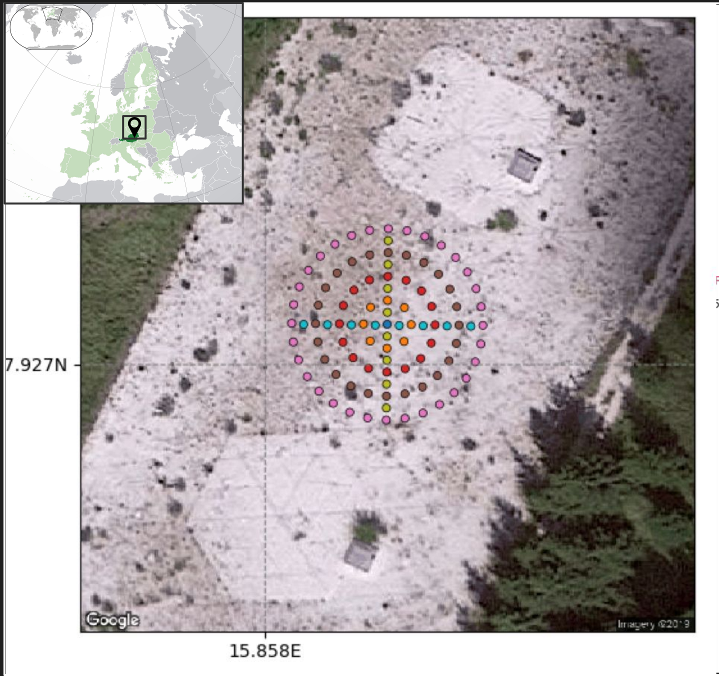


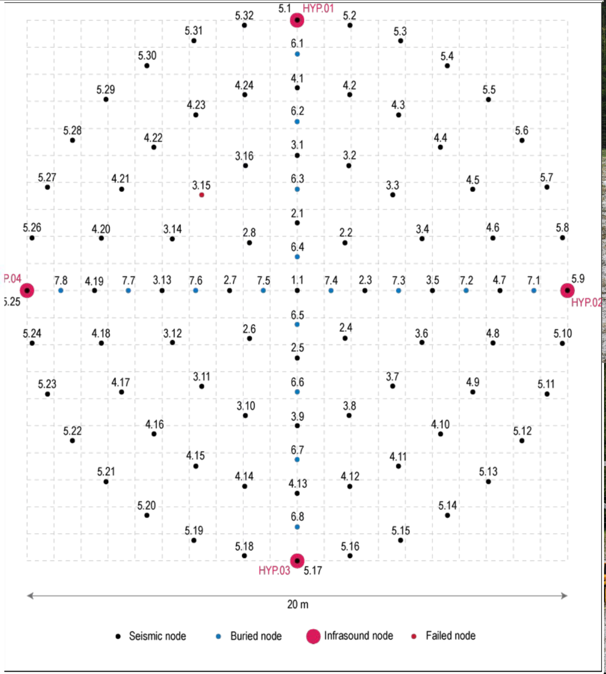
Thunder Sequence



Rocket Sequence

Former CTBT Test Site, Austria





Equipment

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97 x Fairfield Nodal Z-Land Gen2 3C geophones (5 Hz)

4 x seismically decoupled Hyperion IFS-5111 infrasound sensors

1 x Reftek 130-01 data logger

4 x Plastic buckets with holes (wind reduction "system")

Sources

Hammer

Firecrackers

Rockets

Steps

Sources

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Hammer

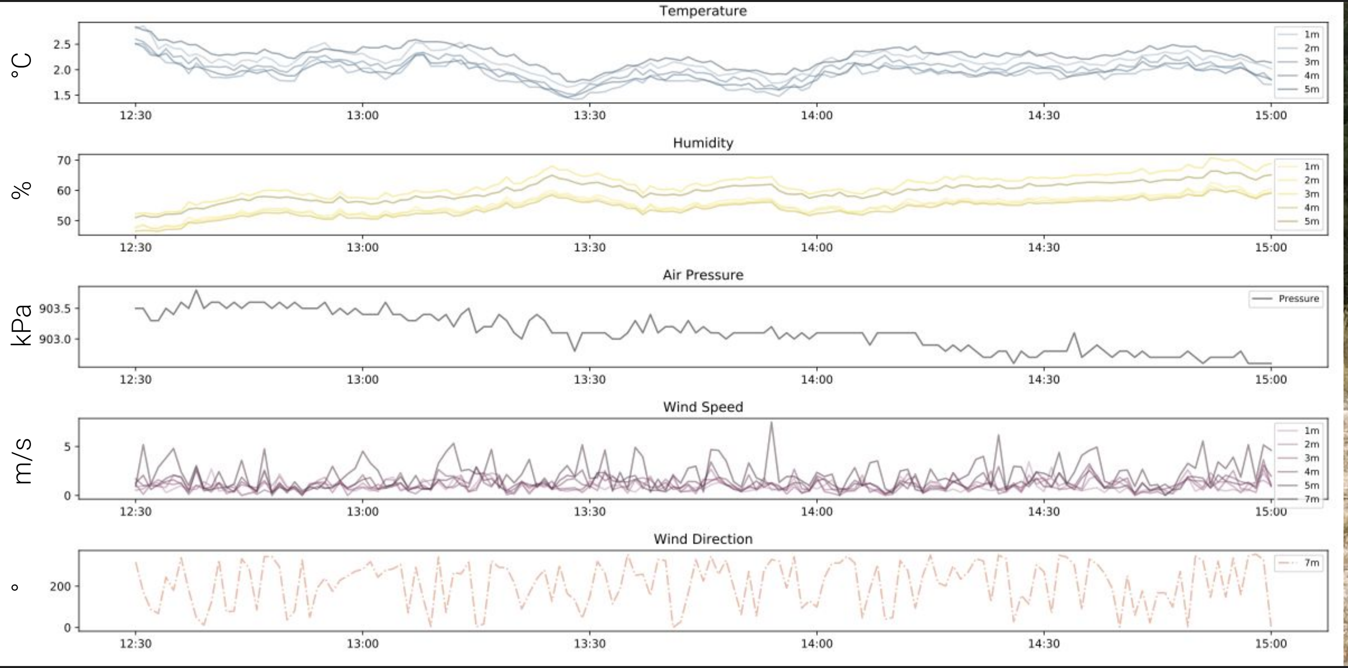
Firecrackers

Rockets

Steps

Meteorological data

MetLift

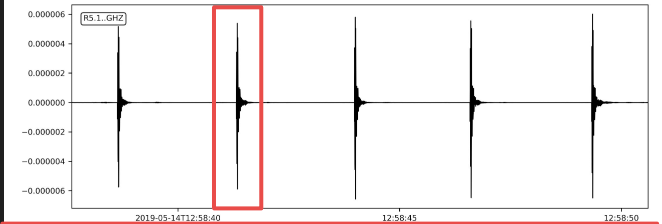


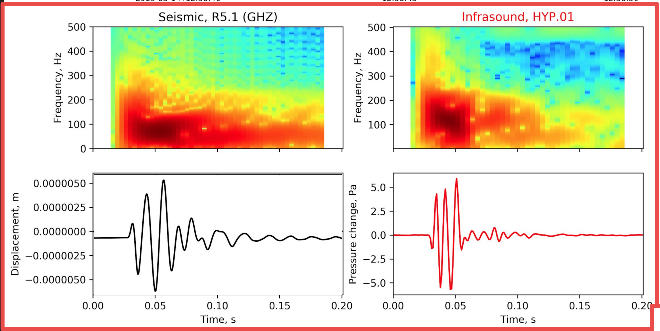
- Vertical meteorological profile from 1 to 7 m above the experiment
- Data sampling with minute periode

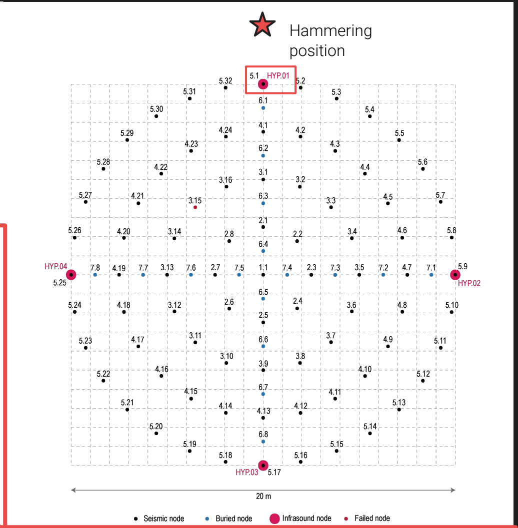
Source signatures on collocated sensors

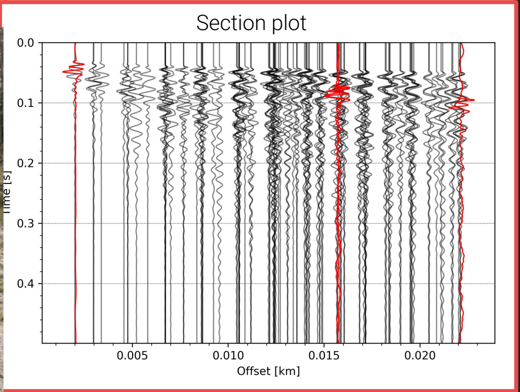
Hammer

Bandpass: 10-499 Hz



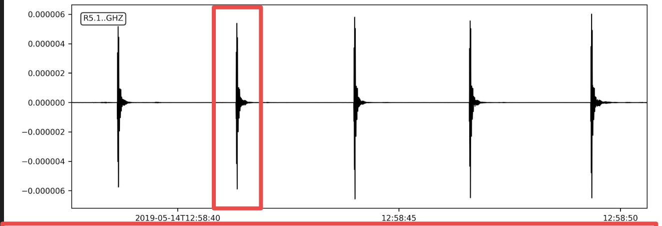


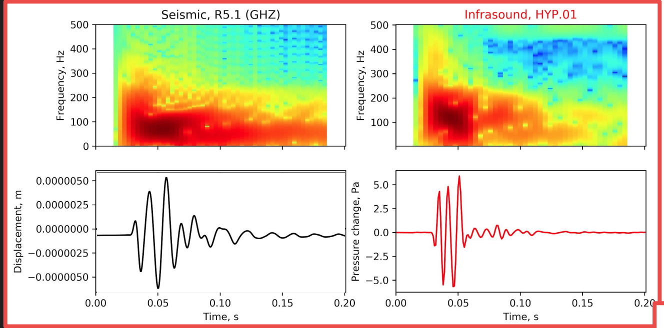


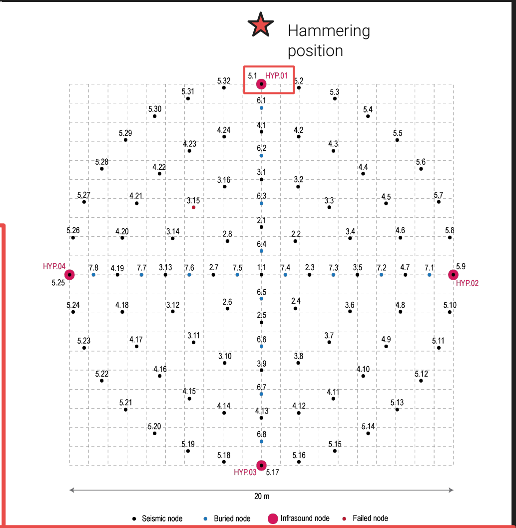


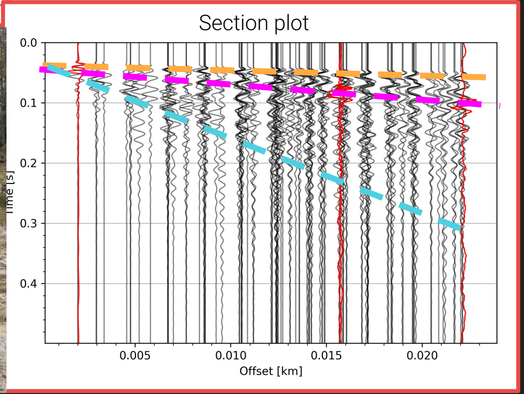
Hammer

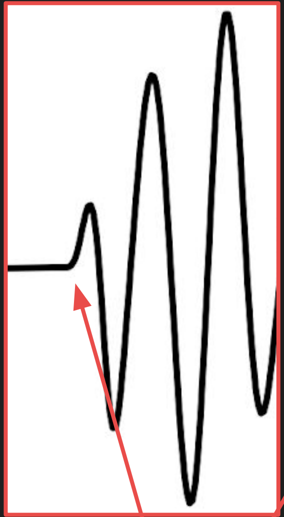
Bandpass: 10-499 Hz

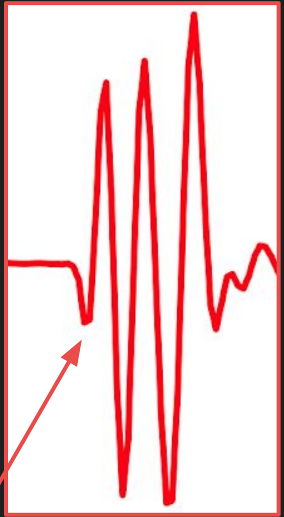










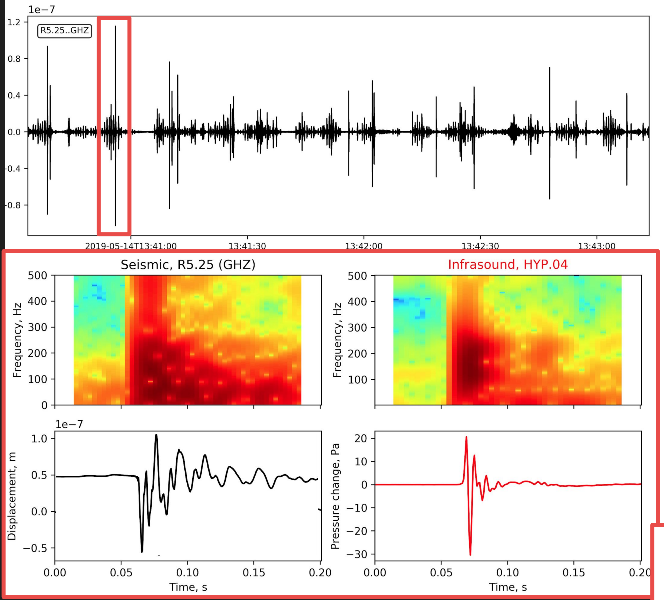


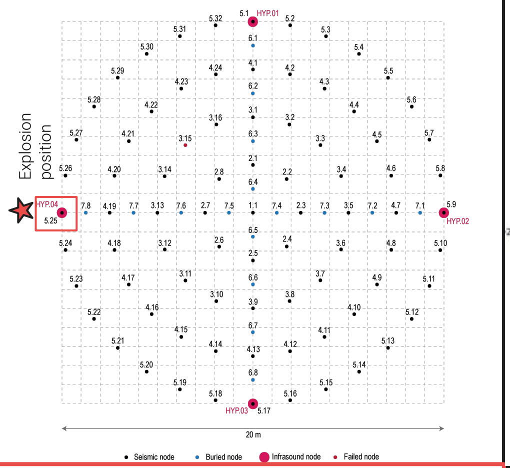
Positive displacement and pressure drop

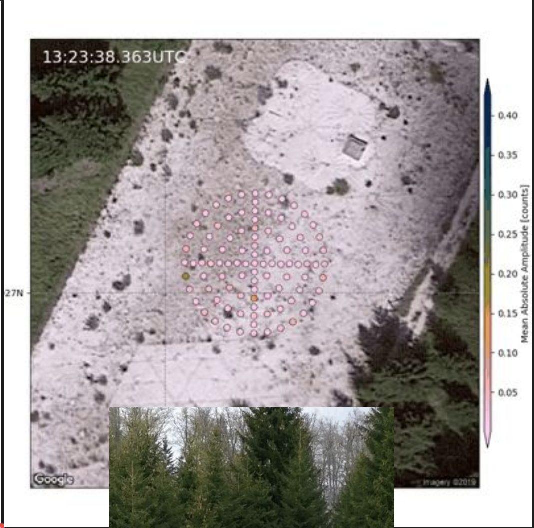
Seismic P-wave
Acoustic wave
Biot (?) wave

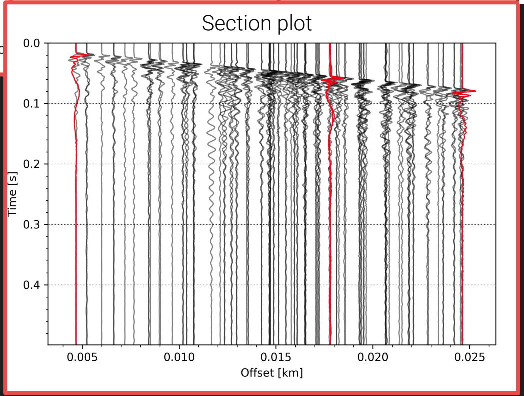
Firecrackers

Bandpass: 10-499 Hz



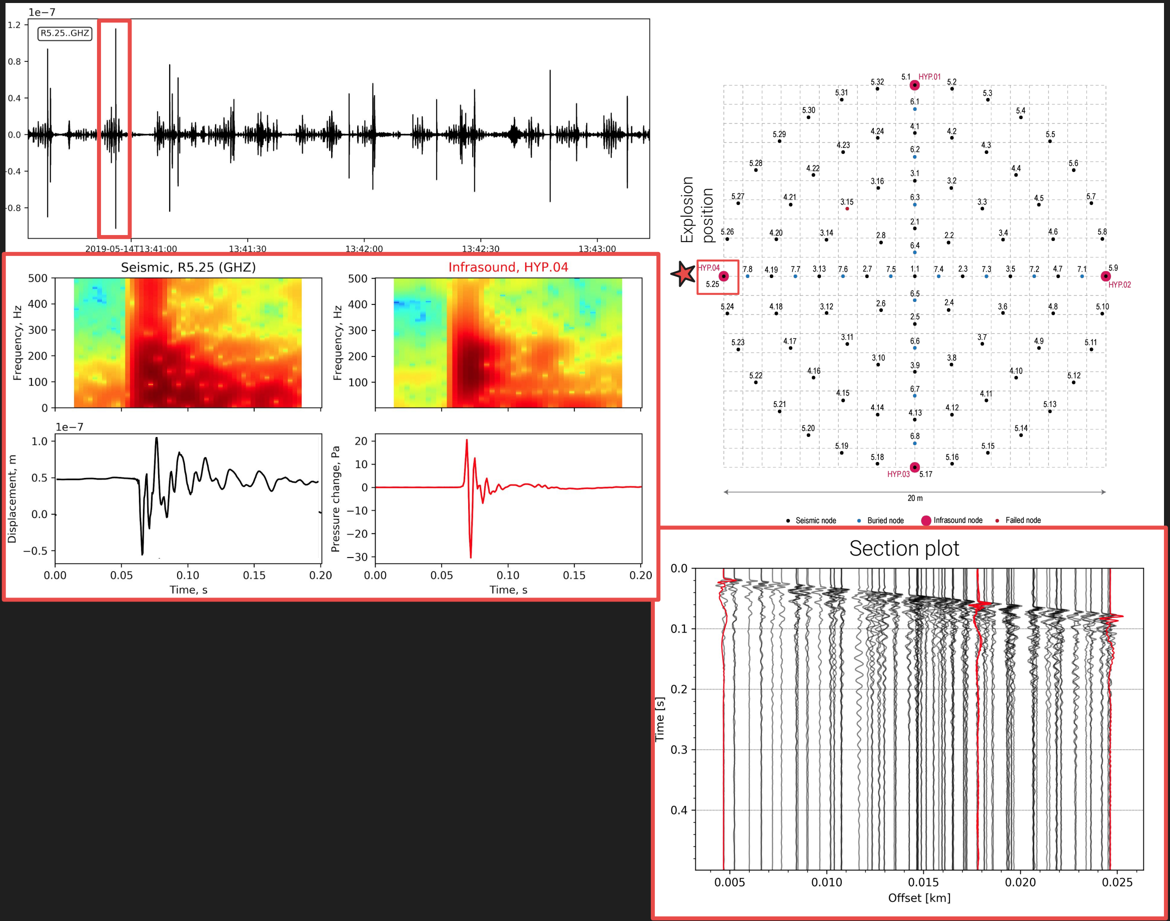


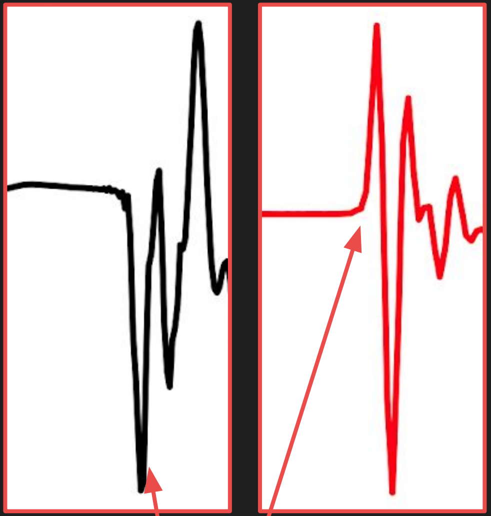




Firecrackers

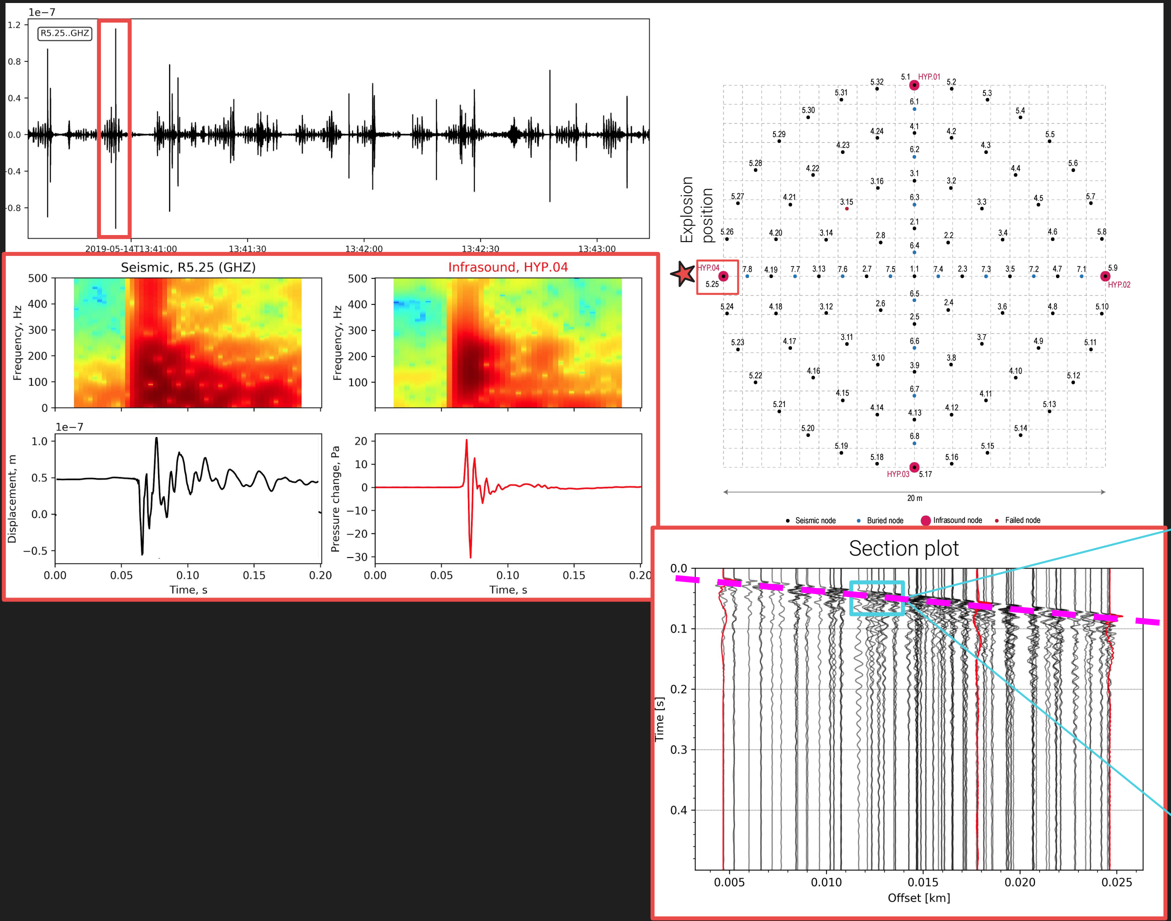
Bandpass: 10-499 Hz





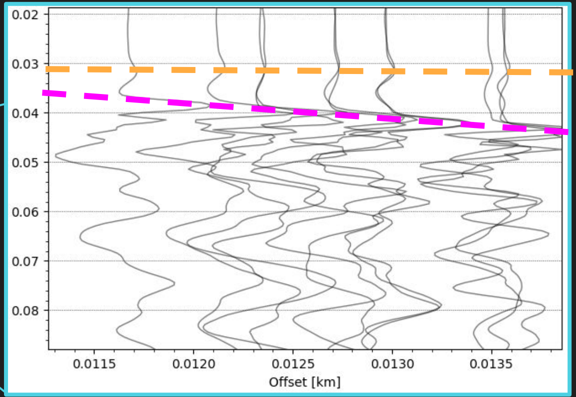
Sudden negative displacement and pressure increase followed by rarefaction

Firecrackers



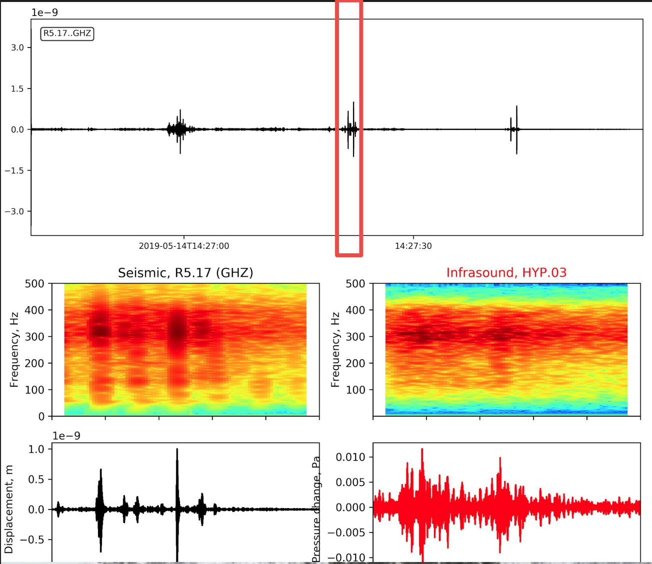
Seismic P-wave

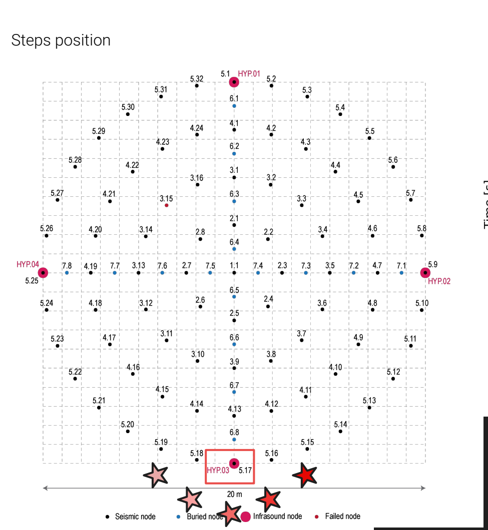
Acoustic wave

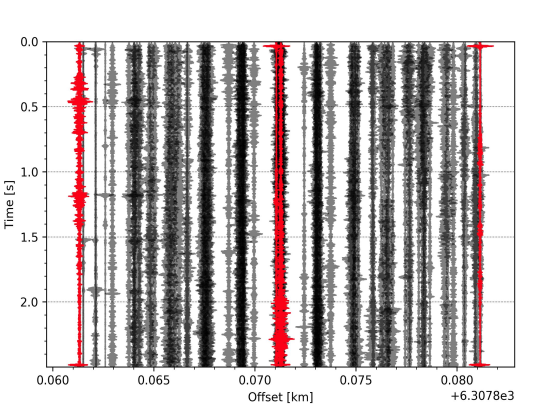


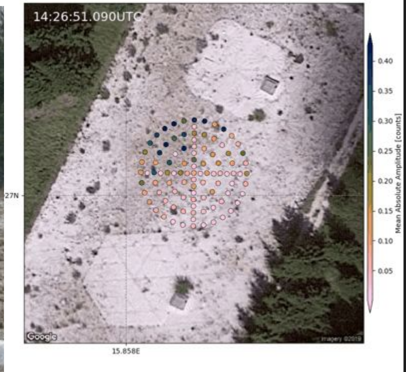
Steps

Bandpass: 300-399 Hz









- Steps are easily identifiable on spectrograms

Parameter estimation

Density and Velocity of air

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Density of air:

$$\rho_a = \frac{\rho M_a}{ZRT}\left[1 - x_v\left(1 - \frac{M_v}{M_a}\right)\right]$$

Where ρ_a - density of air [g/cm3],
ρ - pressure [Pa],
T - temperature [K],
x_v- mole fraction of water vapor,
Ma - molar mass of dry air [g/mol],
Mv - molar mass of water [g/mol],
Z - compressibility factor,
R - molar gas constant [J/mol*K]

Speed of sound in the air:

$$c_0^2 = \gamma \frac{RT}{M}\left(1 + \frac{2pB}{RT}\right)$$

Where c_0 - speed of sound [m/s],
ɣ - specific heat ratio,
M - molecular mass of the air,
B - second virial coefficient

Molecular velocity of the air:

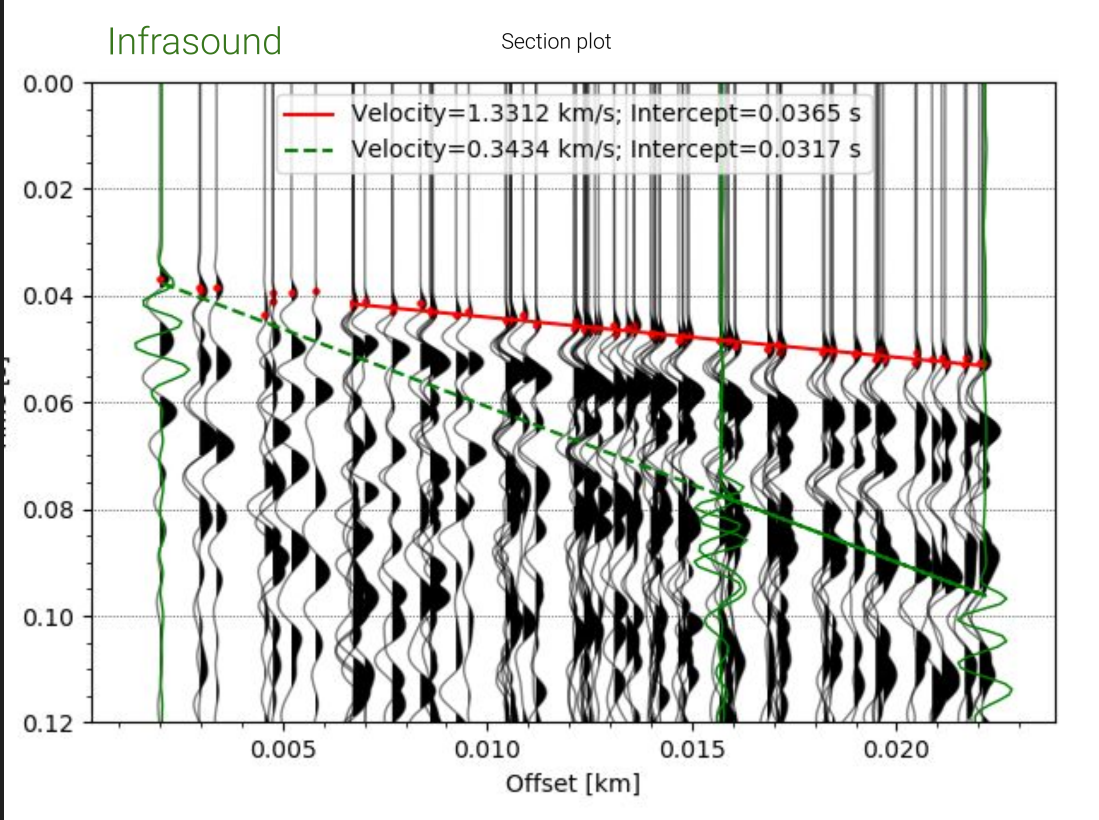
$$v_{air} = \frac{\rho}{\rho_a * c_0}$$

References: Owner Cramer, 1992. The variation of the specific heat ratio and the speed of sound in air with temperature, pressure, humidity, and CO2 concentration.

A Picard et al., 2007. Revised formula for the density of moist air (CIPM-2007)

N. Edwards, 2007. Calibrating infrasonic to seismic coupling using the Stardust sample return capsule shockwave: Implications for seismic observations of meteors

Density and Velocity of the ground



Density of soil: 2.02 g/cm3*
*Assumption

Ground coupling calculations

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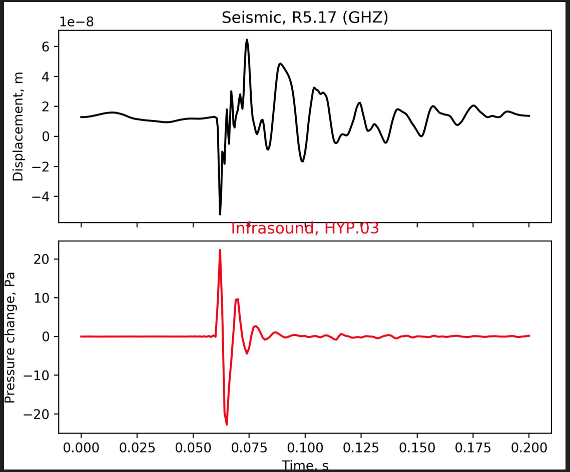
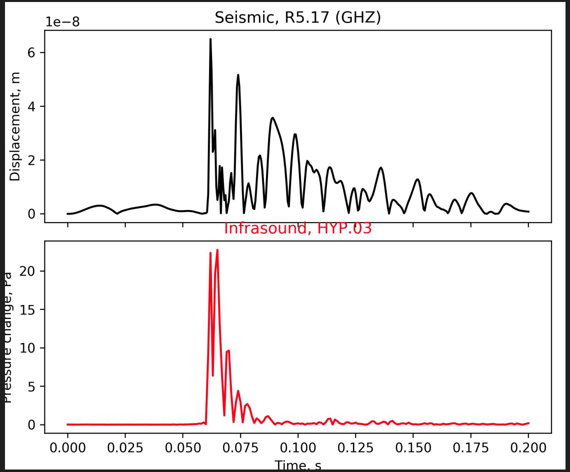
Amplitude record



Absolute Amplitude record



Energy Coupling Efficiency:

$$E_{A-S} = \frac{0.5\rho_{air} v_{air}^2}{0.5\rho_{soil} v_{soil}^2}$$

Coupling Transfer Coefficient:

$$C_{coup-tranf} = \frac{|A_{seis}|}{|A_{hyp}|}$$

Reference: N. Edwards, 2007. Calibrating infrasonic to seismic coupling using the Stardust sample return capsule shockwave: Implications for seismic observations of meteors

Ground coupling calculations

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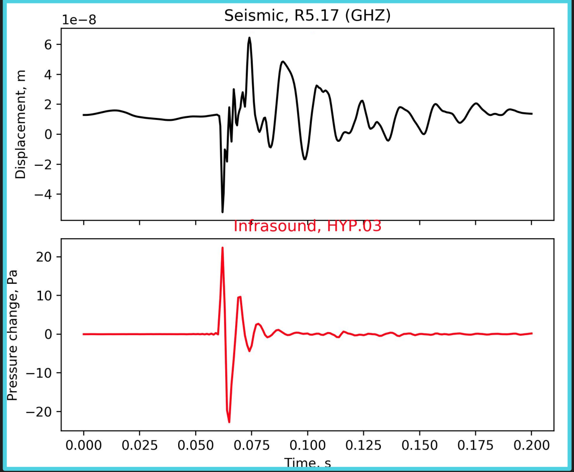

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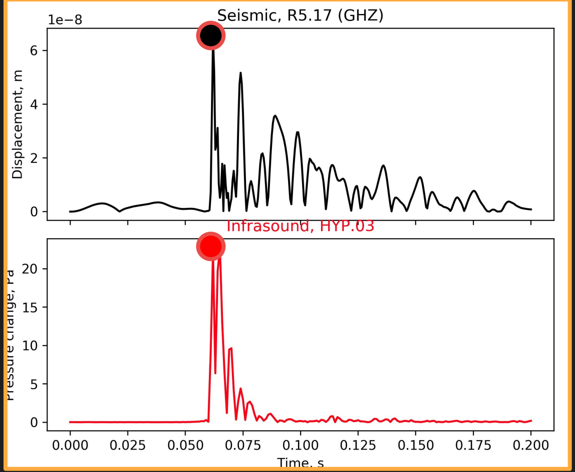

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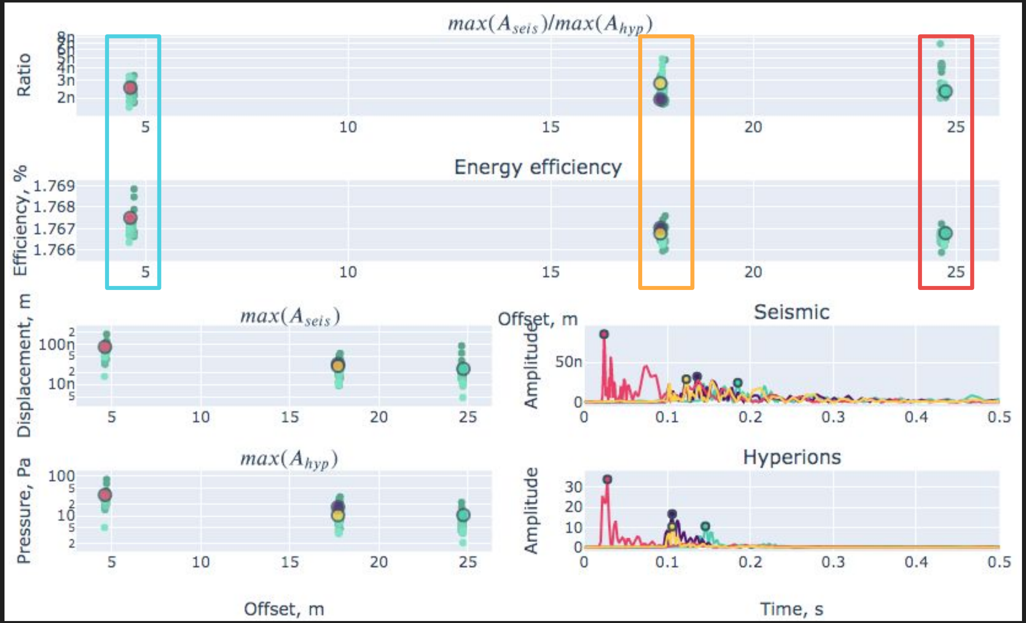
Results

Coupling efficiency



All explosions

Ground Motion Measure	Coupling Transfer Coefficient	Energy Coupling Coefficient
DISP	2.39+-0.5 nm/Pa	1.76 %
VEL	2.62+-0.5 um*s-1/Pa	
ACC	0.005+-0.001 m*s-2/Pa	

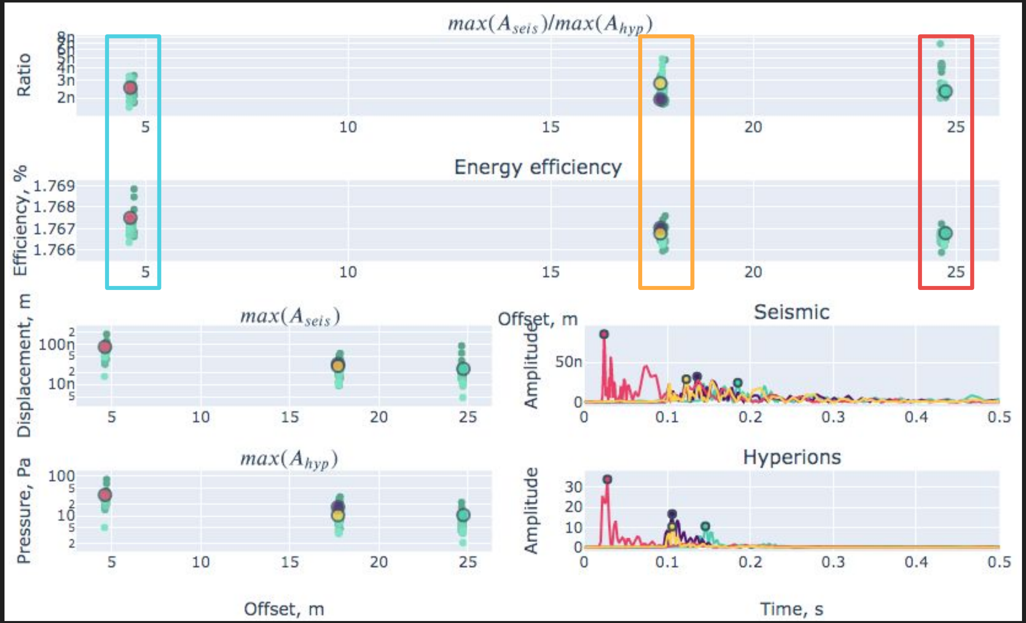
Ground Motion Measure	Coupling Transfer Coefficient	Energy Coupling Coefficient
DISP	2.63+-0.5 nm/Pa	1.76 %
VEL	2.37+-0.5 um*s-1/Pa	
ACC	0.004+-0.001 m*s-2/Pa	

Ground Motion Measure	Coupling Transfer Coefficient	Energy Coupling Coefficient
DISP	2.95+-0.5 nm/Pa	1.76 %
VEL	2.41+-0.5 um*s-1/Pa	
ACC	0.003+-0.001 m*s-2/Pa	

E.g.: Explosion 2-2

Ground Motion Measure	Coupling Transfer Coefficient	Energy Coupling Coefficient
DISP	3+-1 nm/Pa	1.76 %
VEL	2.5+-0.1 um*s-1/Pa	
ACC	0.004 m*s-2/Pa	

Coupling efficiency



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DISP	2.95+-0.5 nm/Pa	1.76 %
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Displacement: increases with offset
Velocity: not conclusive
Acceleration: decreases with offset

Summary and Conclusions

Summary

We have talked about:

- Experiment
- Sources signatures on collocated stations
- Parameter estimation
- Results

Conclusions

Coupling efficiency and coefficients are on the order of magnitude reported by previous authors, which means that this holds true for very small offsets and high frequencies just as well as for any other offsets and frequencies

Acknowledgments

Goetz Bokelmann, Florian Fuchs, IMGW UniVie group

Thank you for your attention!

Any mind shattering ideas what to do with our data?

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