Results presented in the presentation has been already published in the following paper:

Kwiatek, G., and Y. Ben-Zion (2016). Theoretical limits on detection and analysis of small earthquakes, *Journal of Geophysical Research-Solid Earth* **121**, doi 10.1002/2016JB012908.

Please consider referring to the above paper if you find this presentation useful!

# Theoretical limits on detection and analysis of small earthquakes

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# Study

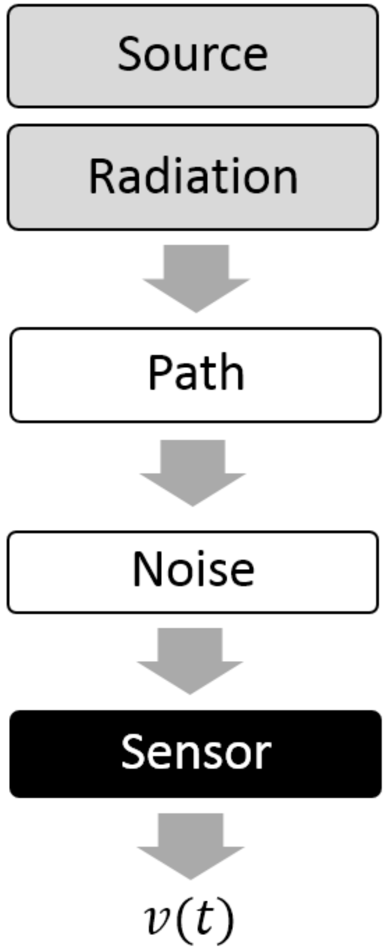
- Improve understanding of theoretical limits to detection of seismic events
- Clarify limitations for reliable derivation of source characteristics

*Can we detect and reliably analyze earthquake in a particular combination of source, path, sensor and noise characteristics?*

*Can we provide first-order guidelines on designing local/regional seismic networks in various geological environments to reliably estimate the source characteristics?*

# Simulation parameters

- **Seismic source**
  - *size, slip, rupture velocity*
  - *radiation pattern*
  - *STF directionality*
- **Path effects**
  - *geometrical spreading*
  - *attenuation*
- **Noise effects**
  - *HF noise*
- **Sensor effects**
  - *BB, short period*
  - *Fixed sampling rate and AA filter*



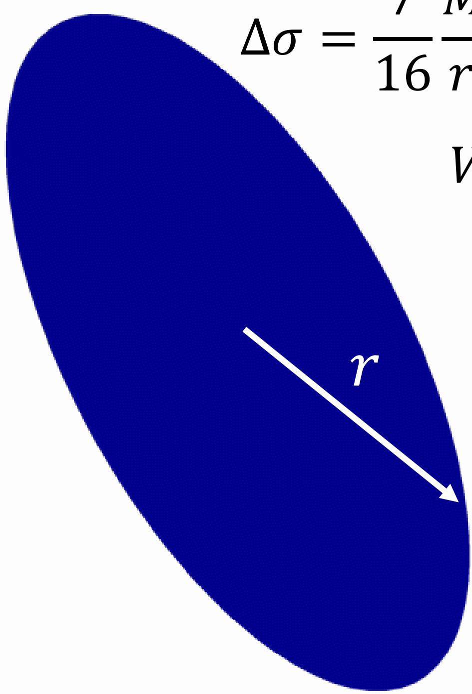
# Source modelling

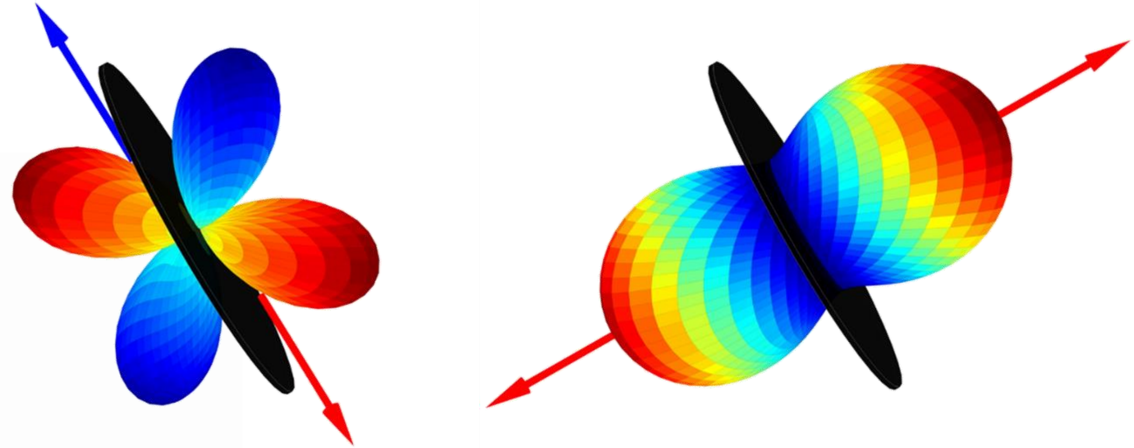
- Rupture process described by $M_0$, $\Delta\sigma$, and $V_R$.
- Rupture propagates radially with constant $V_R$ and stops abruptly
- Radiation pattern: pure shear and pure tensile failure considered

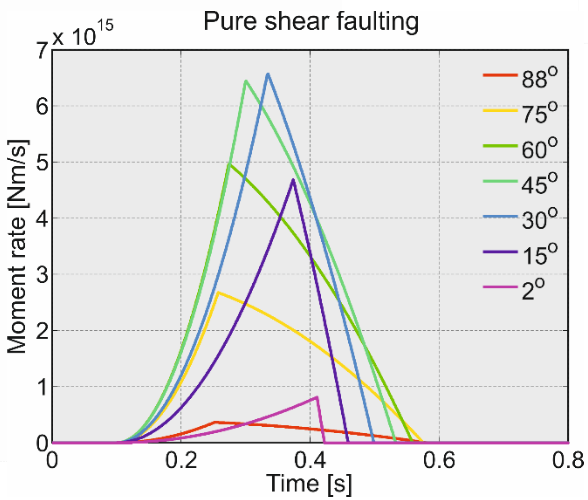
$$M_0 = \mu\, U\, \pi r^2$$

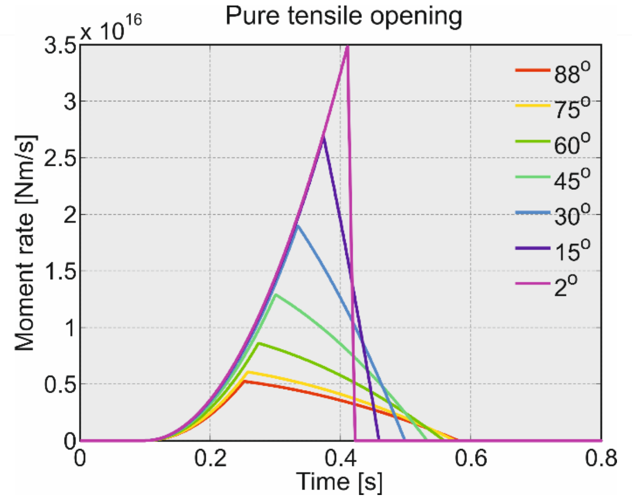
$$\Delta\sigma = \frac{7}{16}\frac{M_0}{r^3}$$

$$V_R$$

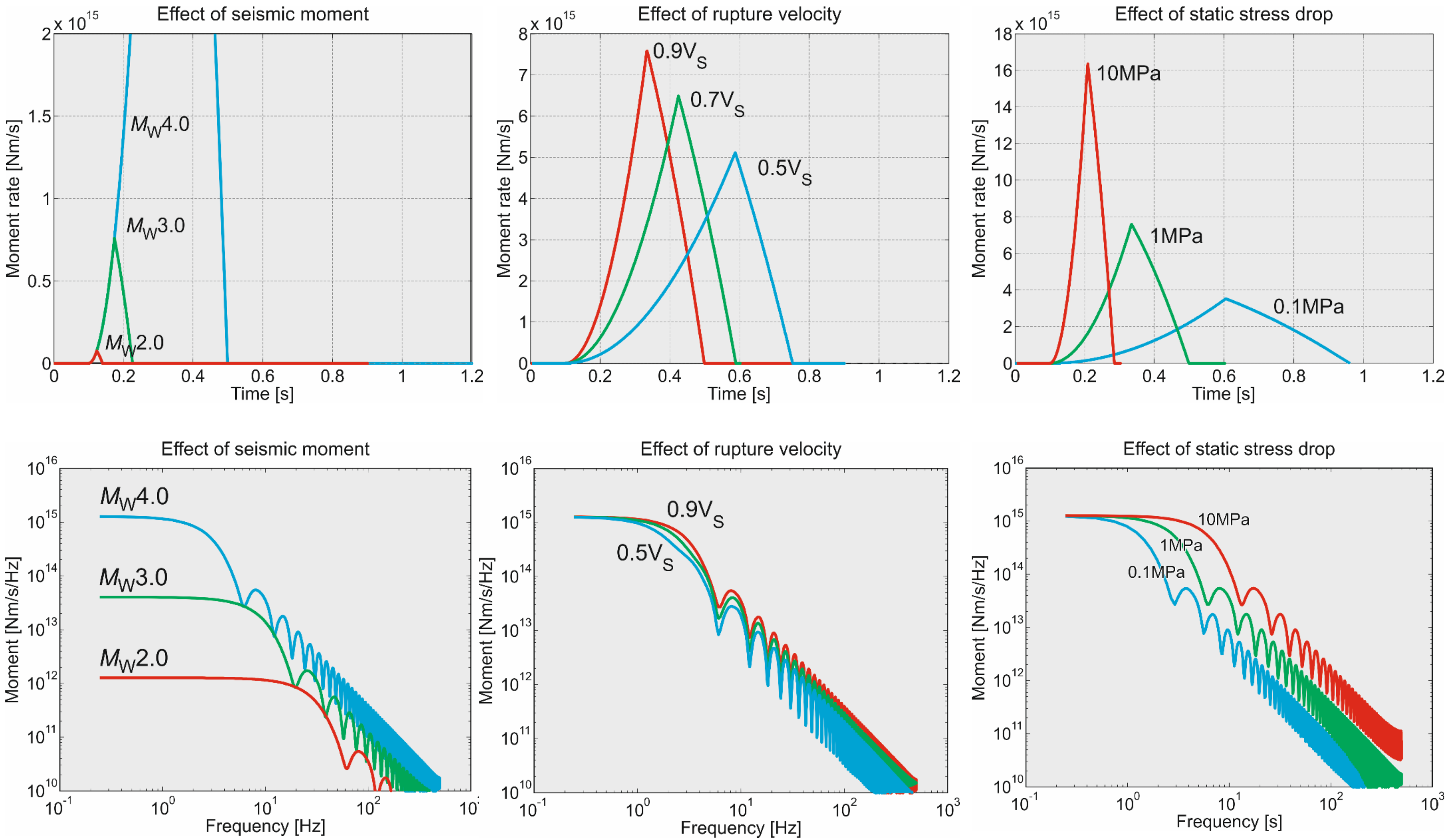




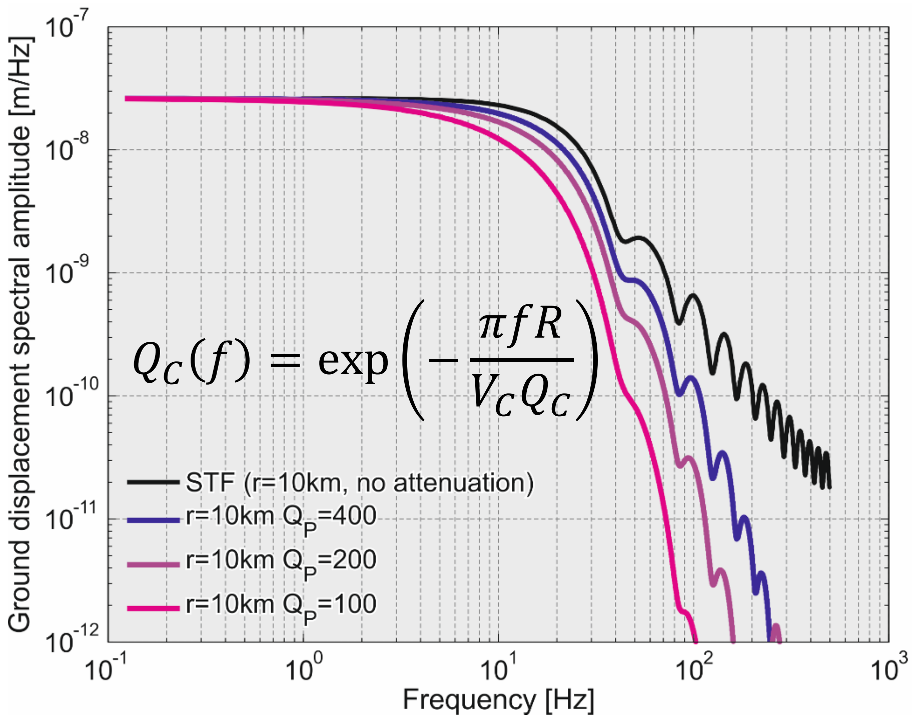
# Source characteristics and amplitude/frequency content

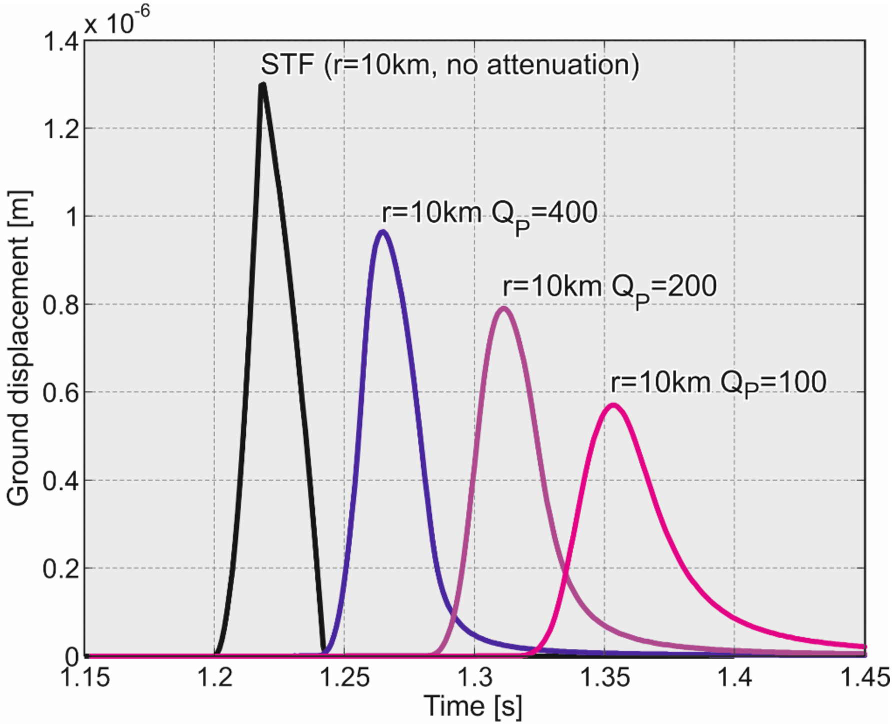



- RMS amplitude variations averaged over focal mechanisms and observations points vary between -23dB and +14dB w/r to source with $\Delta\sigma = 1MPa$ and $V_R = 0.9V_S$

# Influence of attenuation

- Attenuation diminishes the high-frequency content of waves
- Two cases considered: $Q_P = Q_S$ and $Q_P = 9/4Q_S$



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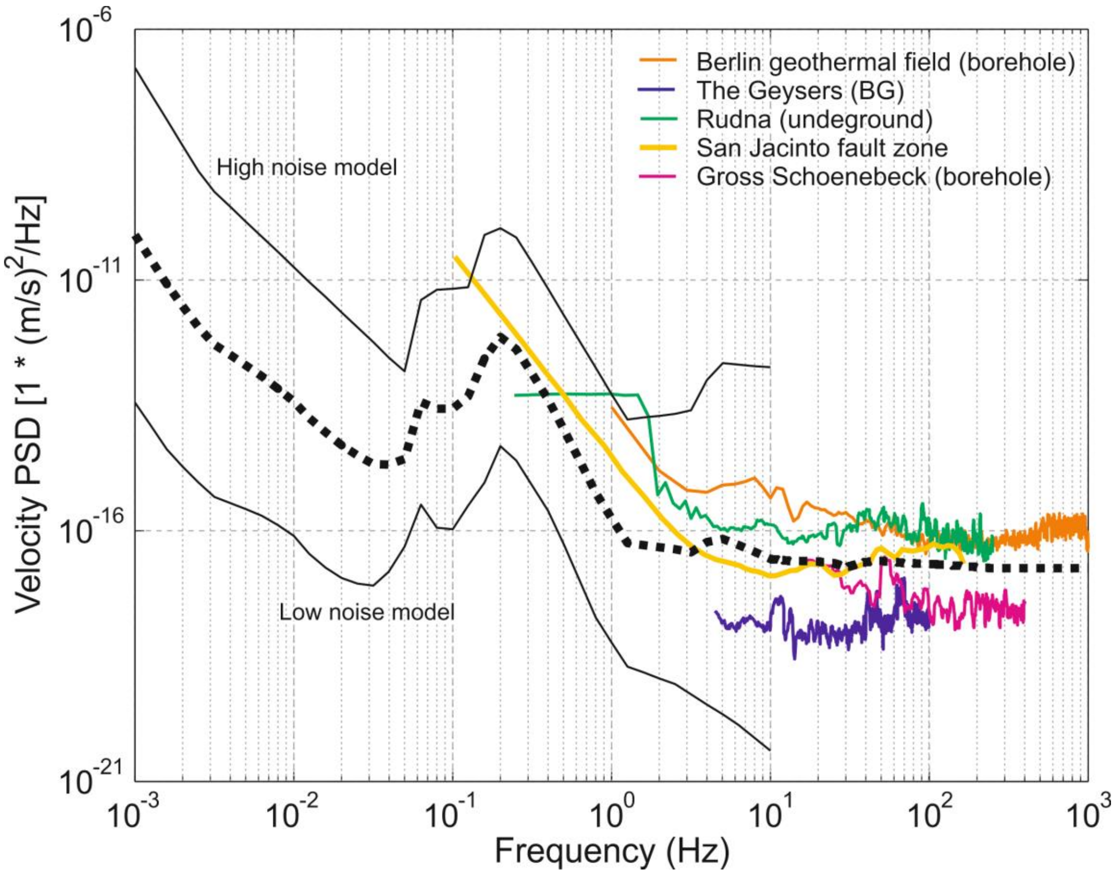
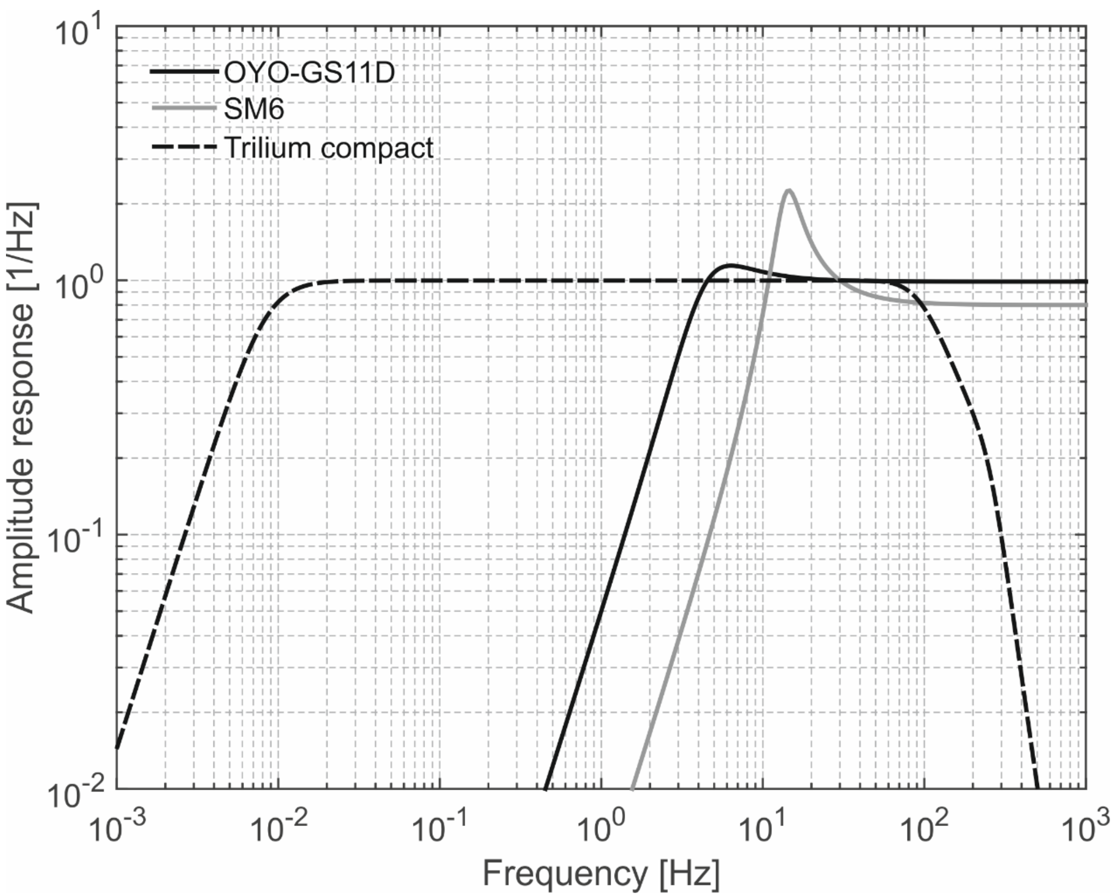
# Noise

- Low frequency noise from *Peterson* (1993)
- High-frequency noise from various sites (surface and borehole sensors)



# Sensor characteristics

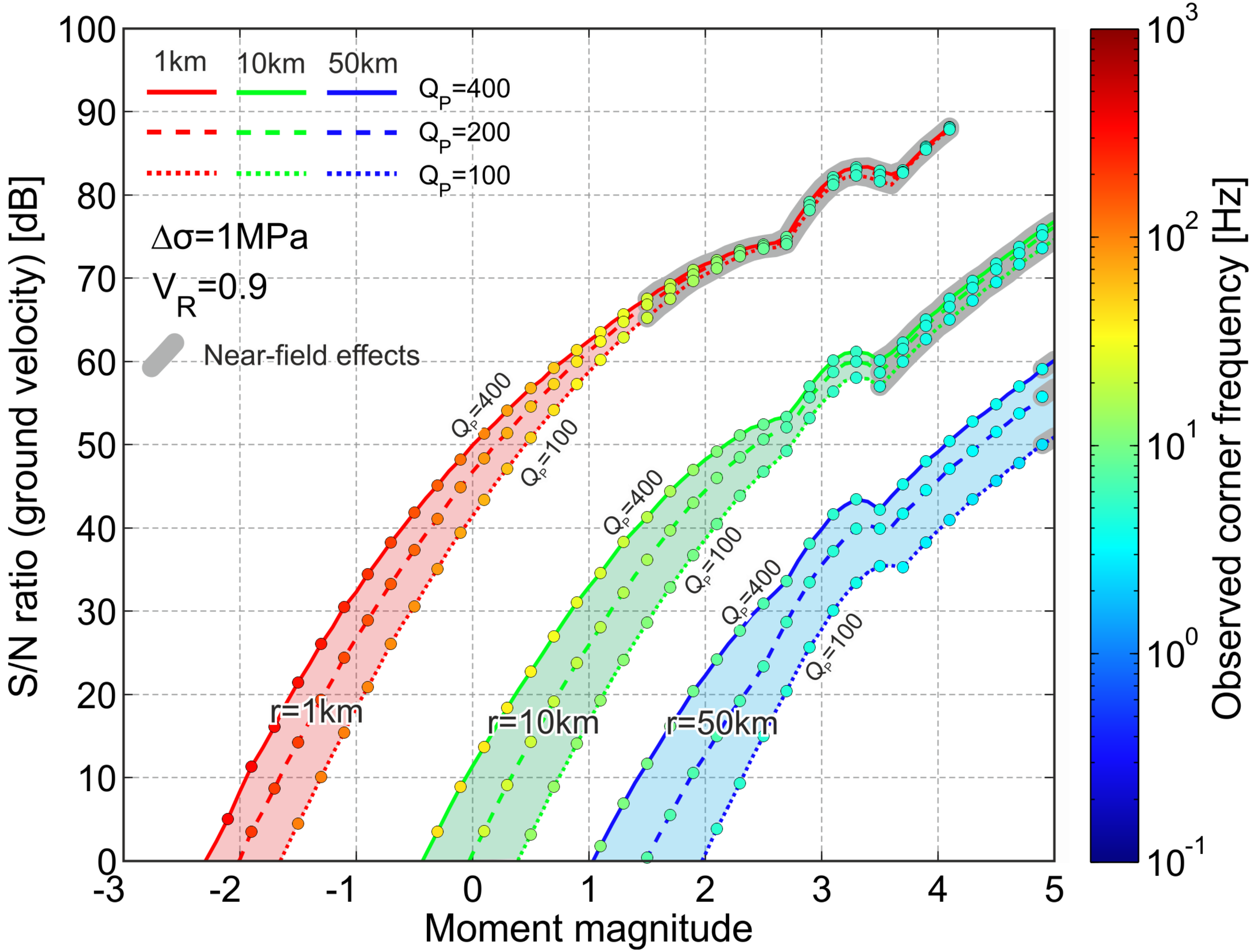
- Different low-frequency cut-off (100s, 4.5Hz, 15Hz)





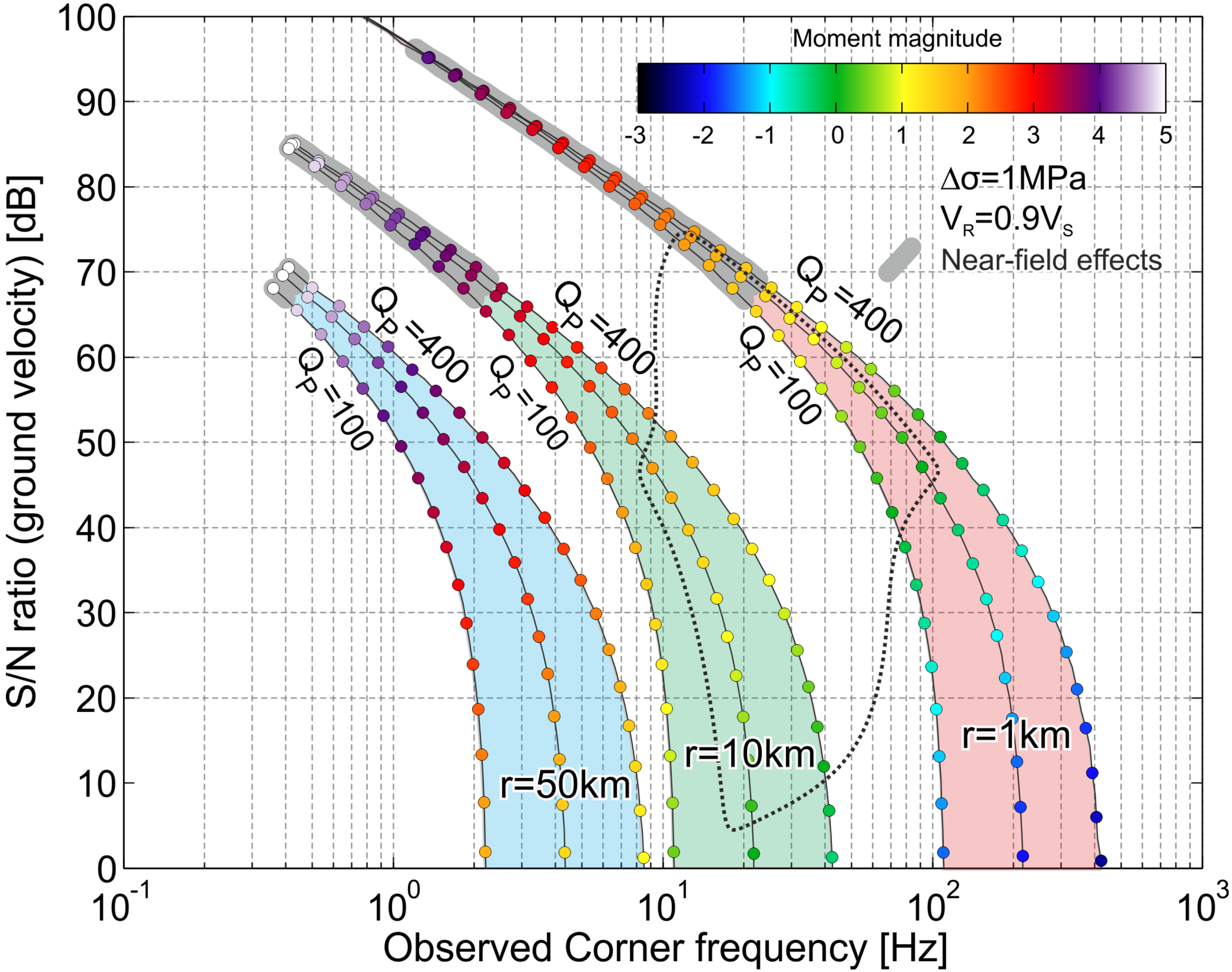
# Results: Detection limits

- Sample detection limits using *P*-waves, GS11D sensor, $\Delta\sigma = 1\text{MPa}$ and $V_R = 0.9V_S$



# Results: Attenuation and distance vs frequency content

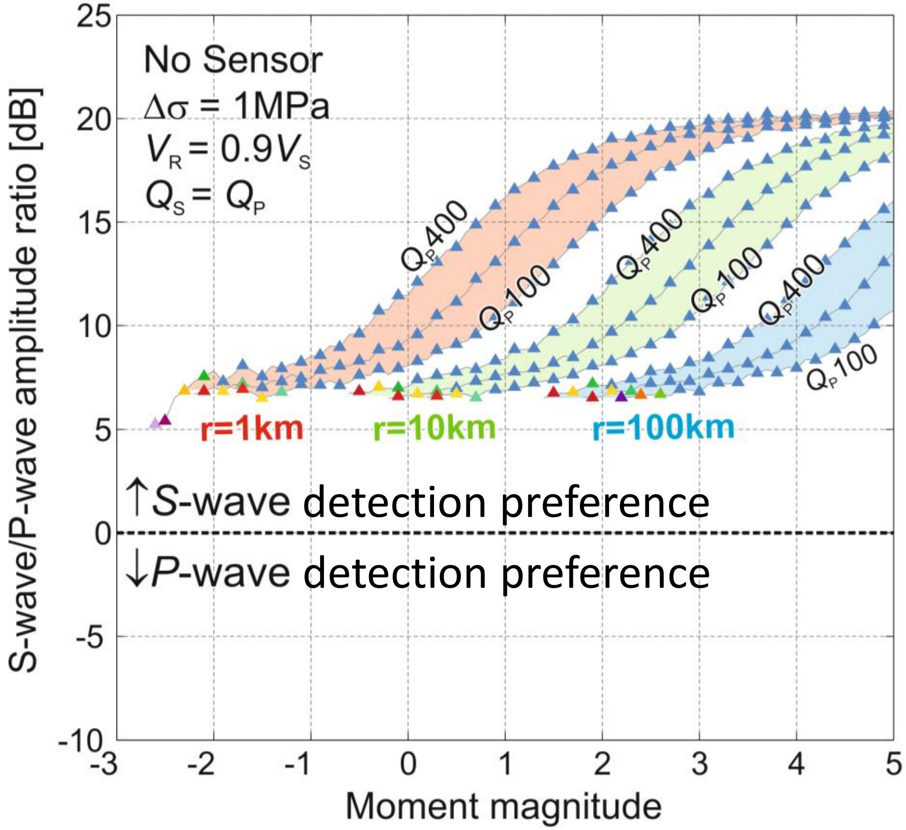
- High frequencies suppressed due to attenuation



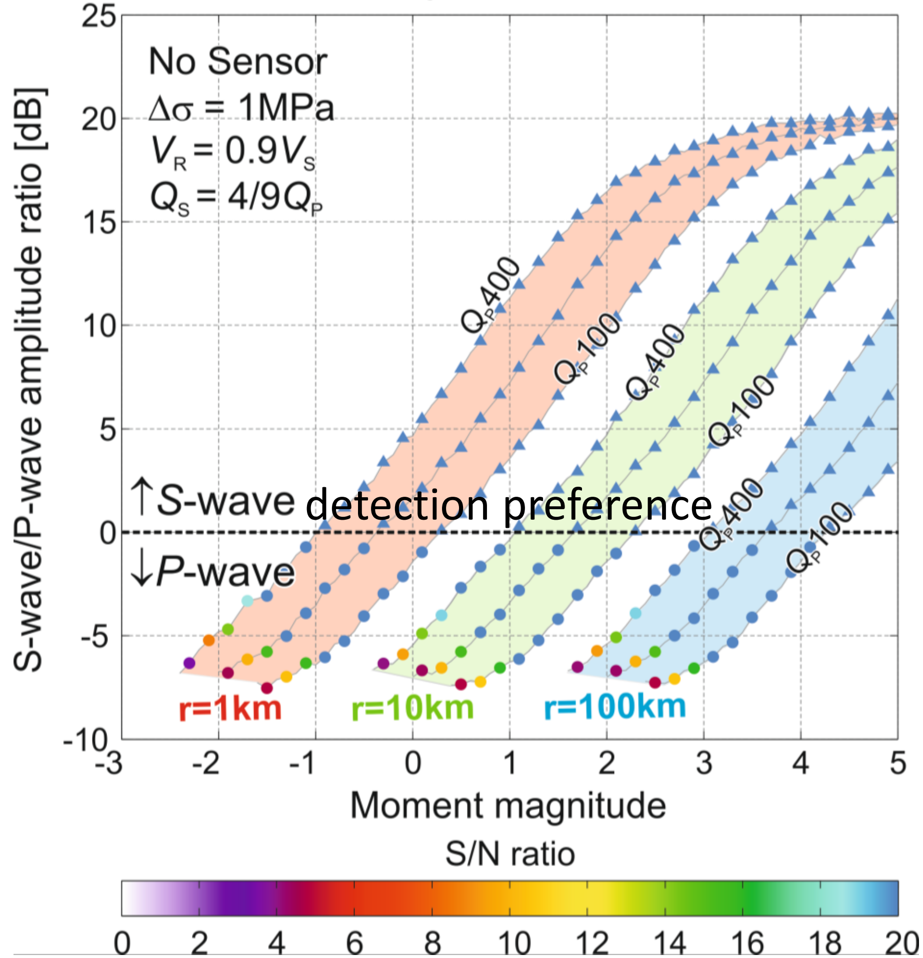
# Results: Should we use P or S wave for detection?

- Amplitude/frequency content of S phases generally more affected by attenuation
- The smaller & further the event, the less preferable is S phase for detection

$Q_S = Q_P$ (~saturated)




$Q_S = 4/9Q_P$ (~Poisson solid)



## Summary

- We investigated theoretical limits on detection and analysis of small earthquakes using synthetic seismograms including influence of path, noise and properties of acquisition systems.
- We provide guidelines on designing local-to-regional seismic networks for detection of small events in various geological environments, and information relevant to a reliable analysis of earthquake source properties.

# Conclusions

- The amplitude RMS-averaged over focal mechanisms and observations points vary between -23dB and +14dB with respect to the standard shear source. The *P*-wave amplitudes of a pure tensile source may be enhanced by up to +12dB (unlikely).
- Amplitude/frequency content of waves excited from source is predominantly affected by $M_W$ and $\Delta\sigma$. The rupture velocity and radiation pattern have minor effects. In realistic scenarios, tensile faulting has no significant influence on S/N ratio.
- Distance and attenuation key limiting factors for EQ detectability and analysis of source properties.
- In certain circumstances, stronger attenuation of S waves may favor earthquake detection using P waves.
- Acquisition system characteristics seriously affect the detection and ability to analyze source properties of both small and large earthquakes.

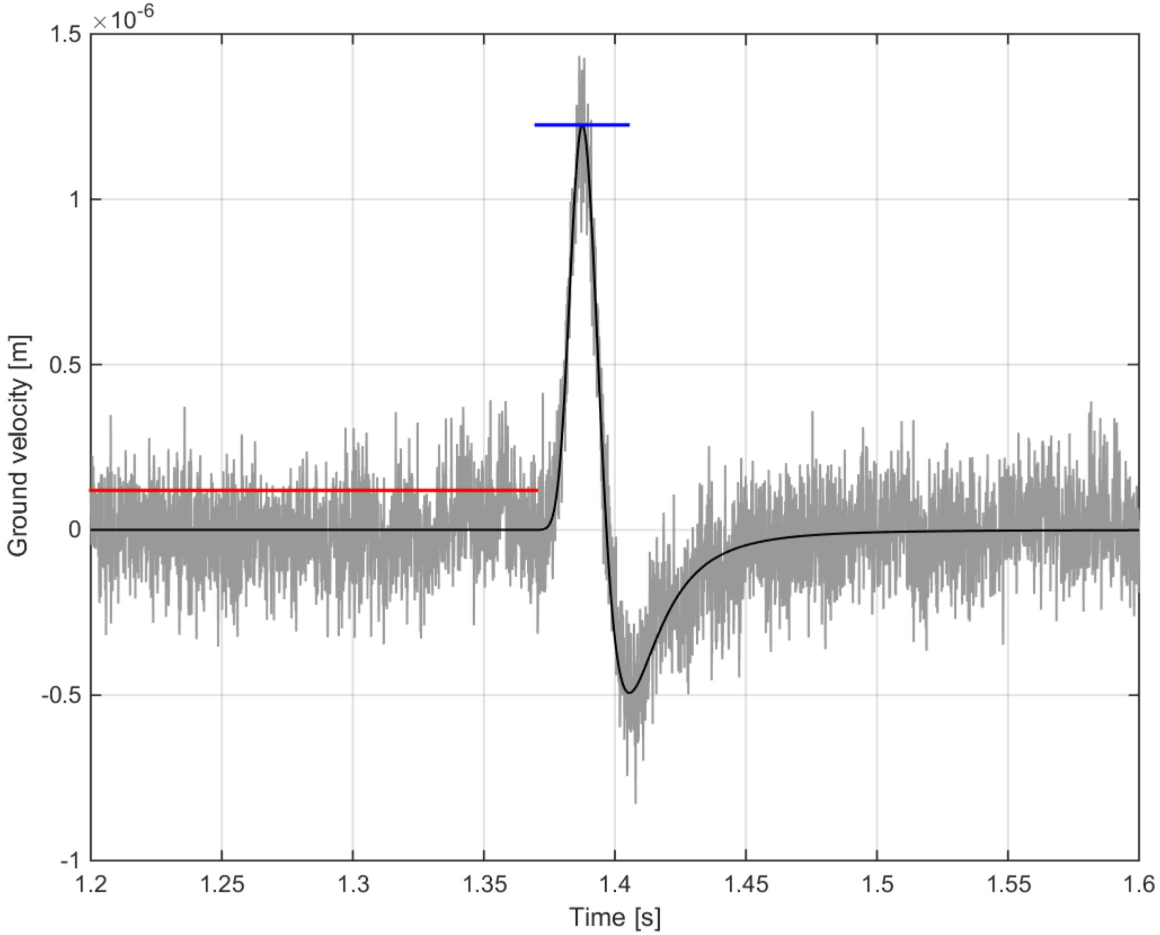
Thank you for your attention!

Questions?

# Signal-to-noise ratio calculation

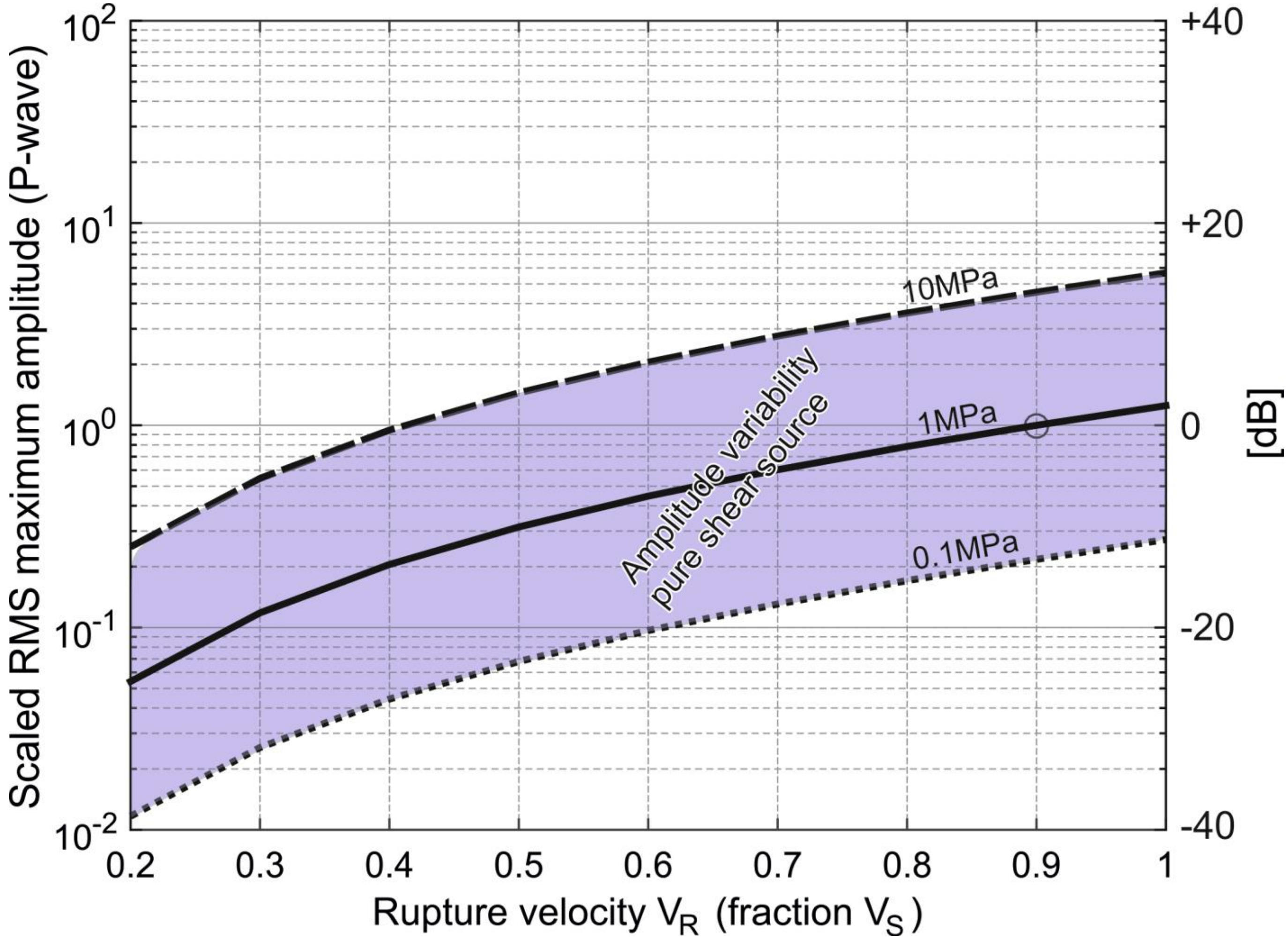
- Bandpass filter 1-1000Hz applied to synthetic trace with superimposed noise

$$\frac{S}{N}[\mathrm{dB}] = 20\log_{10}\frac{\max(V(t))}{\mathrm{rms}(N(t),l)}$$



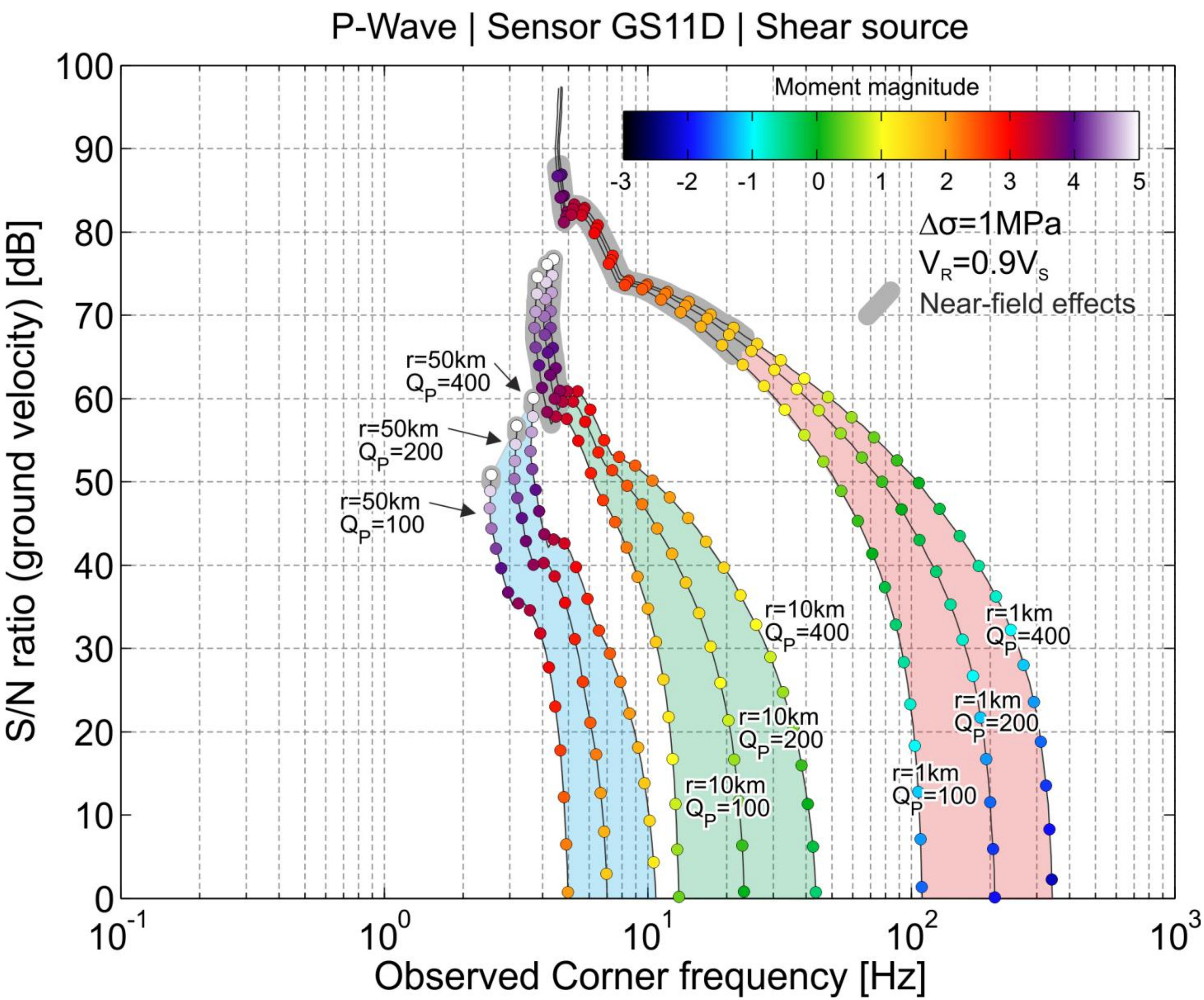
# Results: Source variability vs amplitude

- RMS maximum ground velocity amplitude vary from -23dB to +14dB w/r to the seismic source with $\Delta\sigma = 1\text{MPa}$ and $V_R = 0.9V_S$.
- Pure tensile faulting ehnances RMS *P*-wave radiation by +12dB (unrealistic!)



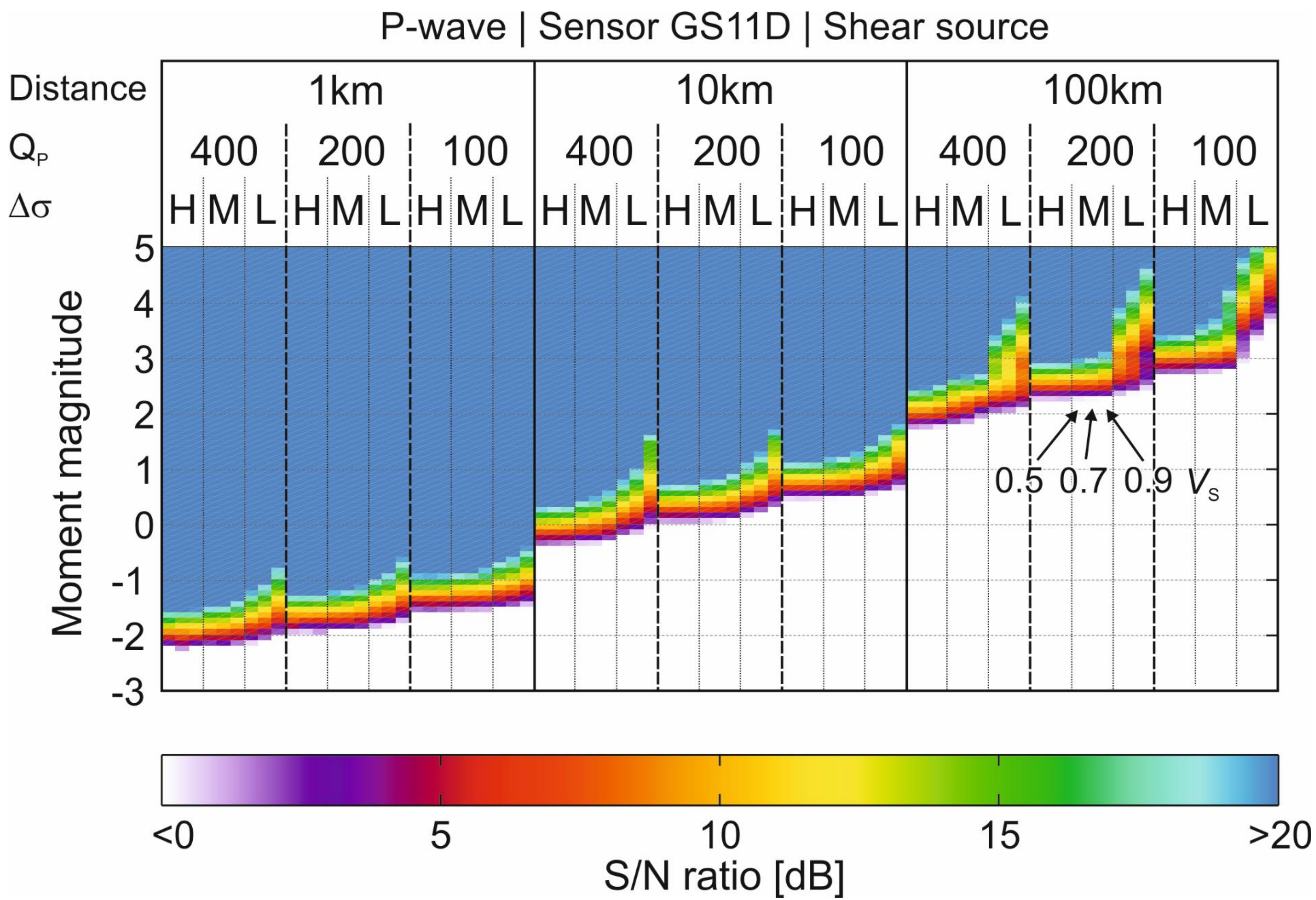
# Effects of attenuation and distance on frequency content

- Influence of sensor characteristics on low-frequenct part of the spectrum

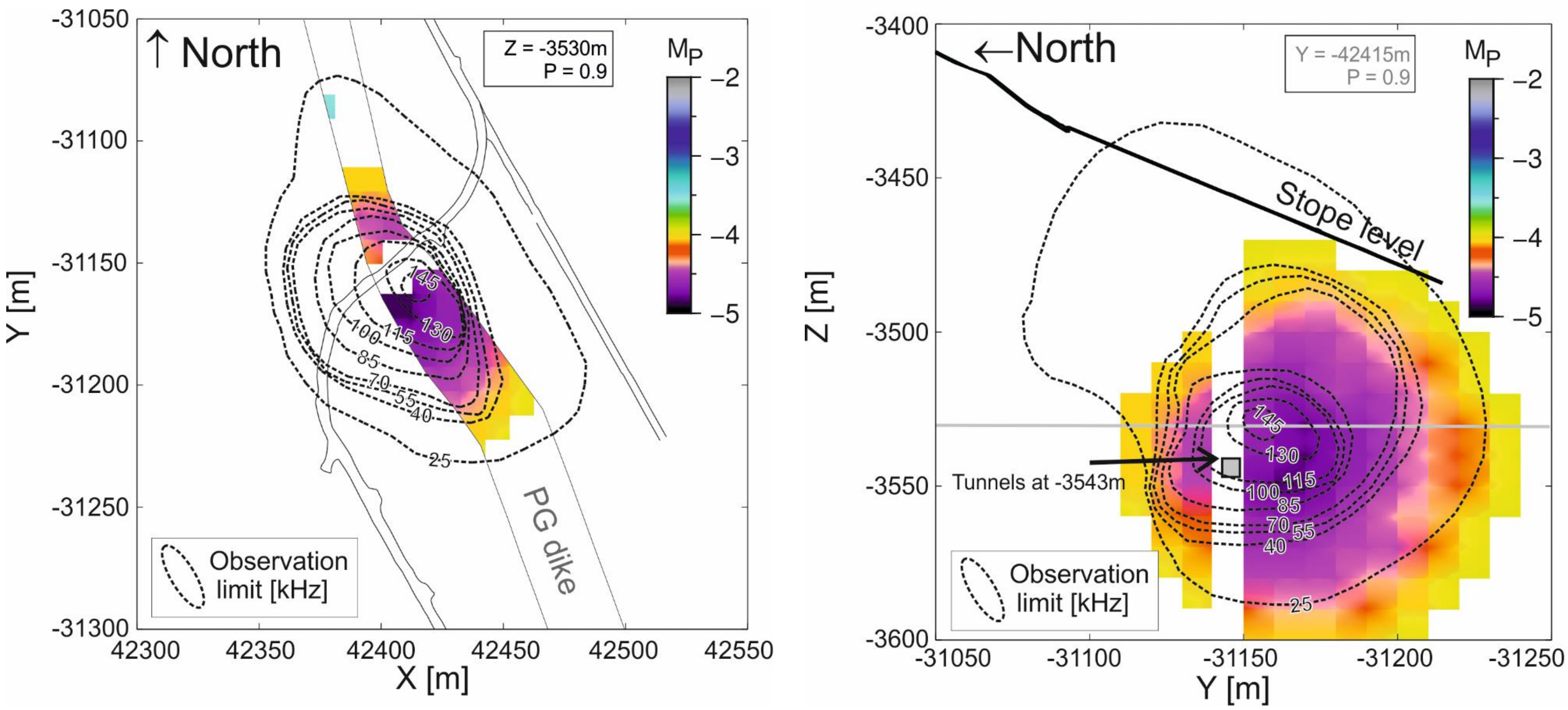


# Detection limits (aggregated source and path characteristics)

- GS11D sensor, *P*-wave



# Motivation




- Detecting smaller events important
  - Increases resolution of monitoring and analyzing seismic processes associated with natural and human-related activities
- Denser networks closer to target source but...
  - Detection limits in various source/path/instrumental effects not well established