Seismic monitoring performance for hydraulic fracturing

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European Seismological Commission
Trieste – September 4-10, 2016

SHale gas Exploration and Exploitation induced Risks

www.sheerproject.eu **www.gfz-potsdam.de**

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1. Introduction

SHale gas Exploration and Exploitation induced Risks

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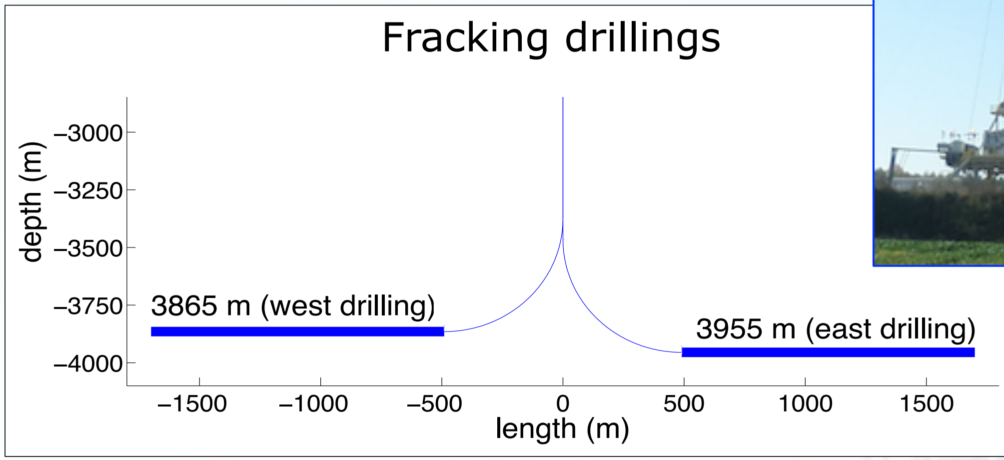
Developing best practices for assessing and mitigating the environmental footprint of shale gas exploration and exploitation

Experiment description

Fracking operations

June, July, August 2016



Objective

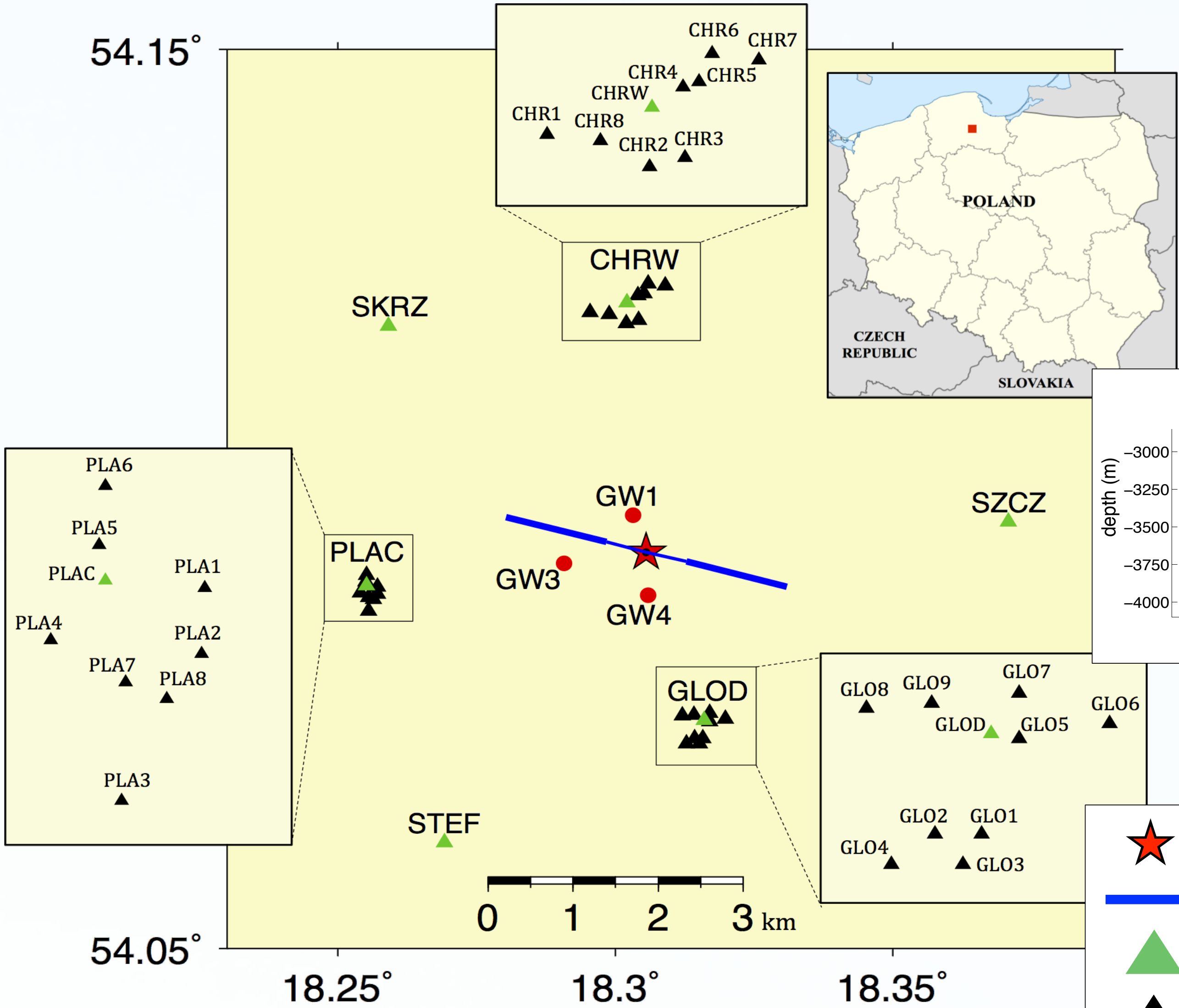
Assessing the monitoring performance before the target hydraulic fracturing using a synthetic dataset

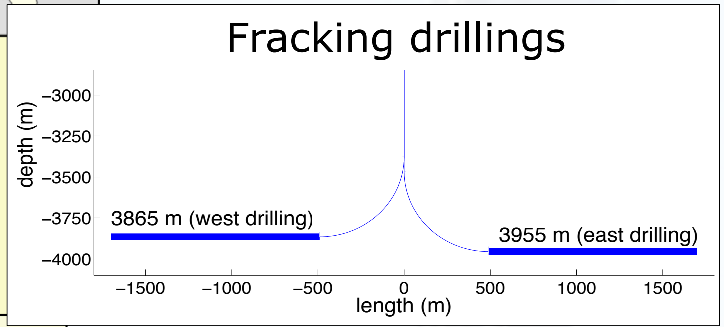
2. Monitoring network

6 Broadband stations

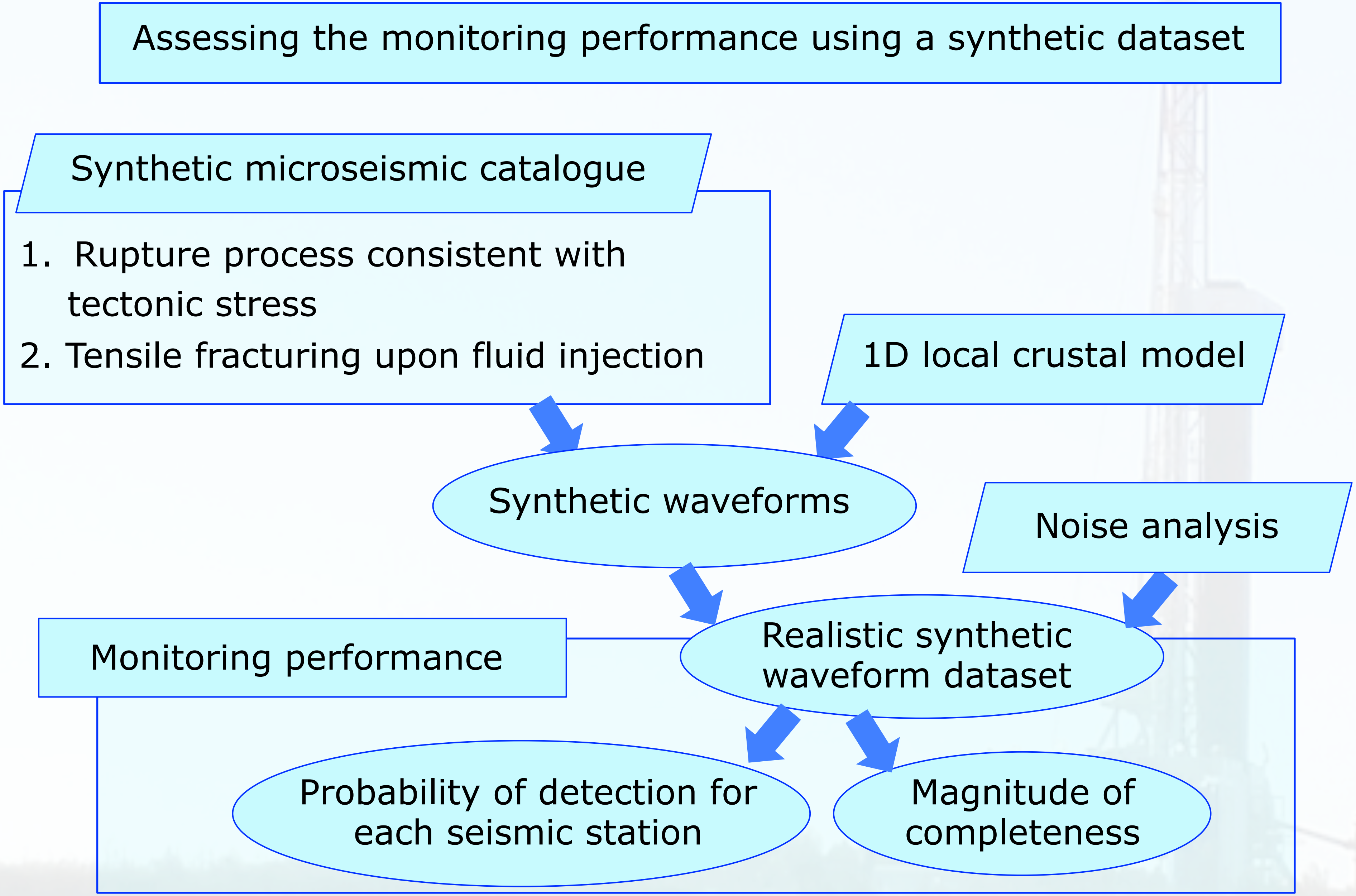
3 Small-scale arrays with
8 or 9 short-period stations

3 Shallow borehole stations
(depth ~ 55 m)





3. Methodology



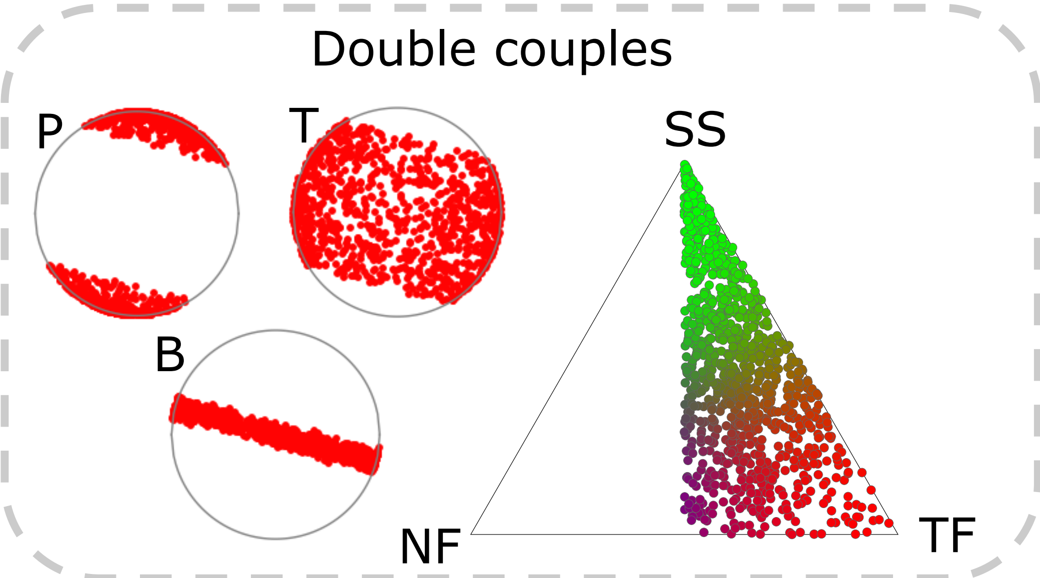
4. Synthetic microseismic catalogue

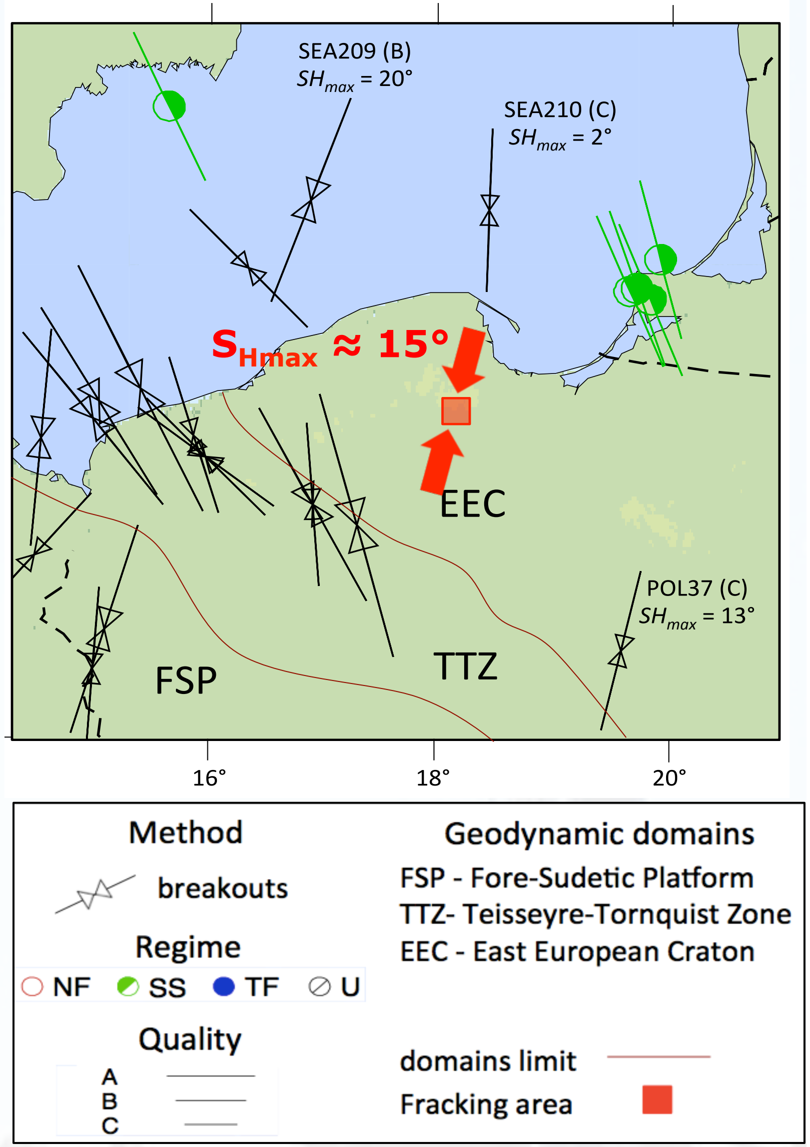
Expected microseismic sources

1 **Rupture process consistent with tectonic stress**

- **Background seismicity** :

Assuming **double couple sources** of random orientations, the **rake is conditioned** by the **maximum horizontal compressive stress (S_{Hmax})**





World Stress Maps (WSM) database release 2008

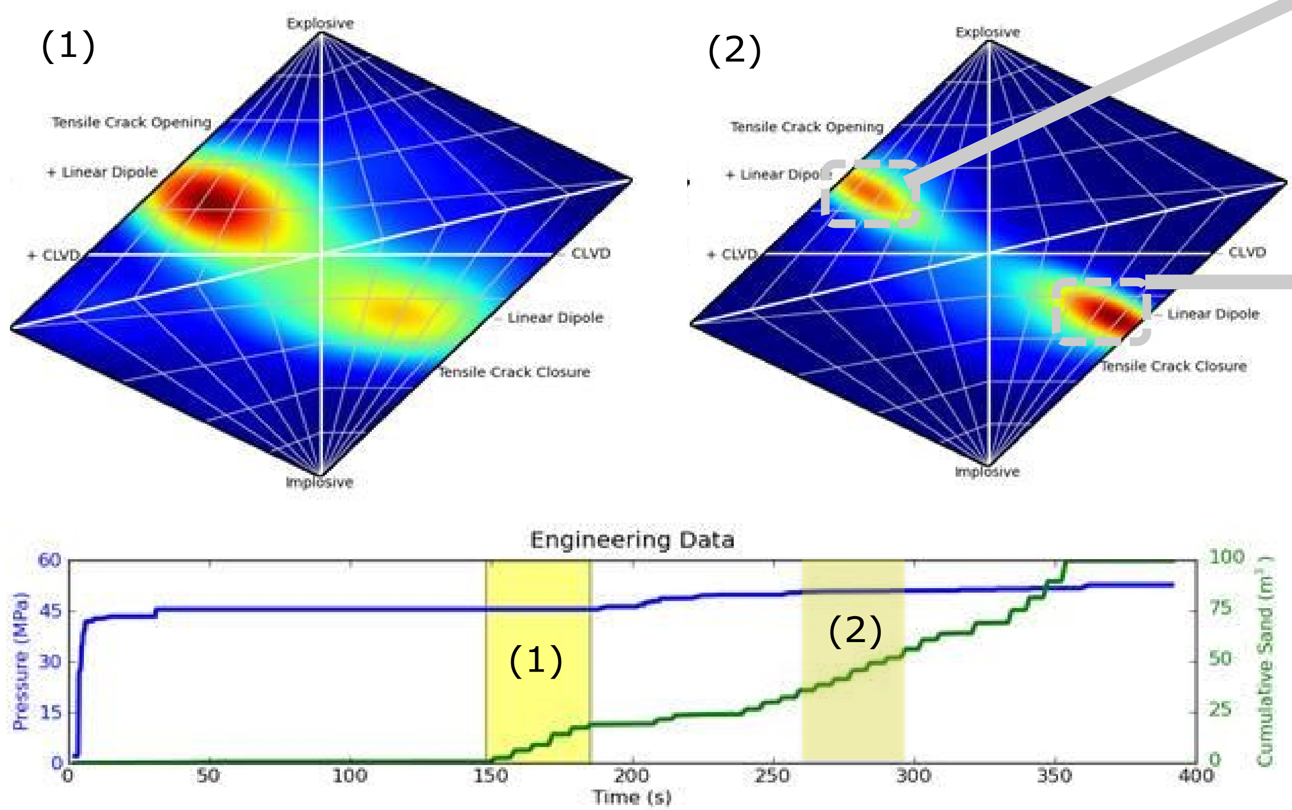
4. Synthetic microseismic catalogue

Expected microseismic sources

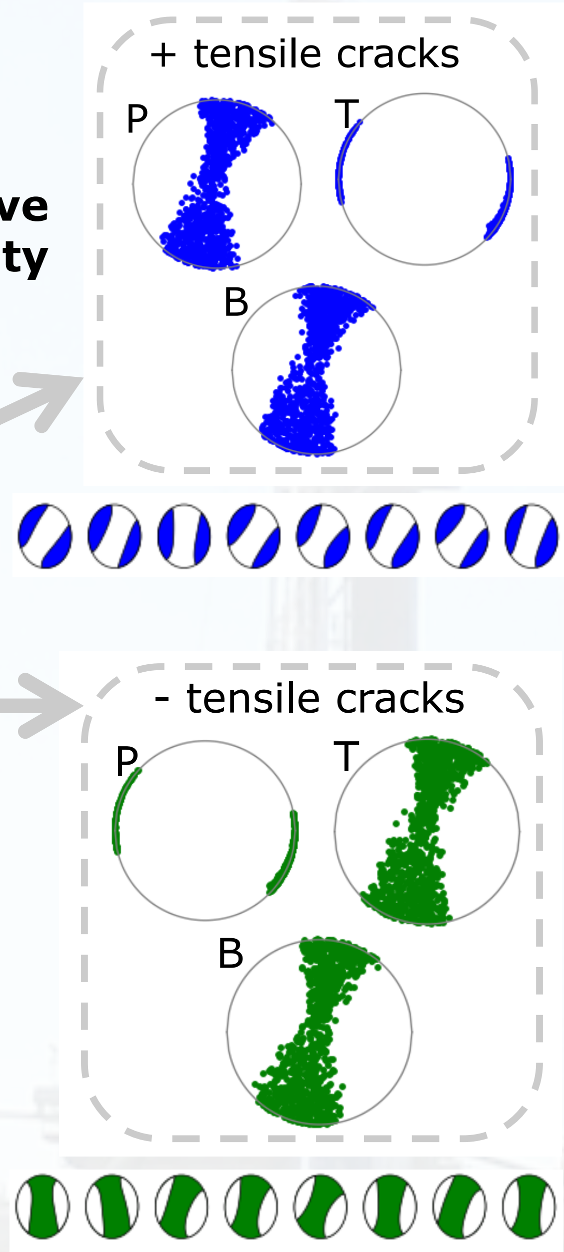
2 **Tensile fracturing upon fluid injection**

We can model this process with **positive and negative dipoles** oriented parallel to **S_{hmin}** with a random **uncertainty of ± 25°** (according the quality data to calculate S_{hmin})

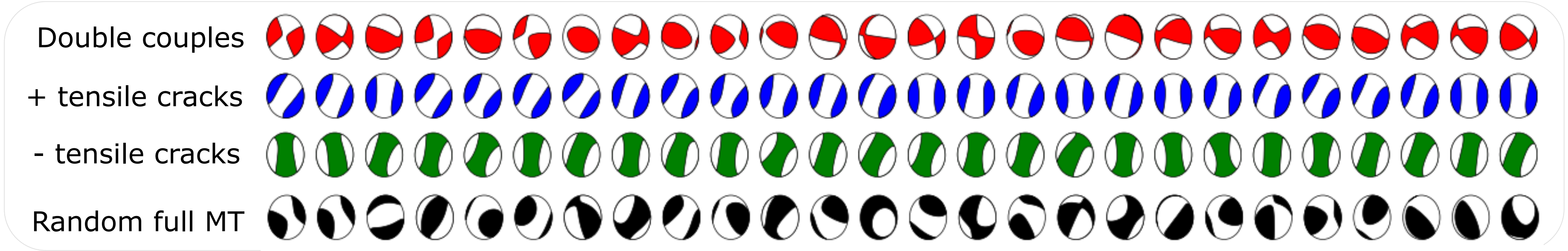
Density contour plot for different windows of the fracking treatment

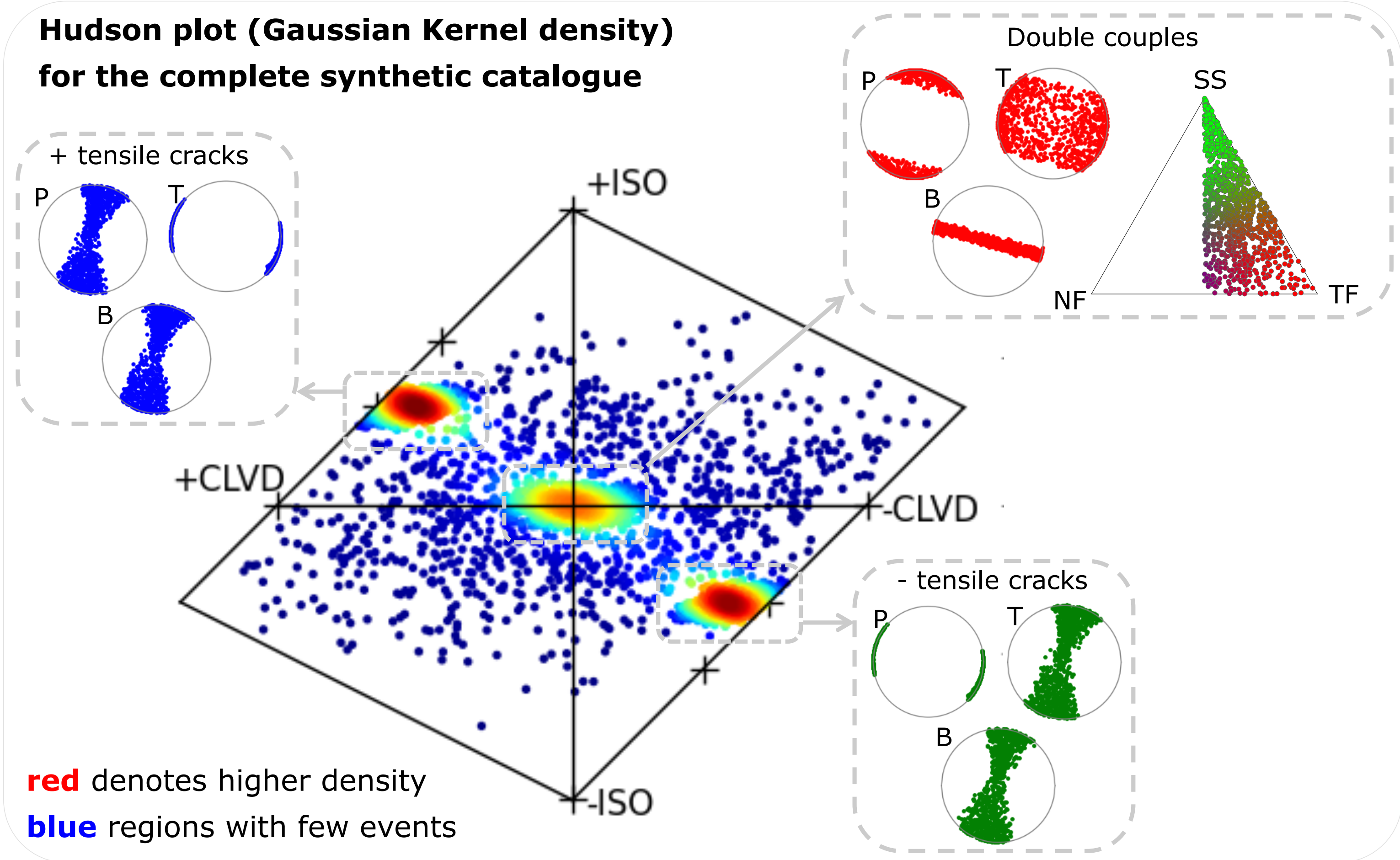


Baig and Urbanic, 2010



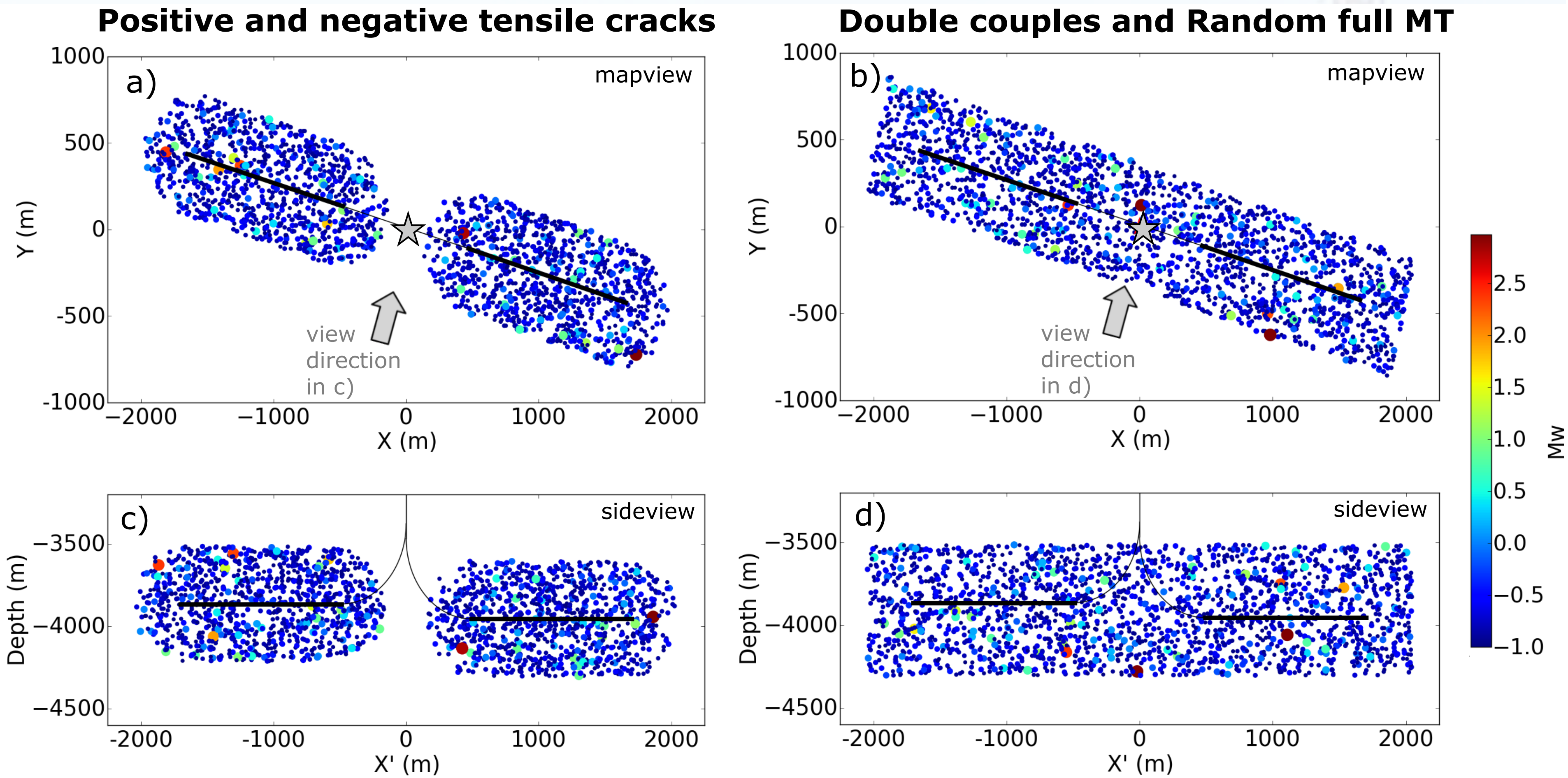
4. Synthetic microseismic catalogue





4. Synthetic microseismic catalogue

Distribution of hypocenters and magnitudes in the fracturing area



- ➢ Frequency-magnitude distribution (**-1 < Mw < 3**) follows a **Gutenberg-Richter law** with **b = 1** and **a = 1.84** according 1000 events for each family
- ➢ **Maximum rupture length = 350 m** (considering a circular fault model of Madariaga, 1976 and stress drop average = 2.7 Mpa, Kwiatek et al., 2011). Reasonable value according other experiences (Davies et al., 2012; Fisher and Warpinski 2012)

5. Local crustal model

A priori, we do not dispose of such information and relied on previous studies on the broader region of interest.

Extract a P-wave velocity profile for the fracking area according:

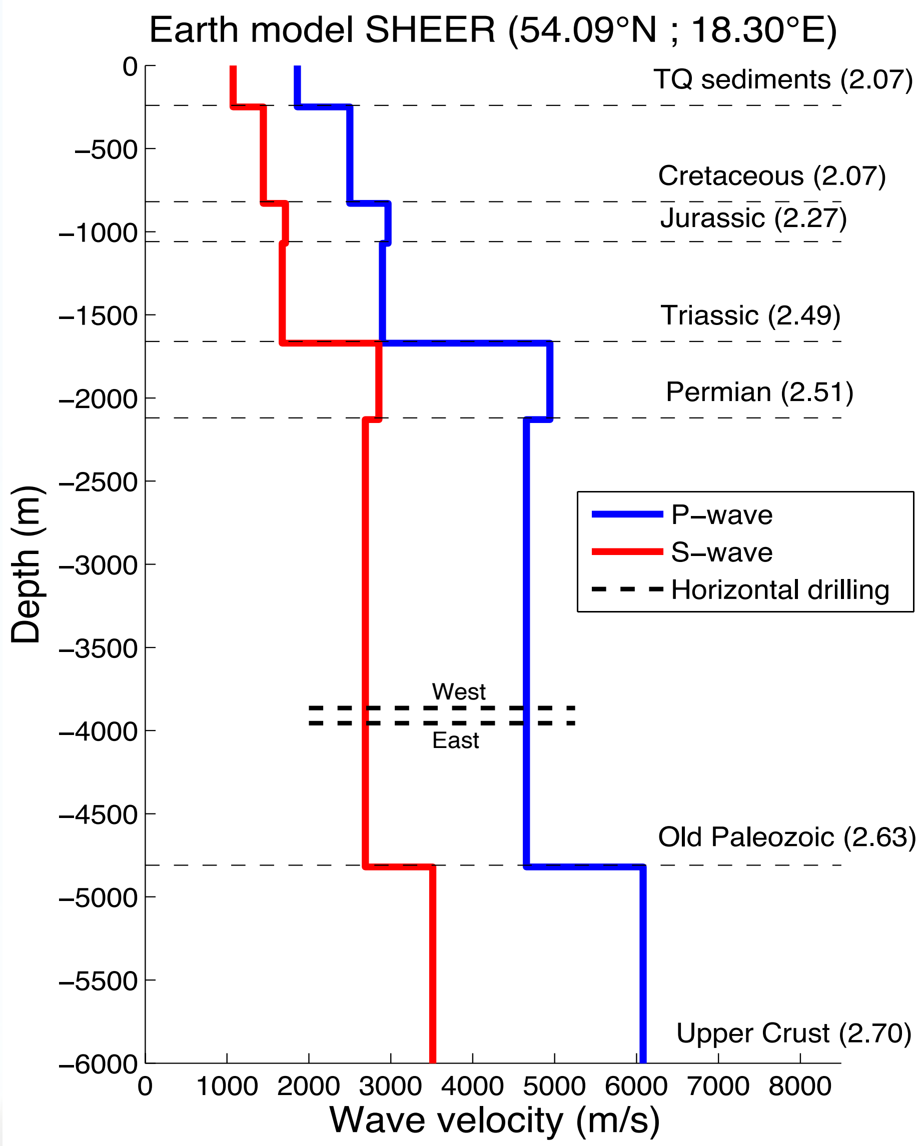
High-resolution 3D seismic model of the crustal and uppermost mantle structure in Poland (Grad et al, 2015)

P-wave velocity → Grad et al., 2015

S-wave velocity → $v_p = 1.73\ v_s$

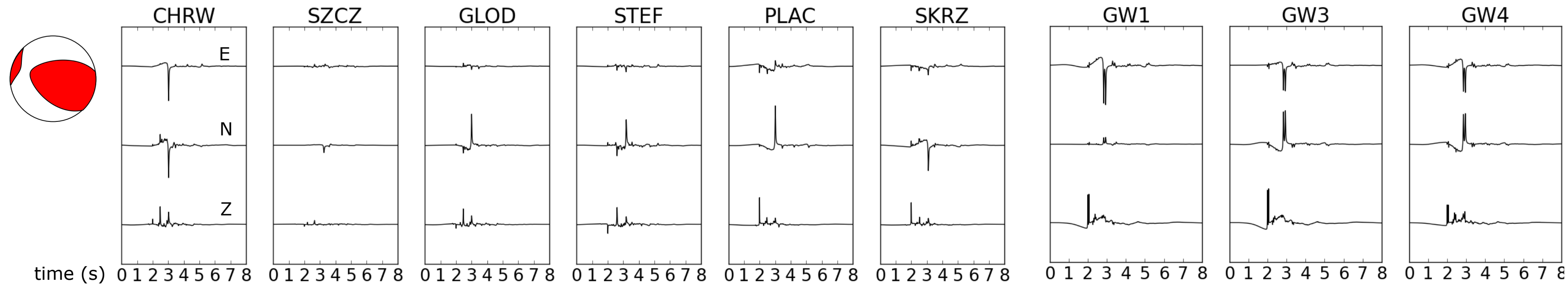
Density (Mg/m^3) → Grabowska et al., 1998

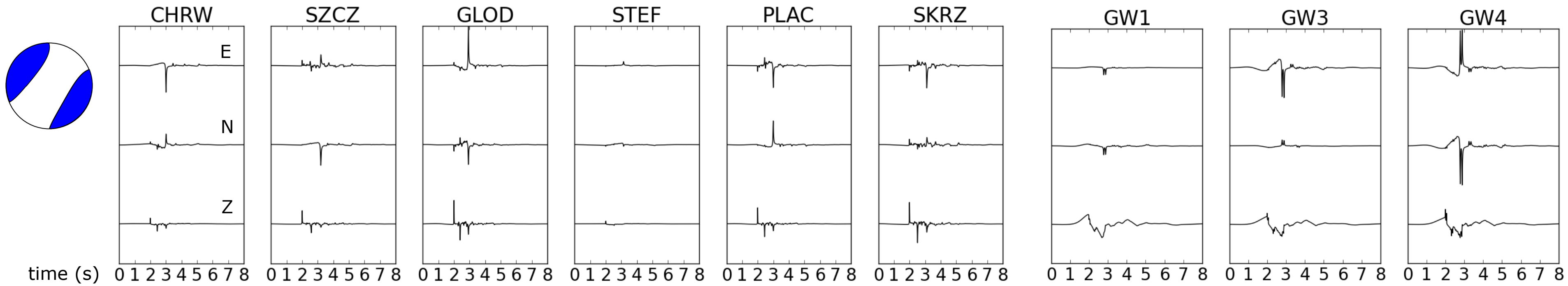
Attenuation → Król et al, 2013
$Q_p = 120$
$Q_s = 60$



6. Synthetic waveform analysis

Pyrocko package
(http://emolch.github.io/pyrocko/)





Double couple
Mw = -0.75
$amp_{max} = 9.58 \cdot 10^{-10}$ m

Positive tensile crack
Mw = 0
$amp_{max} = 1.25 \cdot 10^{-8}$ m

6. Synthetic waveform analysis

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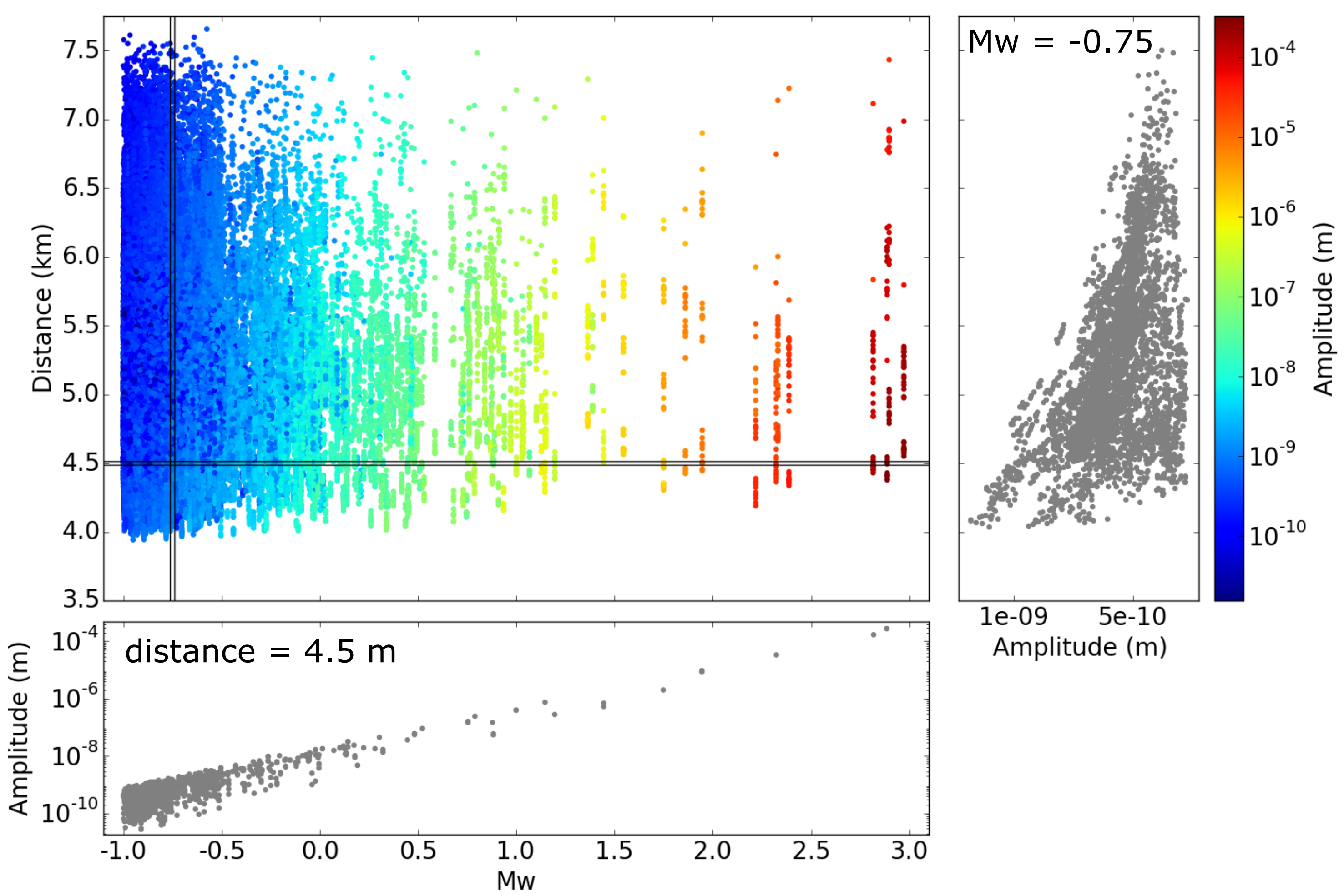
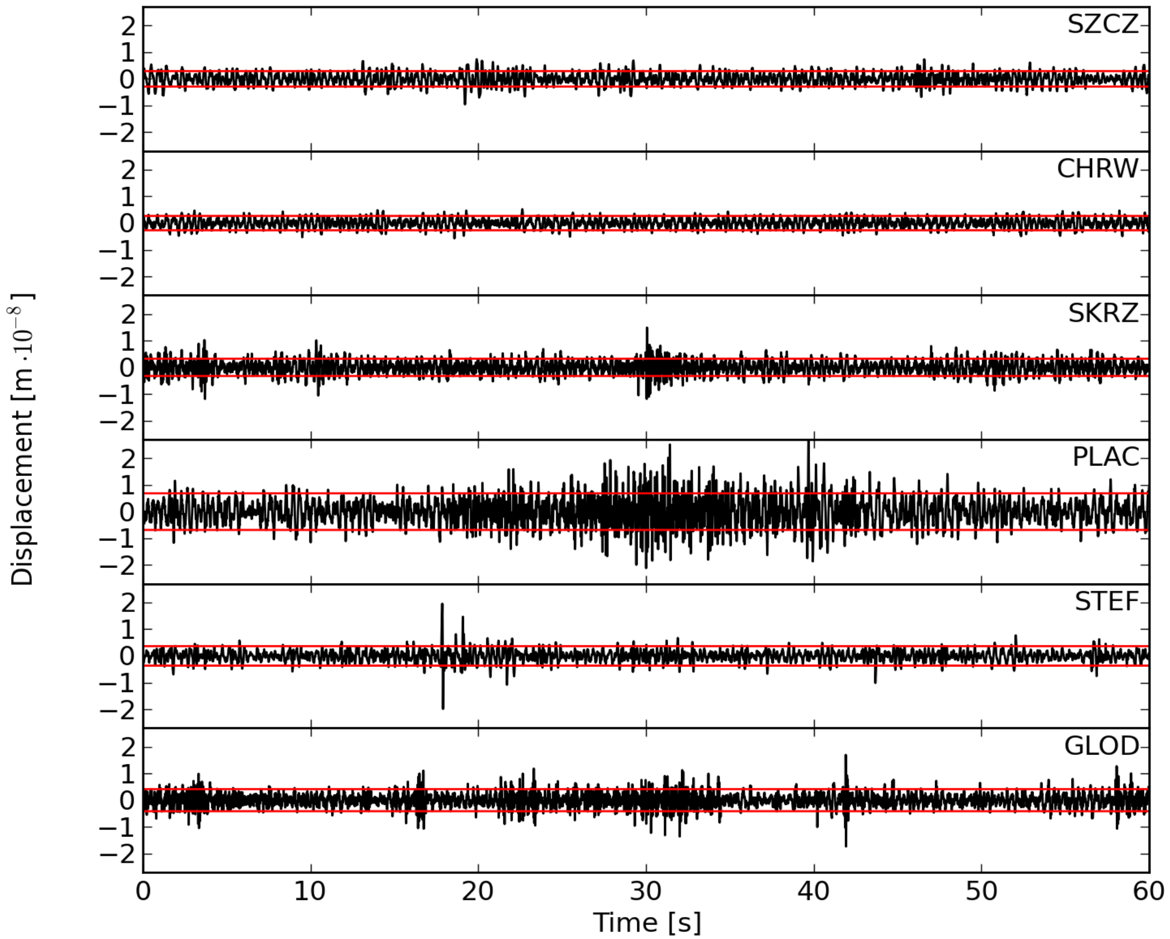
Maximum amplitudes according to the M_W and the hypocentral distance for each station



- The amplitude increases exponentially with the magnitude
- The effects of geometrical spreading are observed according to the hypocentral distance

7. Noise analysis

- We take a **random sampling of noise** for each station (one month)
- The **instrument response is removed** and we calculate the **displacement** (meters)
- Band pass filtered 2 - 90 Hz and a notch filter at 50 Hz.
- An **average value** of this noise record is calculated in order to compare with the amplitude of the synthetic seismogram.



$2.90 \cdot 10^{-9}$ m

$2.68 \cdot 10^{-9}$ m

$3.23 \cdot 10^{-9}$ m

$6.85 \cdot 10^{-9}$ m

$3.29 \cdot 10^{-9}$ m

$4.13 \cdot 10^{-9}$ m

8. Monitoring performance

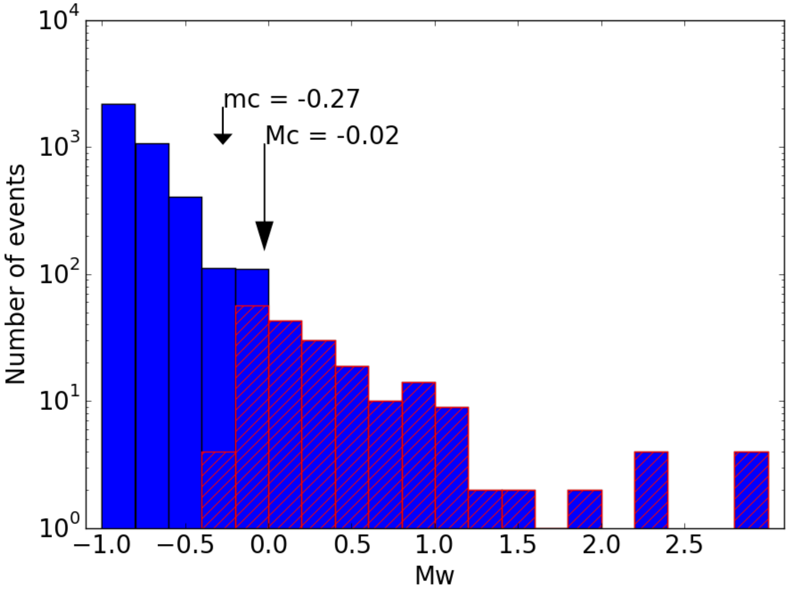
Using amplitude threshold

A synthetic event is considered **detected if the maximum amplitude is larger than 2 times the average noise value**

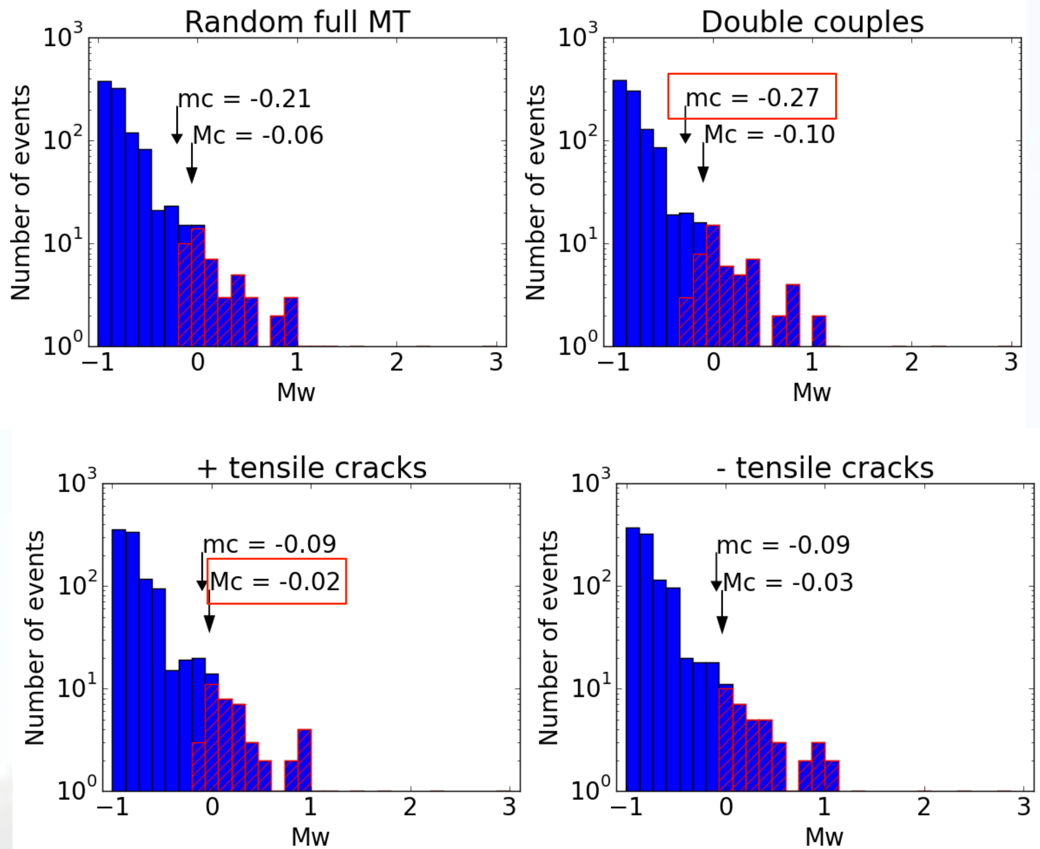
- **Magnitude of completeness, M_c**
- **Minimum magnitude of detection, m_c**

*Same noise for all stations

Complete synthetic catalogue



Families synthetic catalogue



Max amp for tensile cracks are smaller than for double couple

8. Monitoring performance

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Using amplitude threshold

N_+ = Detected events + + +

N_- = Non detected events ○ ○ ○

Probability of detection

$$P_D(M,L) = \frac{N_+}{N_+ + N_-}$$

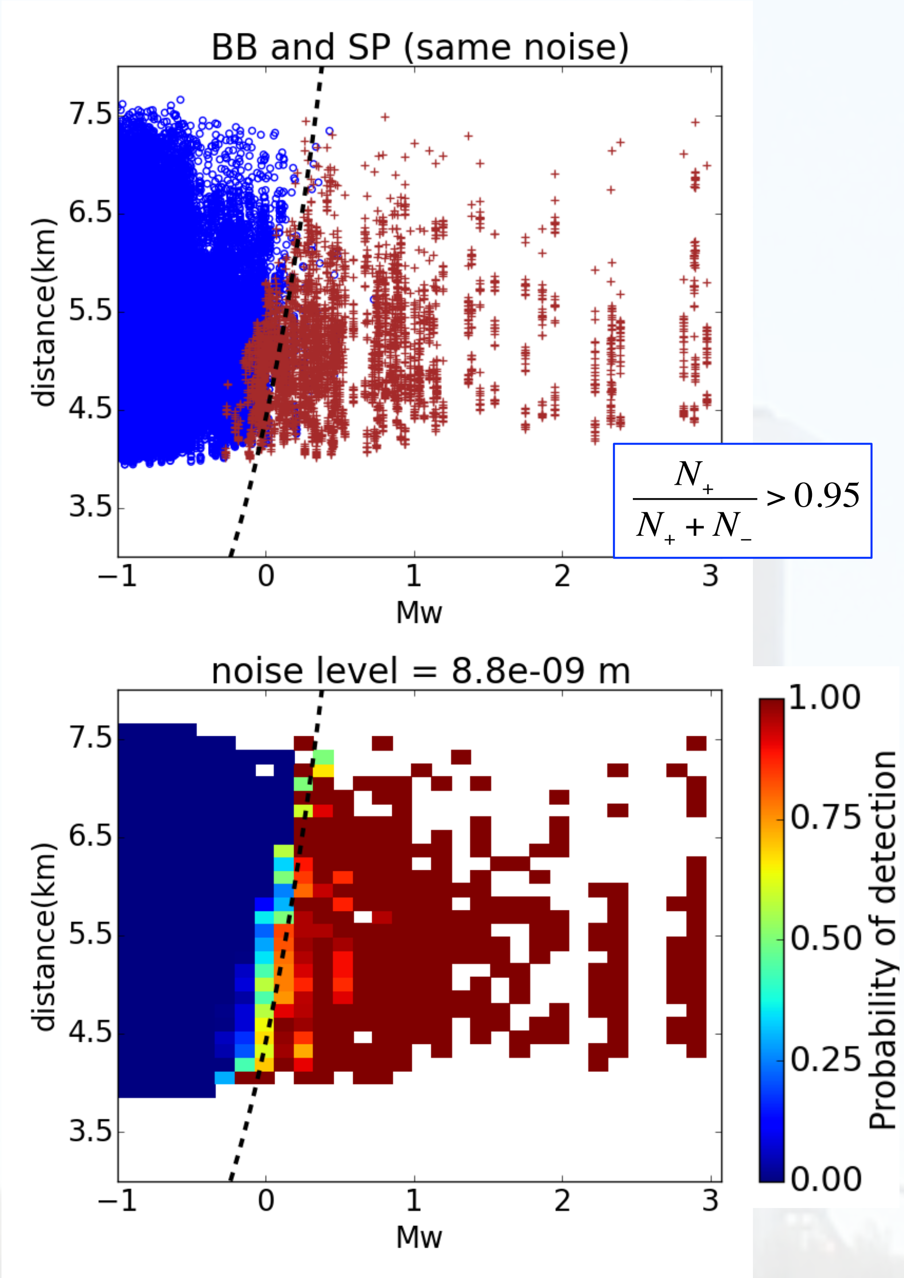
Schorlemmer and Woessner, (2008)

Magnitude of completeness

$$M_c(r) = C_1 + r^{C_2} + C_3$$

fit parameters C_1 , C_2 , C_3

Mignan et al., 2011



8. Monitoring performance

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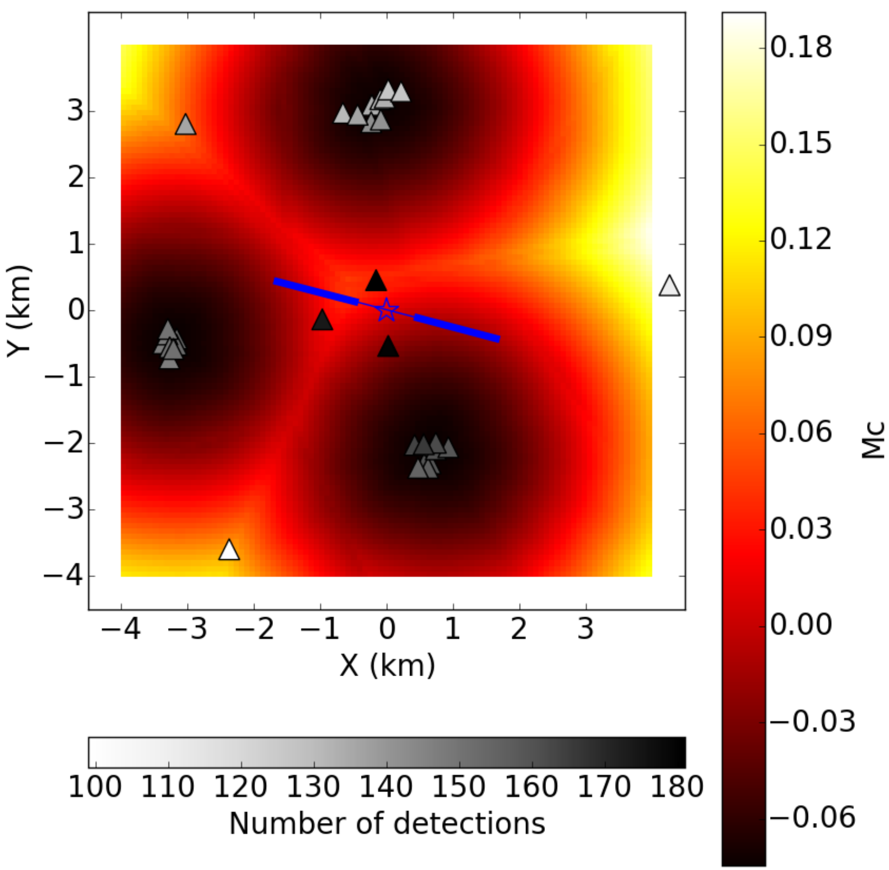
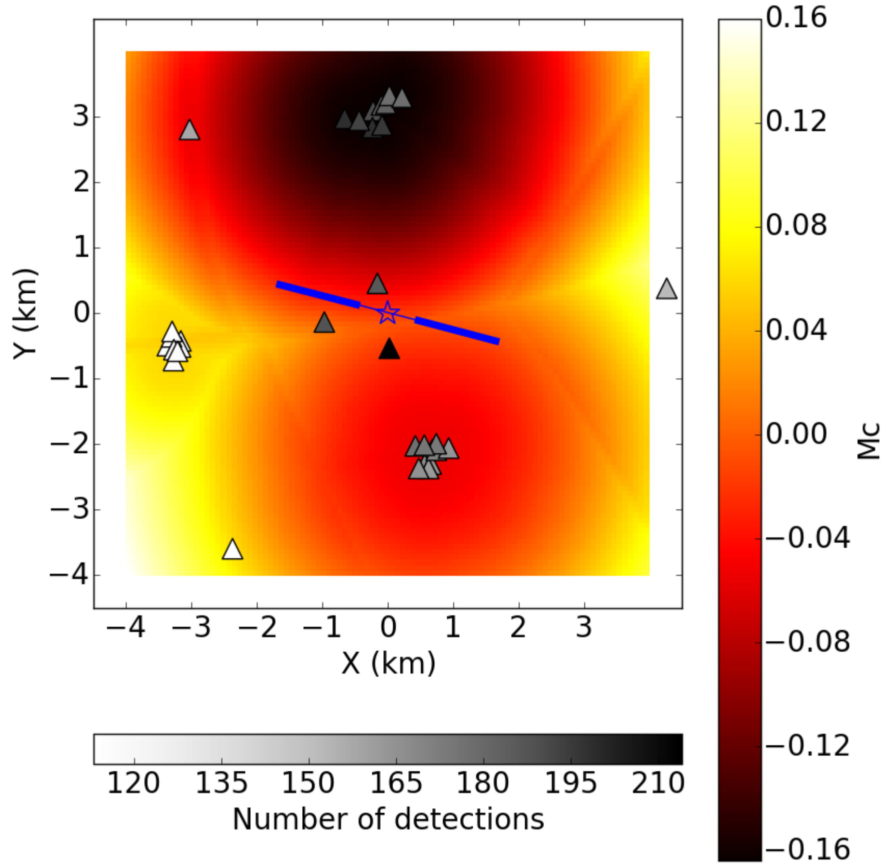
➢ **Magnitude of completeness** is calculated at the fixed depth (**-3910 m**) requiring simultaneous detection by **4 sensors** according the previous **empirical laws.**

1 **using amplitude threshold (same noise)**



2 **using amplitude threshold (realistic noise)**



9. Conclusions

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Realistic synthetic datasets before hydraulic fracturing to assess the monitoring performance (detection, location and moment tensor)

Mapping probability of detection and magnitude of completeness using synthetic seismograms and realistic noise

- Magnitude of completeness ~ 0.0 in the fracking area
- Minimum magnitude of detection of ~ -0.3

Background (DC) earthquakes more detectable than induced (tensile crack) earthquakes

Next step: use a recently developed automated full waveform detection using the continuous synthetic dataset with real noise

- **Poster session, ESC2016-265**. *Automated detection and location of picoseismicity of hydraulic fracturing experiment using continuous waveforms*

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Thank you very much

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