Static stress drop of induced earthquakes in seismic hazard assessment: Preliminary results from The Geysers geothermal site

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SHale gas Exploration and Exploitation induced Risks

Probabilistic Seismic Hazard Assessment

given point on the surface

given time interval

$$p = \Pr\left(a\left(\underbrace{x_0, y_0}; D\right) \geq a_{max}\right)$$

exceedance probability of a_{max}

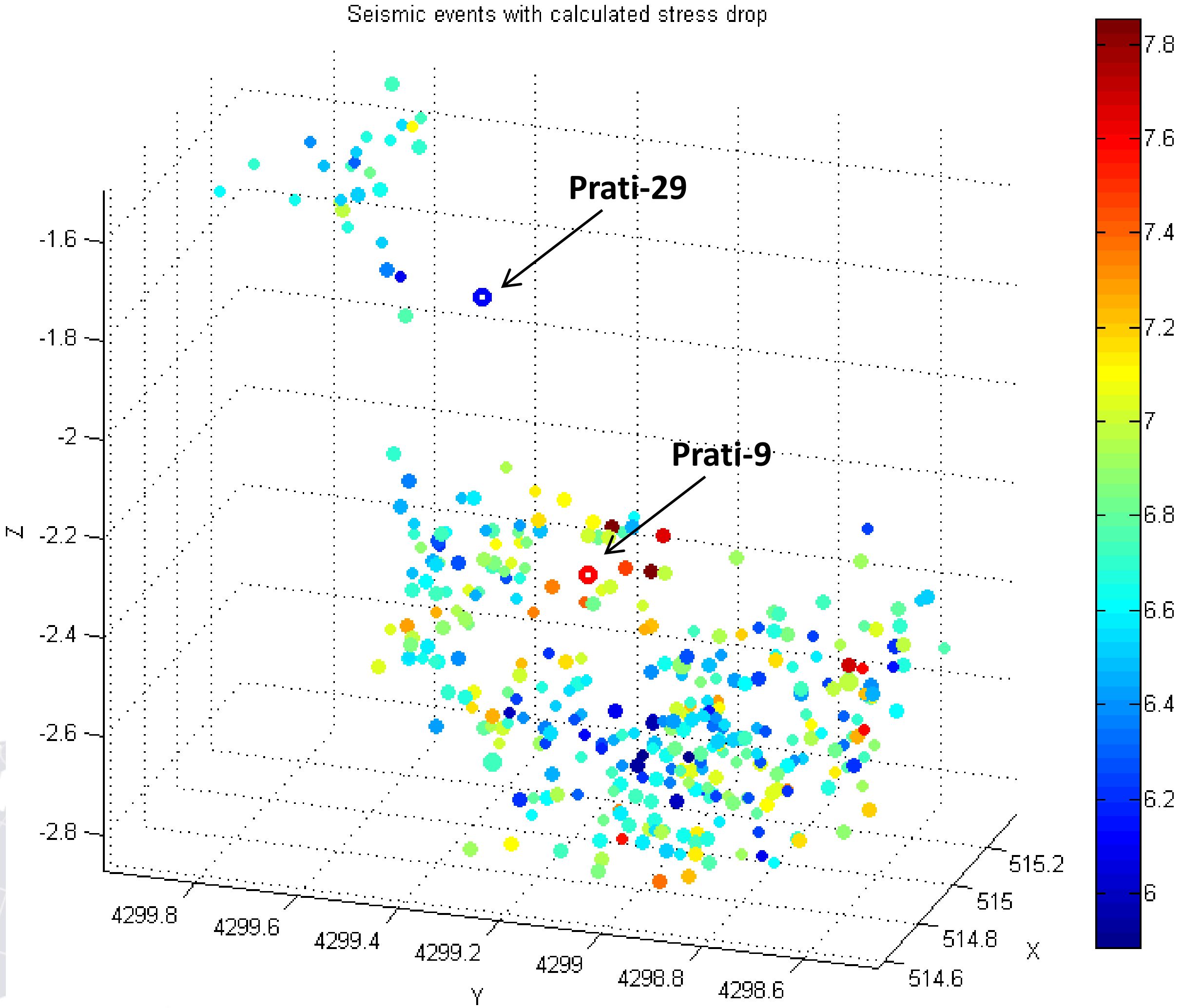
maximum ground motion magnitude at (x_0,y_0) in D time units

Probabilistic Seismic Hazard Assessment is calculated on the basis of probabilistic characteristics of past and present seismic zones.

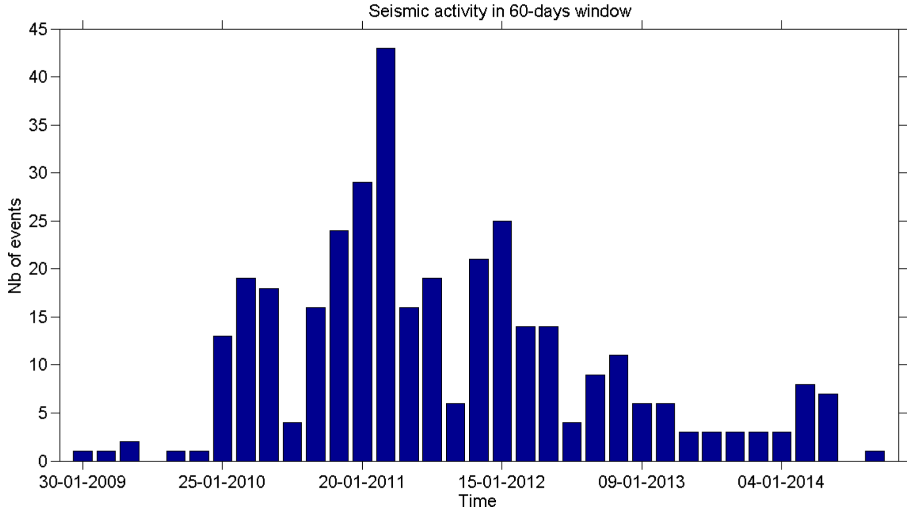
- Distribution of events magnitudes → calculated from Gutenberg-Richter relation / kernel density estimation
- Distribution of events occurrence frequency → calculated on the basis of complete seismic catalogue under assumption that seismicity is a stationary Poisson process
- Spatial distribution of events → uniform distribution of event occurrence probability over entire area

Data: The Geysers Prati-9 and Prati-29 region

354 events → static stress drop calculated with spectral ratio method



	354 events
M_w	1.03 – 3.37
Δσ	0.77 – 71.50 MPa
mean(Δσ)	7.17 MPa
R	9.46 – 200.60 m
Z	1.499 – 2.872 km
Time	31/12/2008 – 07/08/2014



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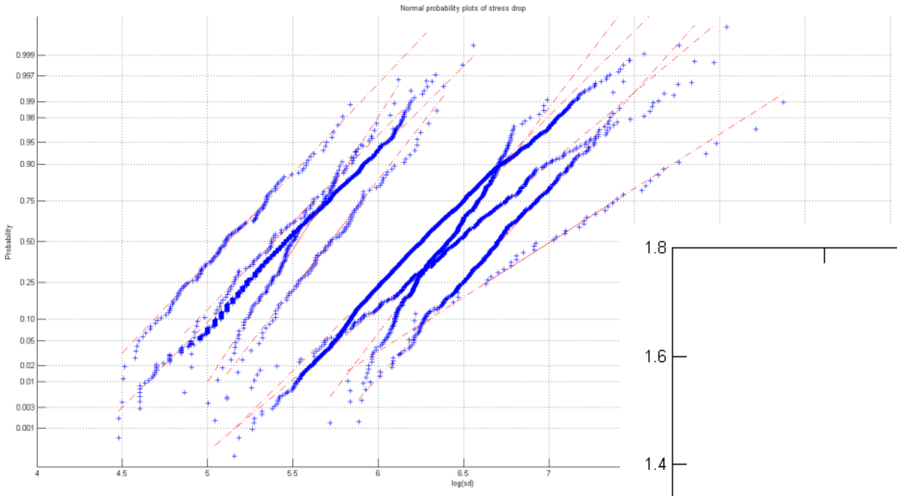
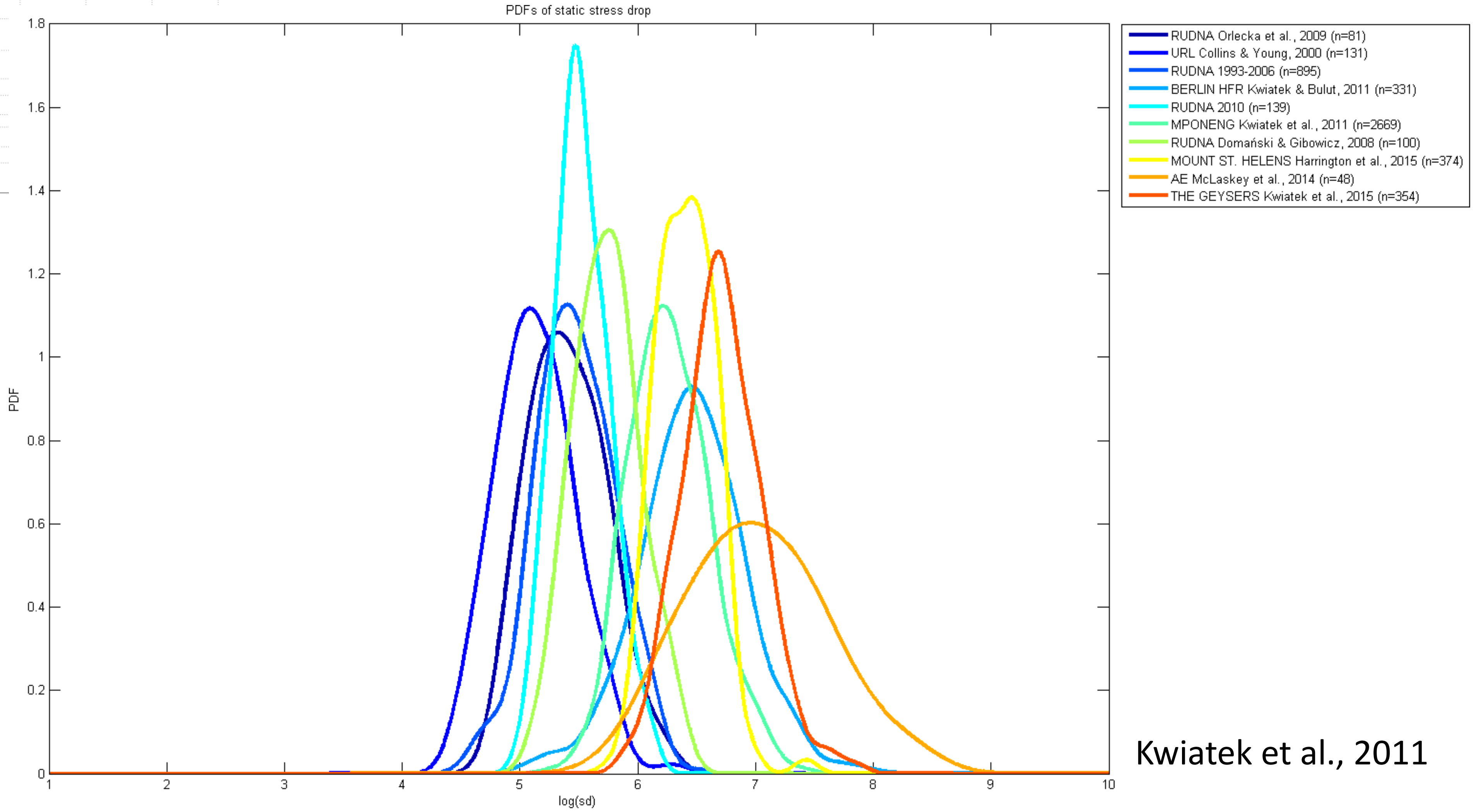
Static stress drop of induced events



(1) Distribution of $\Delta\sigma$ is lognormal

- Baltay et al., 2011
- Causse & Song, 2015
- Allmann & Shearer, 2009



Kwiatek et al., 2011

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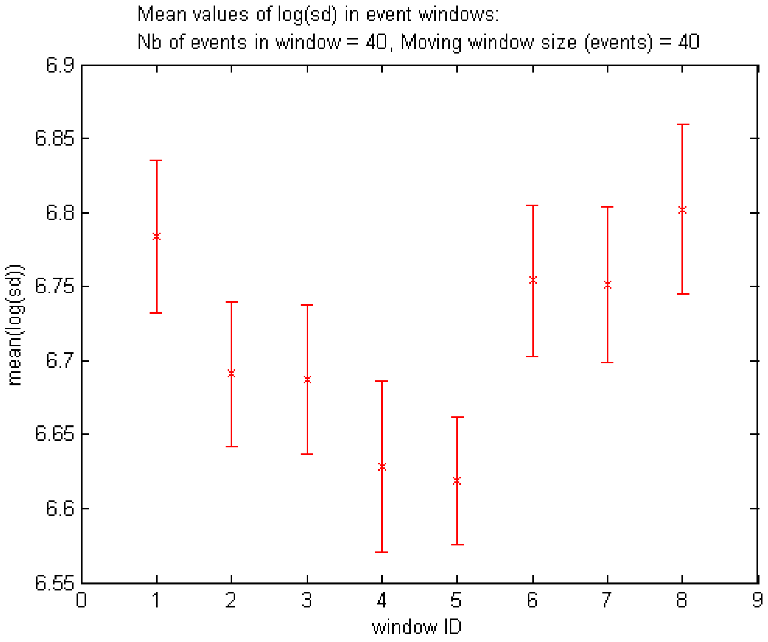
Static stress drop changes in time

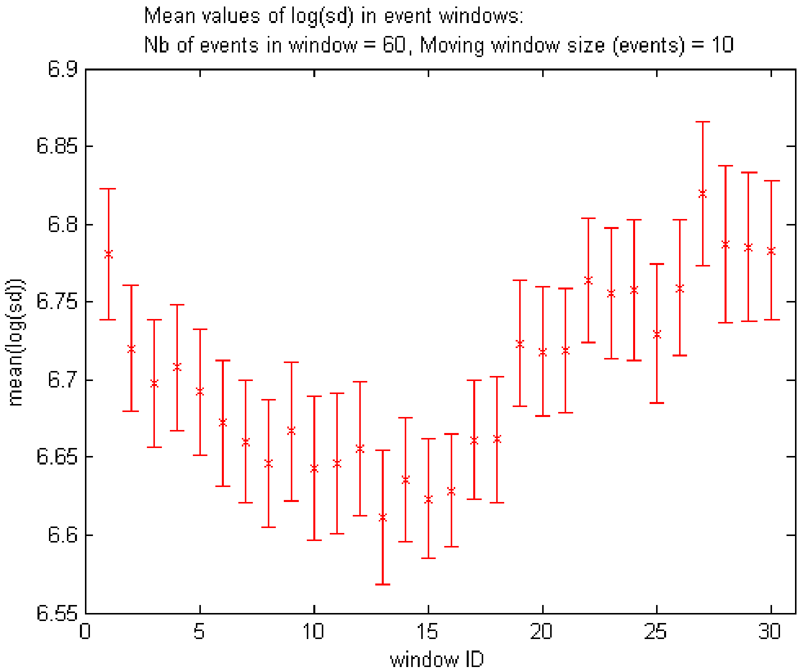


Statistical tests revealed that the differences between mean values in event windows can be statistically significant, e.g. p = 0.0364.

Differences in static stress drop are not a result of estimation error

(2) Distribution of Δσ in time changes gradually

e.g. Canadian mines



However, if we consider windows, which are close to each other the differences between mean values are not statistically significant.

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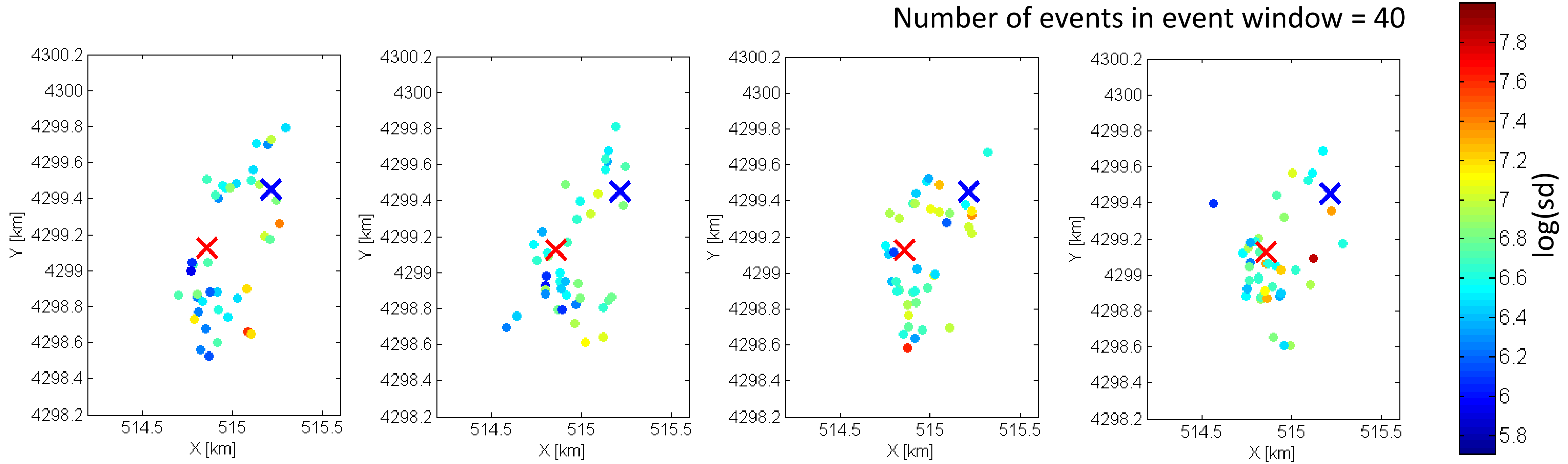
Static stress drop changes in space



- Different state of stress (e.g. Goertz-Allmann et al., 2011)
- Spatial distribution of geomechanical properties (e.g. Hardebeck & Hauksson, 1997, Solvay Mine in France)

(3) Δσ reveals spatial pattern which changes in time

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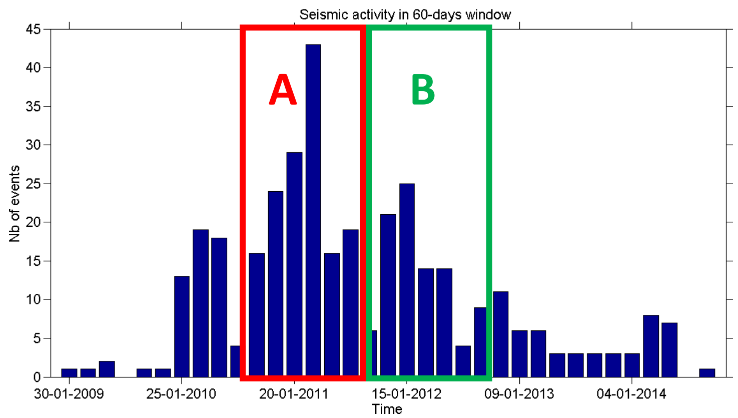
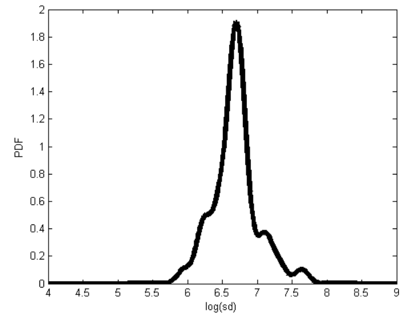
Is it possible to utilize static stress drop distribution to the assessment of spatial distribution of future events?



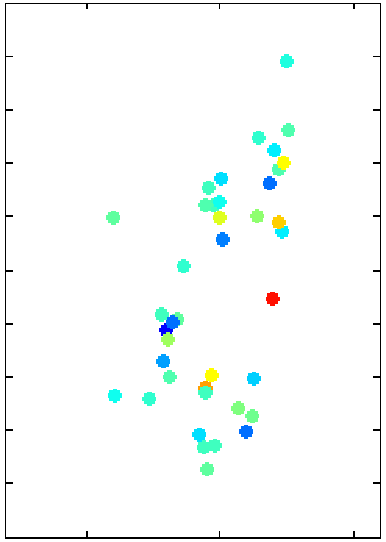
(1) **Empirical static stress drop distribution can be estimated from the window A**
(if static stress drops are known)



(1)

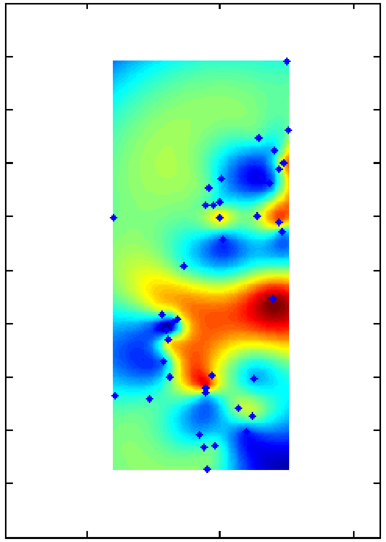
Assumption: $f_A(\Delta\sigma) \approx f_B(\Delta\sigma)$

(2) $\Delta\sigma_A(x,y)$
(if static stress drops and events locations are known)

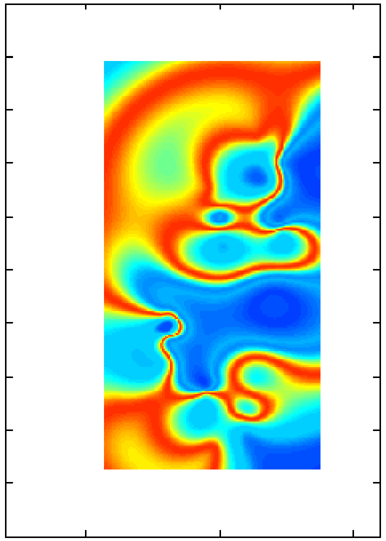


(2)

spline interpolation



(2)



(3)

(3) We can use Δσ distribution to calculate probability of events occurence in window B

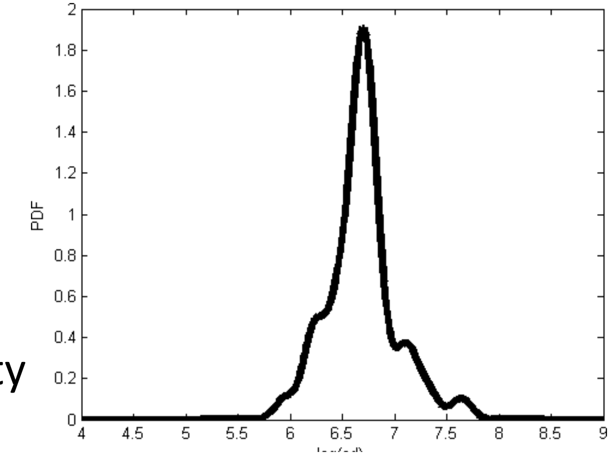
Thesis: Distribution of seismic events depends on the distribution of Δσ of preceding events.

Method of probability estimation on the basis of Δσ distribution

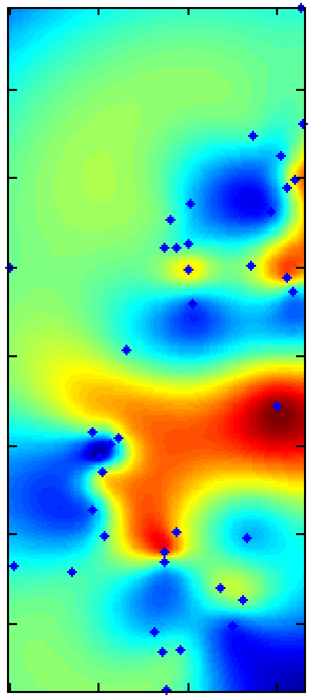
window:
- event = e.g. 40 events
- time = e.g. 90 days

kernel density estimation

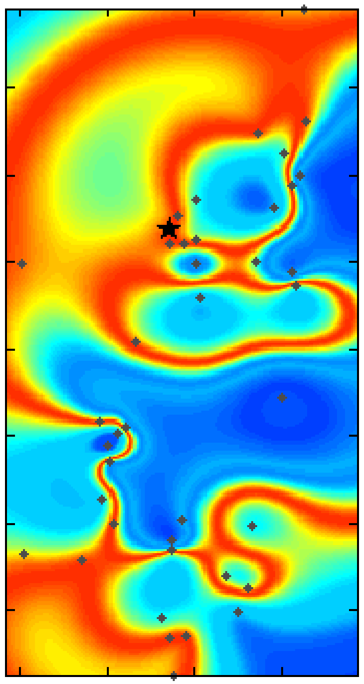
spline interpolation



grid: 5m x 5m



window A



event 1
from window B

Time
08/02/11 04:42:42
08/02/11 04:42:58
08/02/11 04:49:24
10/02/11 02:02:31
10/02/11 02:03:15
12/02/11 14:04:09
14/02/11 22:59:24
17/02/11 05:16:26
20/02/11 21:35:52
22/02/11 04:27:34

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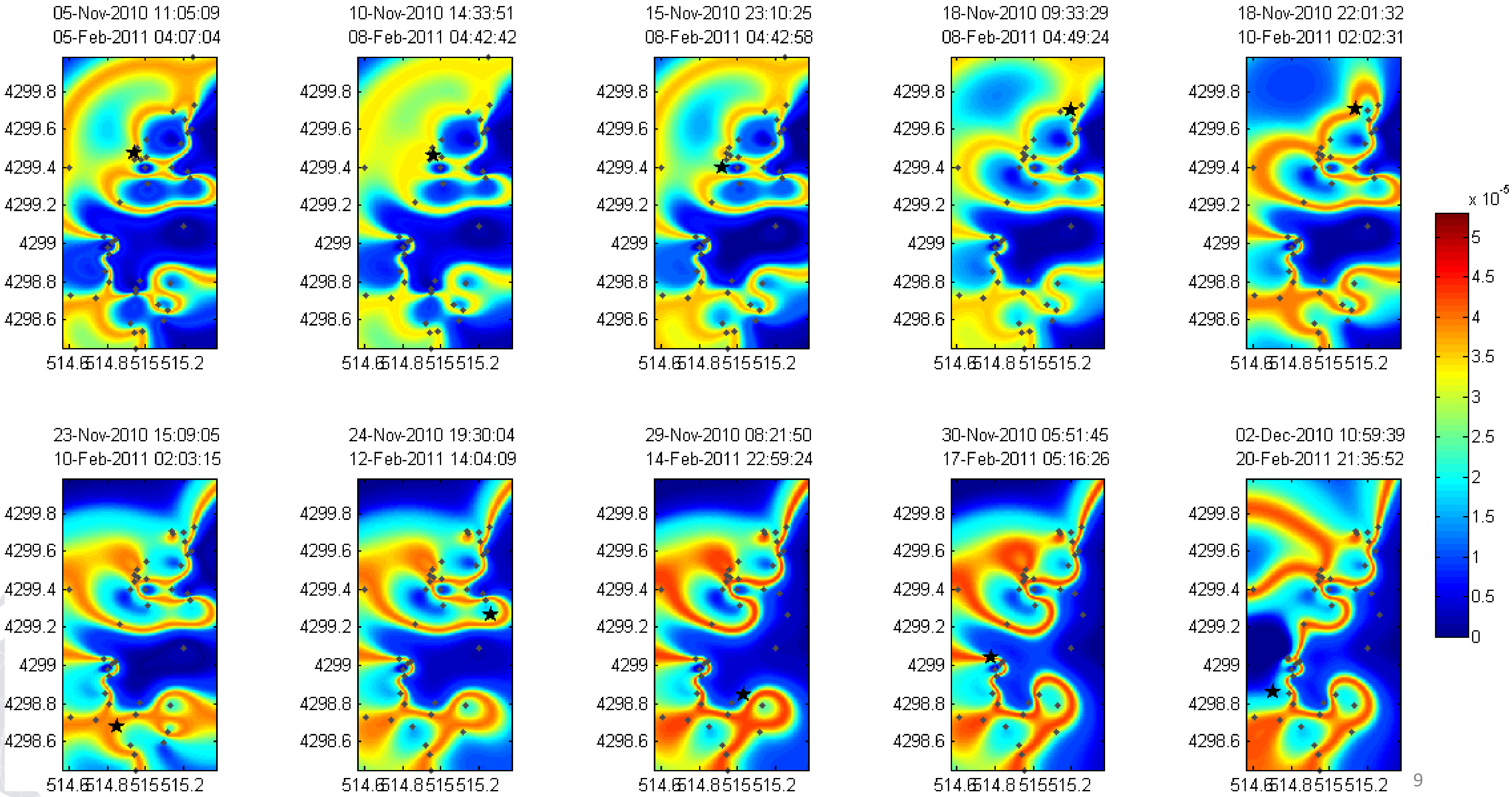
Results (window = 40 events)



Future work

- Thesis verification (comparison of PDF of $\Delta\sigma_{ratio}$ in window B with PDF of $\Delta\sigma_{int}$ in window B)
- Consideration of static stress drop and localization uncertainties in proposed methodology
- Consideration of events depth in proposed methodology
- Determination of boundary conditions of proposed methodology
- Testing the influence of catalogue incompleteness on the results

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Thank you for your attention!