Dynamic Stress Drop and Rupture Velocity for Mining Induced Seismicity

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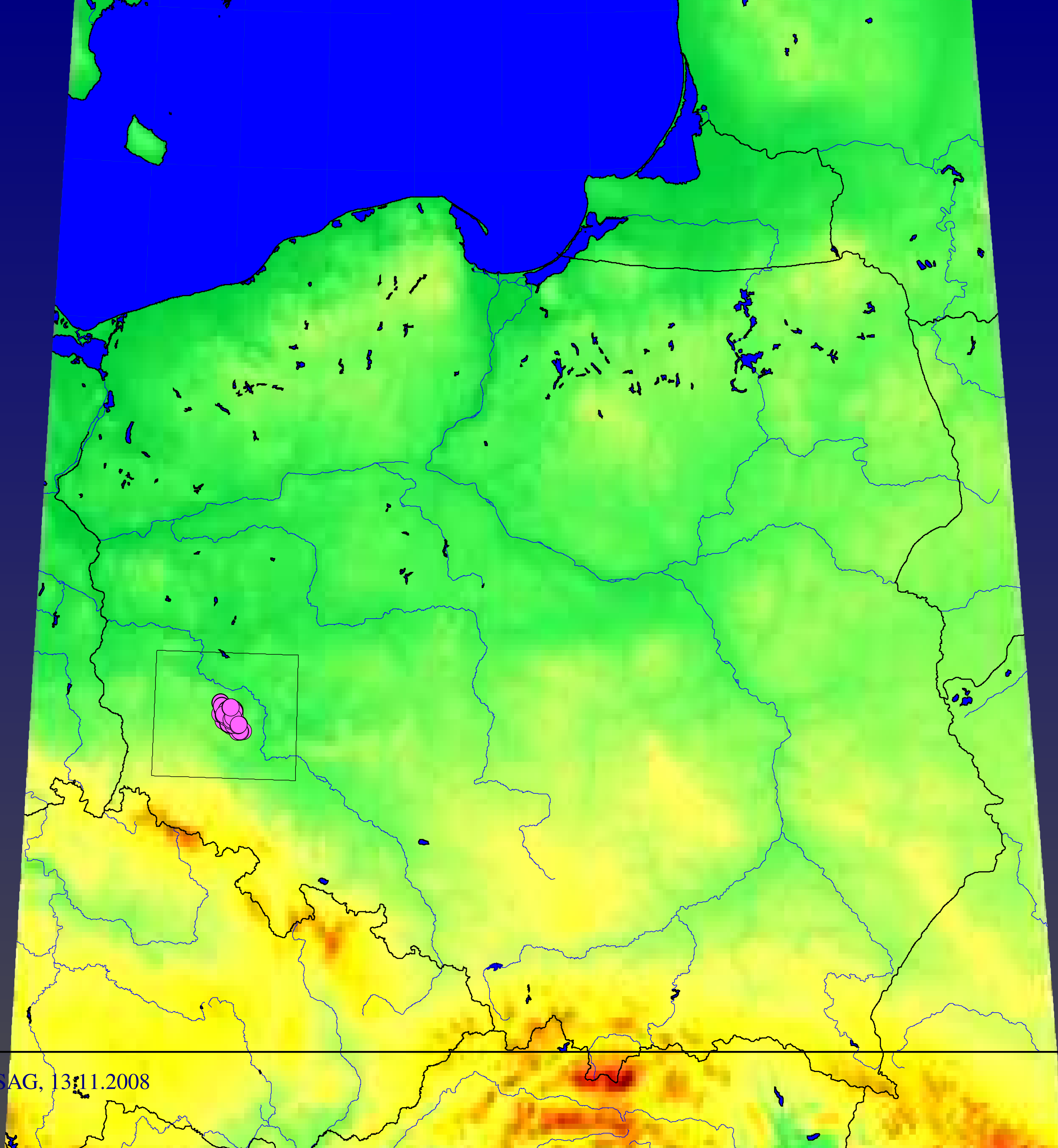
Plan of the talk

- Background review of the seismicity induced by mining in Poland
- Soure parameters from seismic spectra
- ***Rupture velocity and dynamic stress drop***
- Towards the dynamic source tomography
- An accuracy issue: Bayesian and MCMC sampling techniques

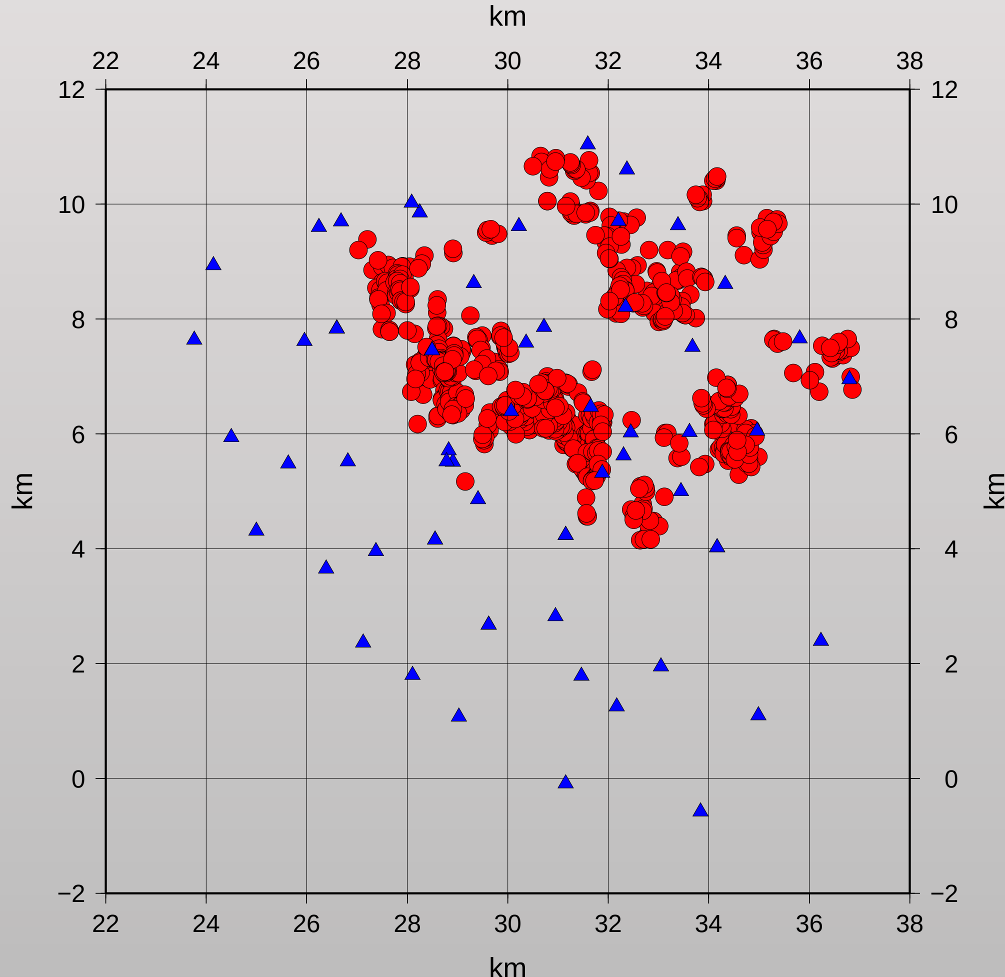


Mining technology

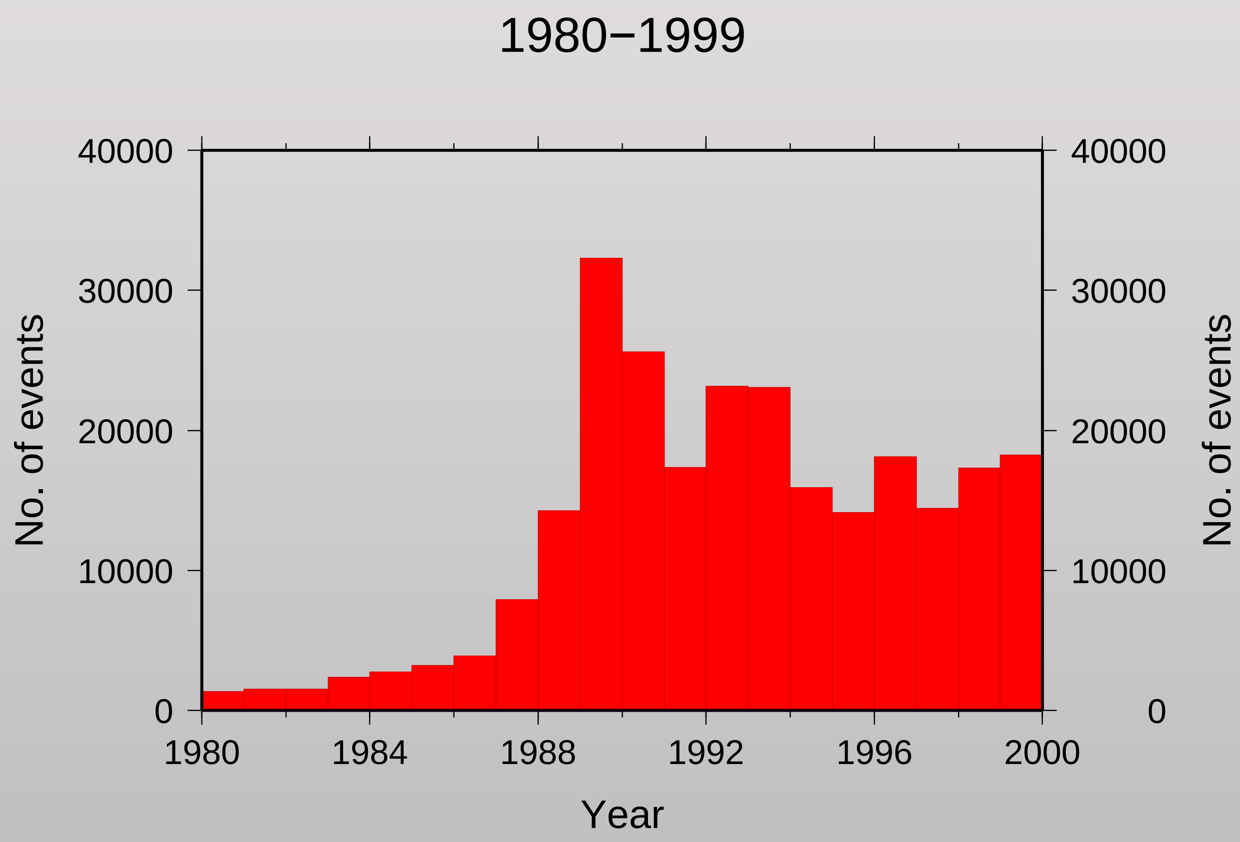
Mining technology (cd)

Mining technology (cd)

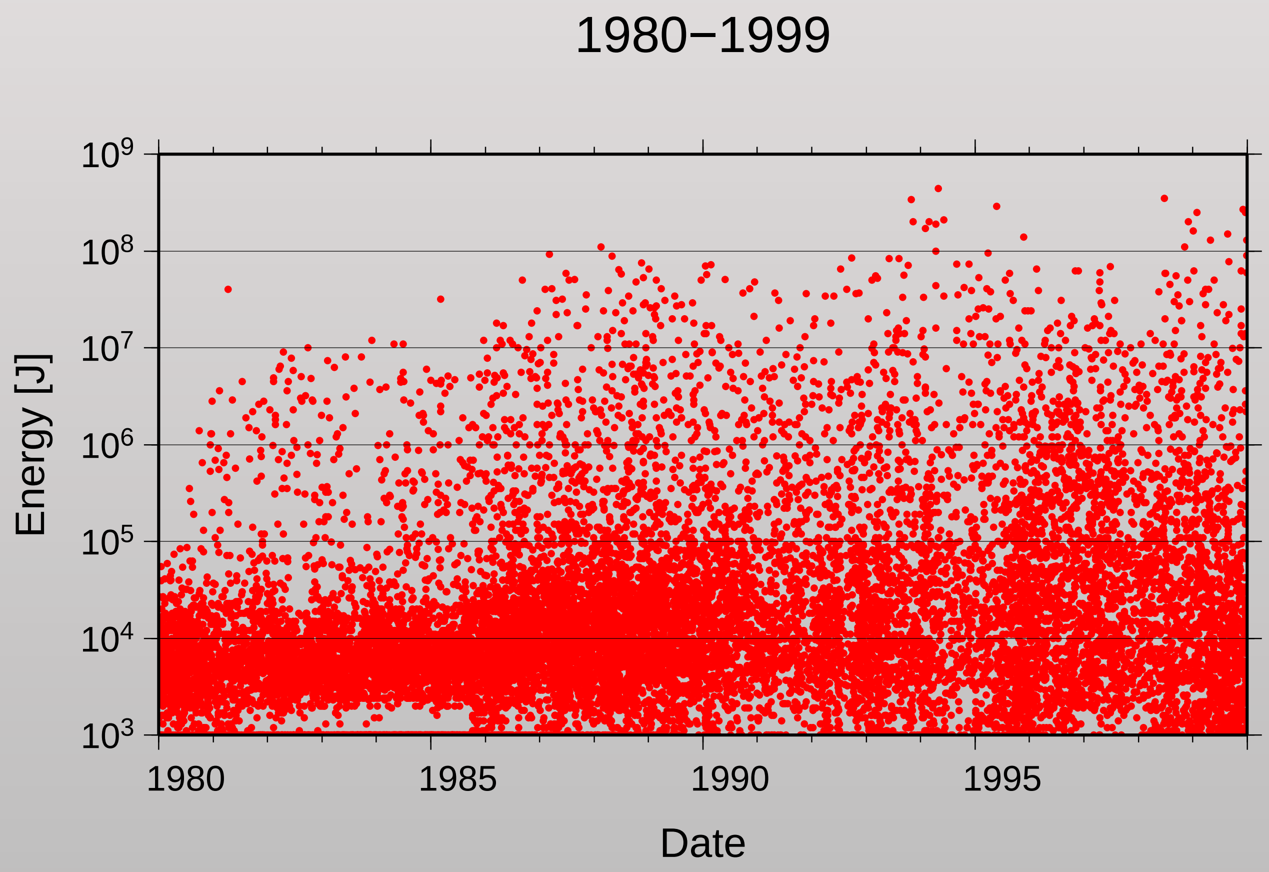
Polish copper mines



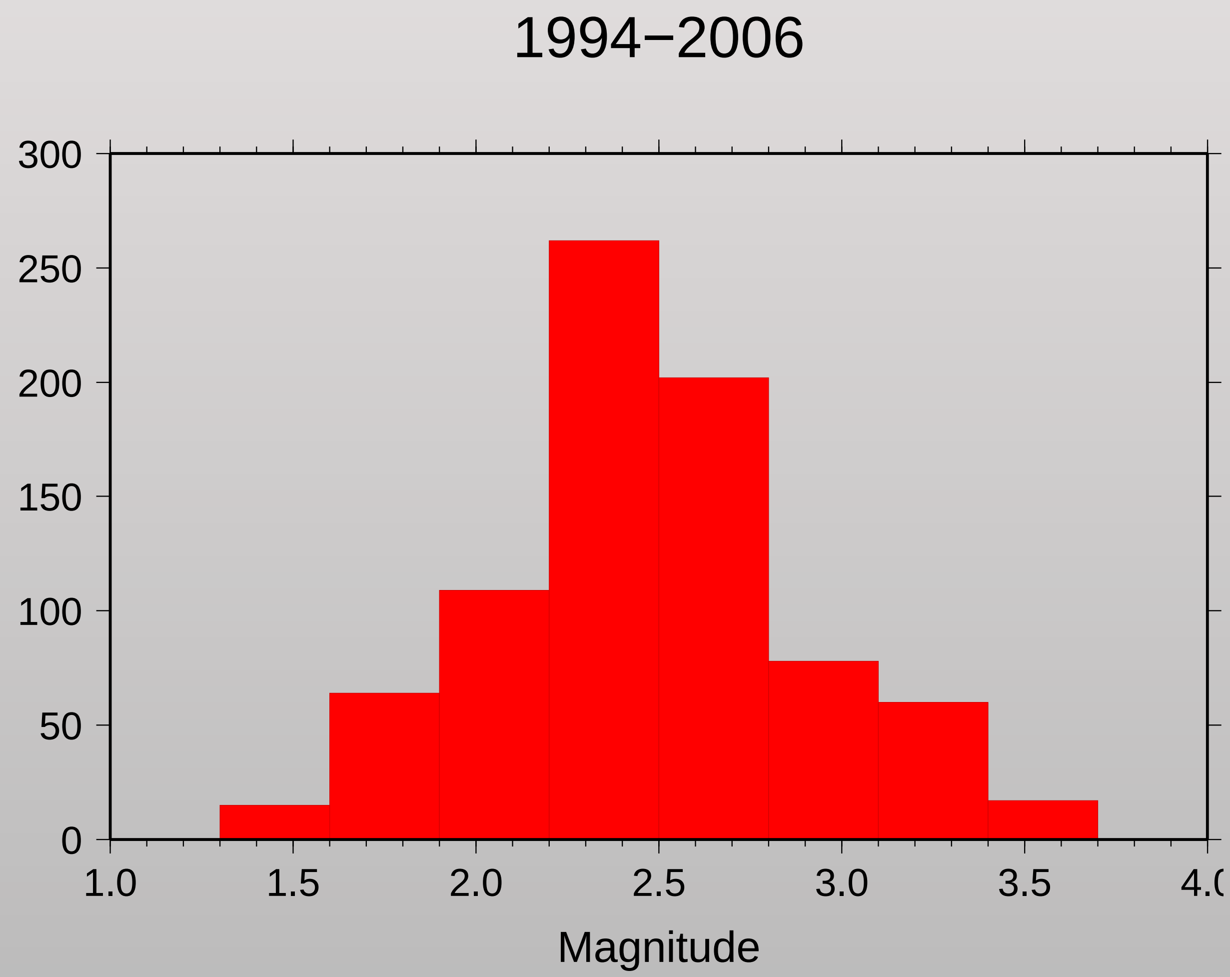
LGOM Seismicity



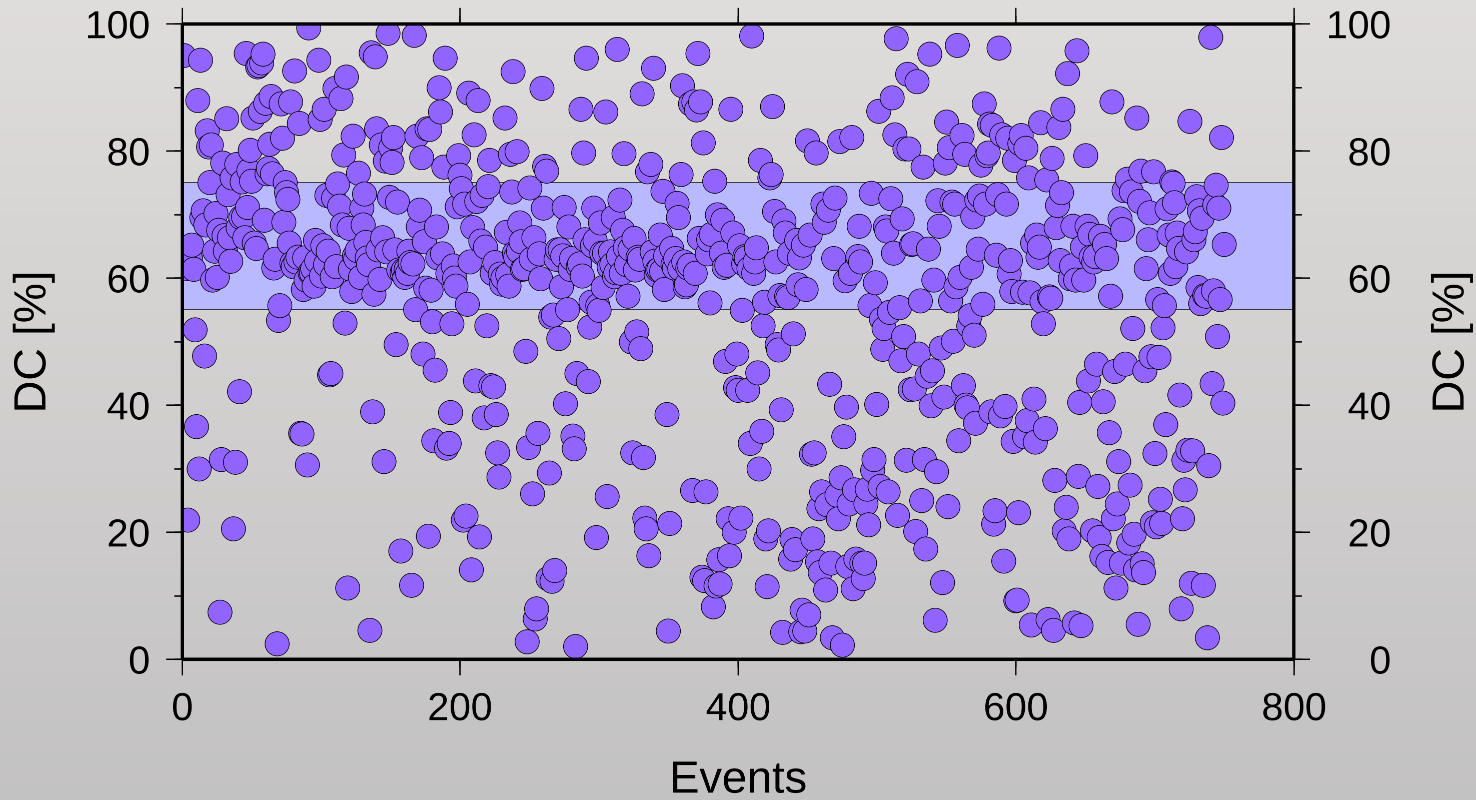
LGOM Seismicity



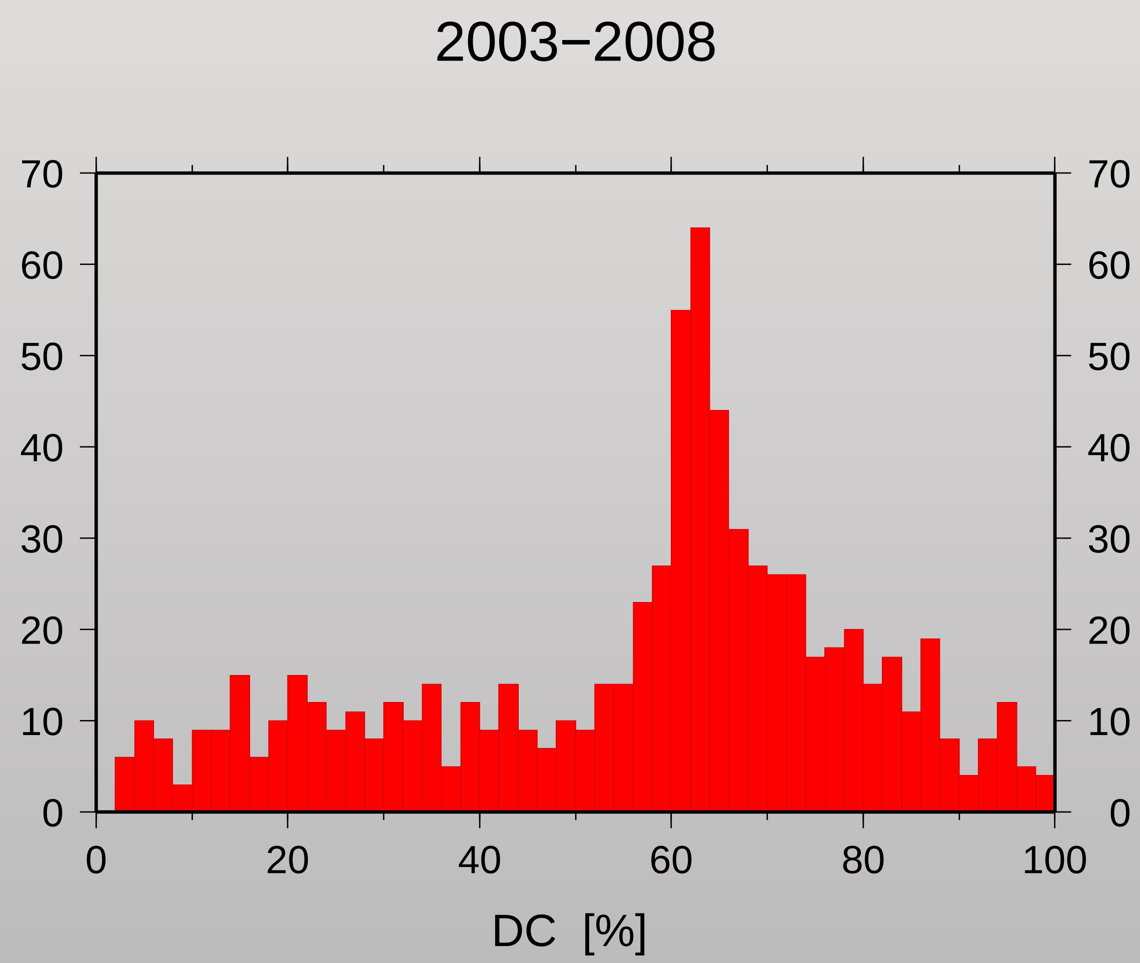
Analyzed data



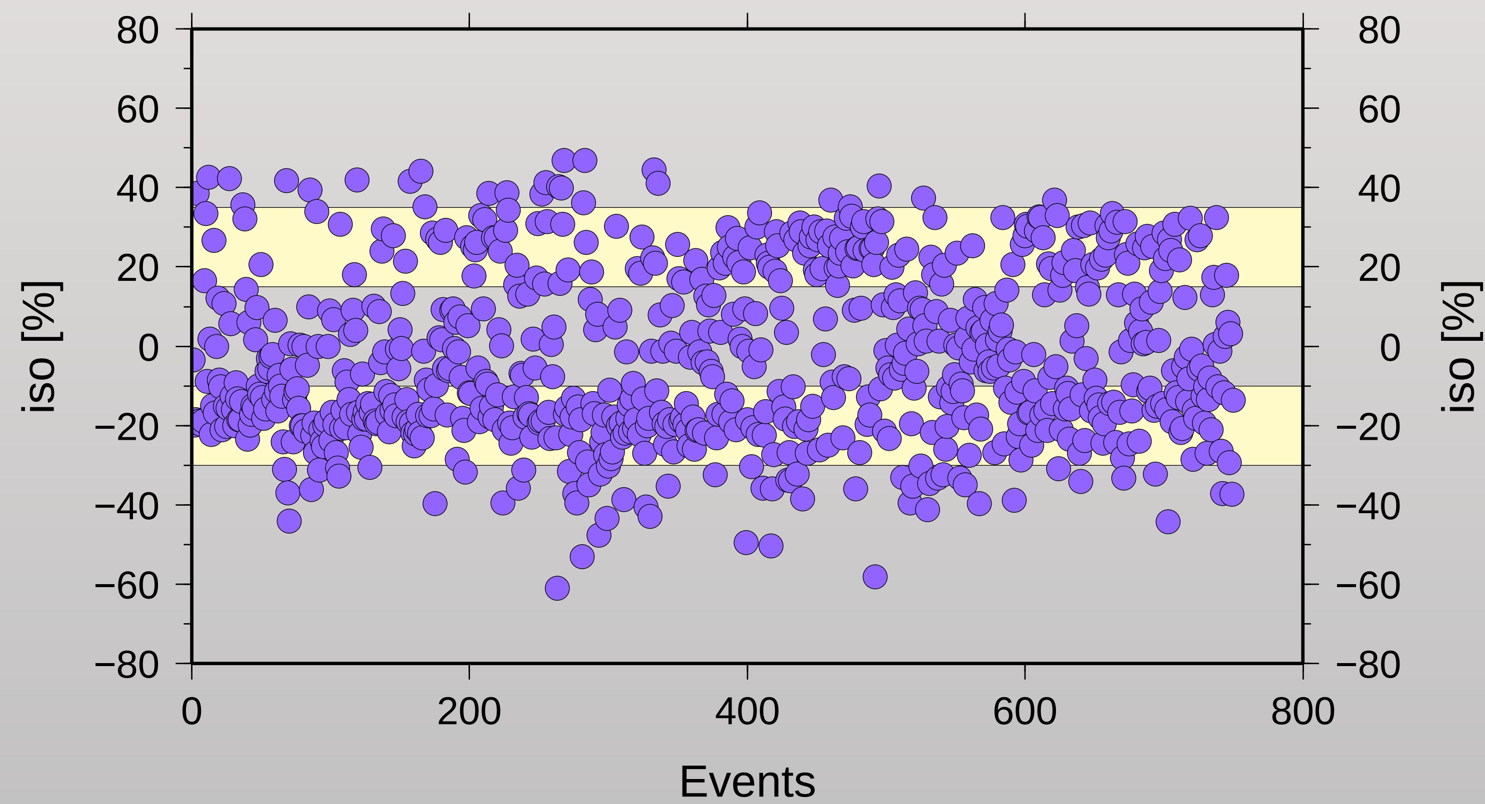
Moment Tensor



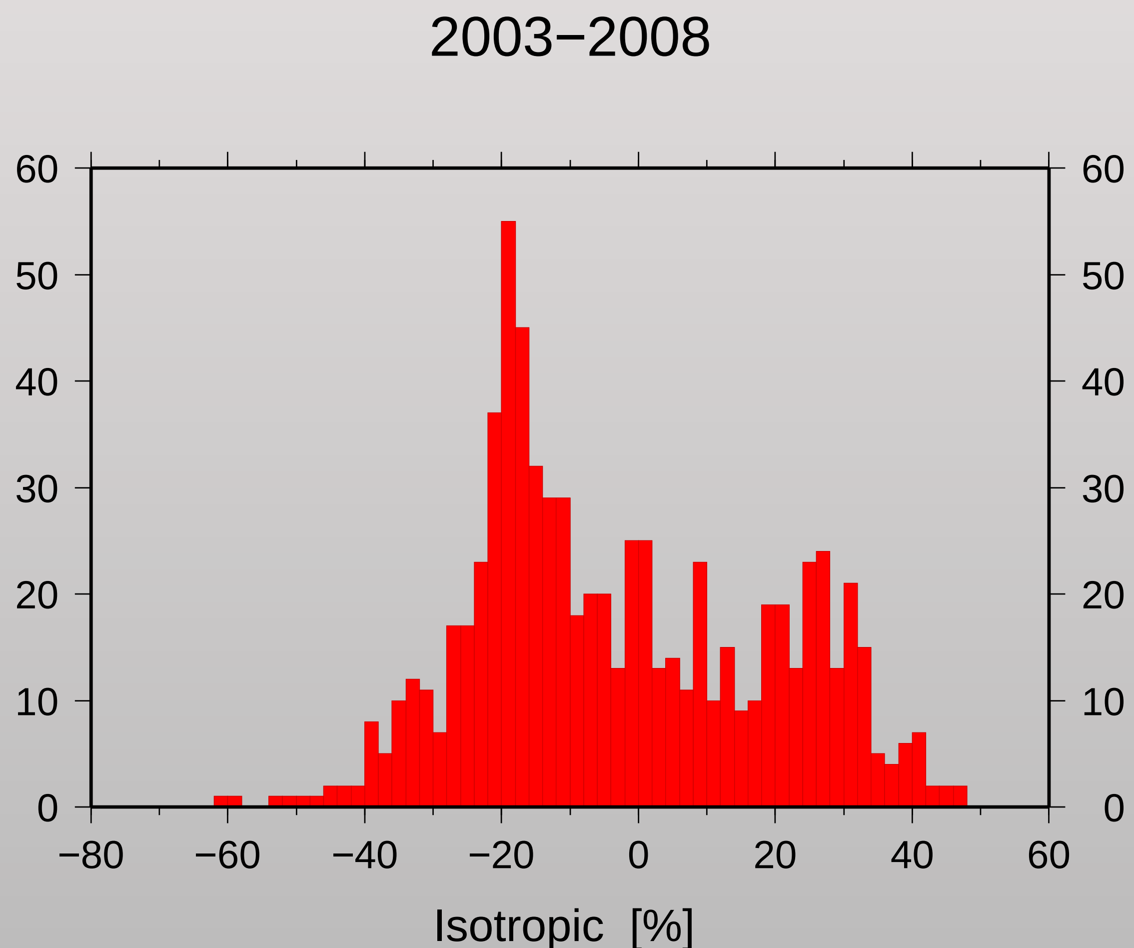
Moment Tensor



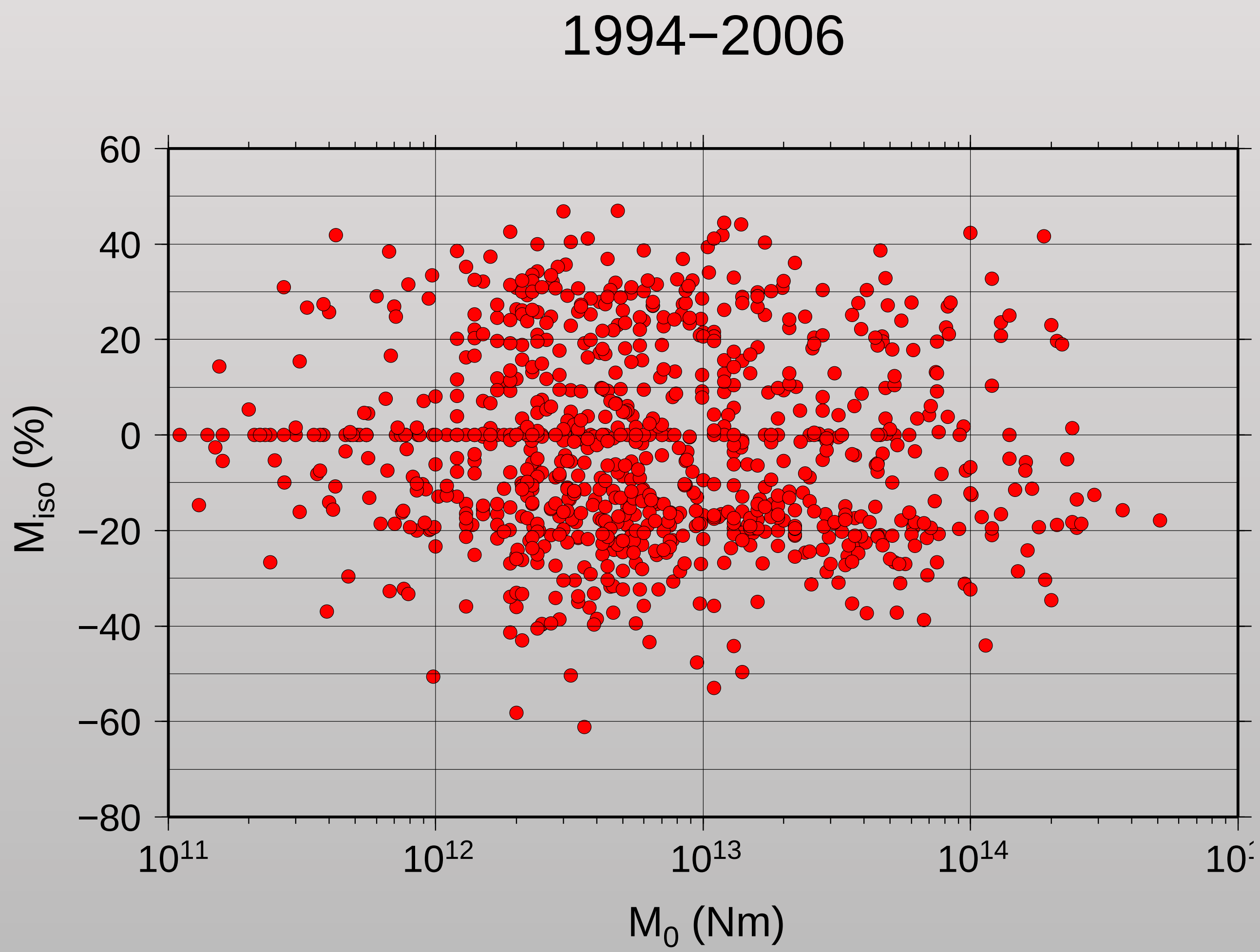
Moment Tensor



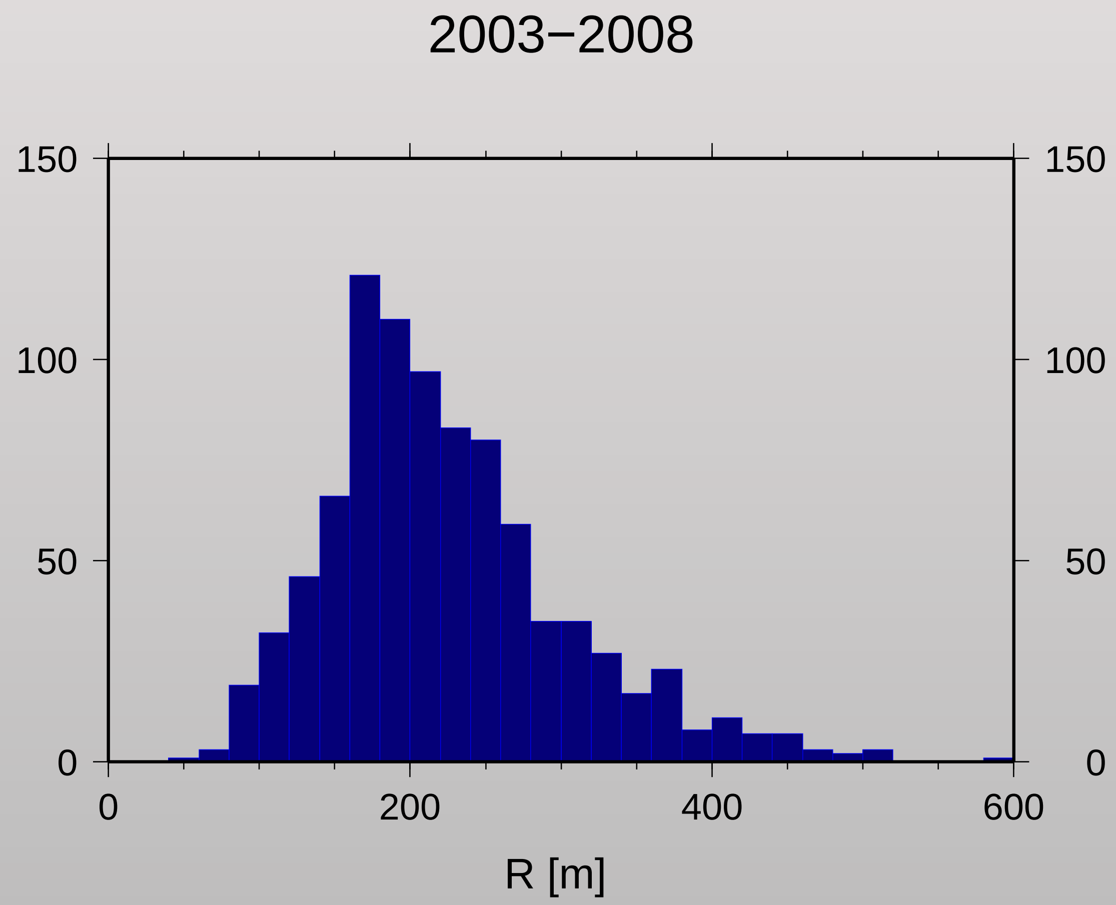
Moment Tensor



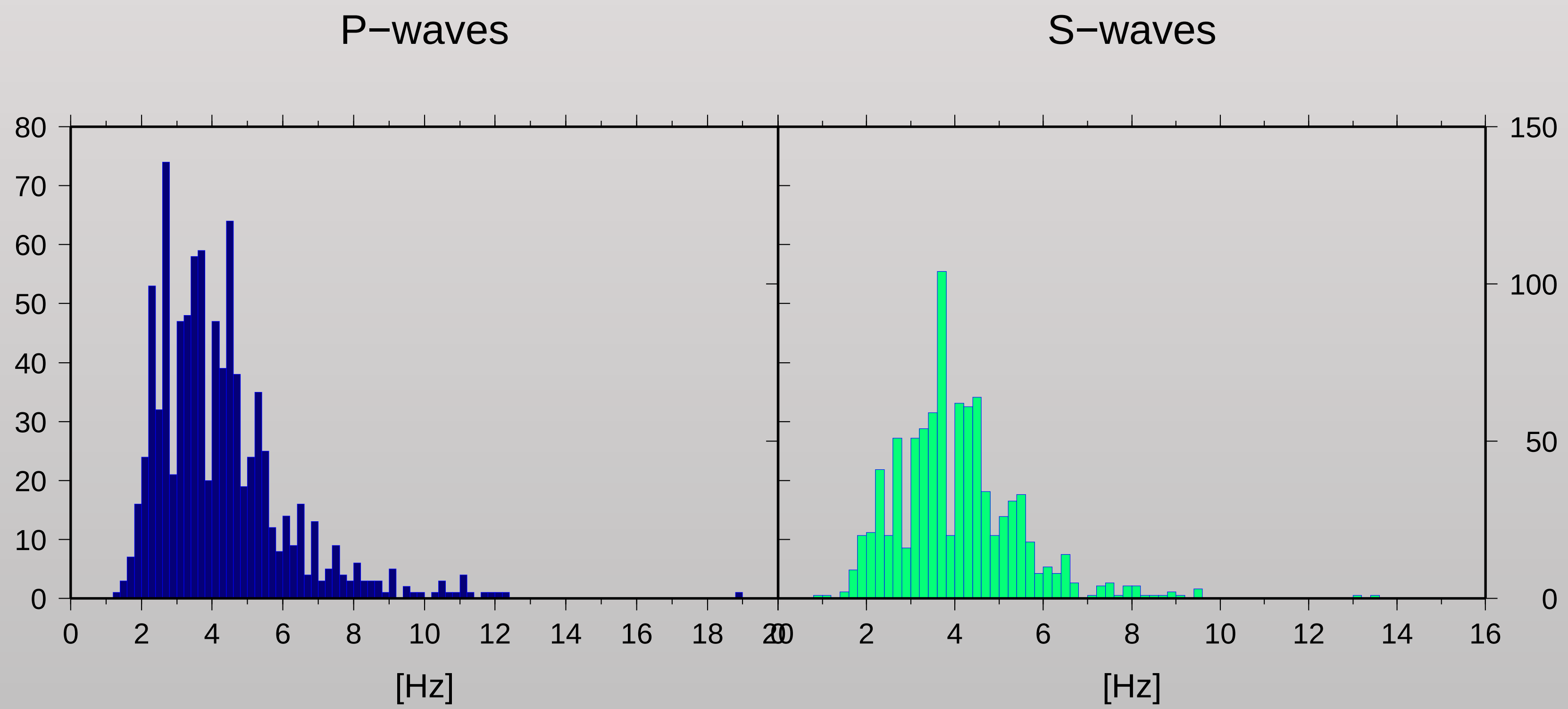
Moment Tensor



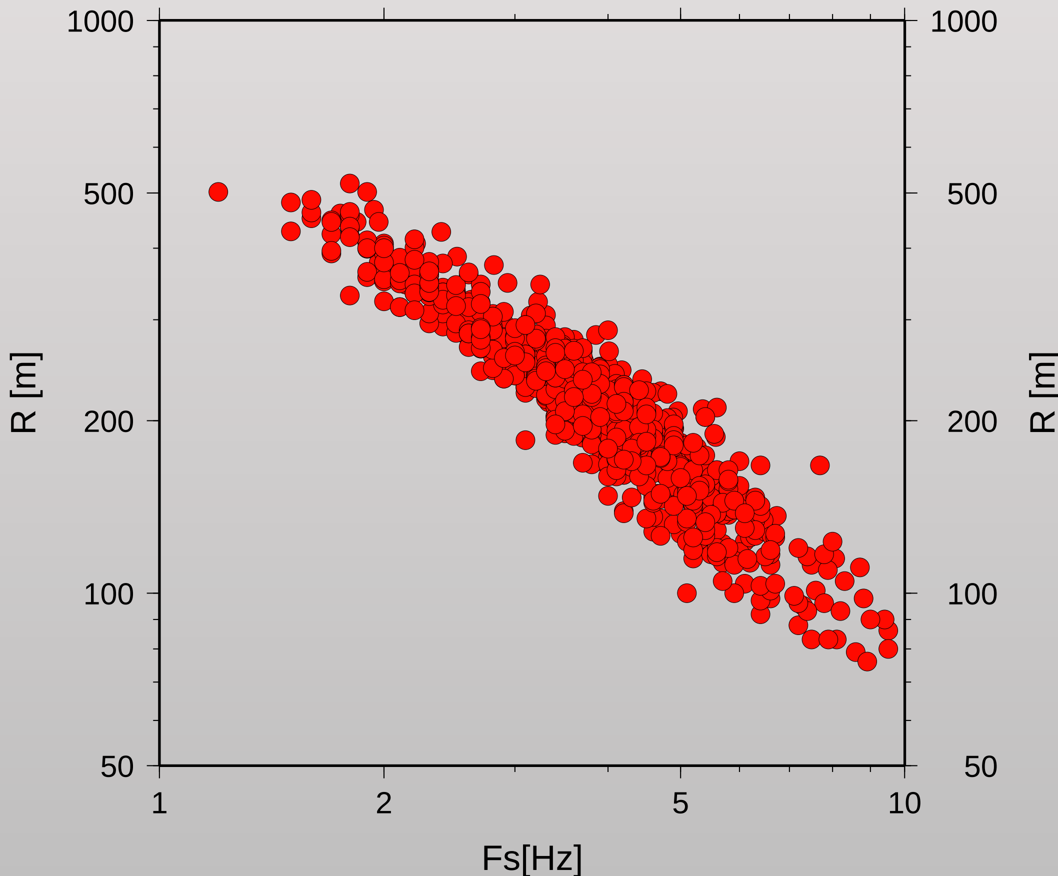
Spectral parameters



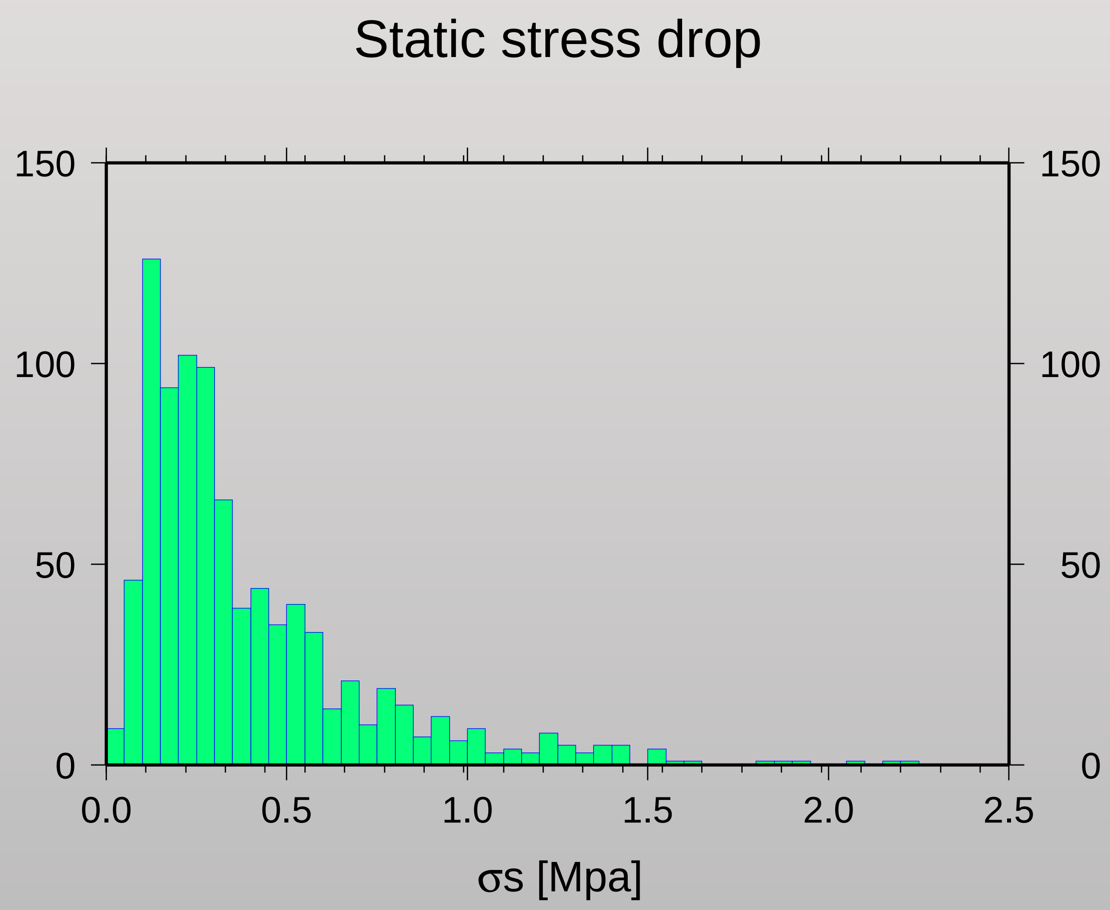
Spectral parameters



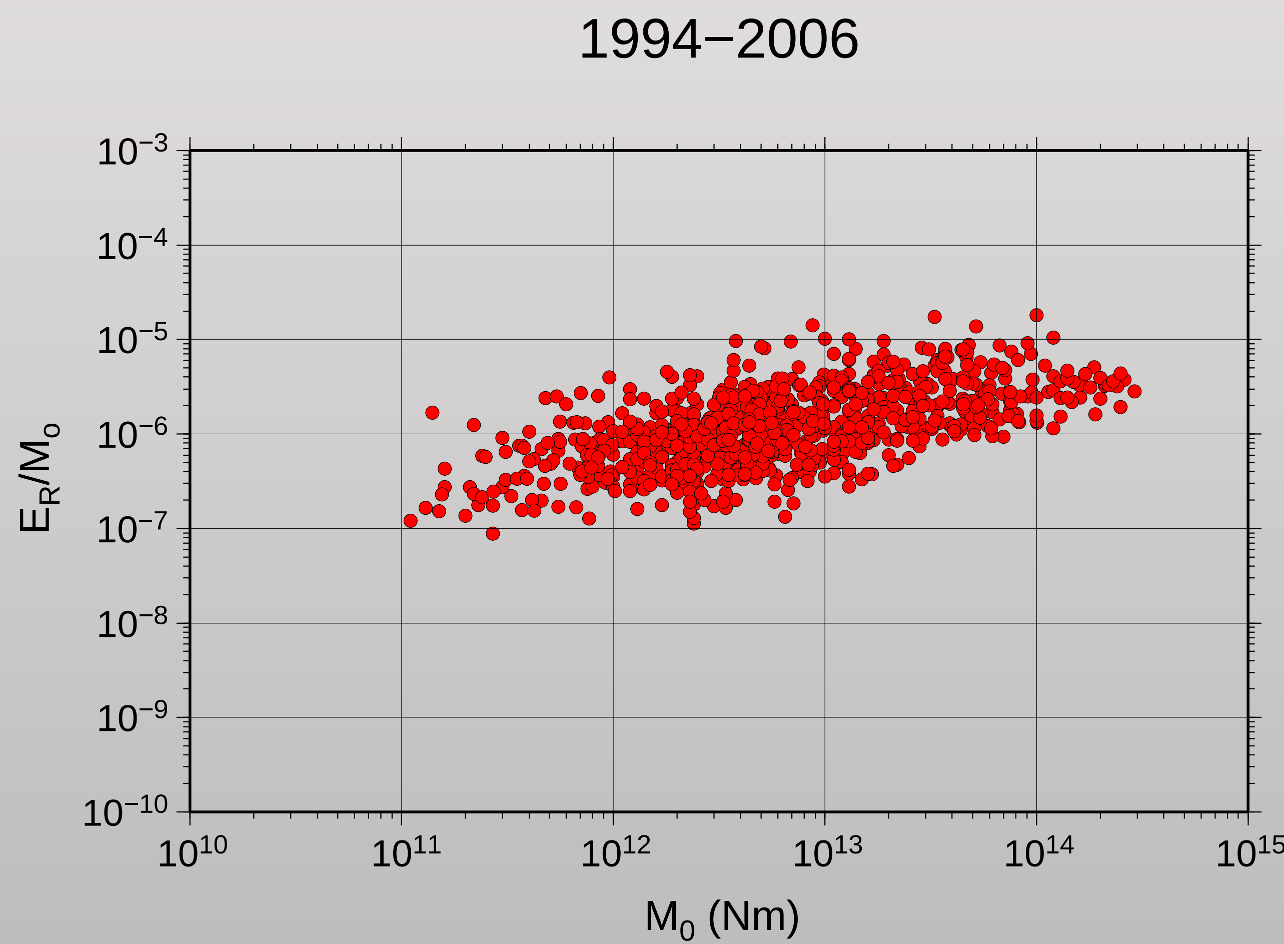
Spectral parameters



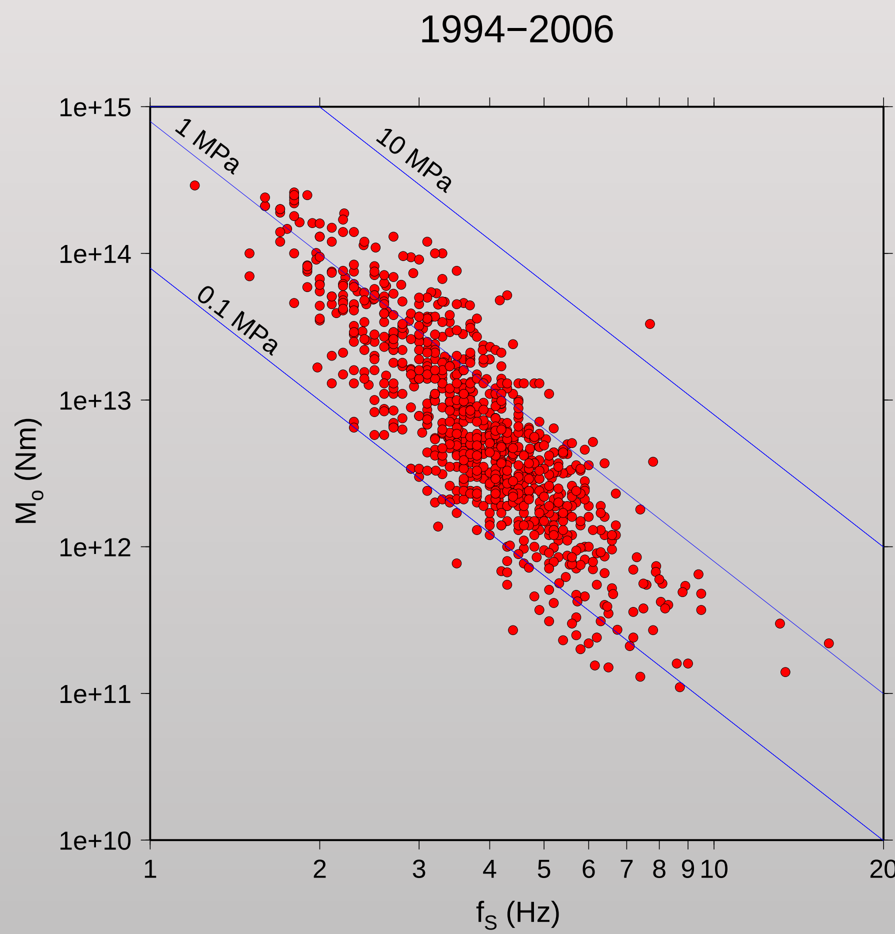
Spectral parameters



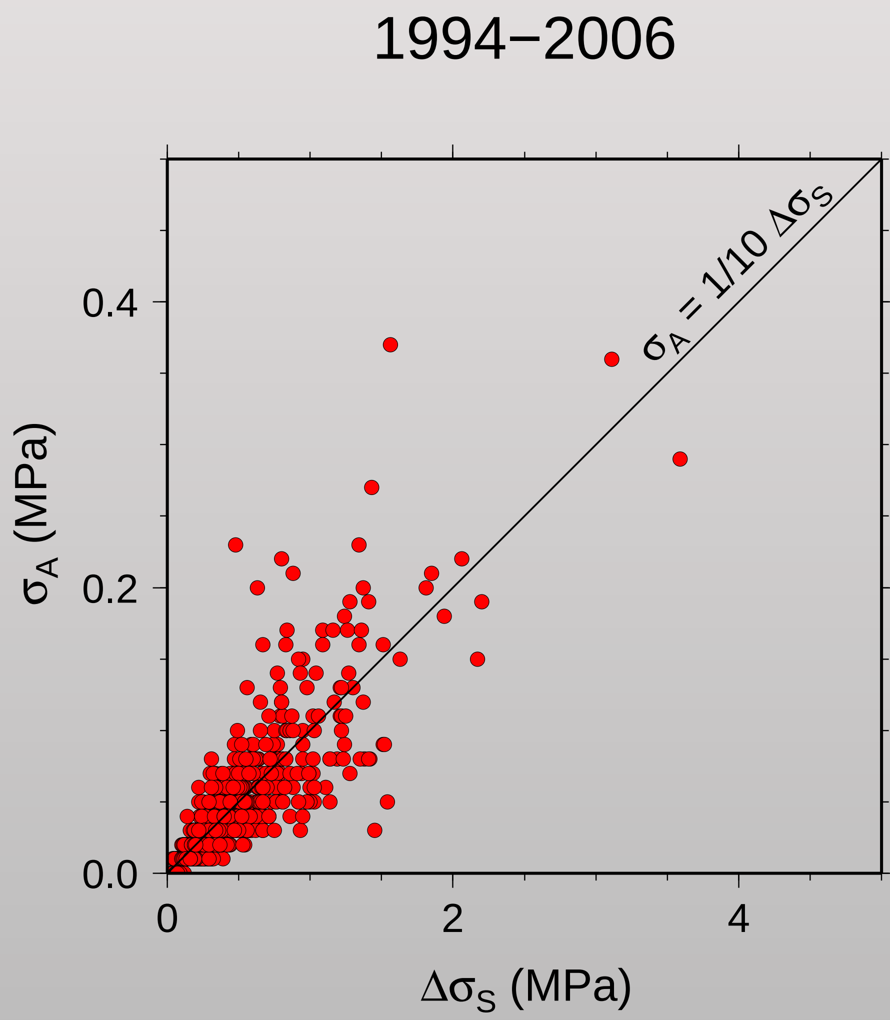
Spectral parameters



Spectral parameters



Spectral parameters



Stress drops - classical estimators

- Static (Brune) stress drop $[\sigma_0 - \sigma_1]$

$$\Delta\sigma_s = \frac{7}{16}\frac{M_0}{R^3}$$

- Apparent stress

$$\sigma_a = \frac{\mu E}{M_0}$$

$$\sigma_a \approx 1/10 \; \Delta\sigma \quad \text{(Rudna copper mine)}$$

Stress drops - classical estimators

- Dynamic stress drop $[\sigma_0 - \sigma_d]$

$$\Delta\sigma_d \;=\; \frac{M_0}{4\pi v_r^3 I}\left(1-\xi^2\right)^2 \frac{\mathrm{d}S}{\mathrm{d}t}$$

$$I \;=\; \int_0^T S(t)\,\mathrm{d}t$$

- Mo - seismic moment
- v_r - constant (assumption!) rupture velocity
- ξ - geometrical (directional) factor - assumed to be 0.75
- S - STF
- T - rupture duration time

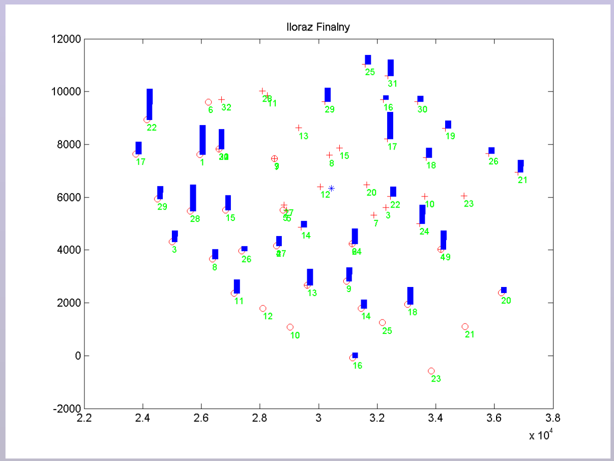
Partial stress drop/overshooting

$$\gamma_d \; = \; \Delta\sigma_d/\Delta\sigma_s \;\; \approx \; \frac{\sigma_0 - \sigma_d}{\sigma_0 - \sigma_1}$$

$$\gamma_d \quad \begin{cases} = 1 \quad \text{Orowan's model} & \sigma_d = \sigma_1 \\ > 1 \quad \text{partial stress drop} & \sigma_d < \sigma_1 \\ < 1 \quad \text{“overshooting”} & \sigma_d > \sigma_1 \end{cases}$$

Rupture velocity

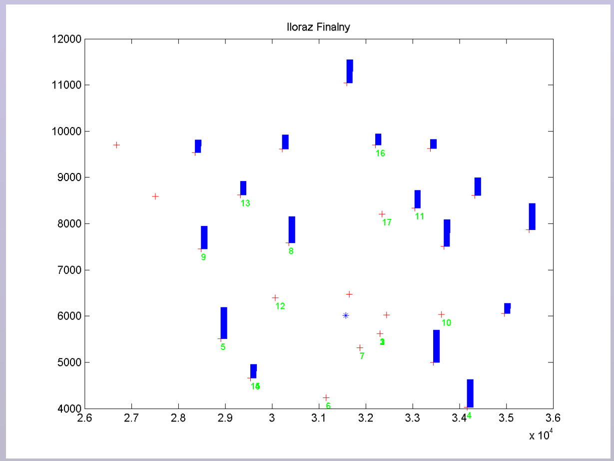
“circular type”



no visible directivity

$$V_r = 0.5V_s$$

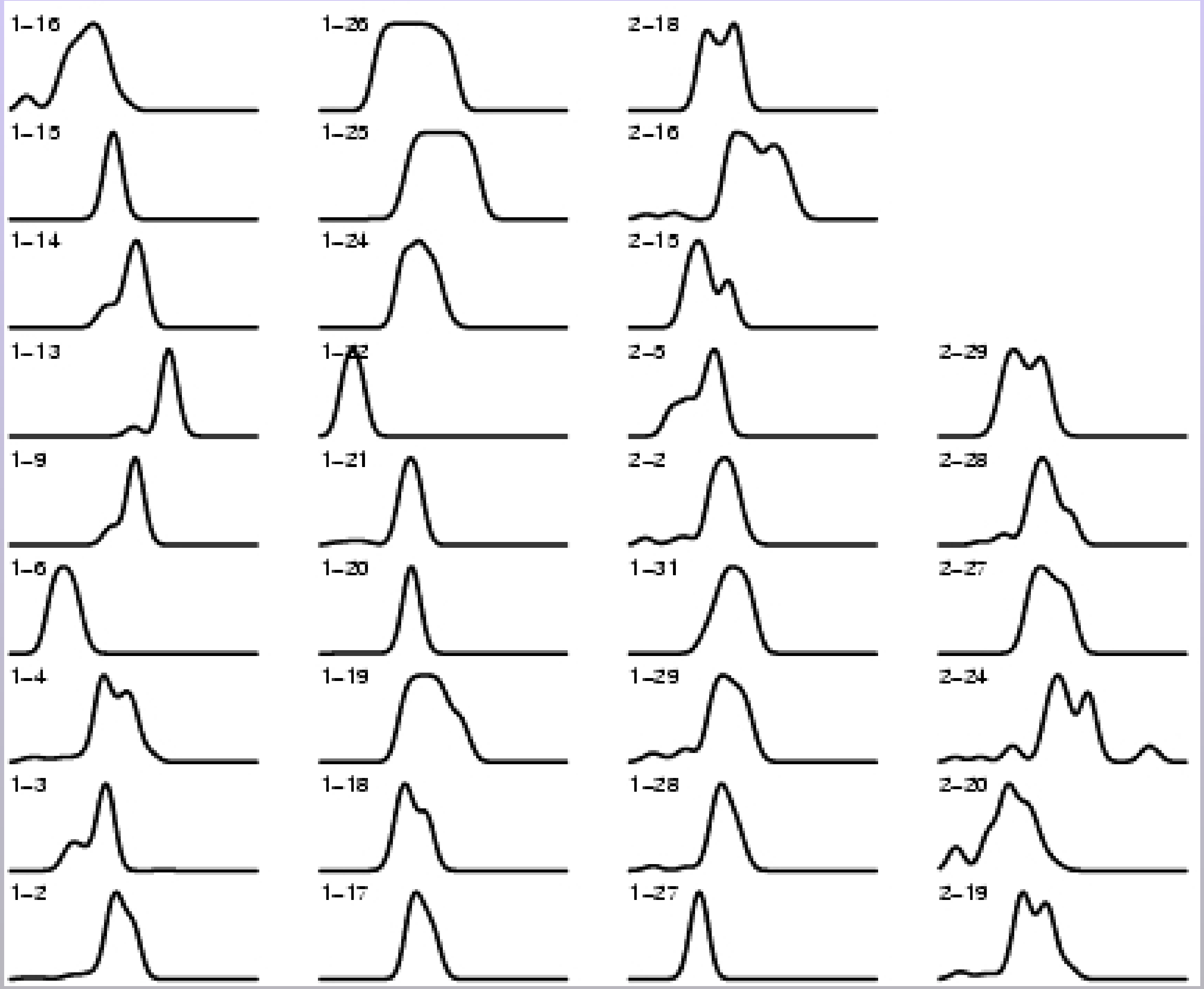
“unilateral type”



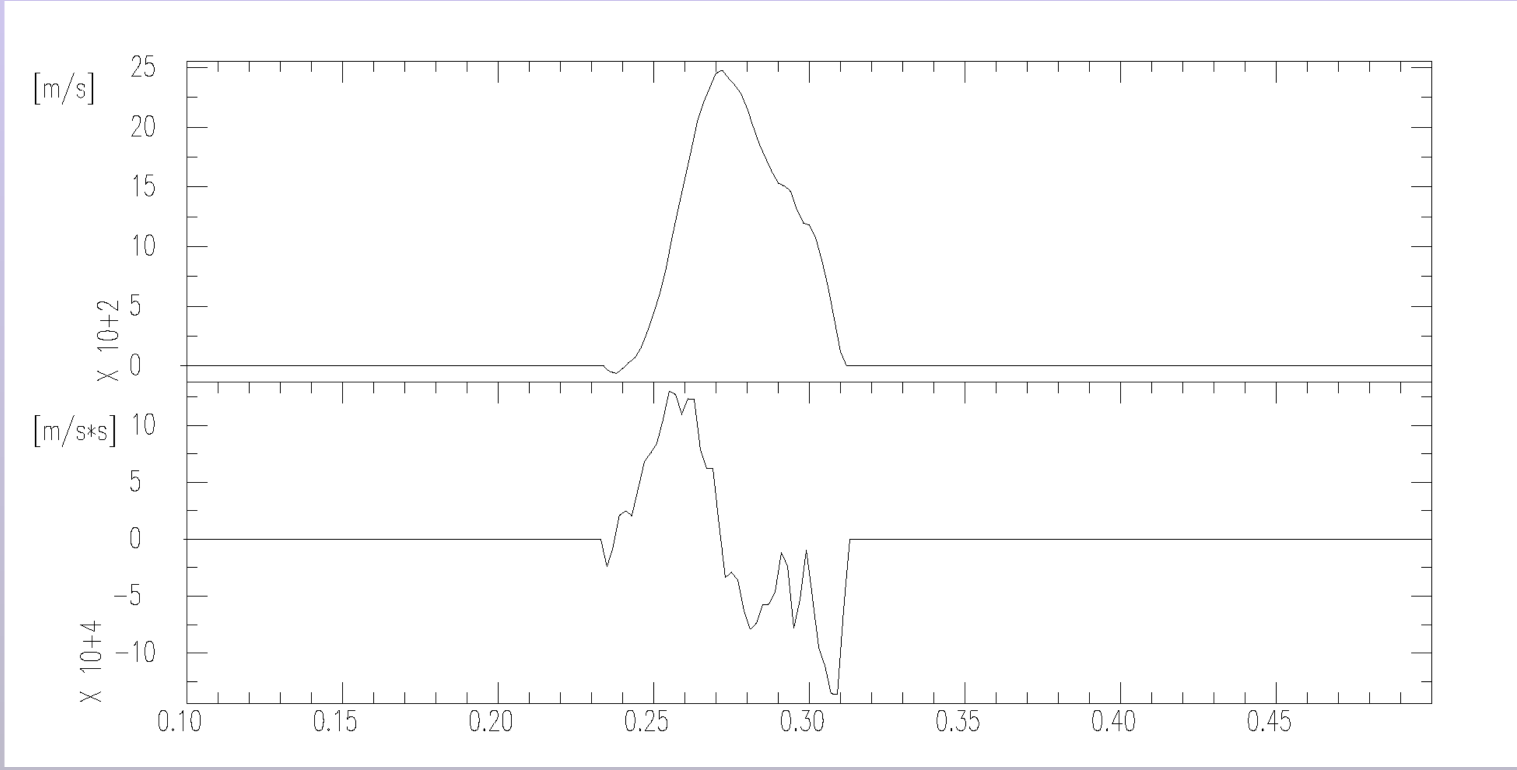
directivity of T distribution

$$T(\theta) = \frac{L}{V_r} - \frac{L}{V_P}\cos(\theta)$$

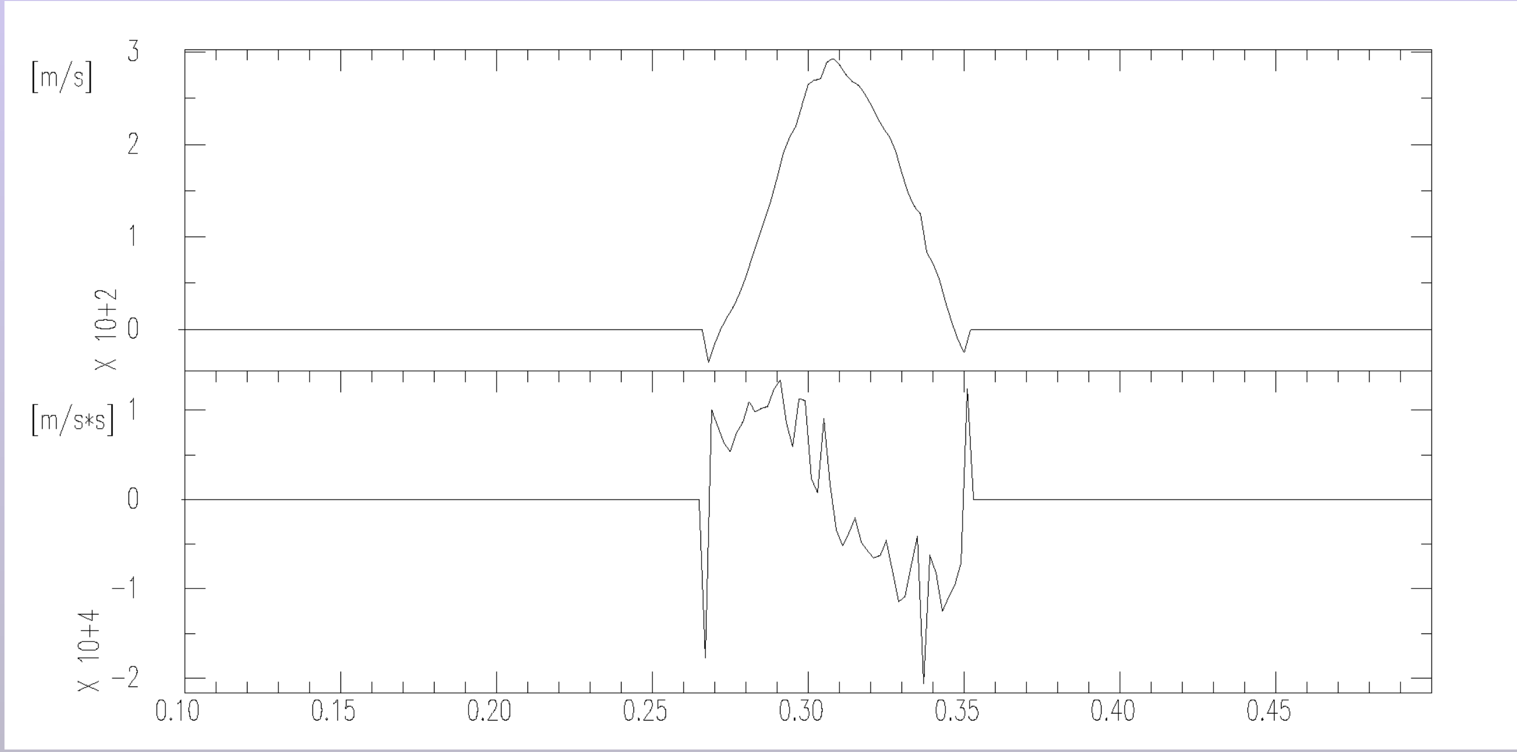
STF- spatial distribution



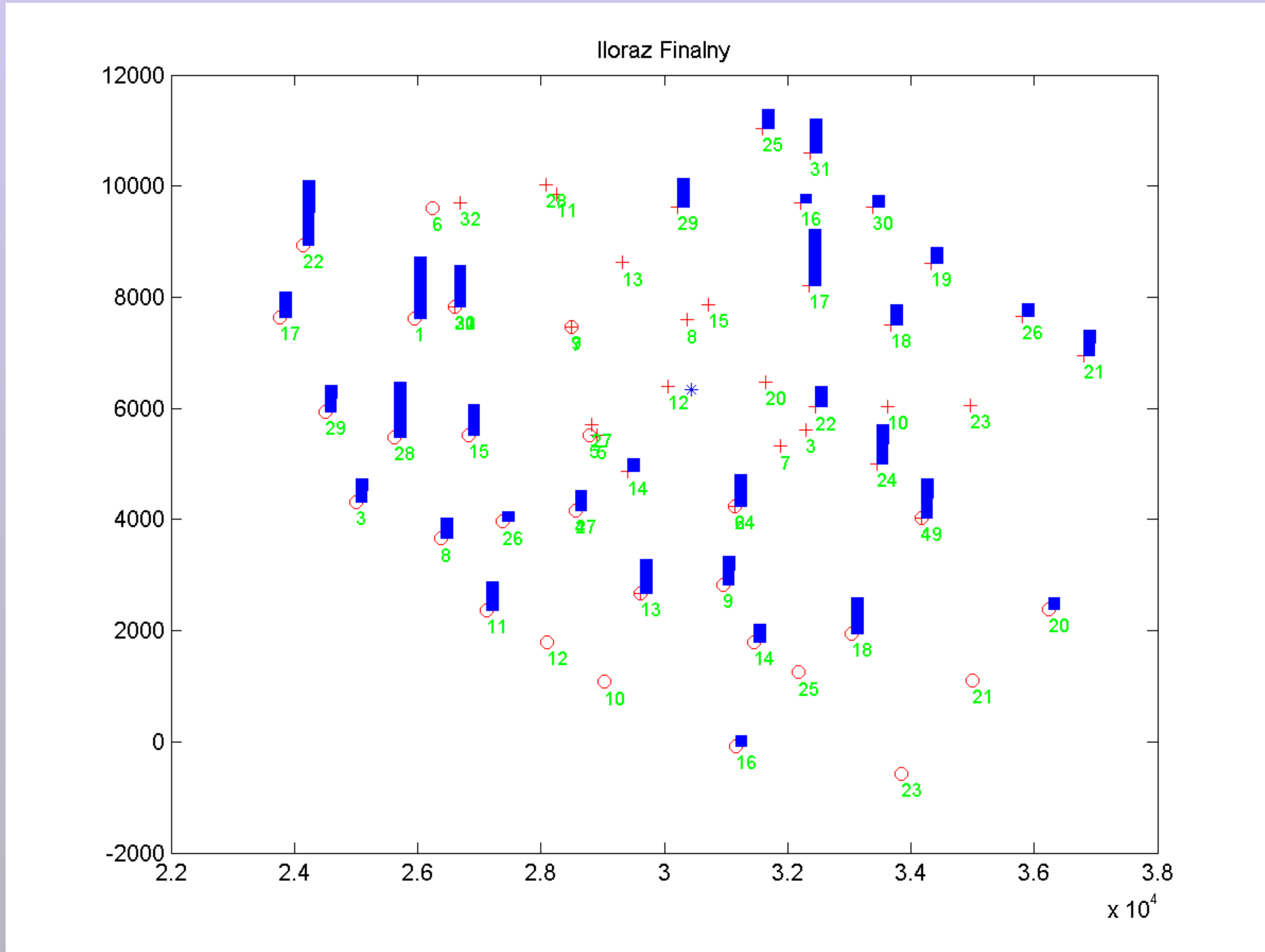
Source Time Function



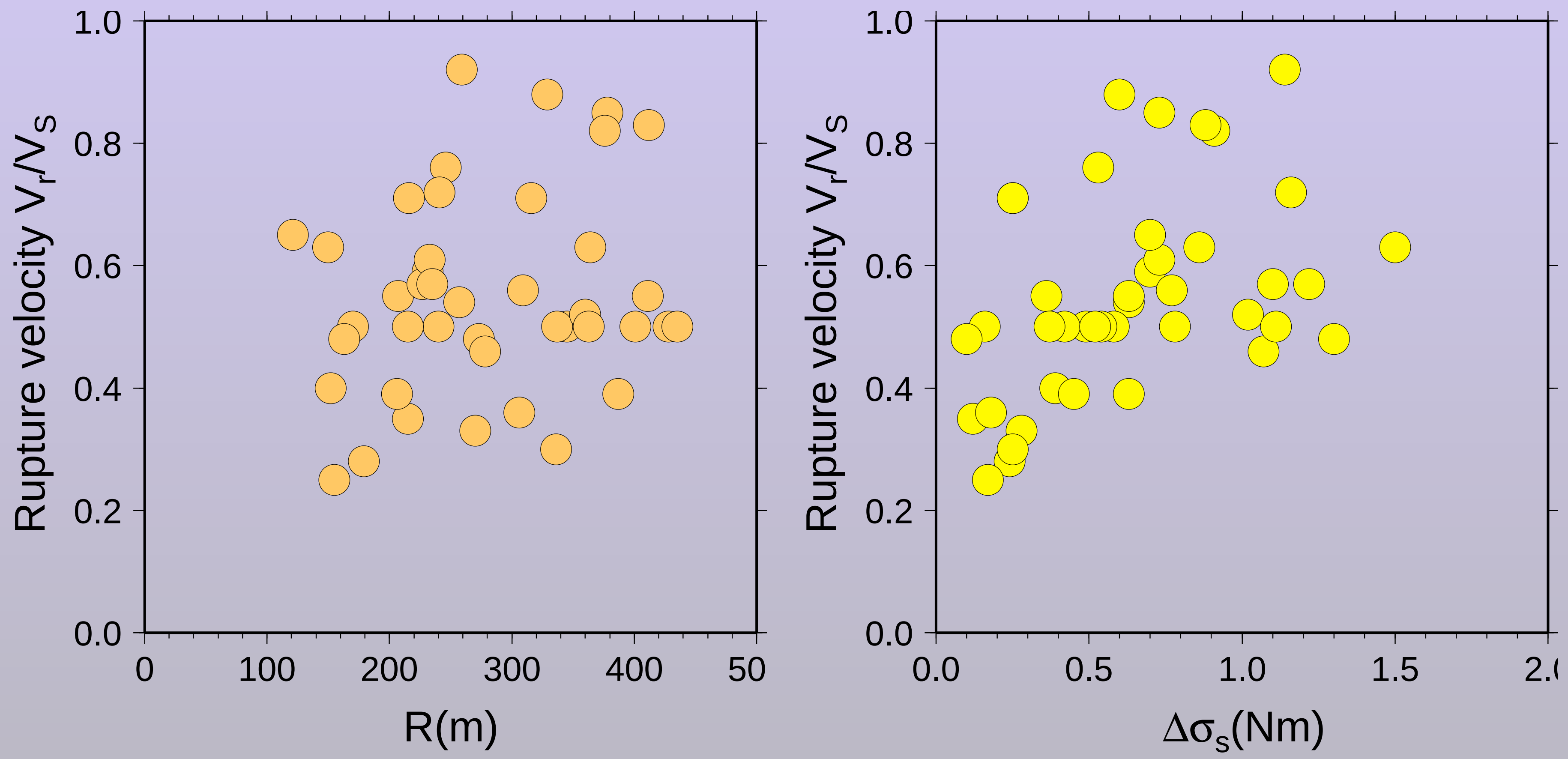
Source Time Function



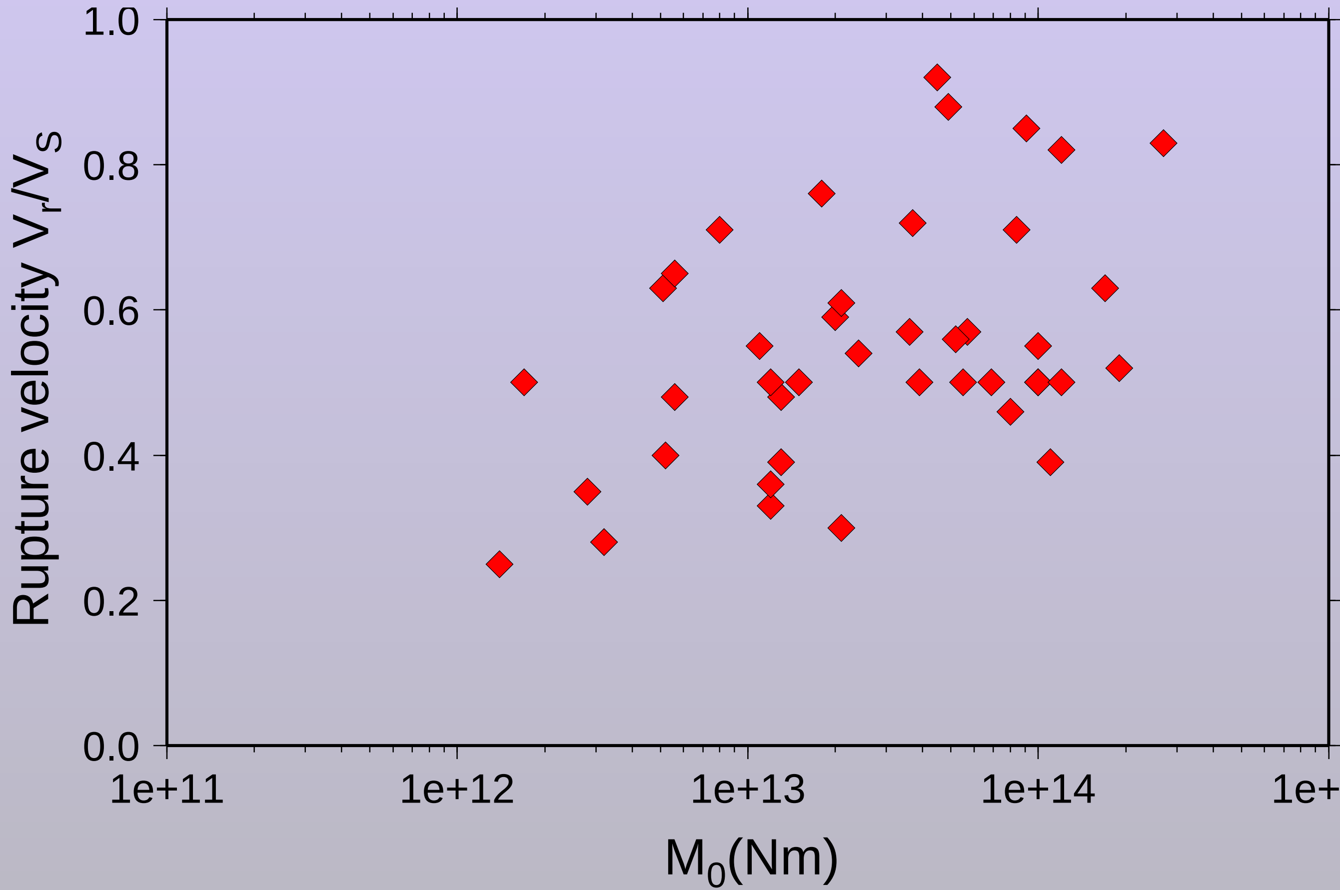
STW width - spatial distribution



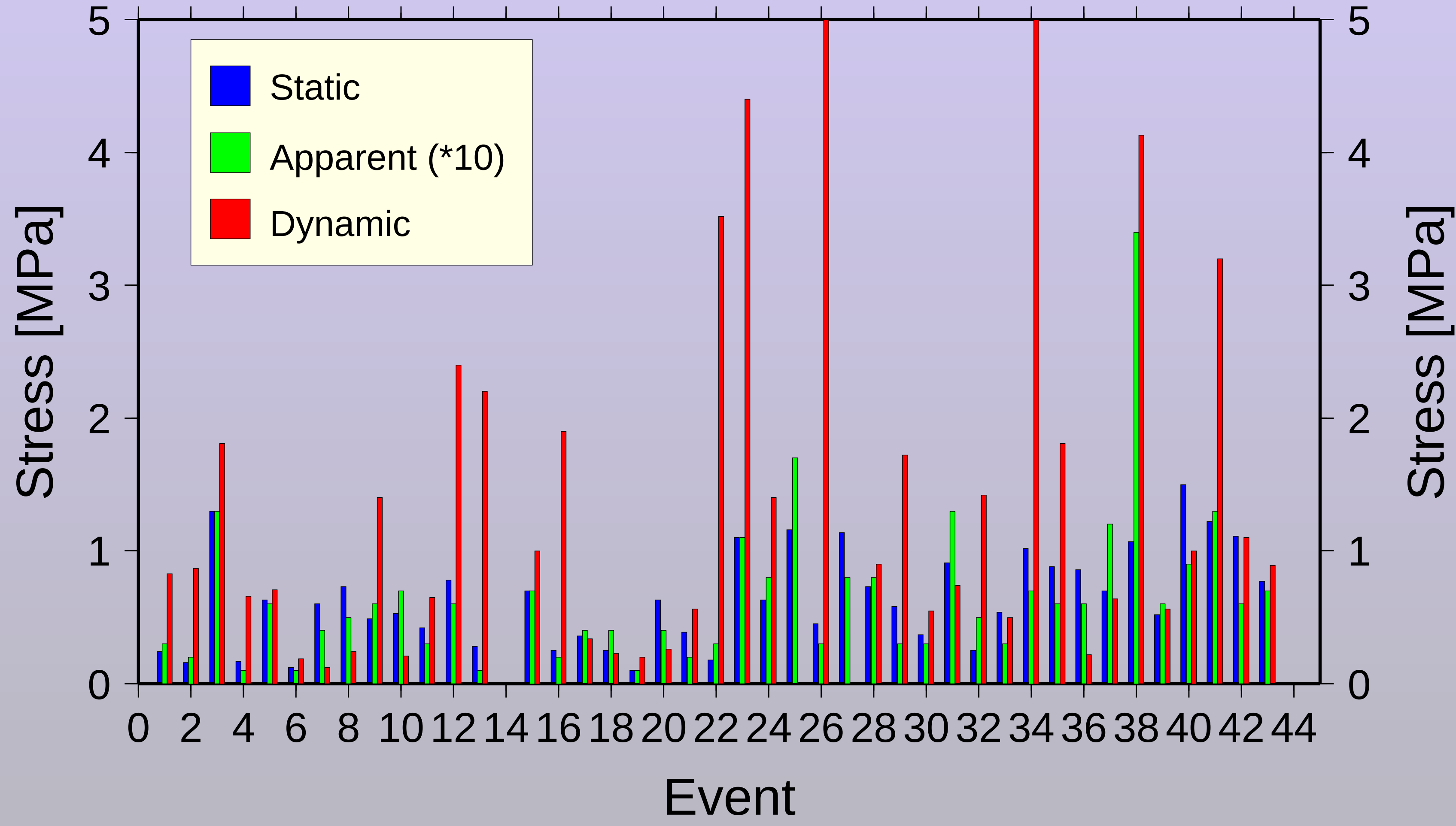
Rupture velocity



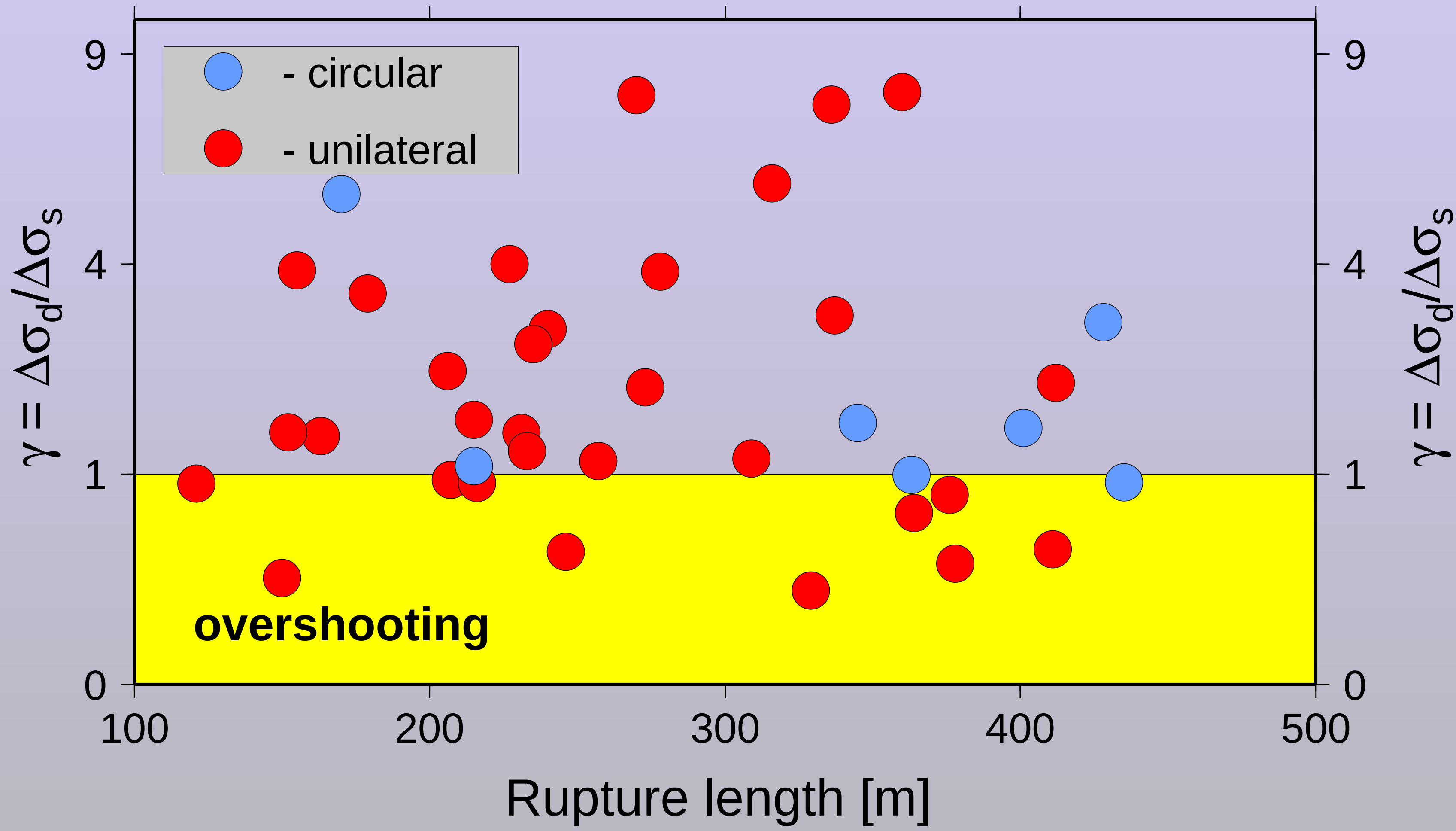
Rupture velocity



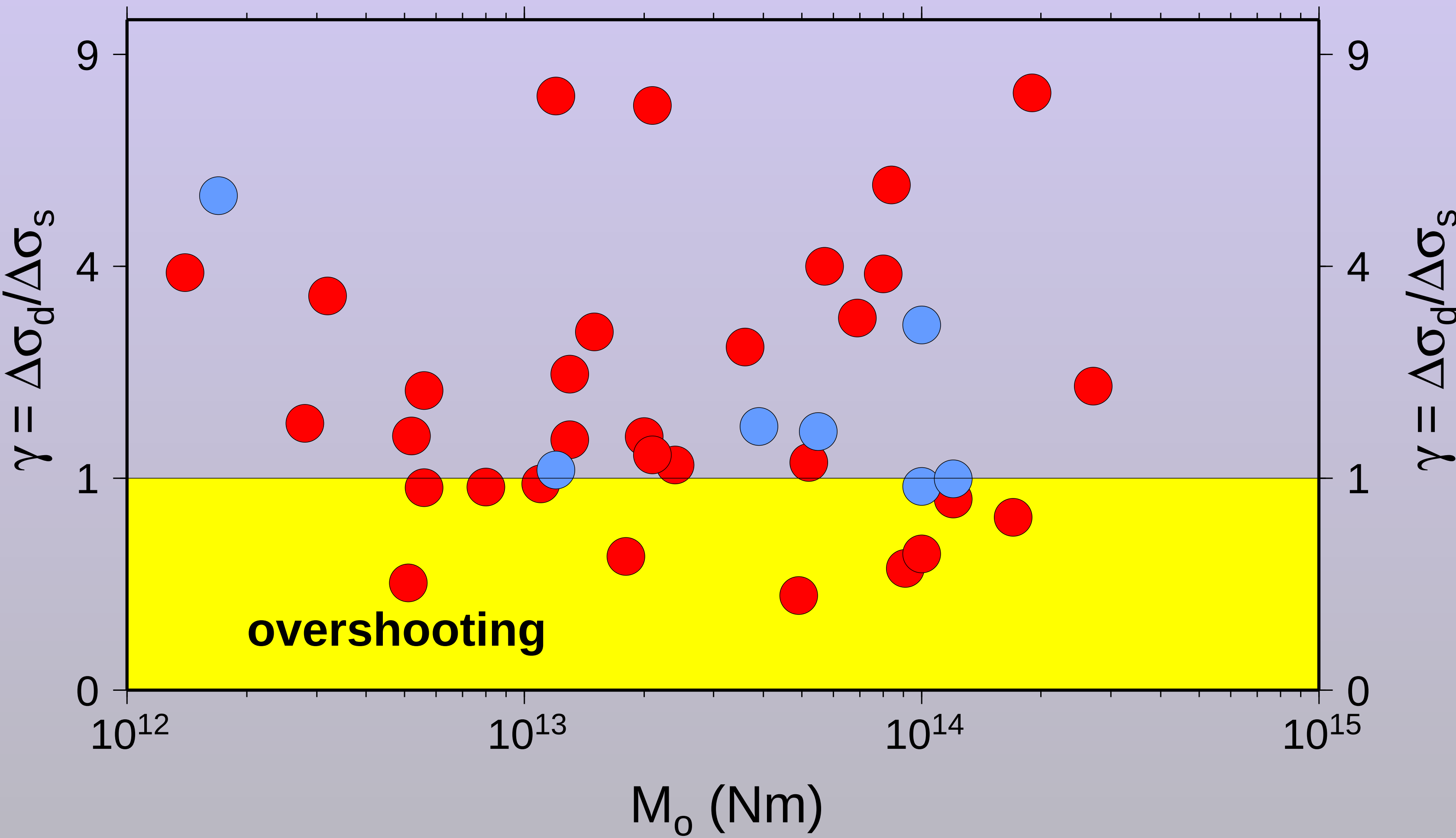
Stress estimates



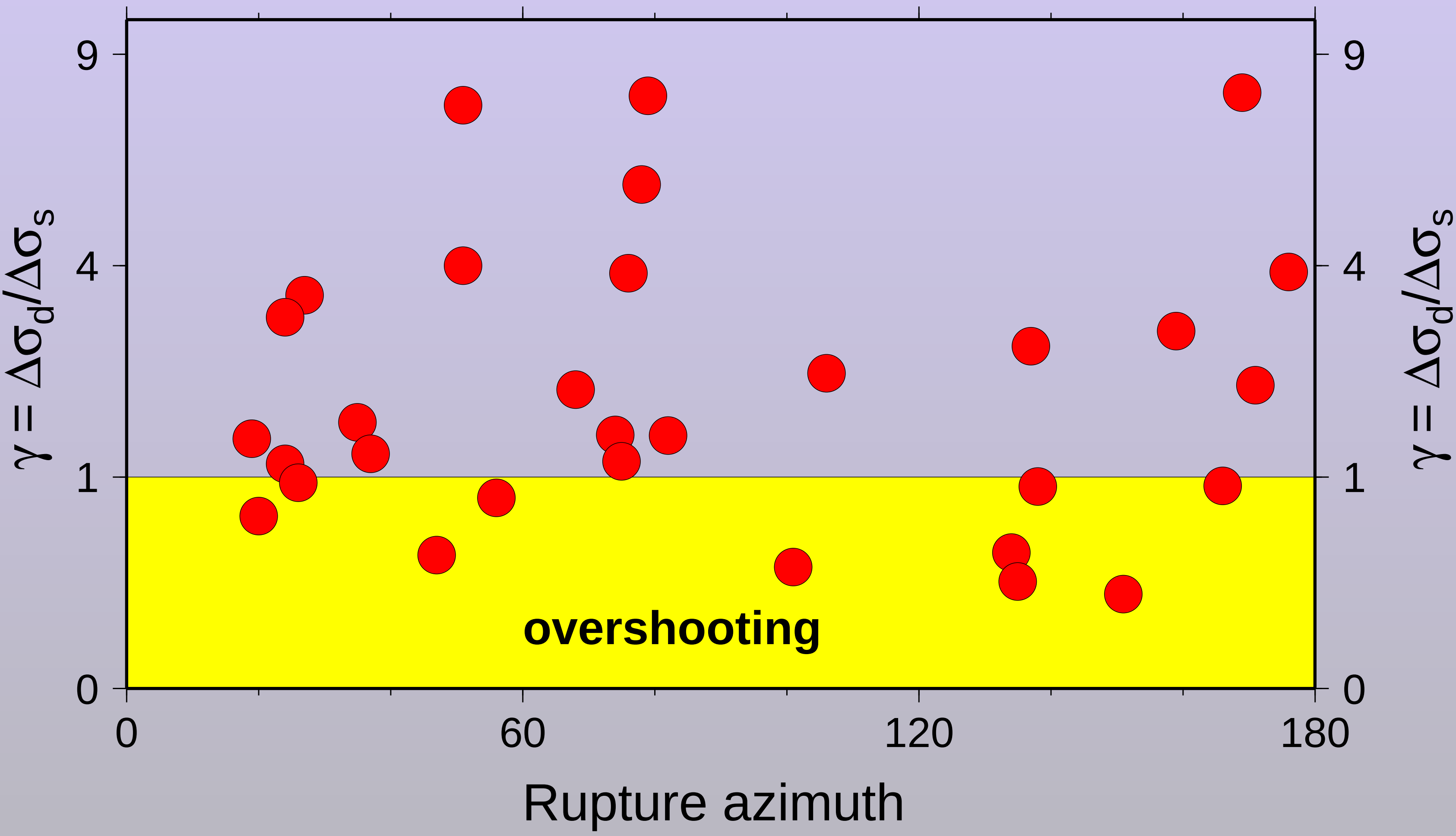
Correlations



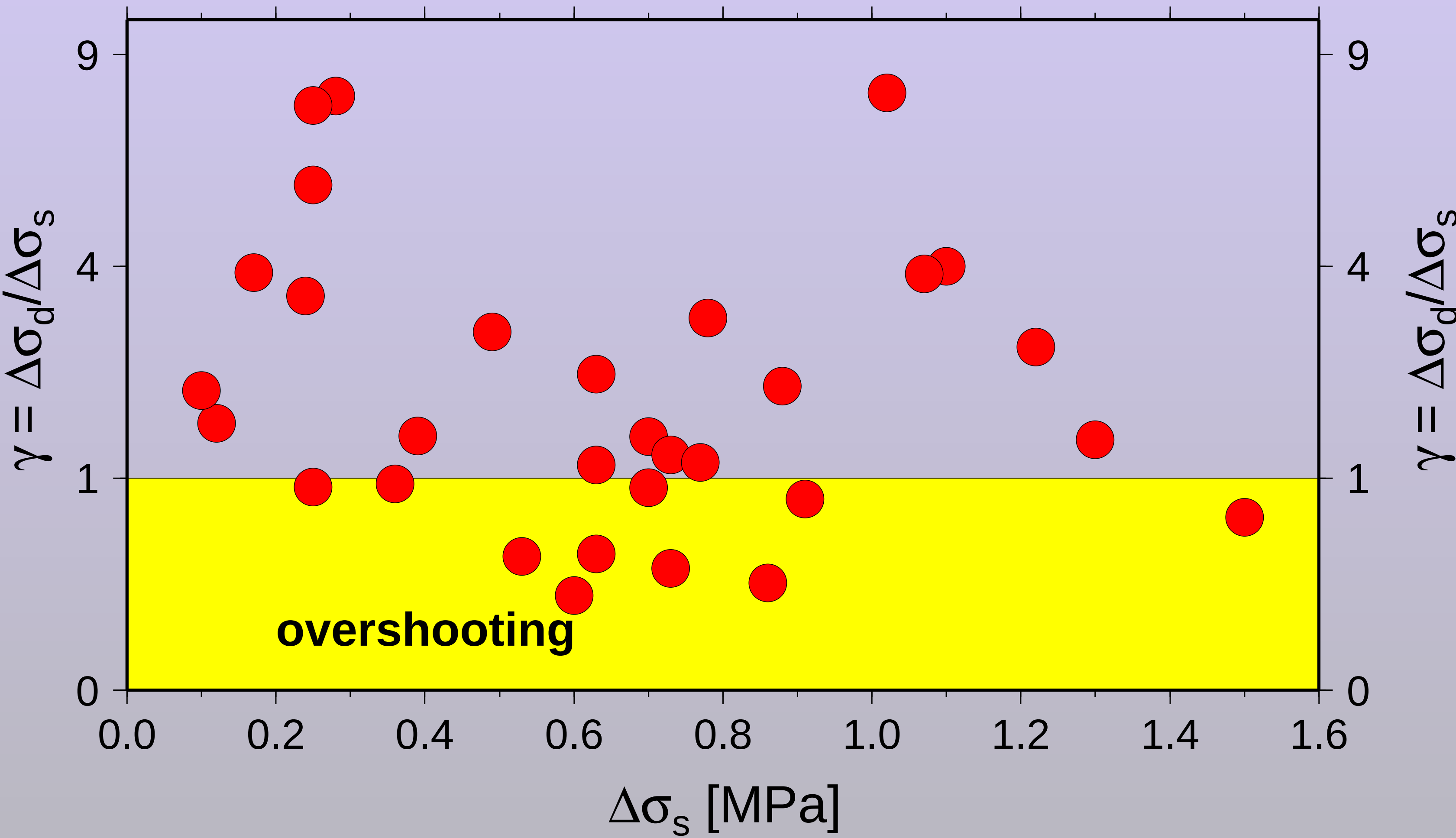
Correlations



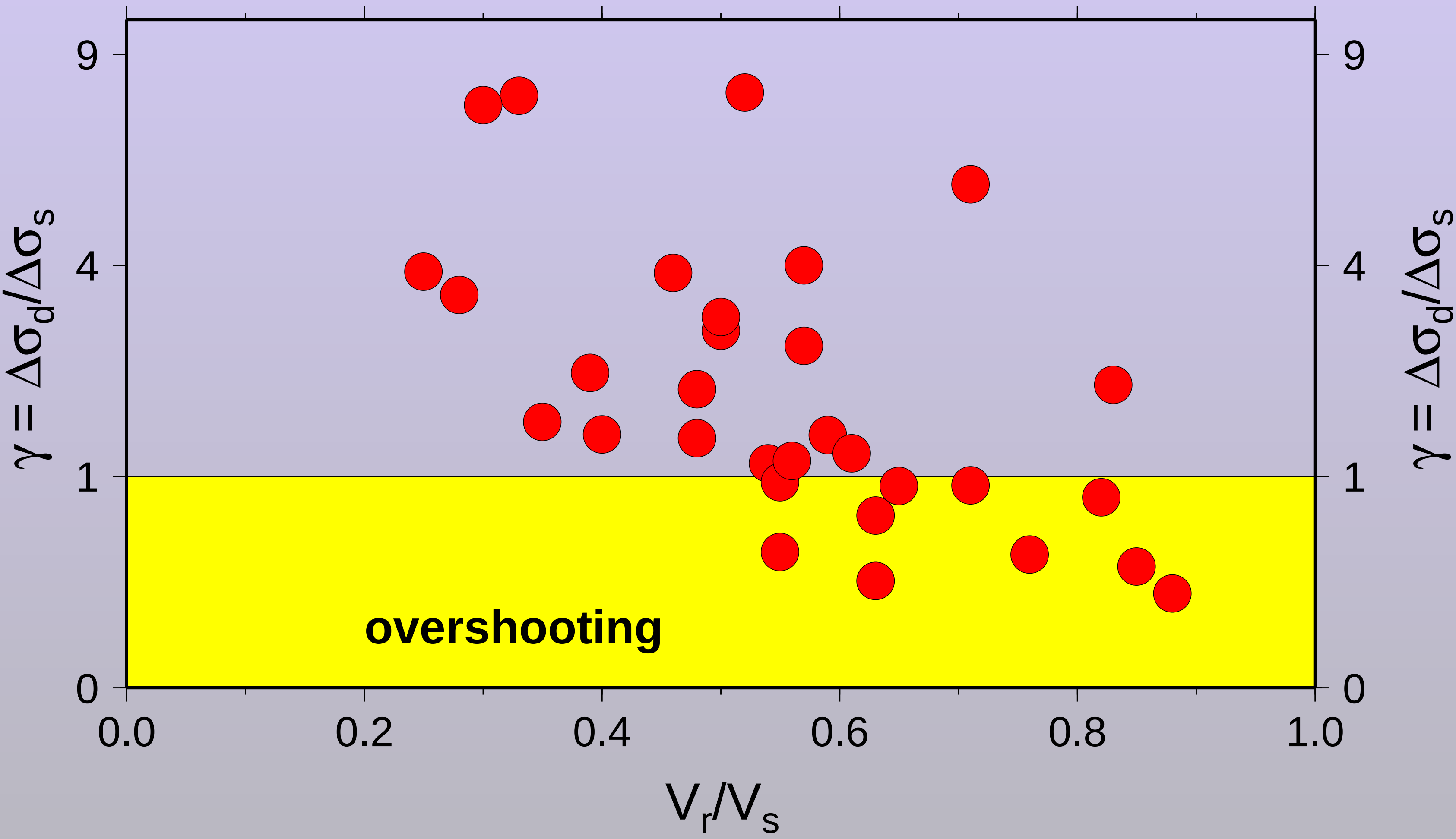
Correlations



Correlations

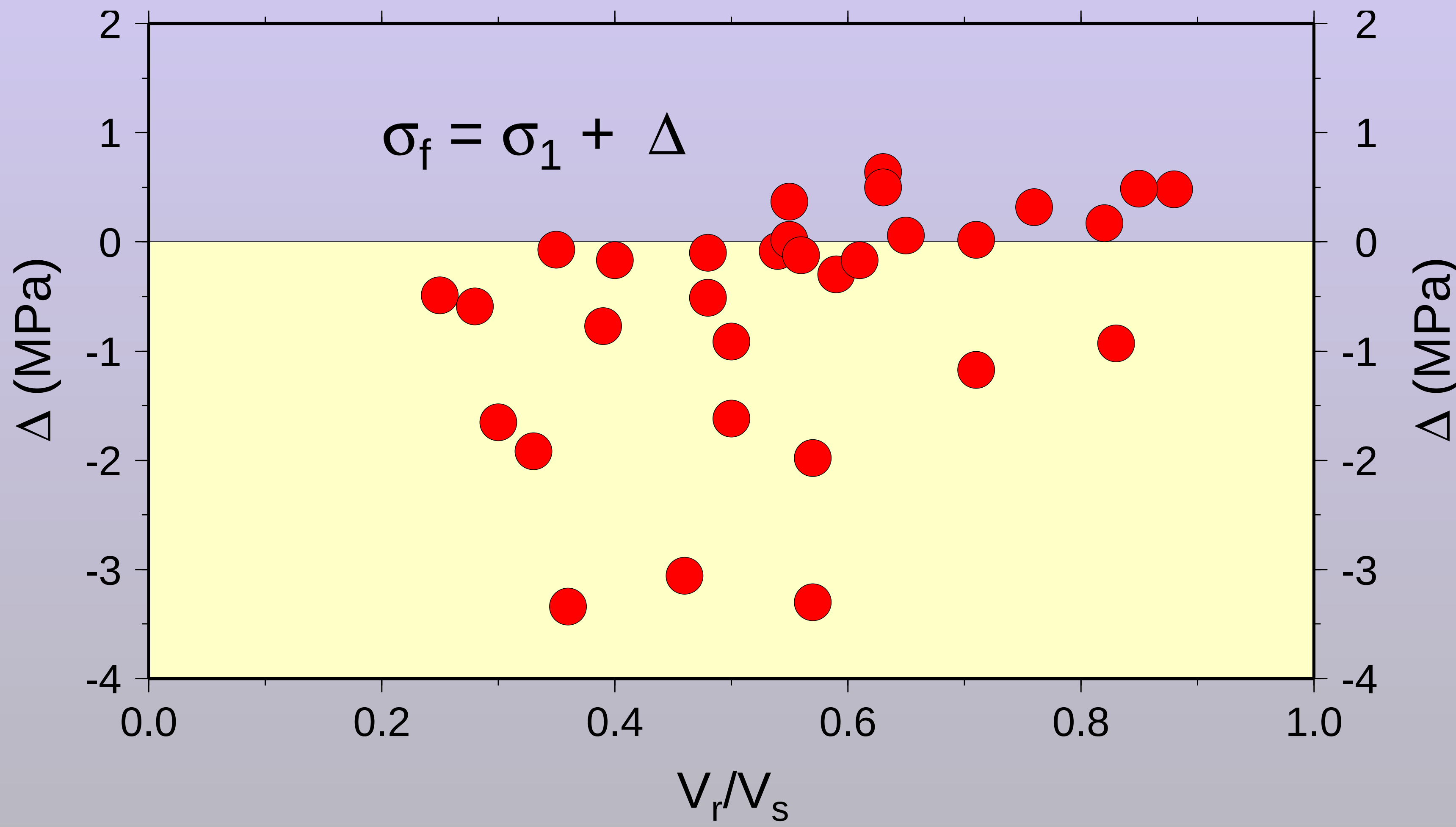


Velocity

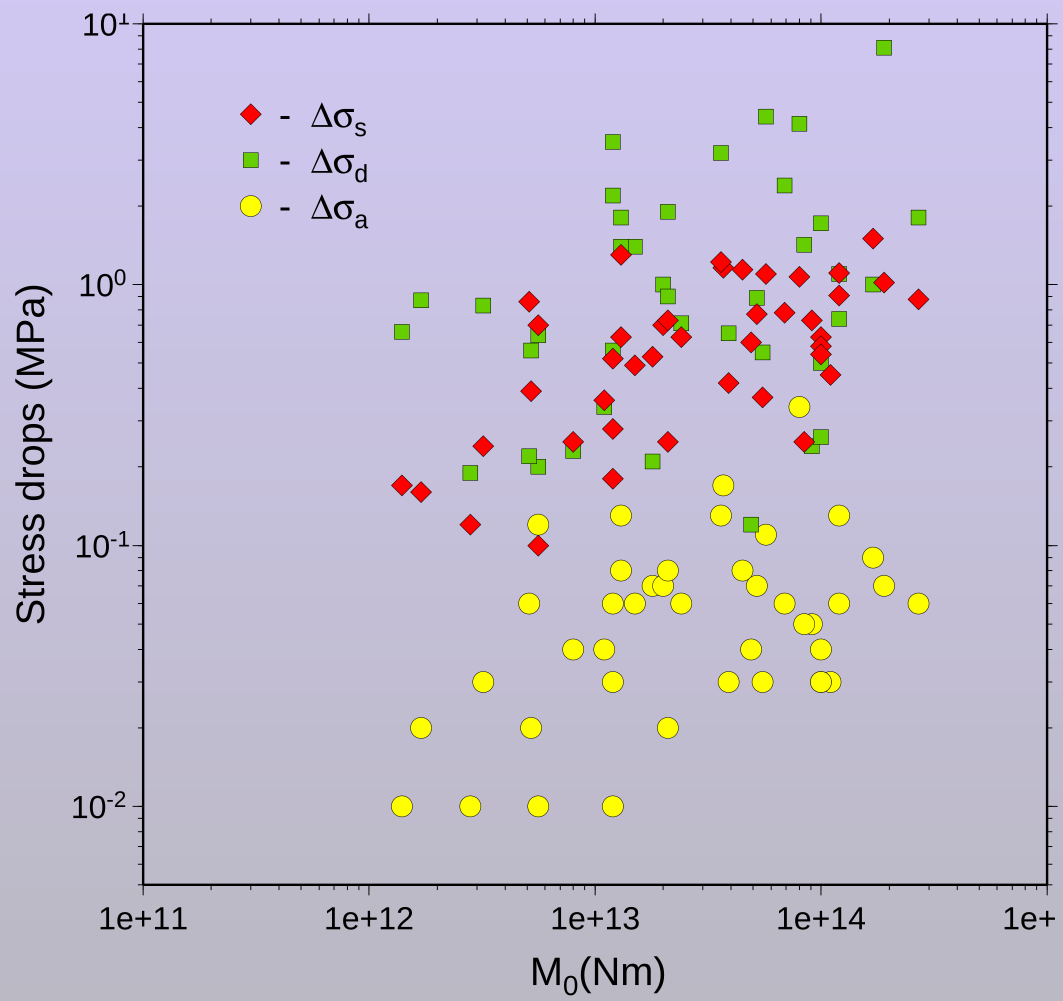


9
4
1
0
9
4
1
0
$\gamma = \Delta\sigma_d/\Delta\sigma_s$
$\gamma = \Delta\sigma_d/\Delta\sigma_s$
overshooting
0.0
0.2
0.4
0.6
0.8
1.0
V_r/V_s

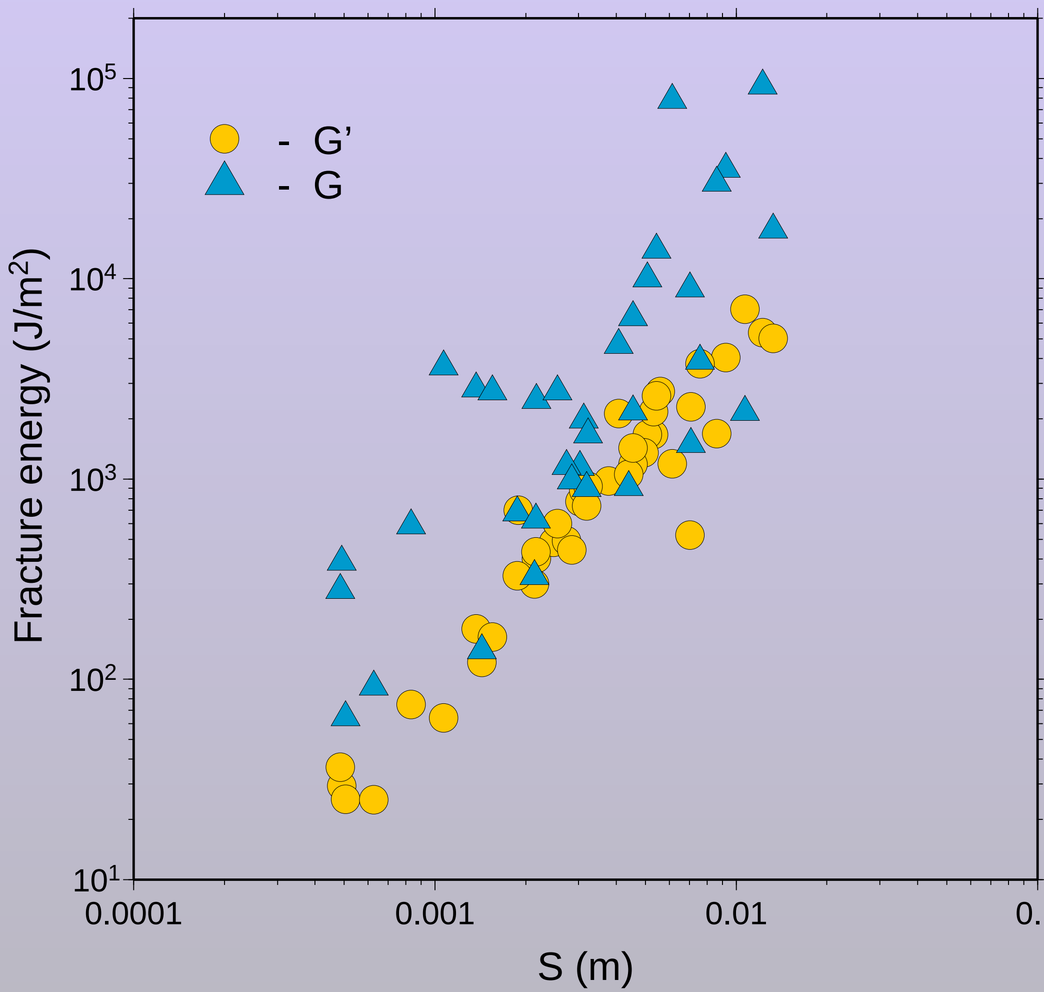
“Overshhoting” stress



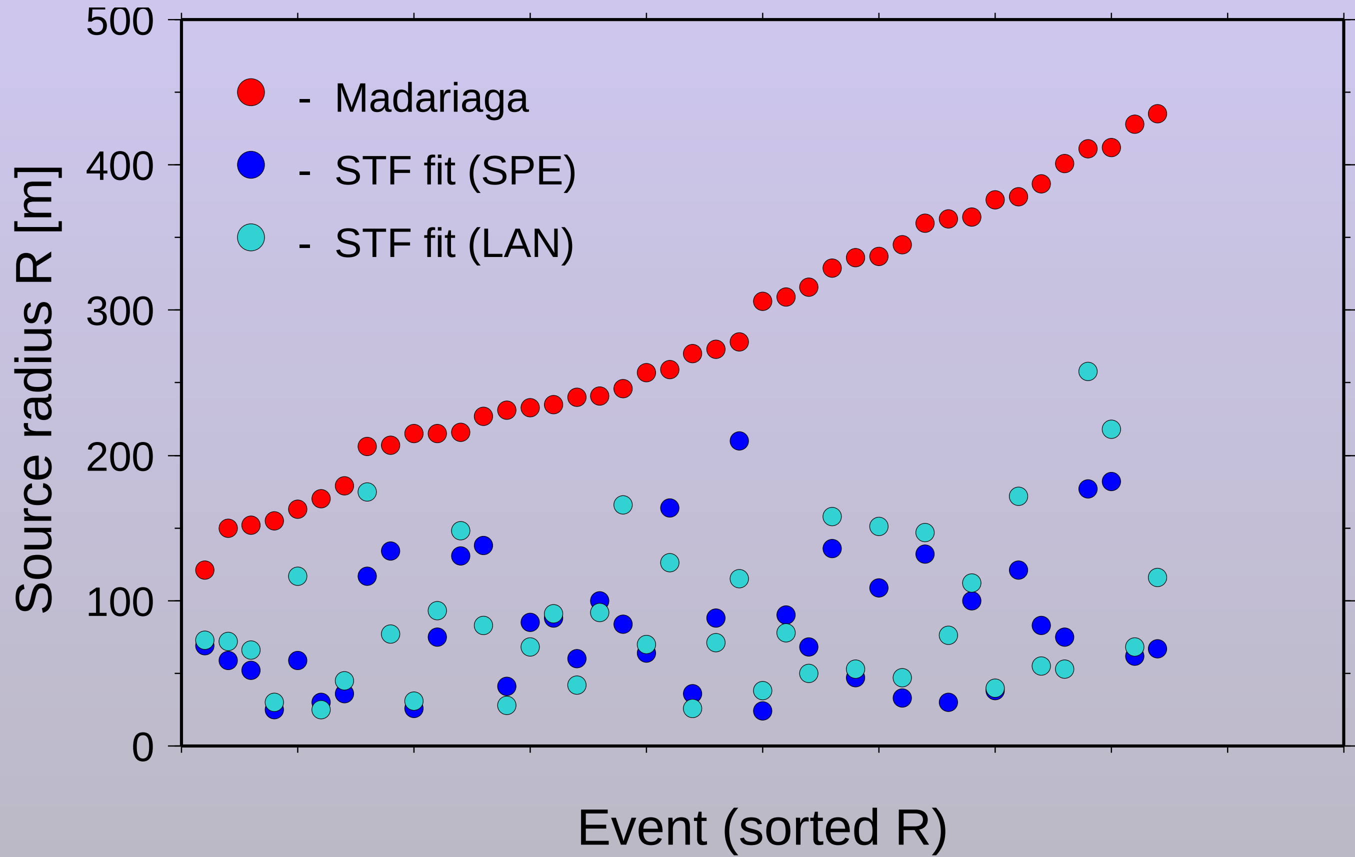
Scaling stresses with M_0



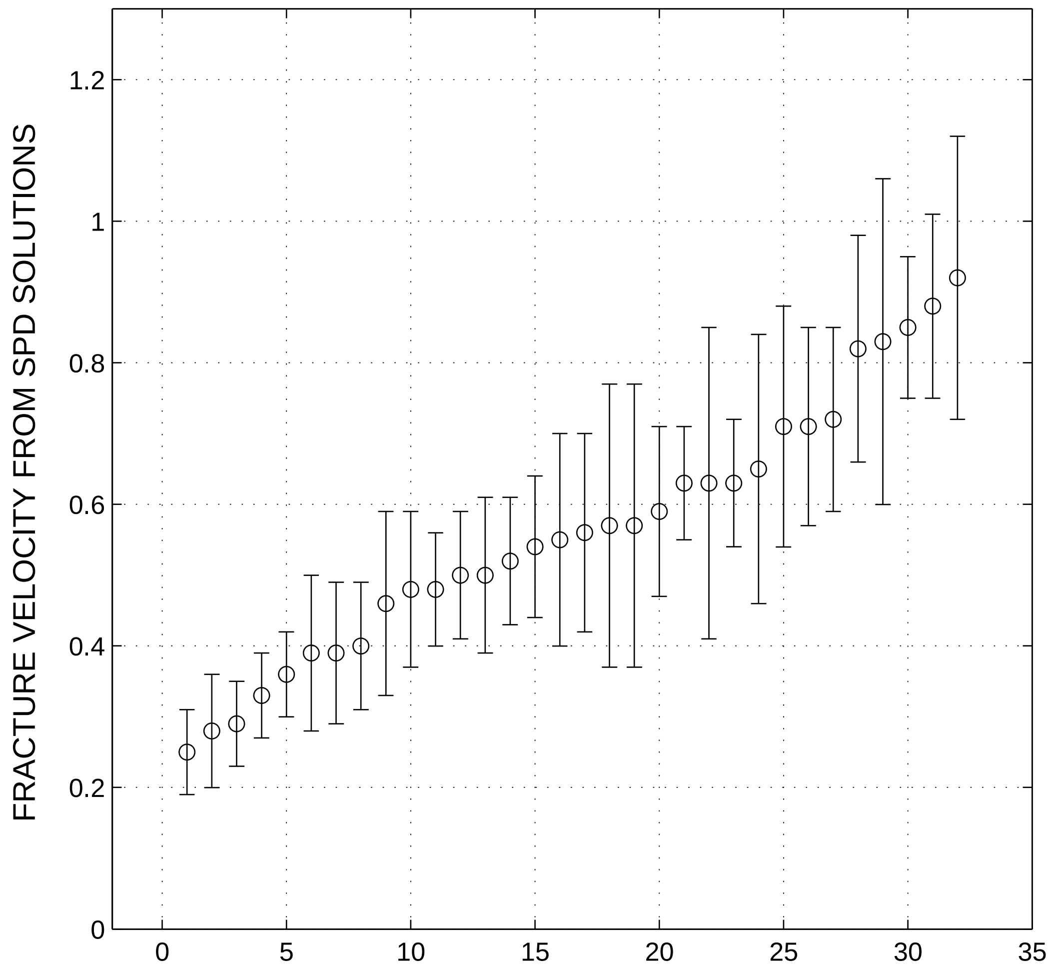
Fracture energy



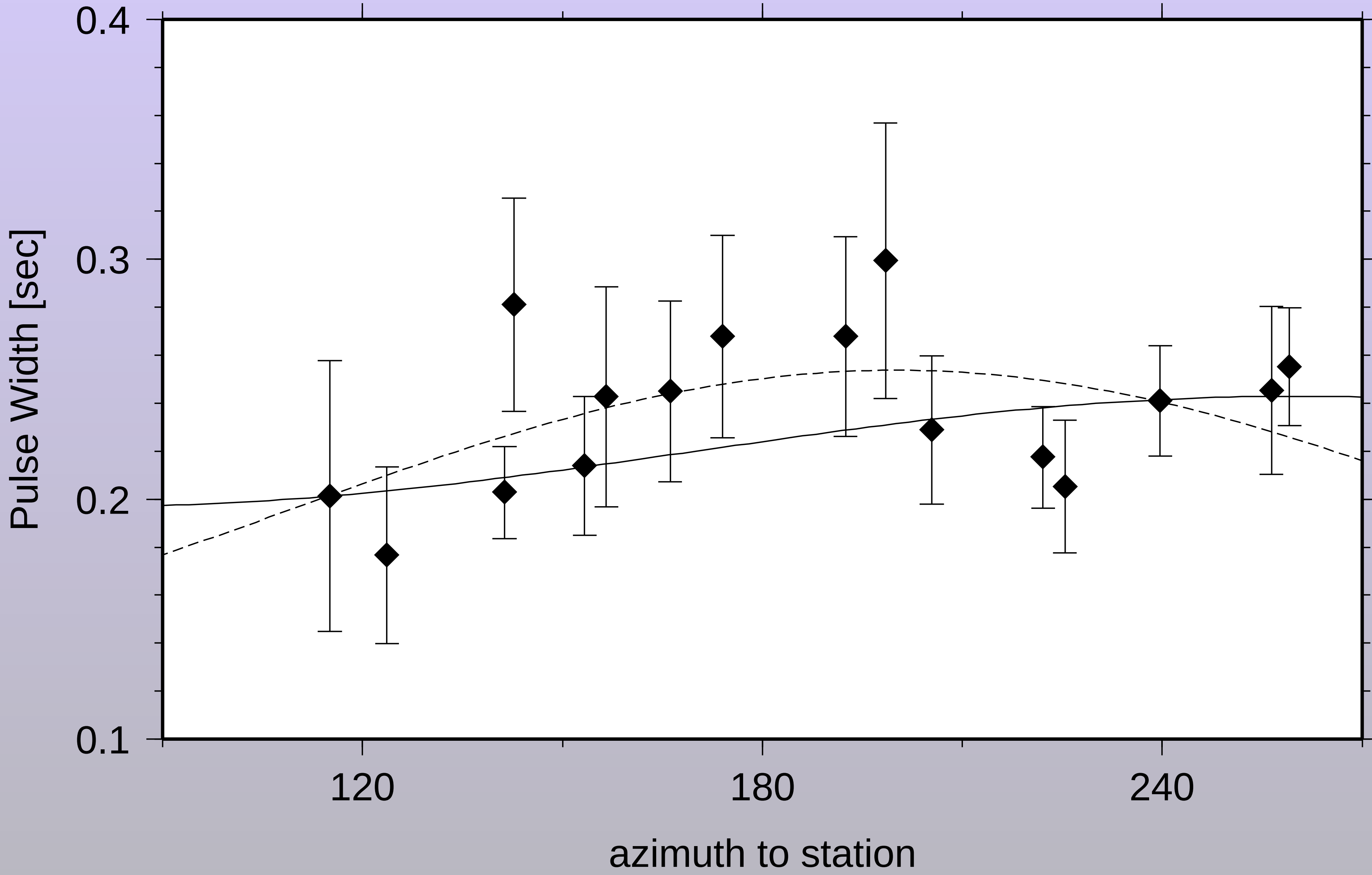
Source size: Madariaga, Brune, or ...



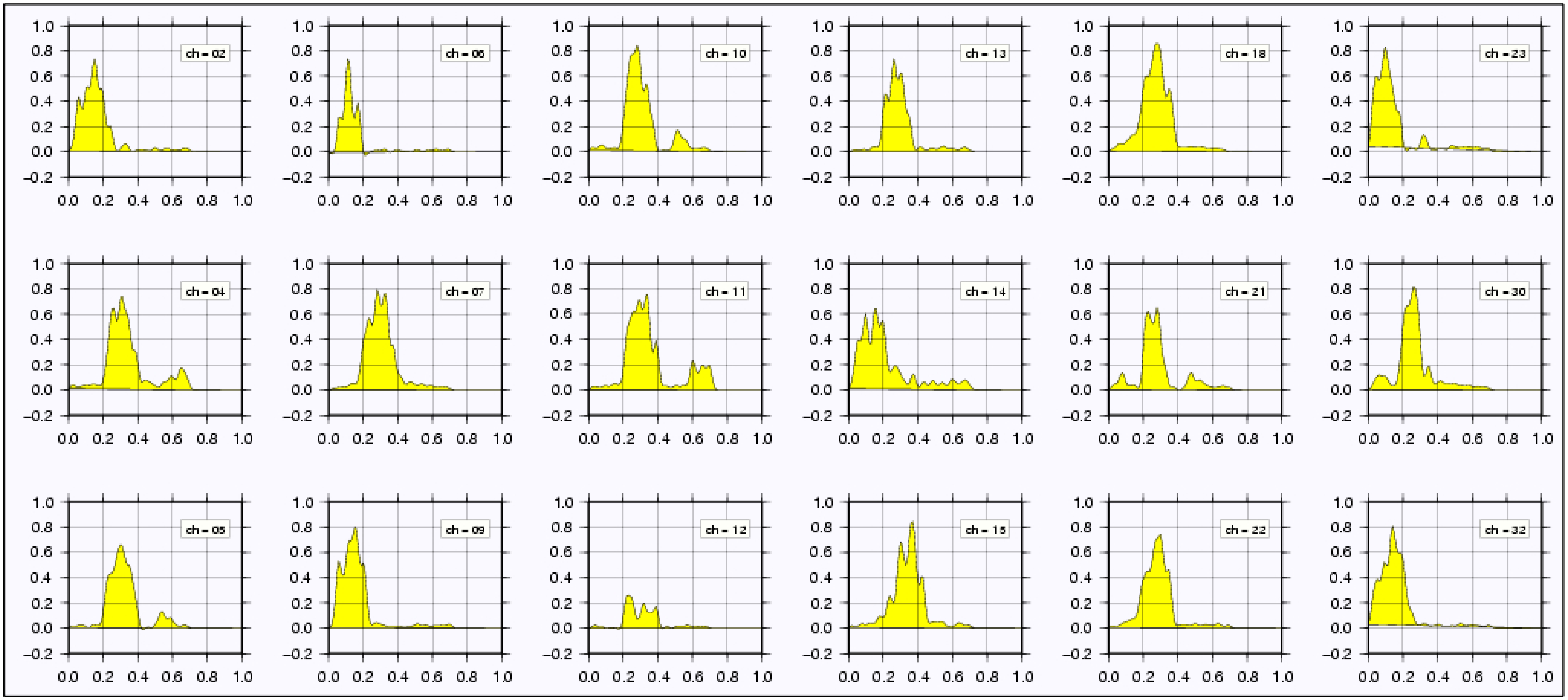
Uncertainties (a)



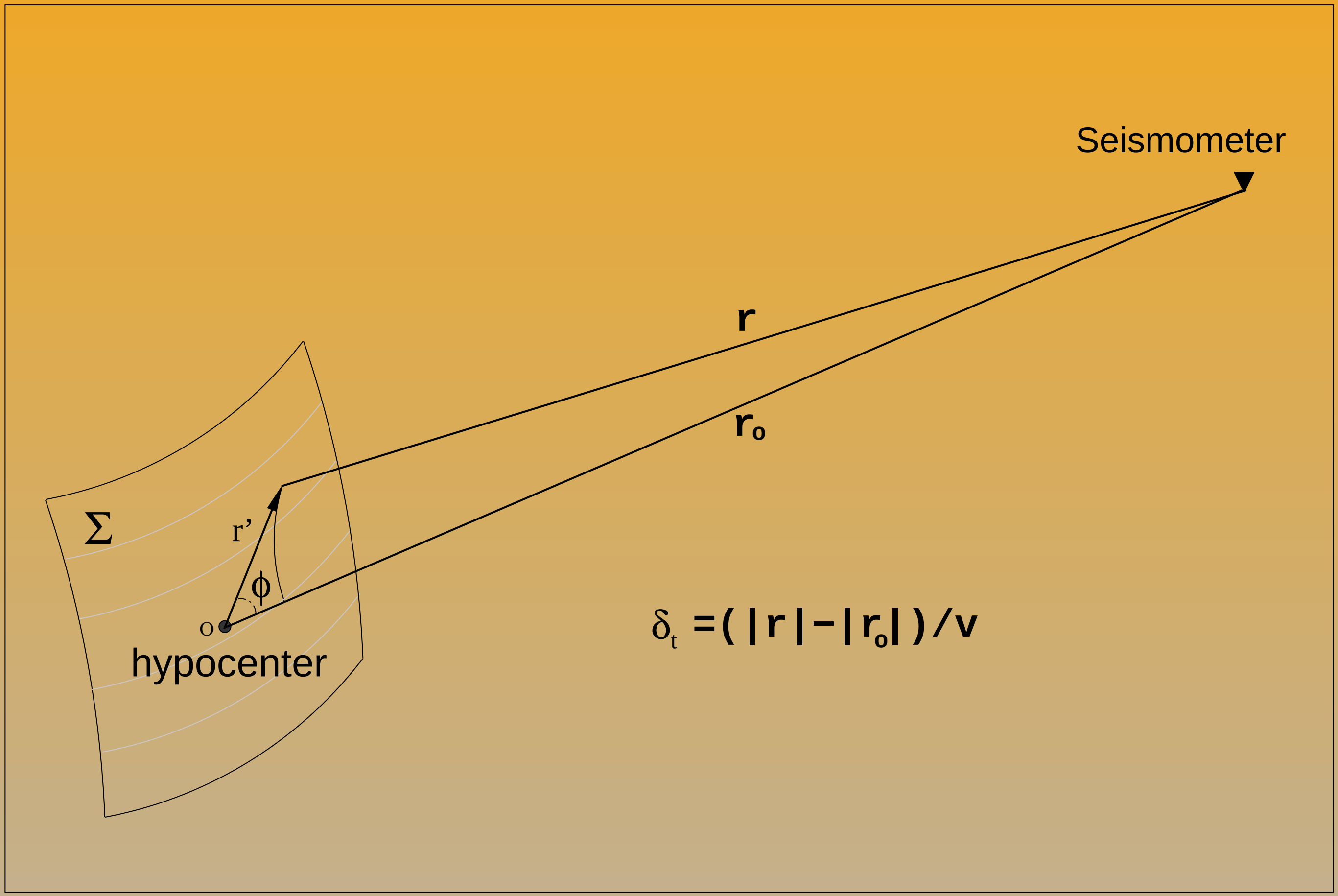
Uncertainties (b)



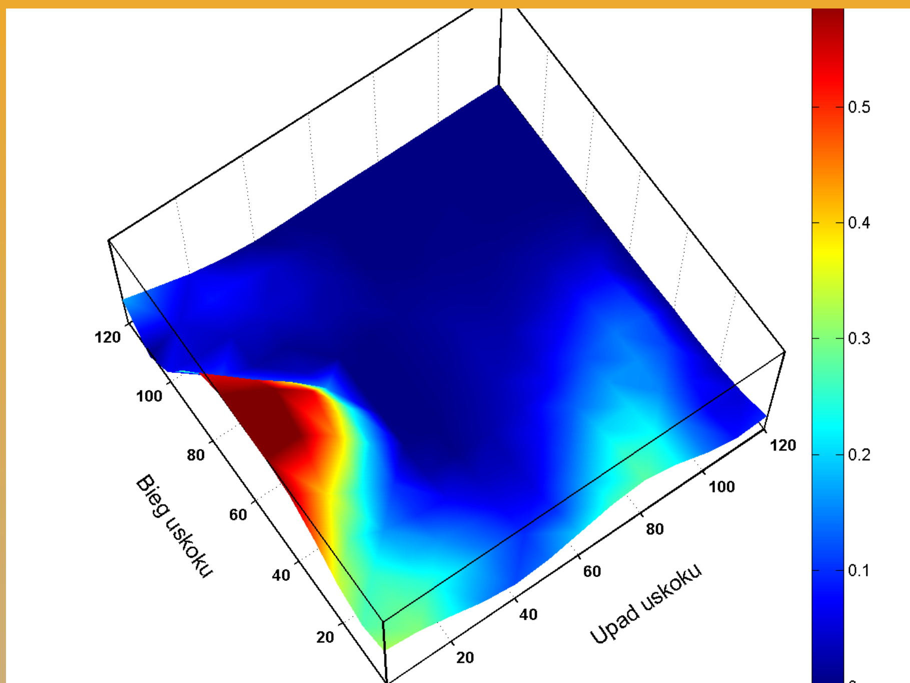
Finite size sources



Finite size sources



Case - A


120
100
80
60
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20
Bieg uskoku
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100
120
Upad uskoku
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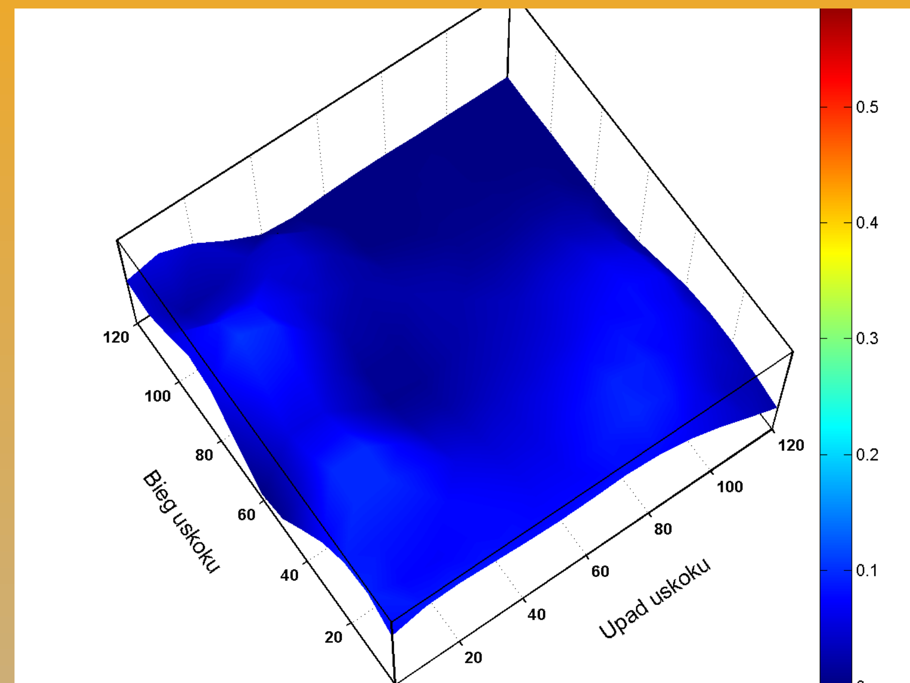
0.4
0.3
0.2
0.1
0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Bieg uskoku
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Upad uskoku
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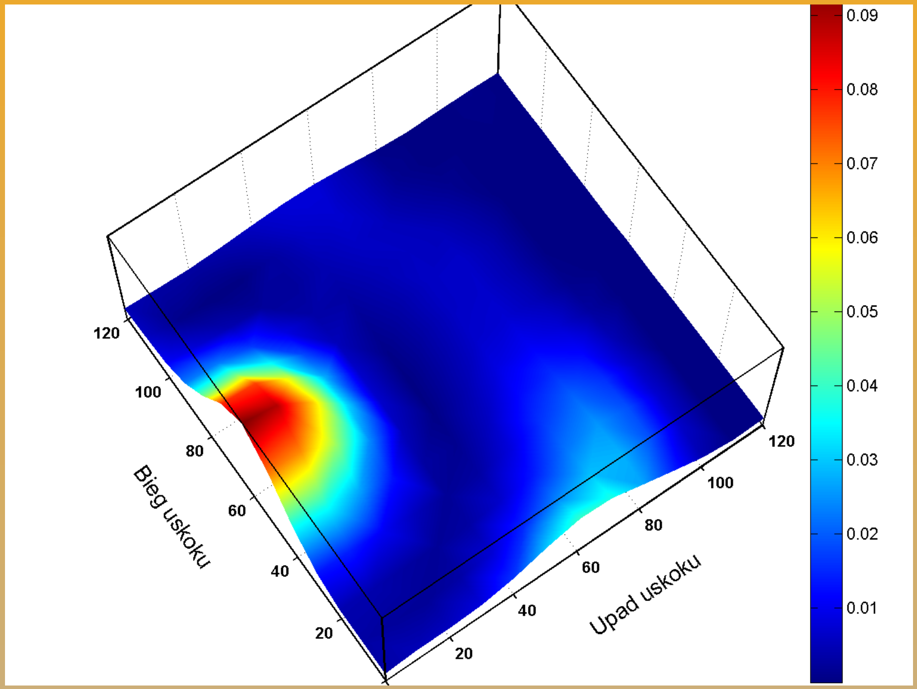
Case - B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0.05
0.04
0.03
0.02
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120
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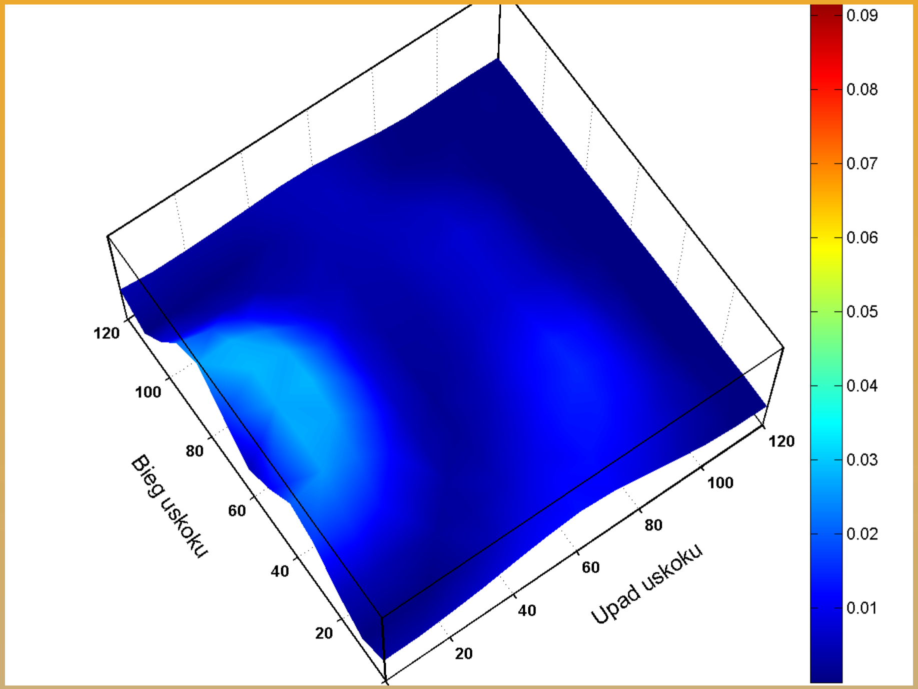
Bieg uskoku
20
40
60
80
100
120
Upad uskoku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0.08
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0.02
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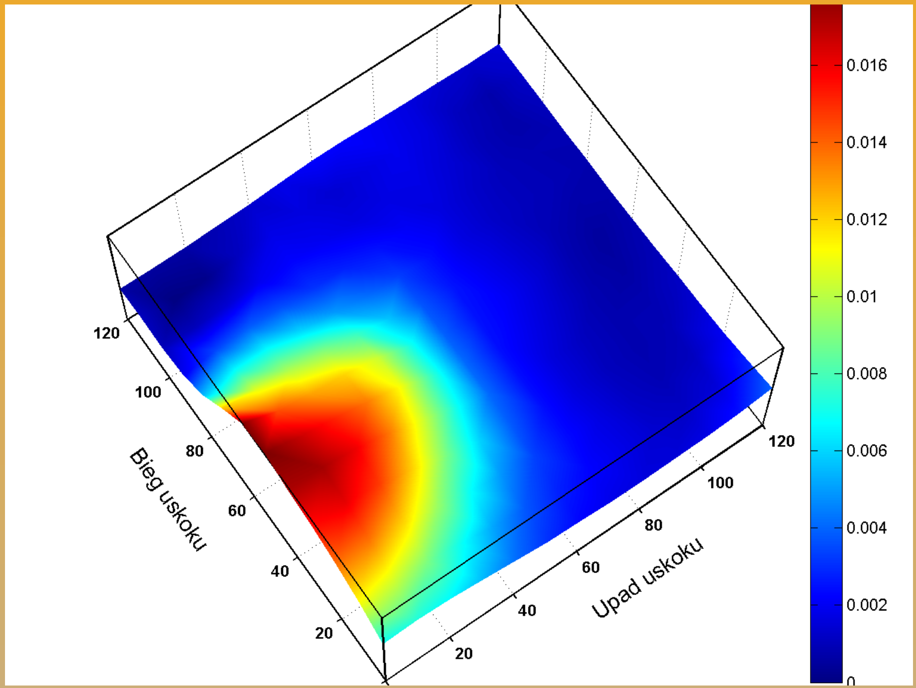
20
Bieg uskoku
20
40
60
80
100
120
Upad uskoku

Case - C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0.014
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0.002
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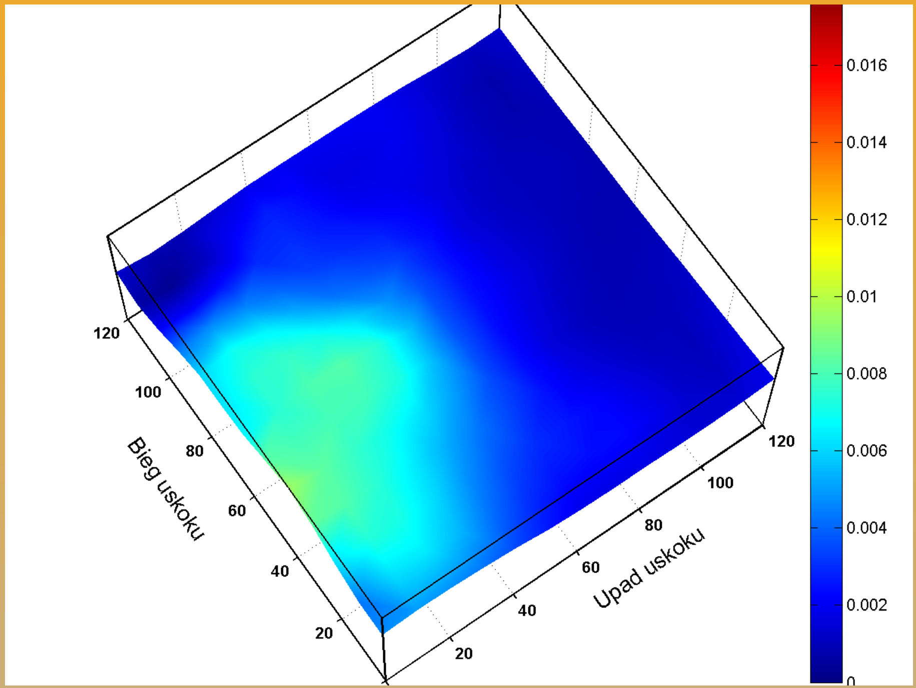
60
40
20
Bieg uskoku
Upad uskoku


0.016
0.014
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0.008
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0.004
0.002
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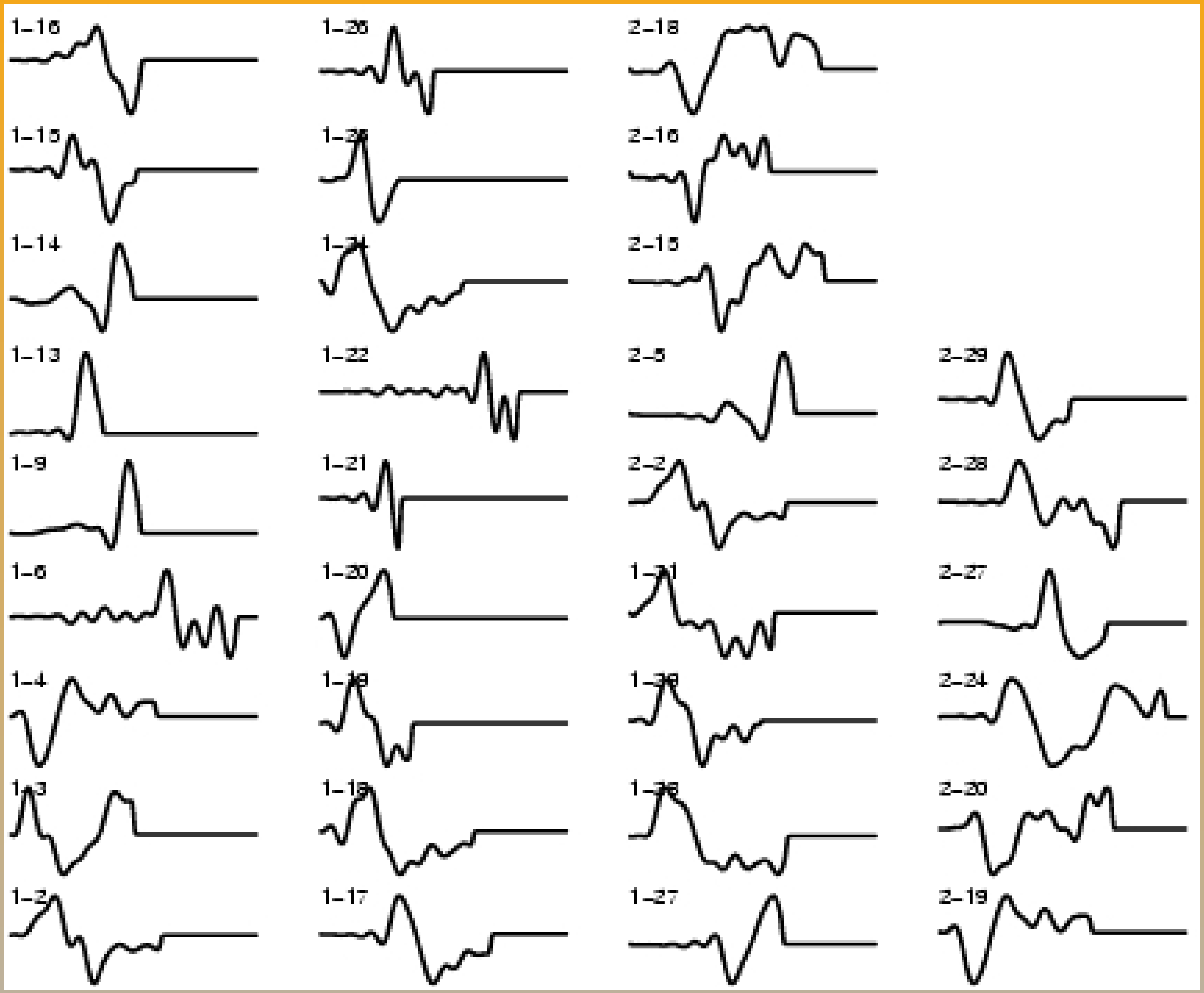
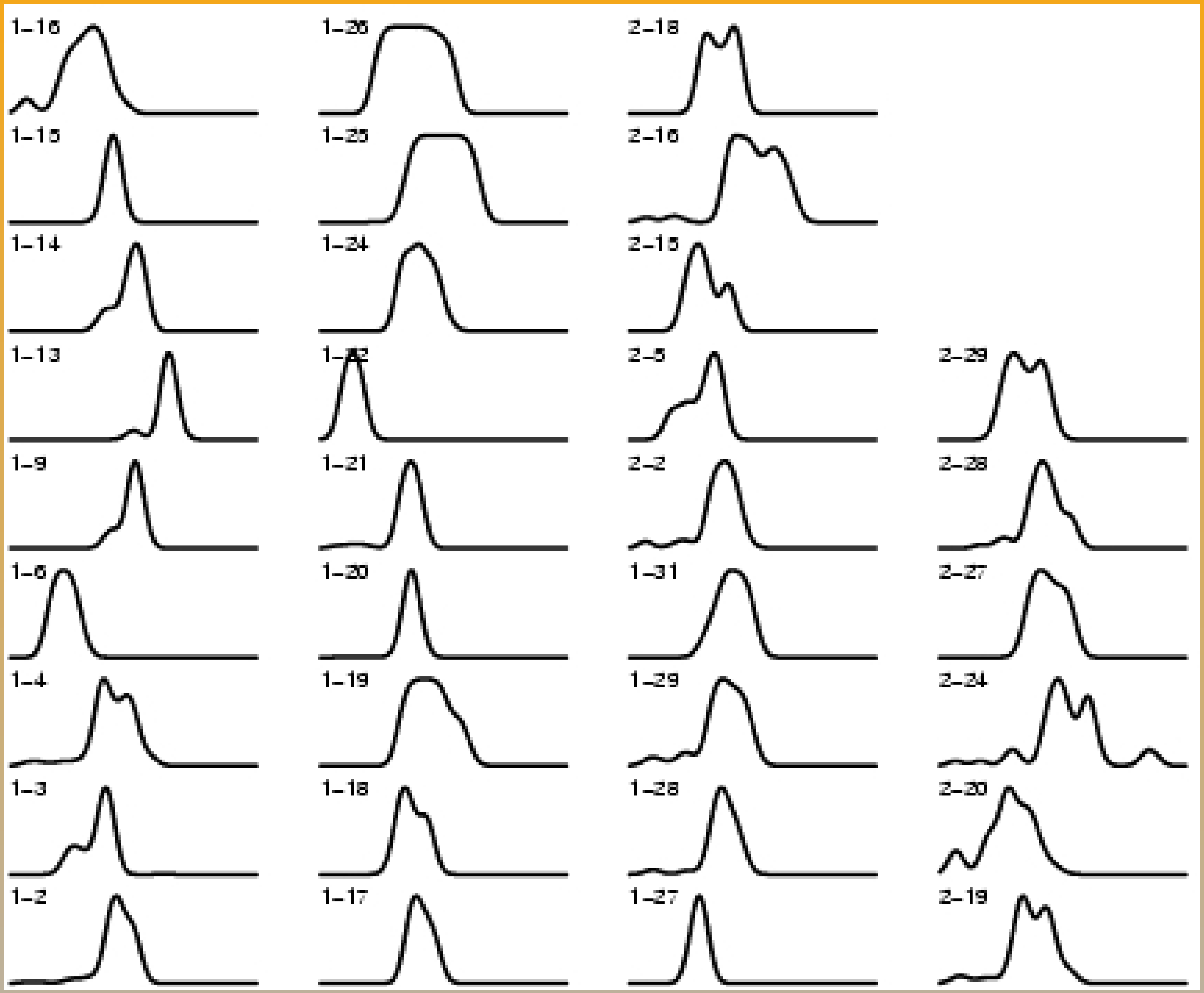
120
100
80
60
40
20
Bieg uskoku
Upad uskoku

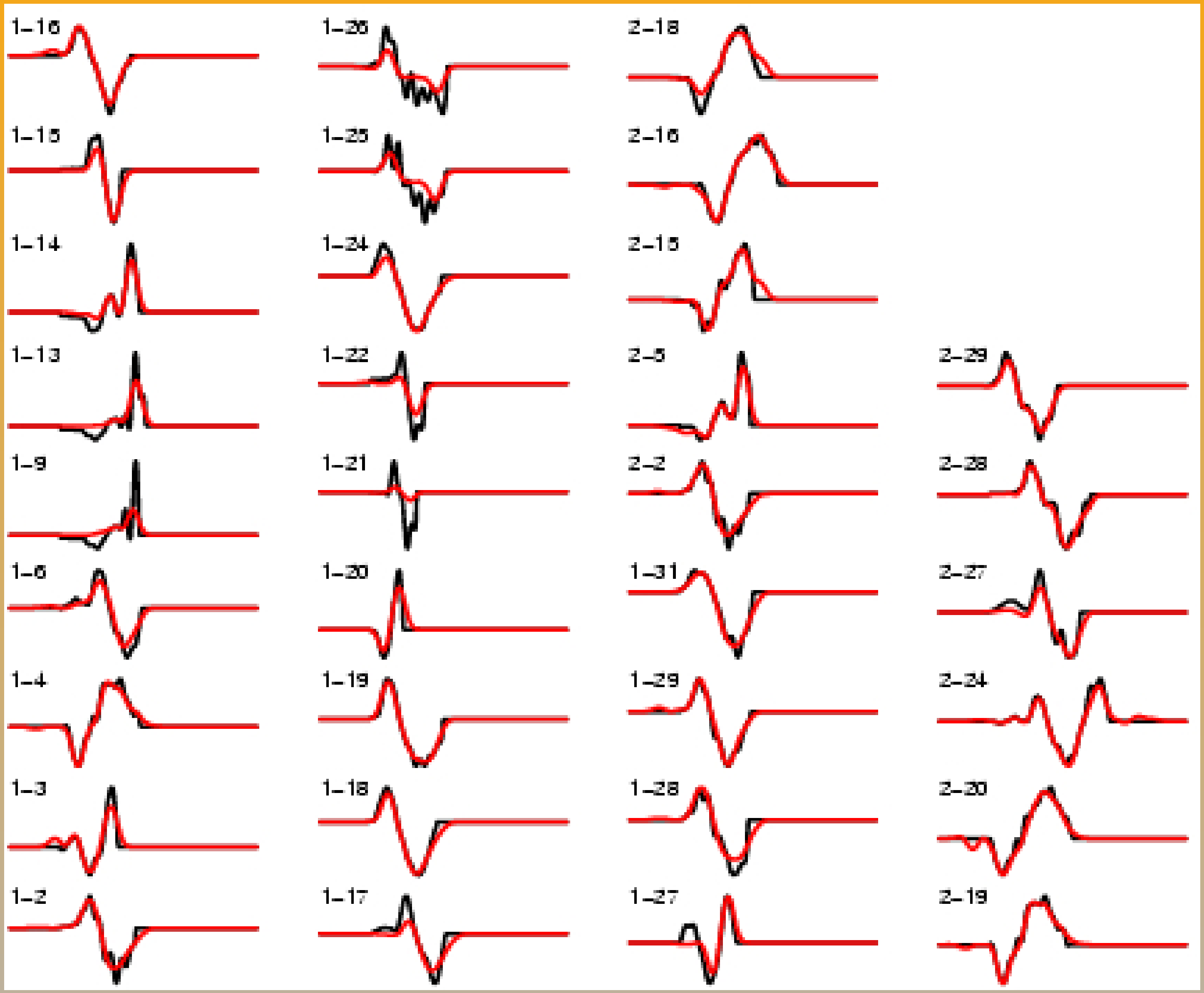
Empirical Green Functions



Source Time Function



Synthetics/Seismograms



Inverse problem - Indirect Measurements

$$\mathbf{d}^{obs} \Longrightarrow \mathbf{m}$$

Solution

$$||\mathbf{d}^{obs} - \mathbf{d}^{th}(\mathbf{m})|| + \lambda||\mathbf{m}^{ml} - \mathbf{m}^{apr}|| = \min$$

Errors

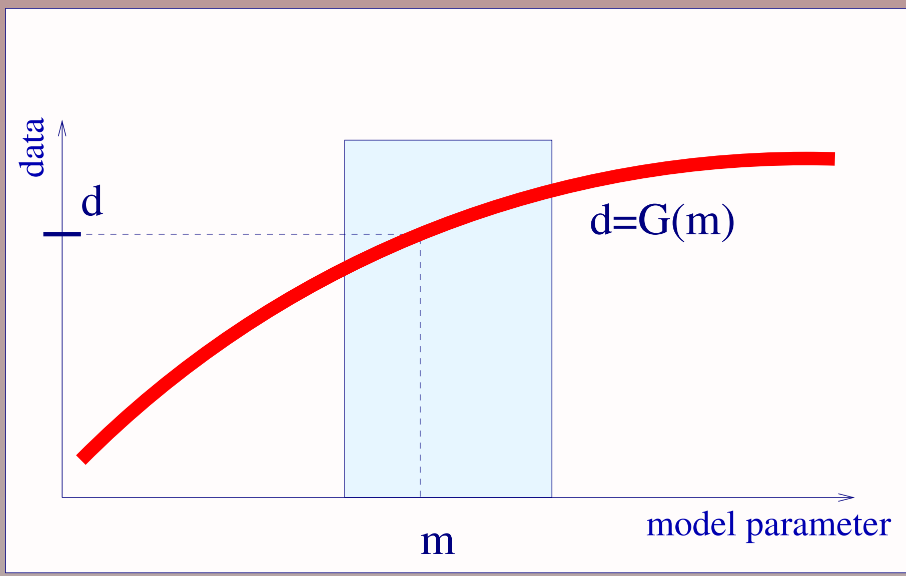
$$\mathbf{m}^{true} = \mathbf{m}^{ml} + \epsilon_{\mathbf{m}}$$

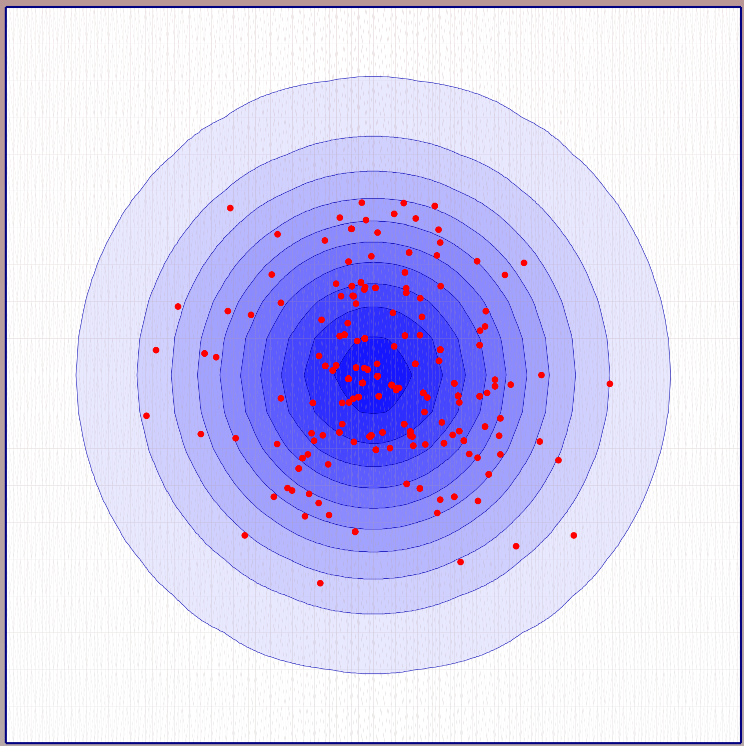
$$\epsilon_{\mathbf{m}} = ???$$

Inversion Algorithms

Method	Advantages	Limitations
Algebraic (LSQR)	- Simplicity	- Only linear problems
$\mathbf{m}^{ml} = (\mathbf{G}^T\mathbf{G} + \gamma\mathbf{I})^{-1}\mathbf{G}^T \cdot \mathbf{d}^{obs}$	- Large scale problems	- Lack of robustness
Optimization	- Simplicity	- Difficult error estimation
$\|\mathbf{G}(\mathbf{m}) - \mathbf{d}^{obs}\| + \lambda\|\mathbf{m}) - \mathbf{m}^a\| \ = \ \min$	- Fully nonlinear	
Bayesian	- Fully nonlinear	- More complex theory
$\sigma(\mathbf{m}) = f(\mathbf{m})L(\mathbf{m}, \mathbf{d}^{obs})$	- Full error handling	- Requires efficient sampler

Inversion algorithms

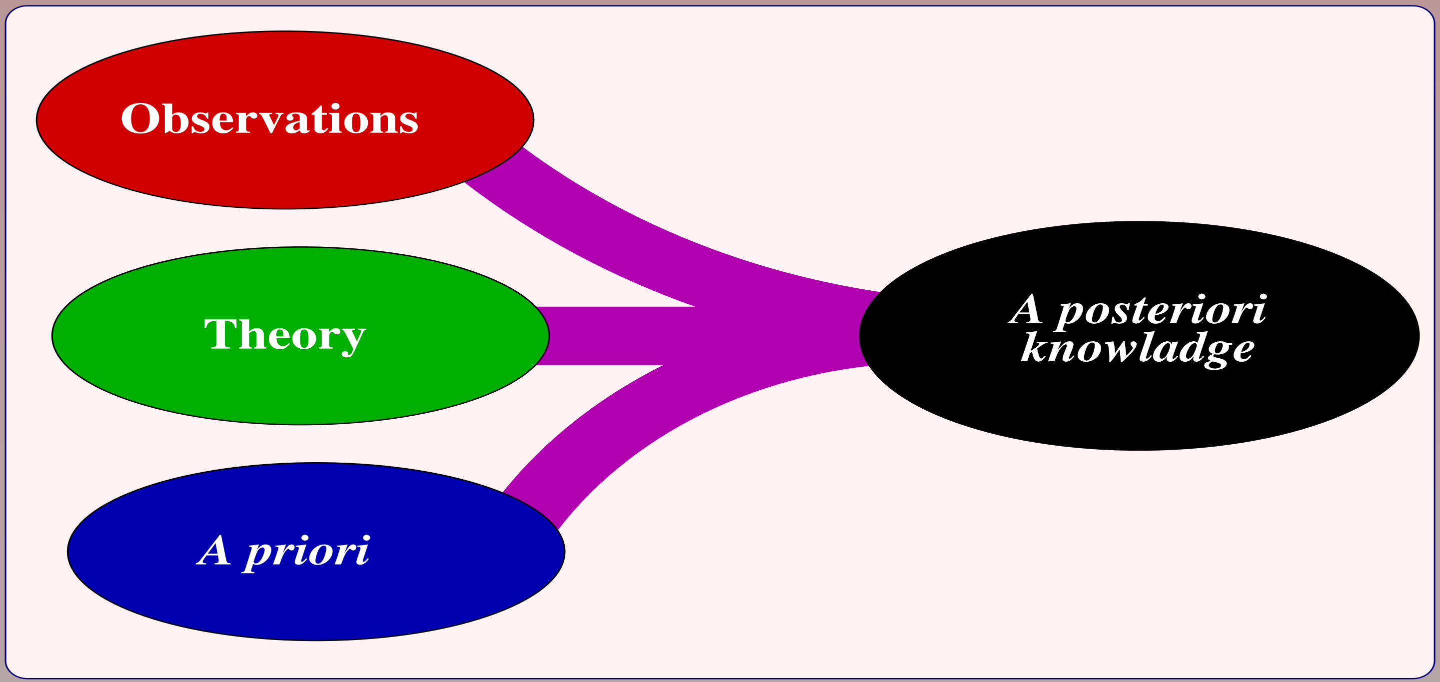




Back projection

Model space search

Bayesian Inversion - Basic Ideas



$$p_{post}(\mathbf{m}|\mathbf{d}) = \frac{p_{th}(\mathbf{d}|\mathbf{m})p_{apr}(\mathbf{m})}{p_{obs}(\mathbf{d})}$$

Probabilistic approach

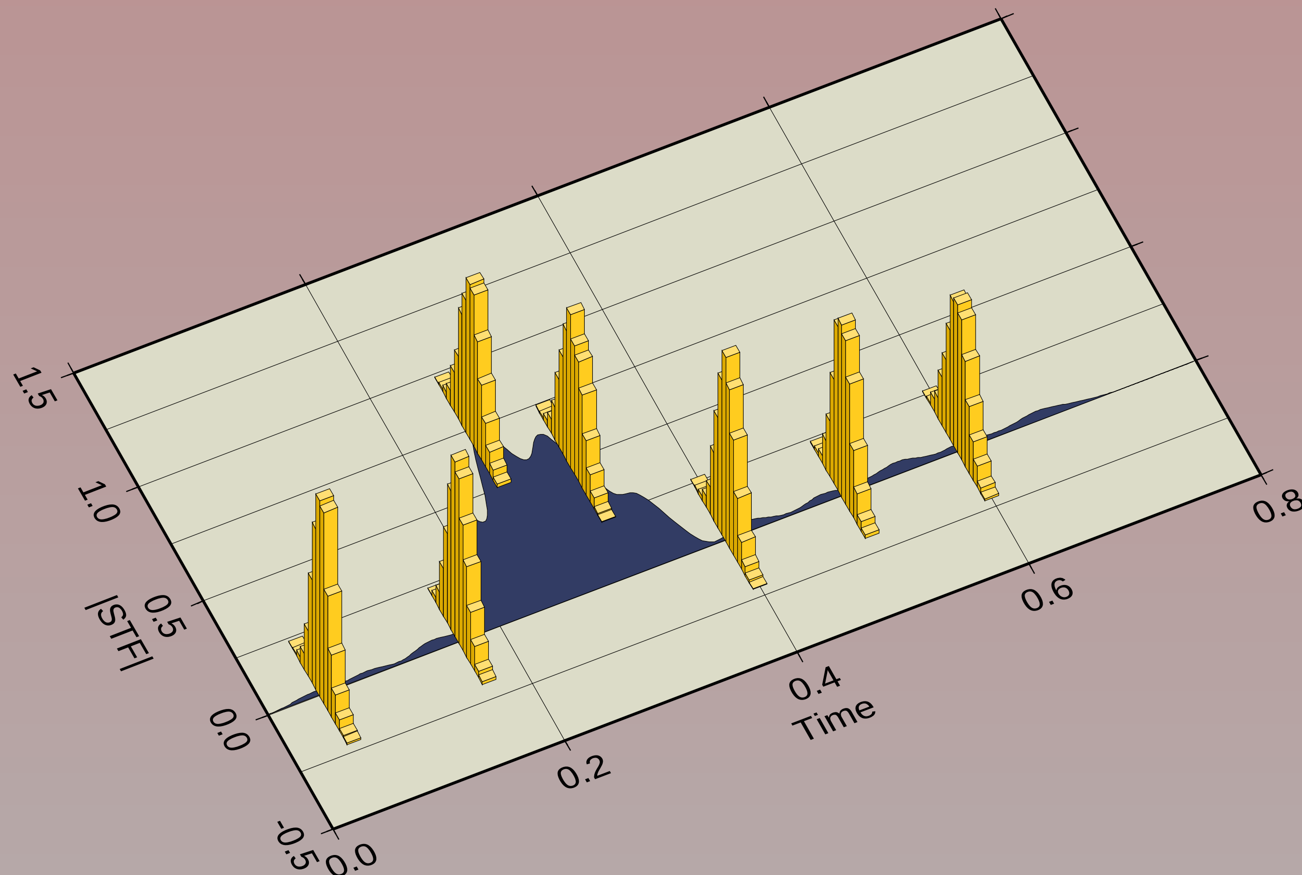
A posteriori pdf $\sigma(m, d)$:

- always exists
- is unique
- describes all information
- is the solution of an inverse problem

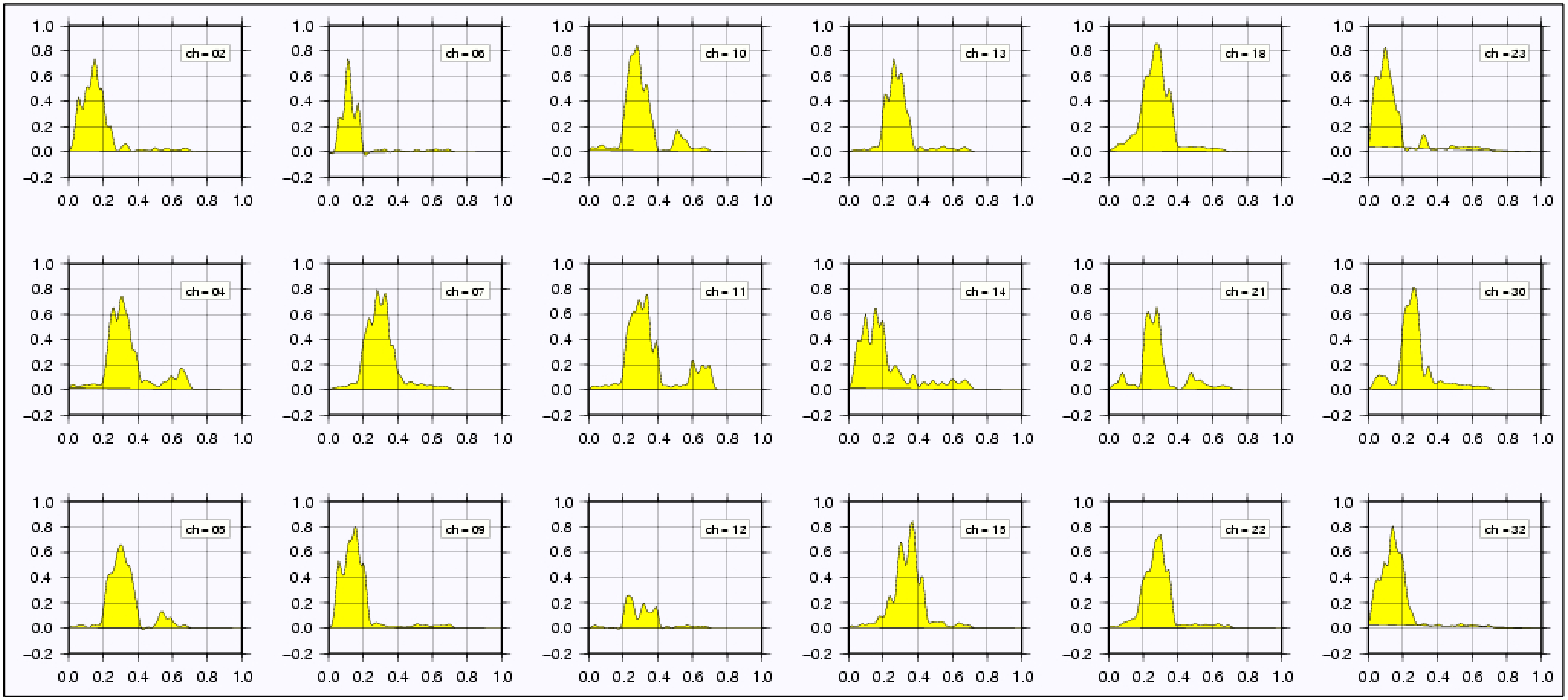
When and why we need to use this approach ???

ERROR ANALYSIS !!!

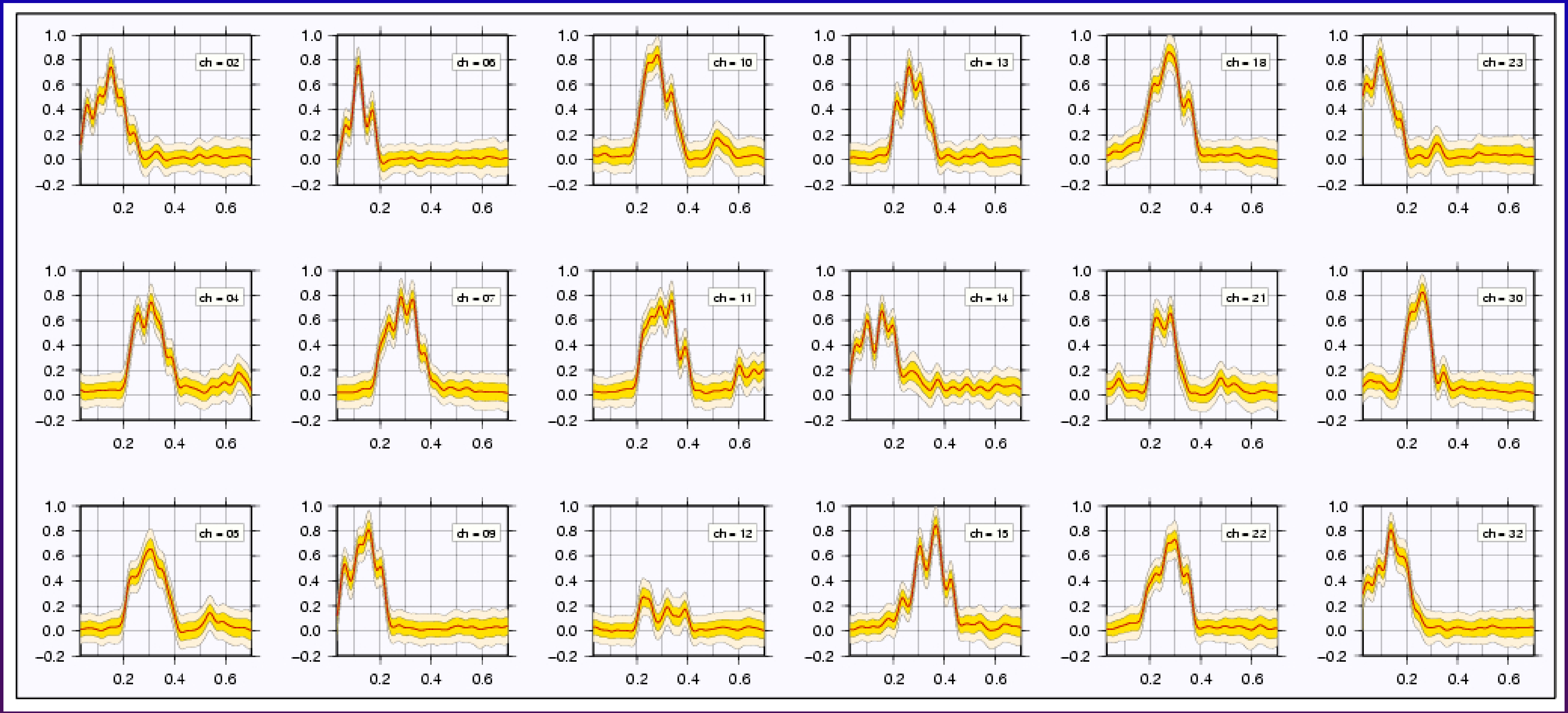
STF - channel 13



All channels



STF- errors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ch = 06
ch = 10
ch = 13
ch = 18
ch = 23
ch = 04
ch = 07
ch = 11
ch = 14
ch = 21
ch = 30
ch = 05
ch = 09
ch = 12
ch = 15
ch = 22
ch = 32

Warsaw team

- prof. S.J. Gibowicz
- dr P. Wiejacz
- dr B Domański
- dr G. Kwiatek (on leave GFZ, Potsdam)
- dr G. Lizurek
- L. Rudziński
- M. Dec
- dr hab. W. Dębski