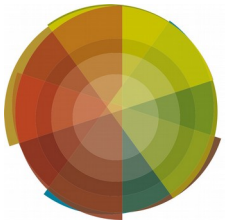
Waveform cross-correlations in seismic applications – possibilities and experiences

Martin Bachura [1]



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Waveform cross-correlation – what is it?

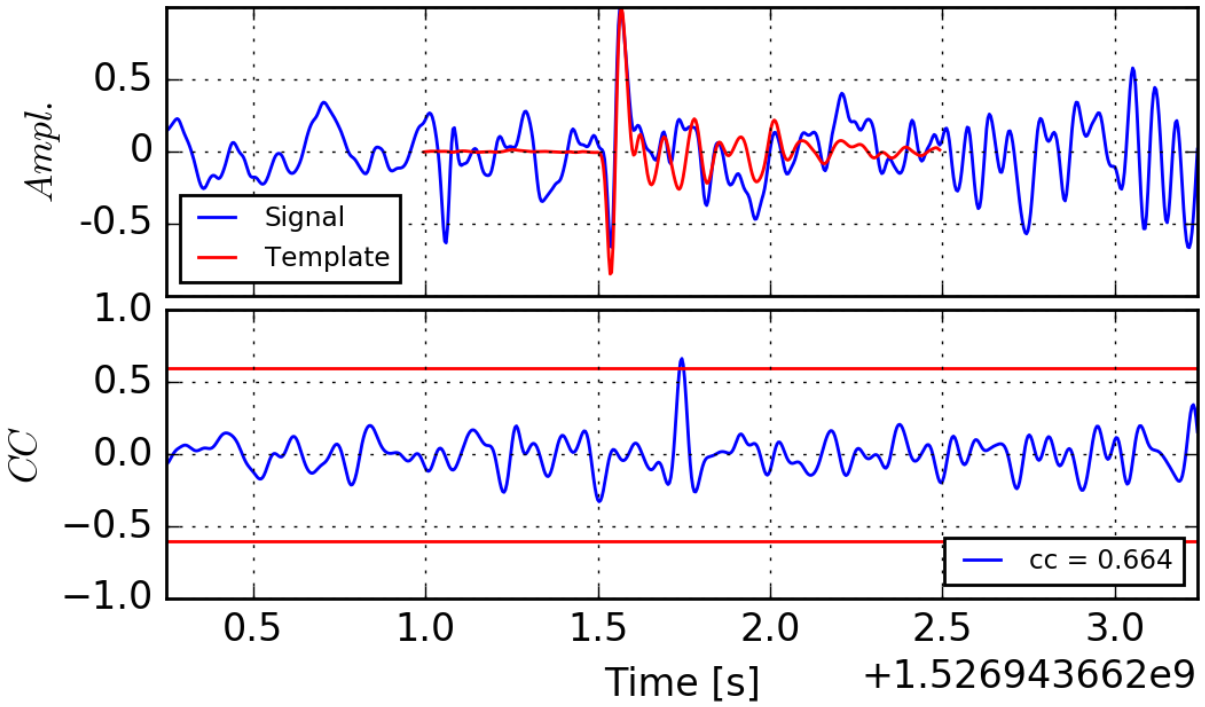
Signal processing tool

Measure of similarity of two series (y_1 and y_2) as a function of delay τ

$$CC(\tau) = \frac{\sum_t^{t+\tau} y_1(t) y_2(t-\tau)}{\sqrt{\sigma(y_1(t))\sigma(y_2(t))}}$$

Normalized convolution of two signals – cross-correlation coefficient CC

Waveform cross-correlation – what is it?

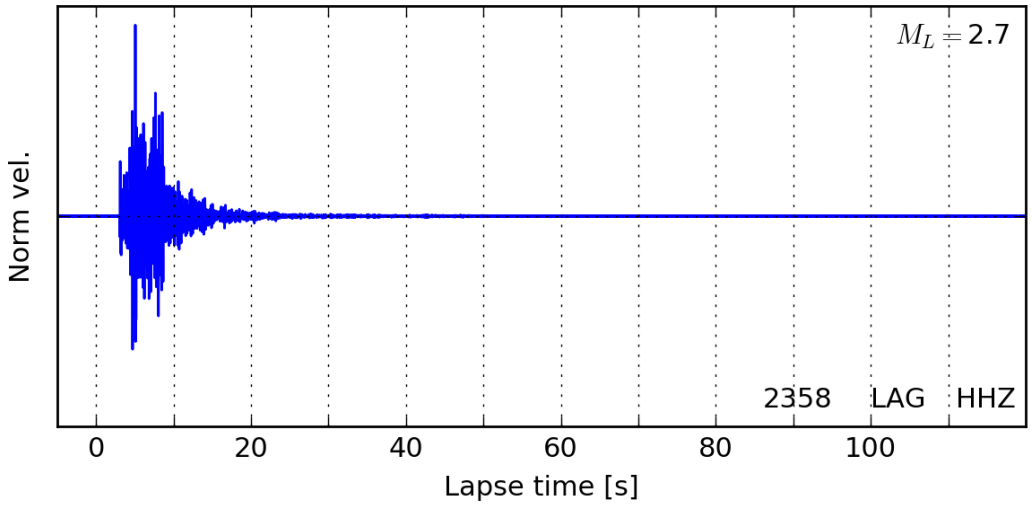


$$CC(\tau) = \frac{\sum_t^{t+\tau} y_1(t) y_2(t-\tau)}{\sqrt{\sigma(y_1(t))\sigma(y_2(t))}}$$

Two results – *CC(τ)* and *delay between two signals*

Waveform cross-correlation – how to use it?

Record | Detect | Locate | Analyze



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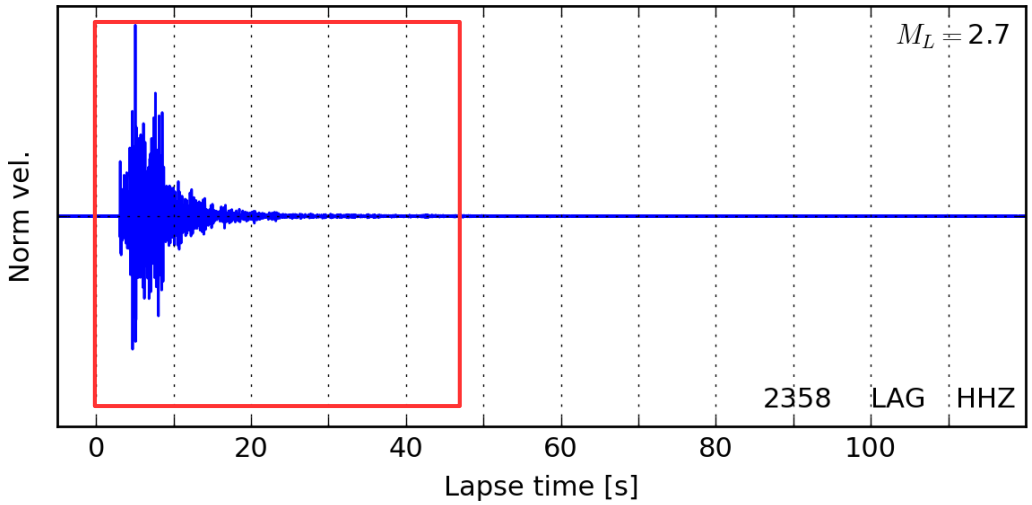

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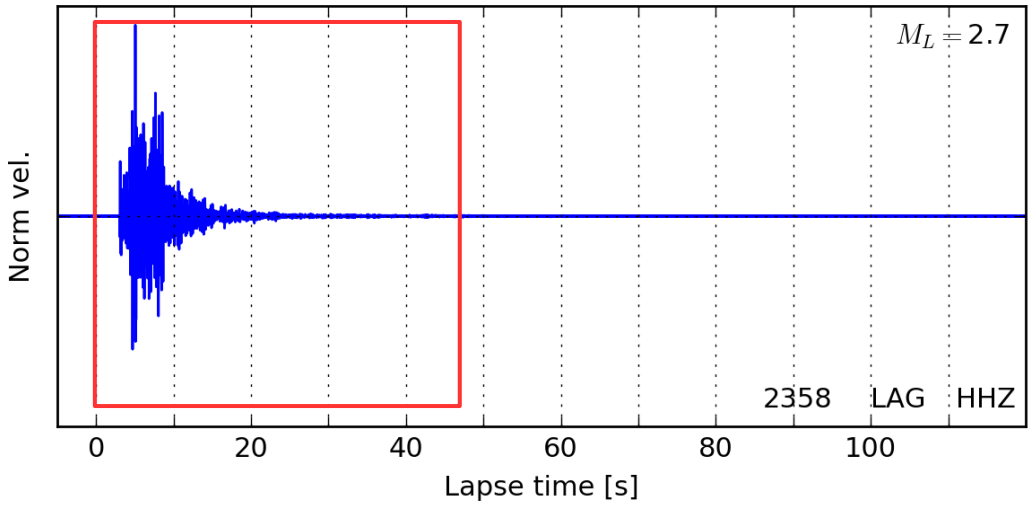
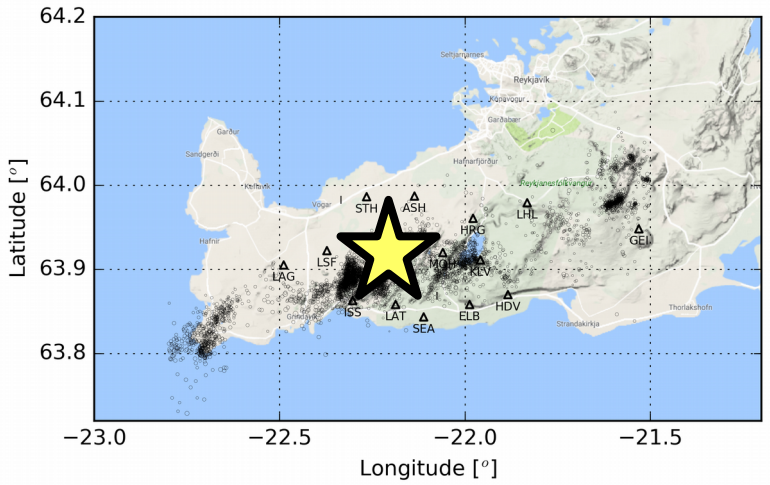
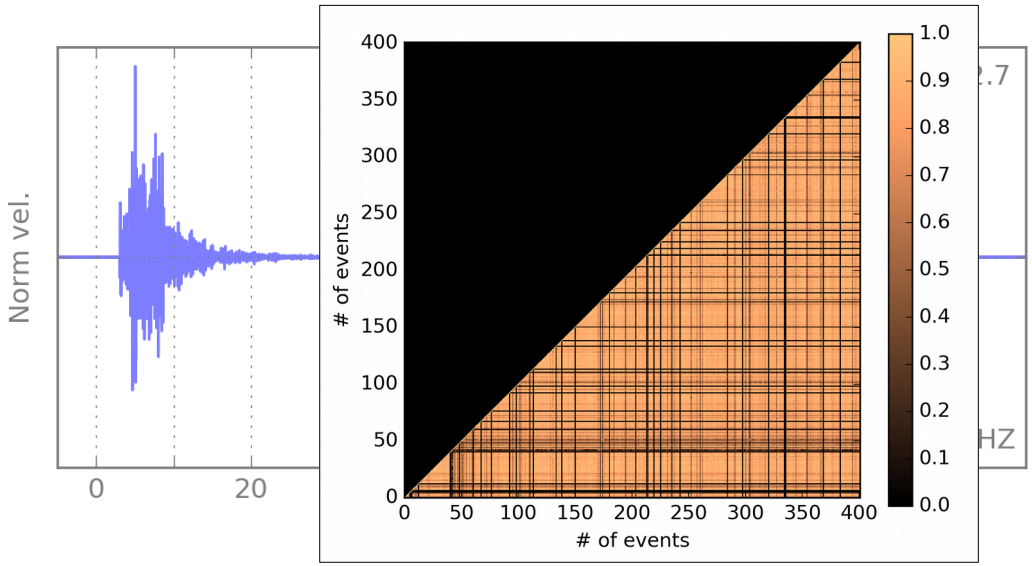
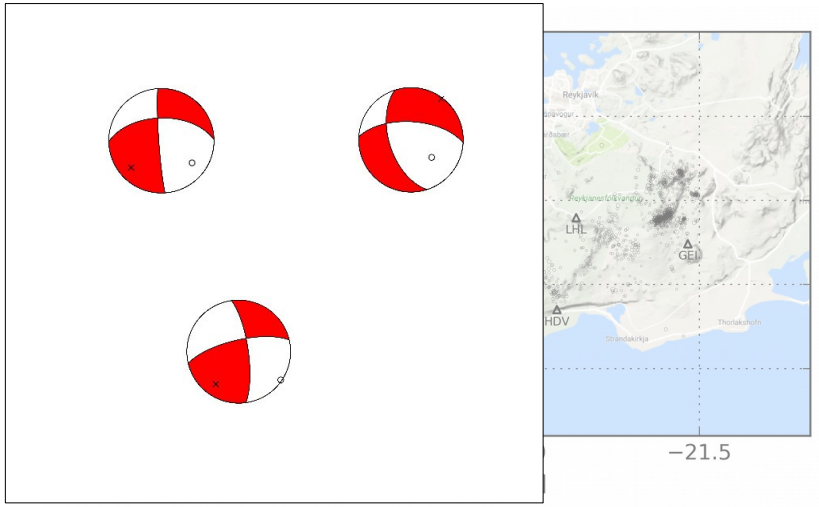




Waveform cross-correlation – how to use it?

Record → Detect → Locate → **Analyze**





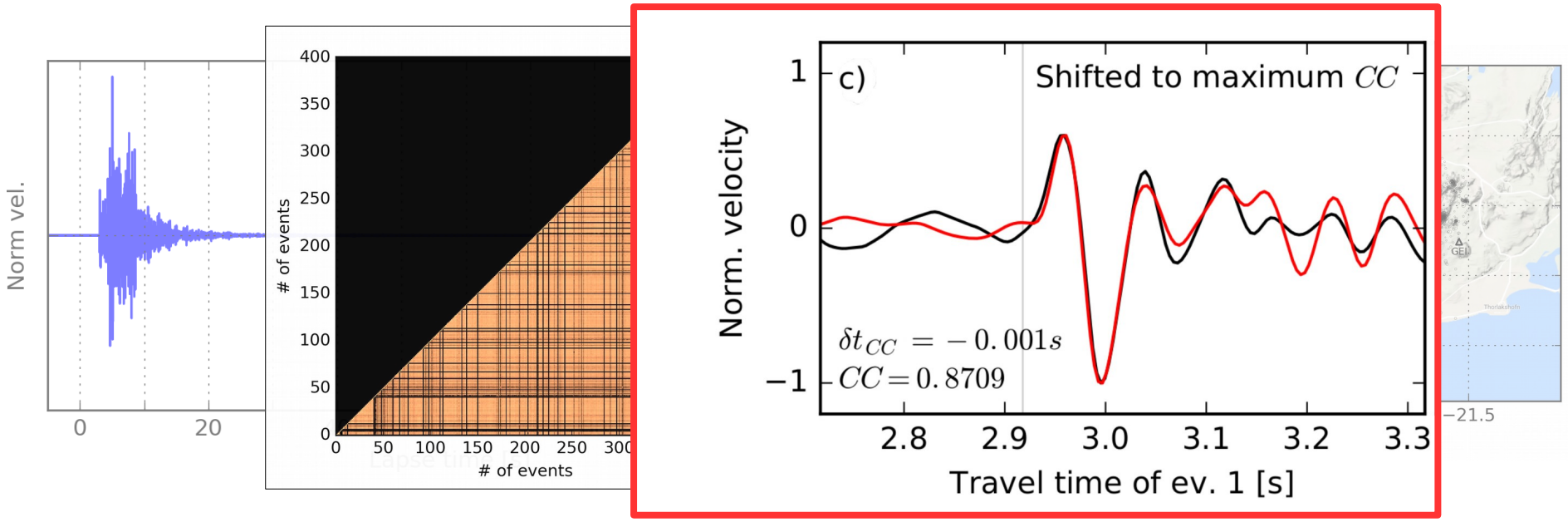
Waveform cross-correlation – how to use it?

Record

Detect

Locate

Analyze

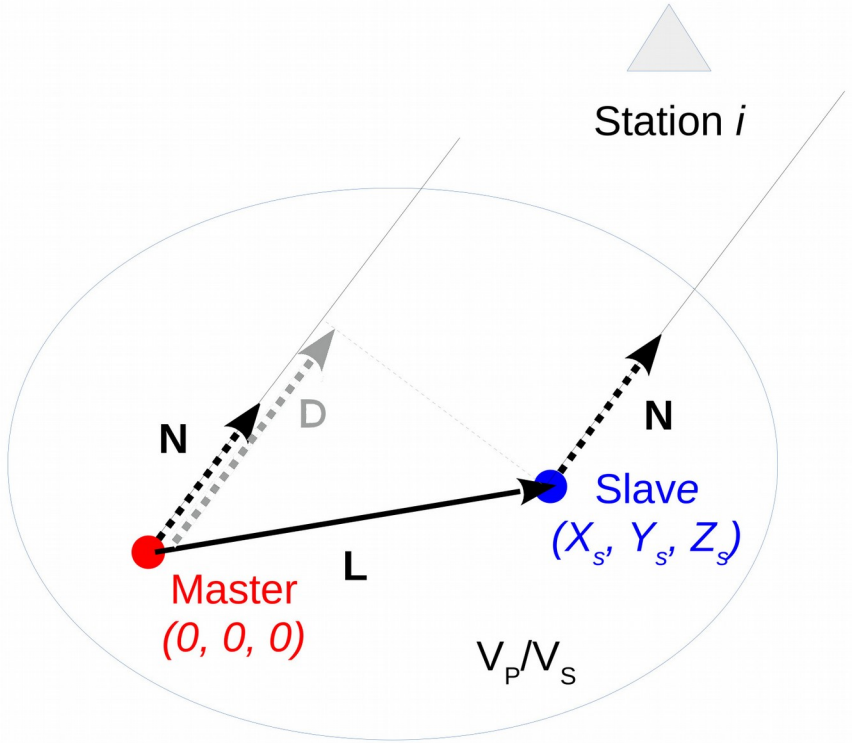


Waveform cross-correlation in DD locations

Joint (re)location of a large number of clustered earthquakes

Searching the relative positions of the earthquakes

Use of DIFFERENTIAL TIMES instead absolute phase arrival times



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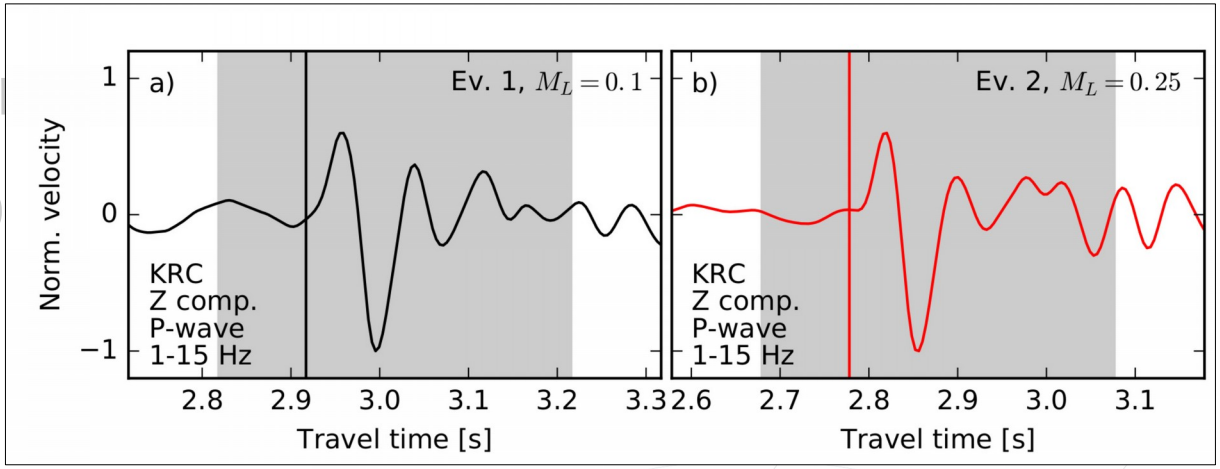
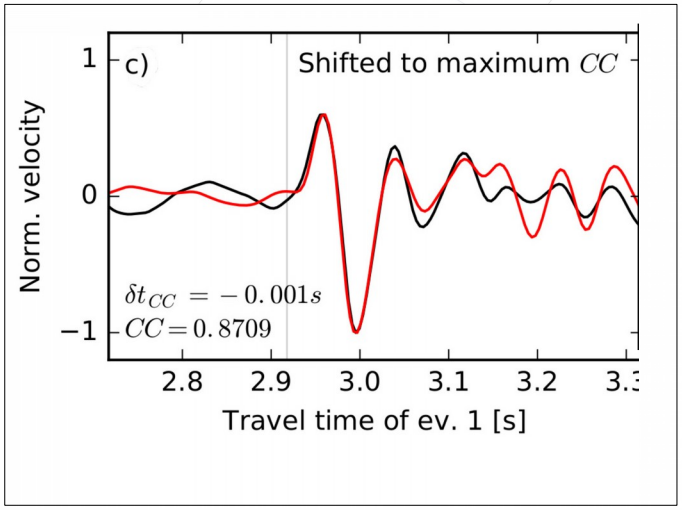
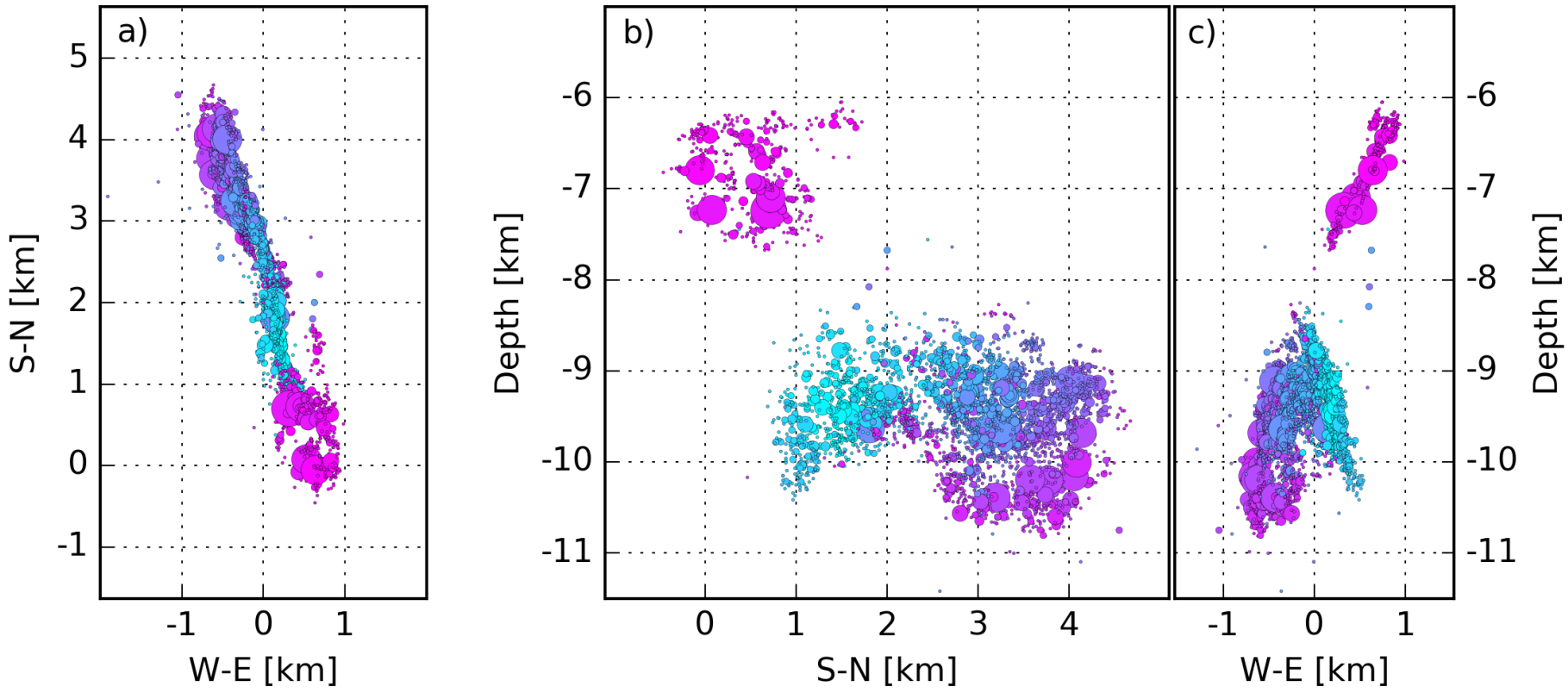


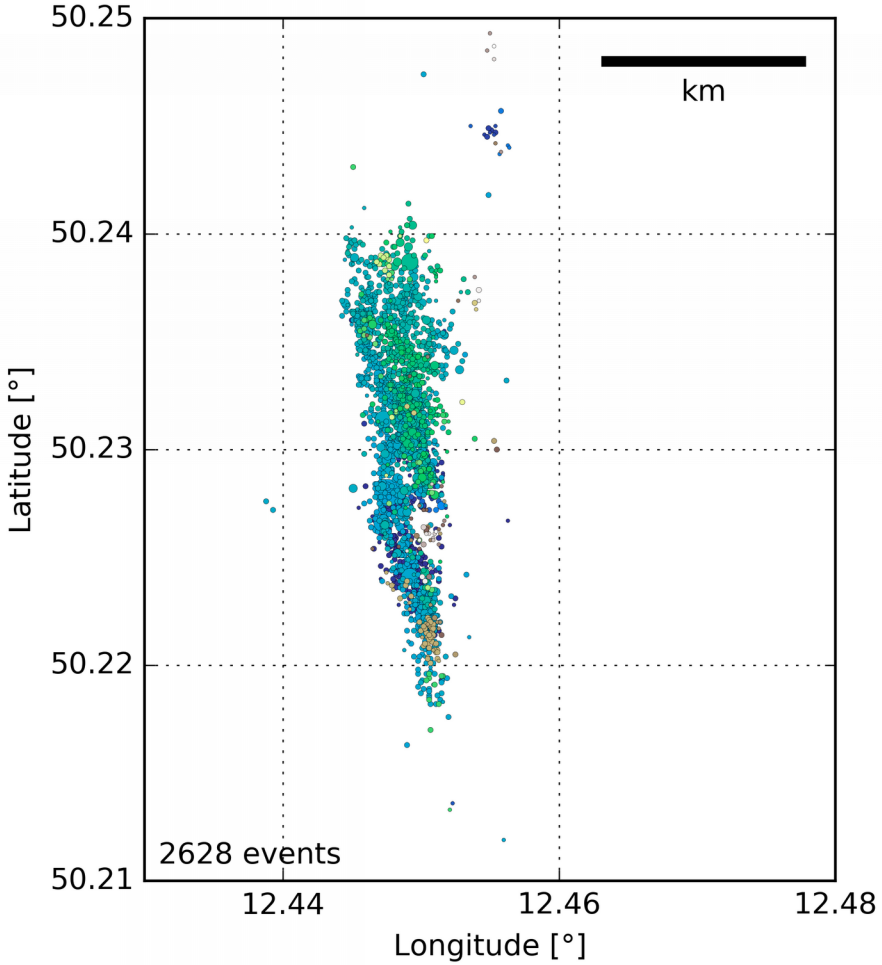


Waveform cross-correlation in DD locations

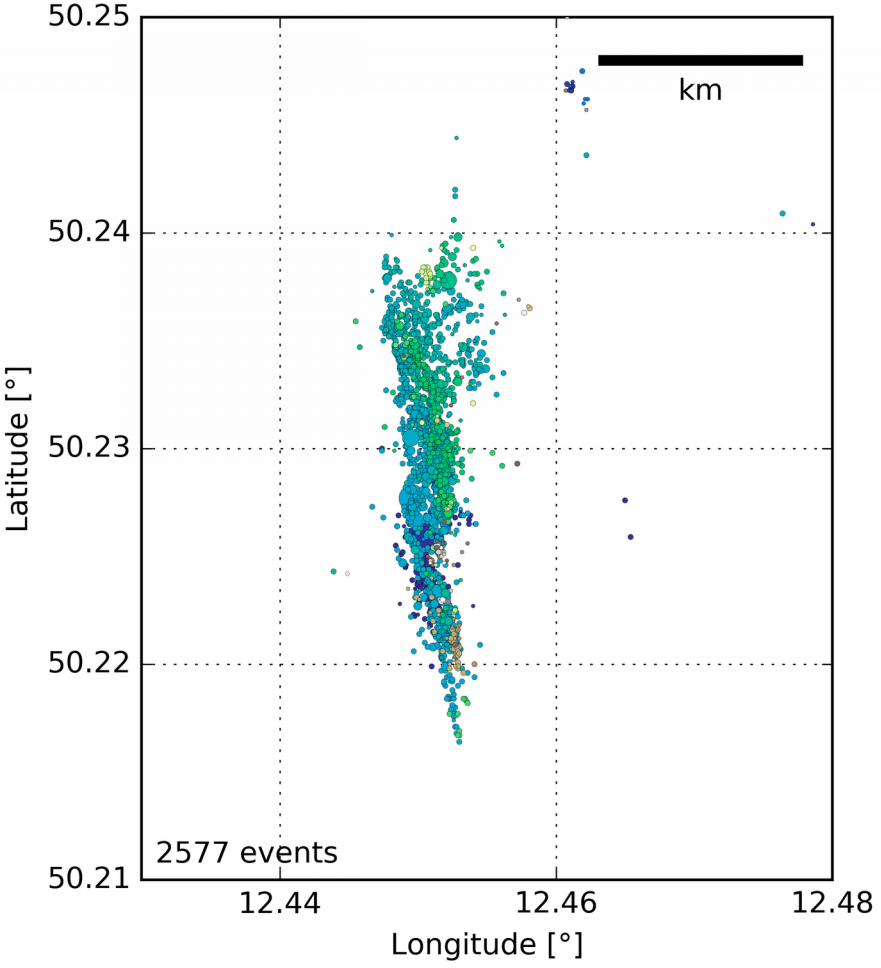


West Bohemia: 2018

DD locations: CC vs. manual

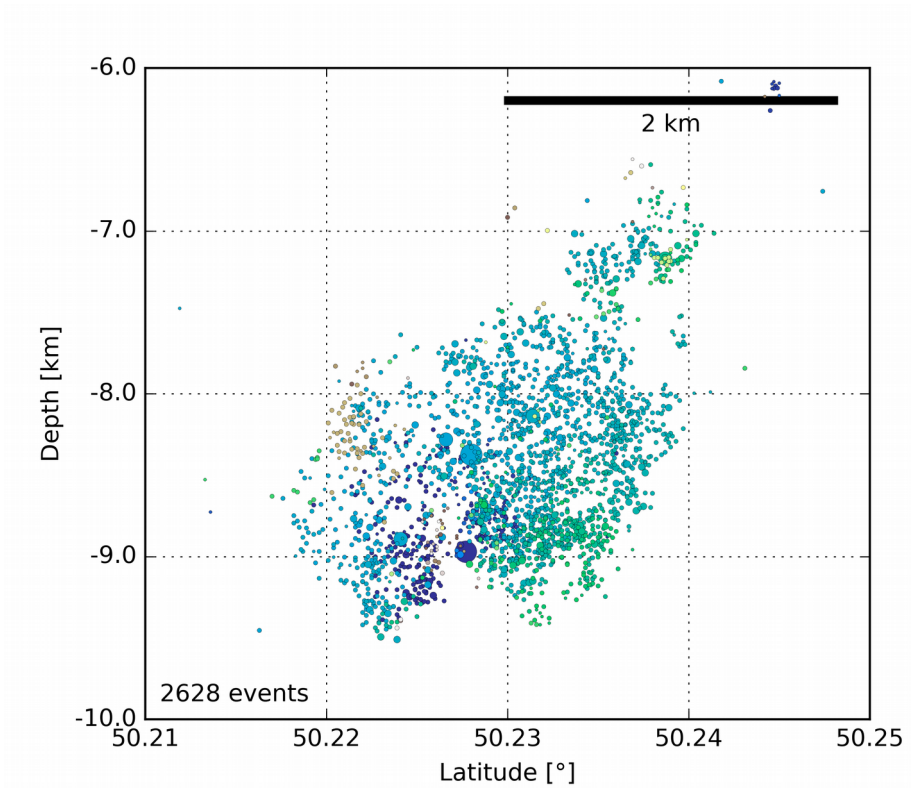


Manual



CC

DD locations: CC vs. manual



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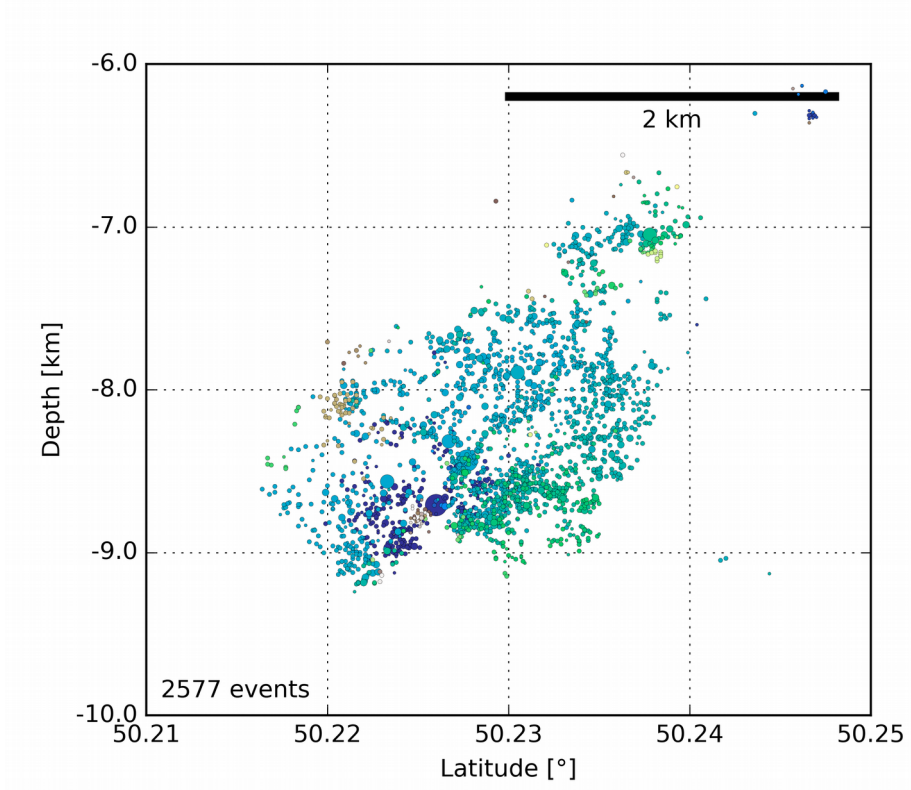
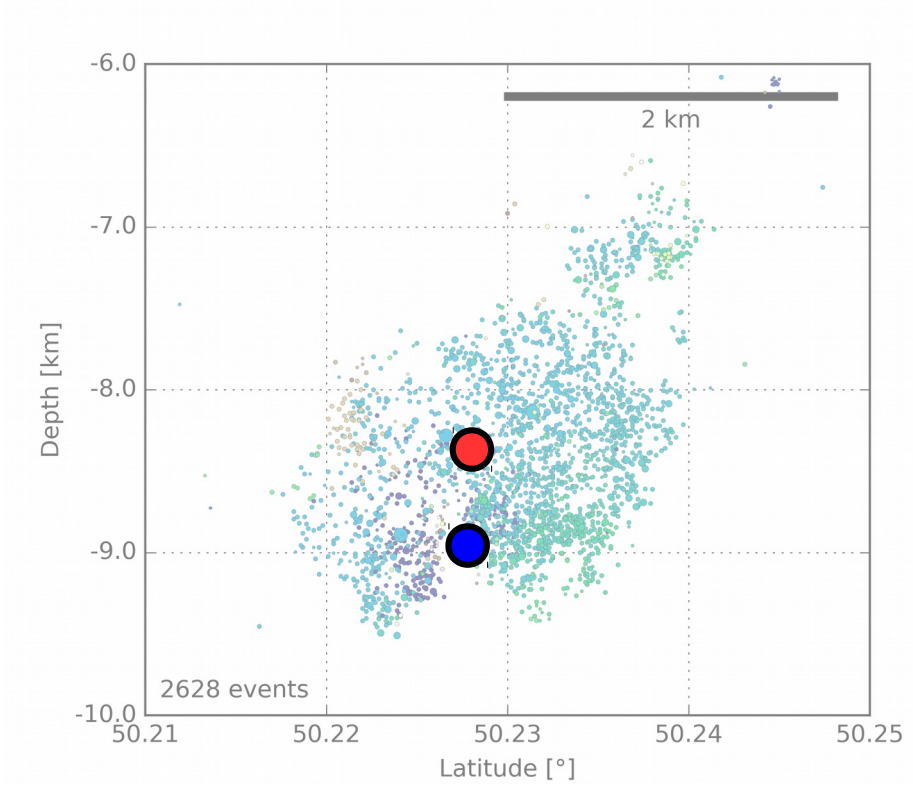
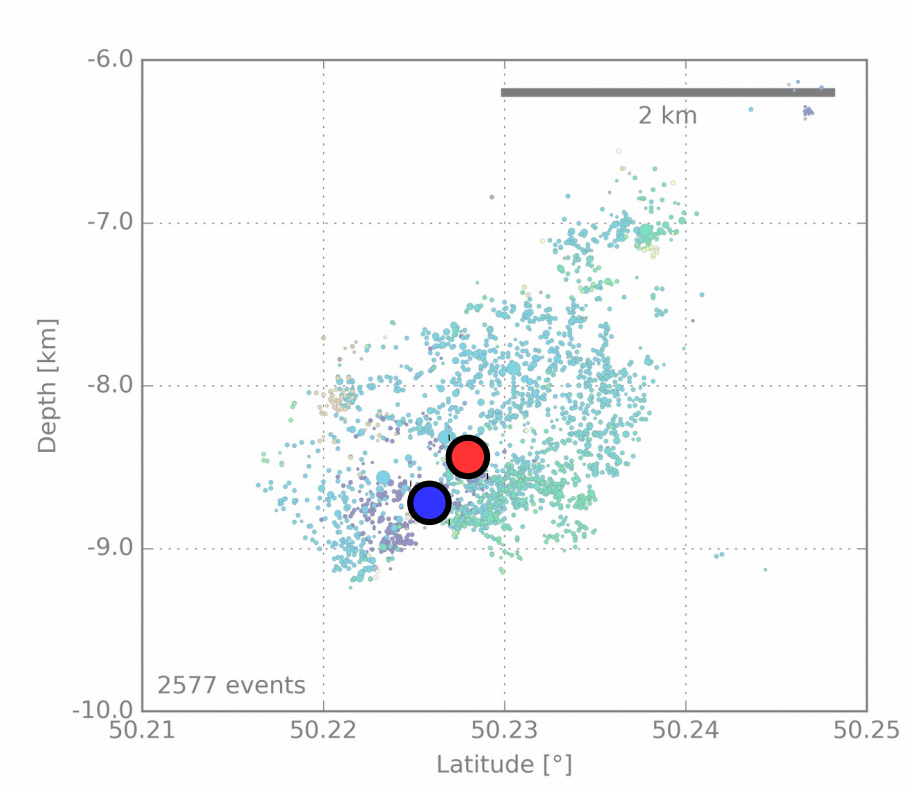


CC

DD locations: CC vs. manual

Bias in stronger events locations (M_L>3)



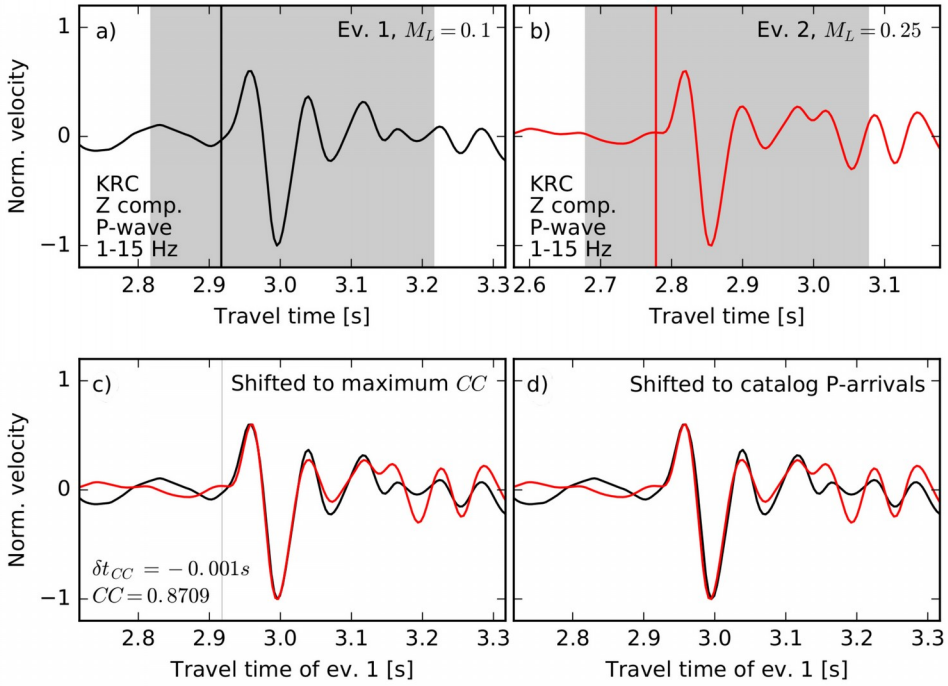


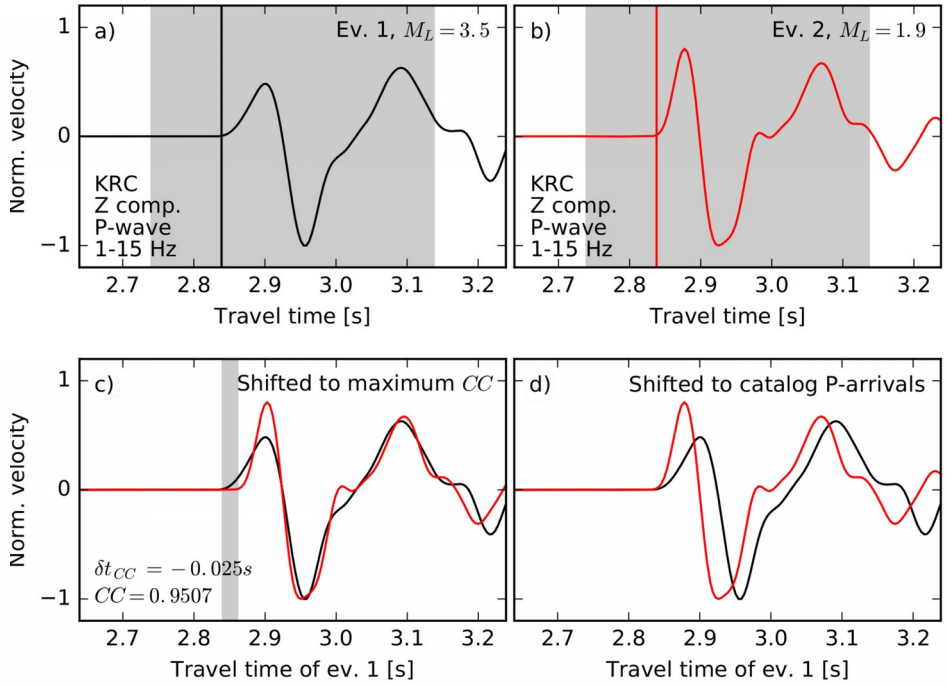
Manual

CC

Bias in cross-correlated data

Result of pulse widths differences





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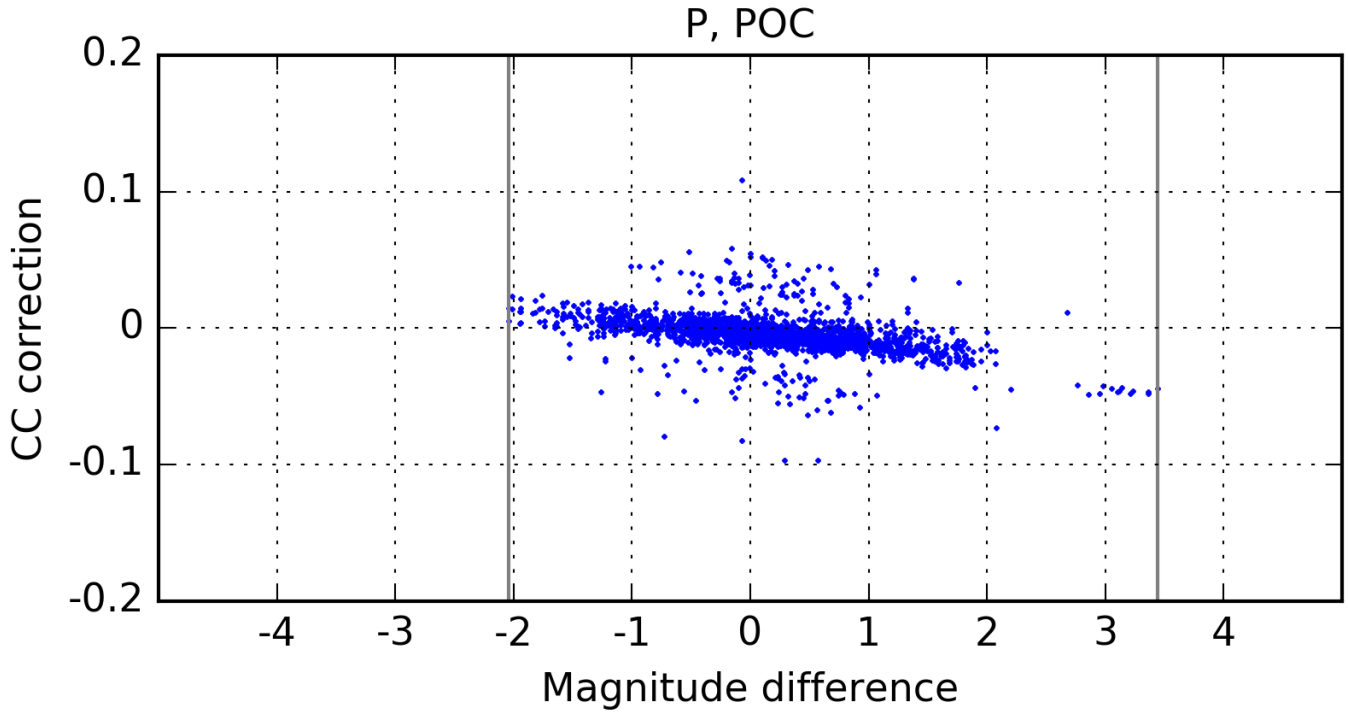
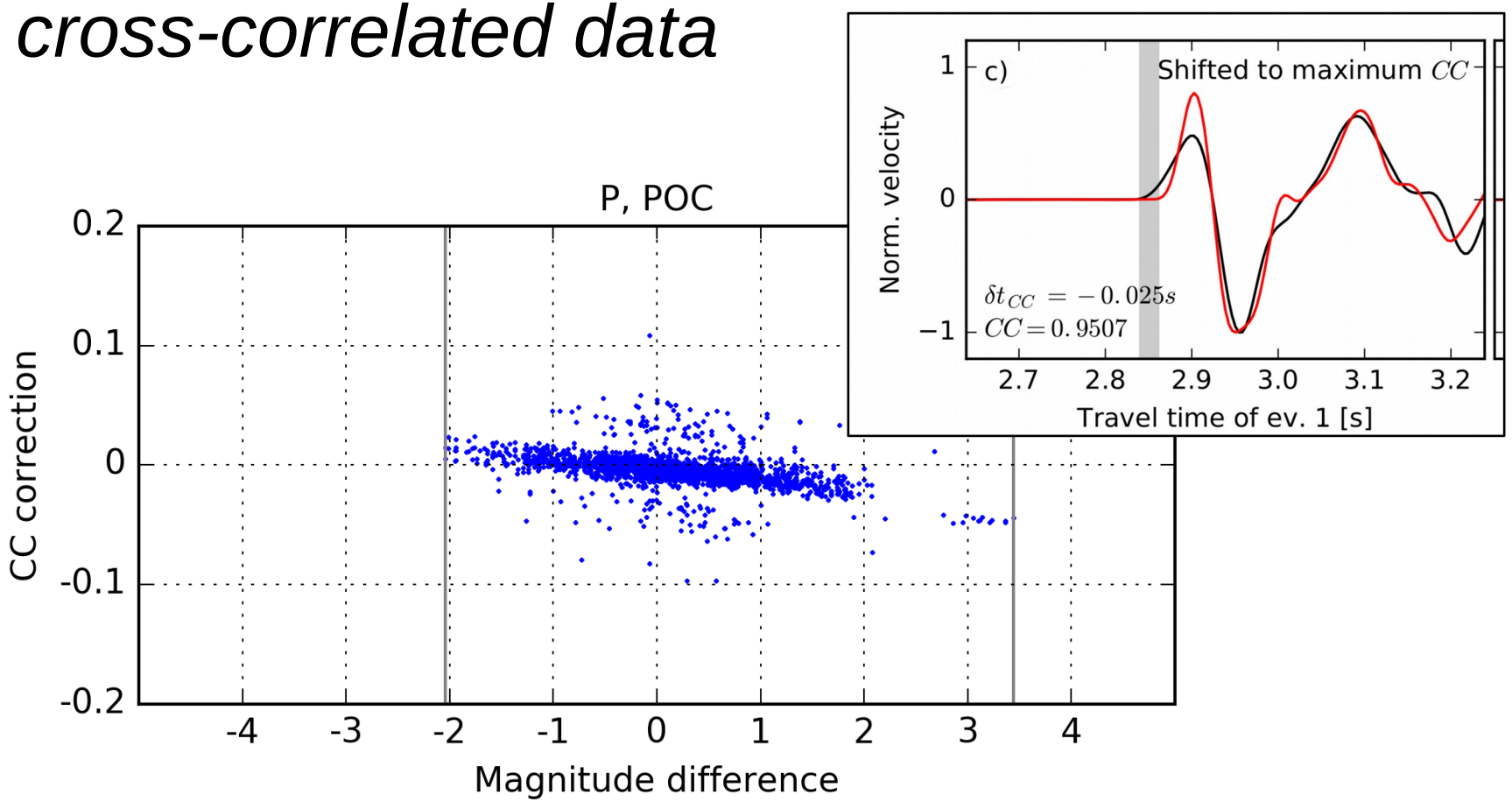


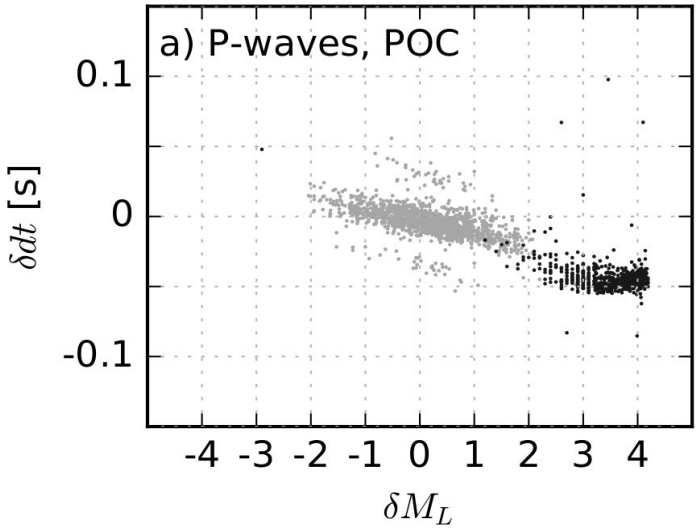
Difference between CC and manual differential times for M_L between 0 and 3.5 (200 events, all possible event pairs)

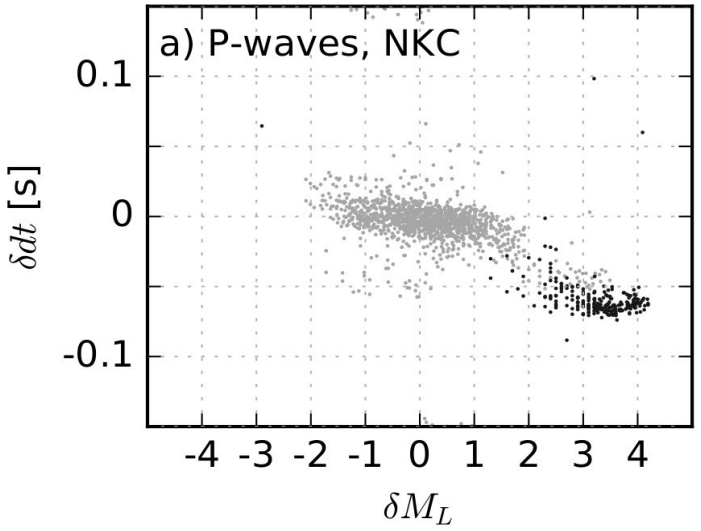
Bias in cross-correlated data



Pulse width differences introduce systematic error in differential times estimations – result of ***different spectral contents*** of signals – effect of ***magnitude differences***

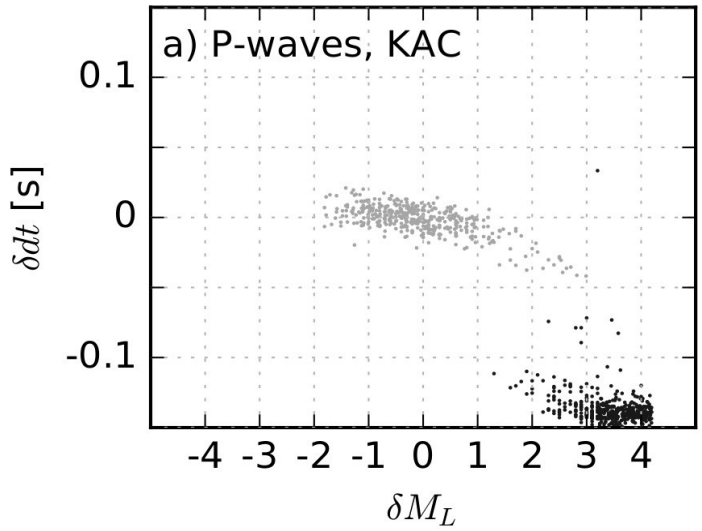
Bias in cross-correlated data – strong events



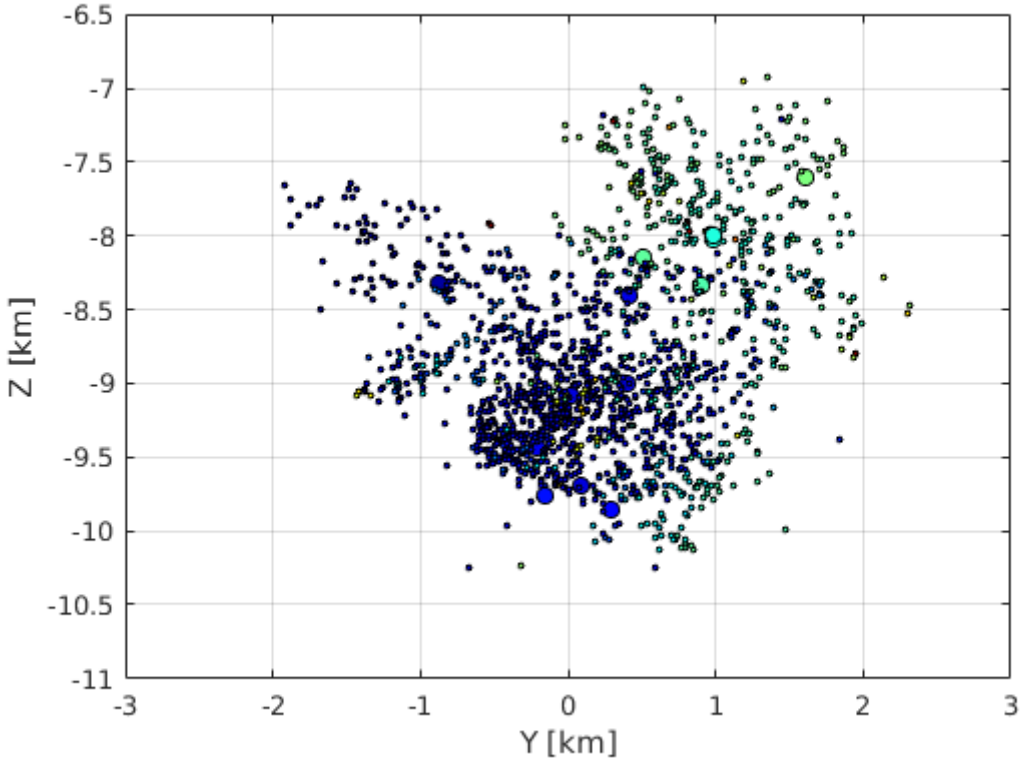


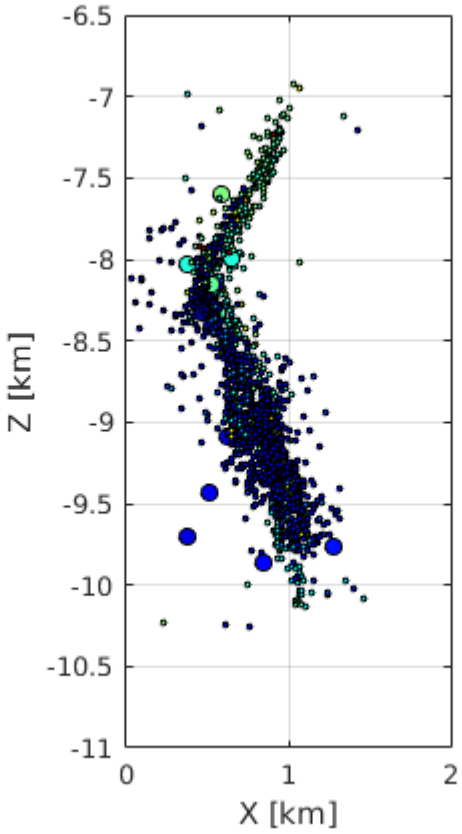
Differential time difference of event pairs with M_L=*4.2* event and its aftershocks down to M_L=*0*

Effect of ***directivity***



Bias in cross-correlated data – examples





West Bohemia: 2011

Bias in cross-correlated data – solutions?

Fully cross-correlated datasets – always biased

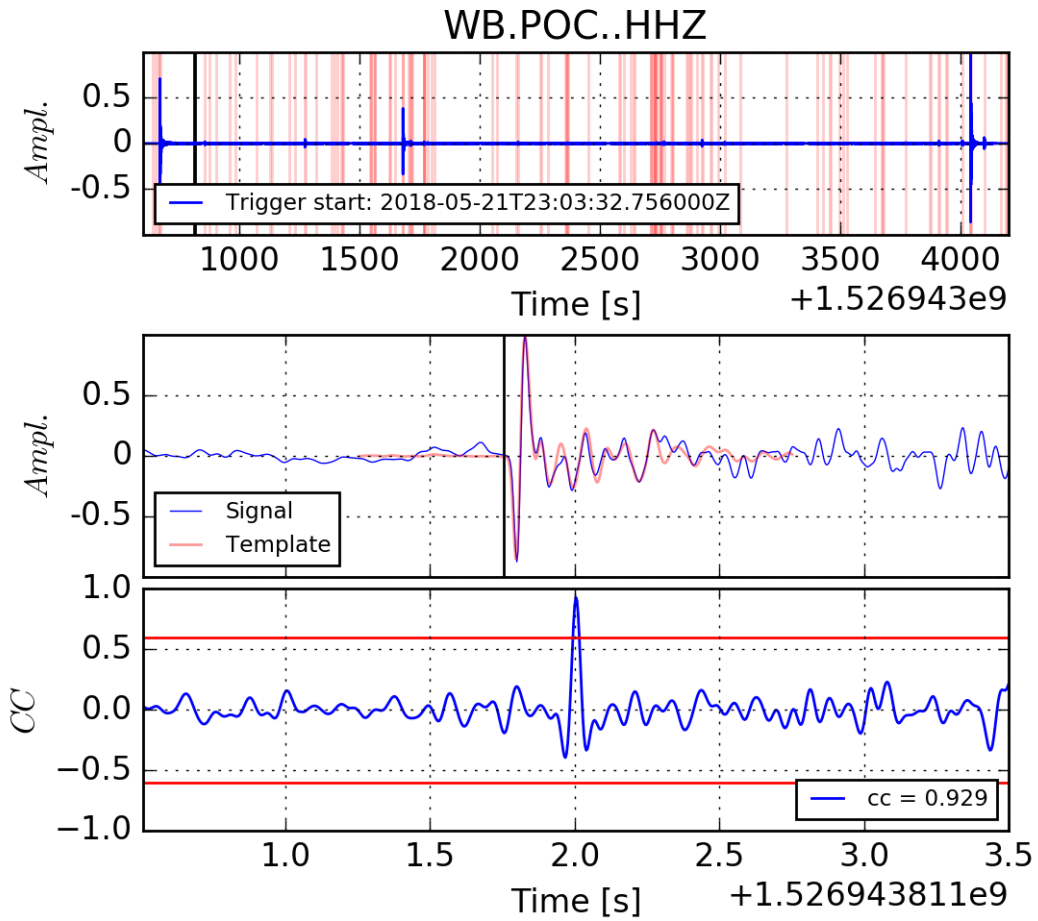
Combination of manual and cross-correlated dataset – one possible solution

Different filtering and data processing – no desired effect

There is no simple and elegant solution...for now

Cross-correlations in other applications

Template matching



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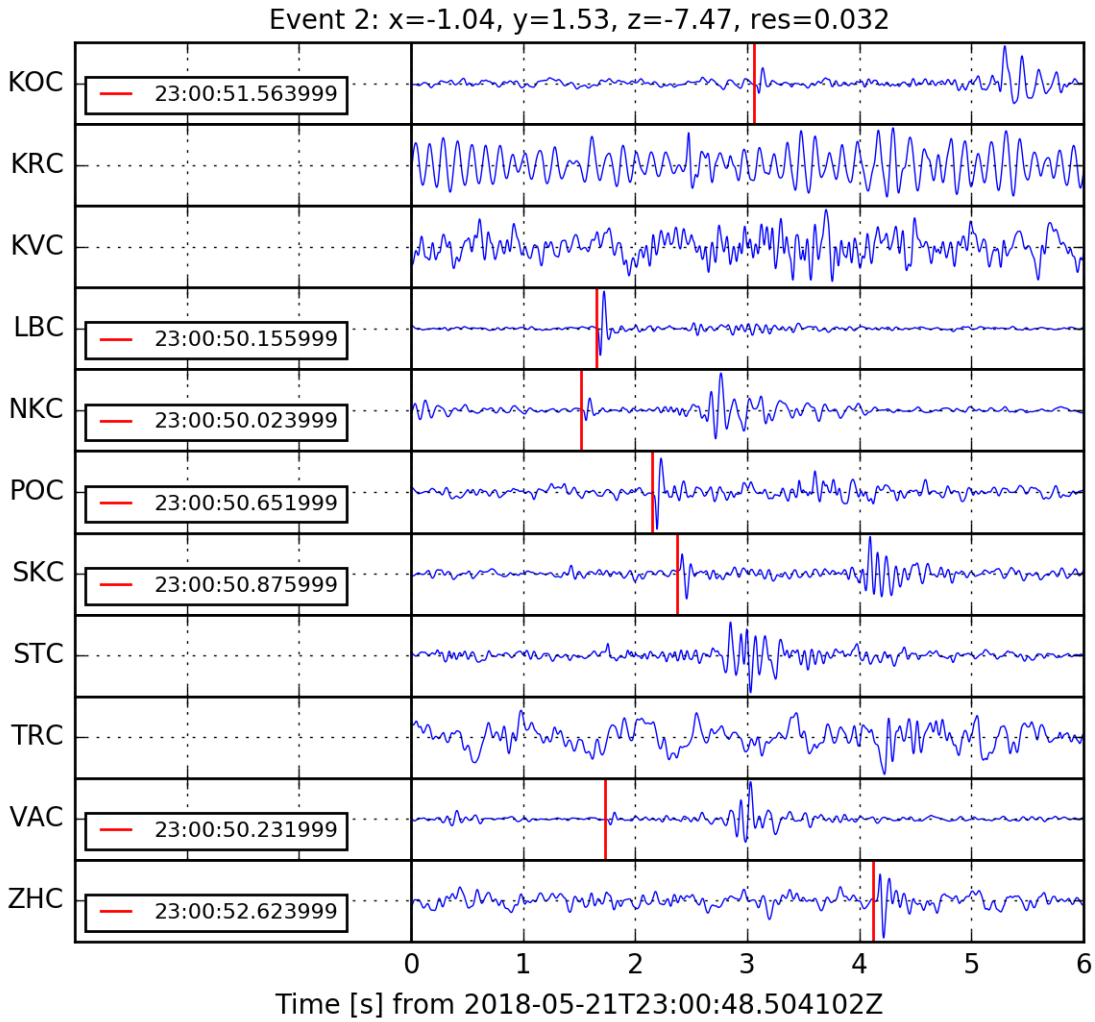
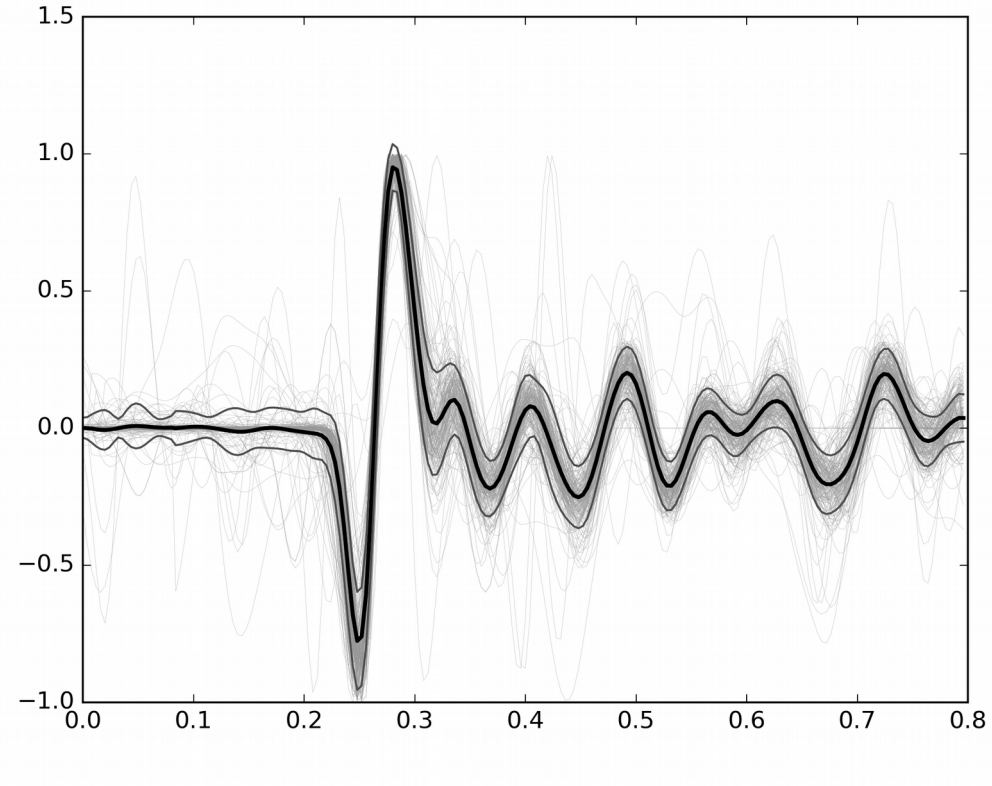
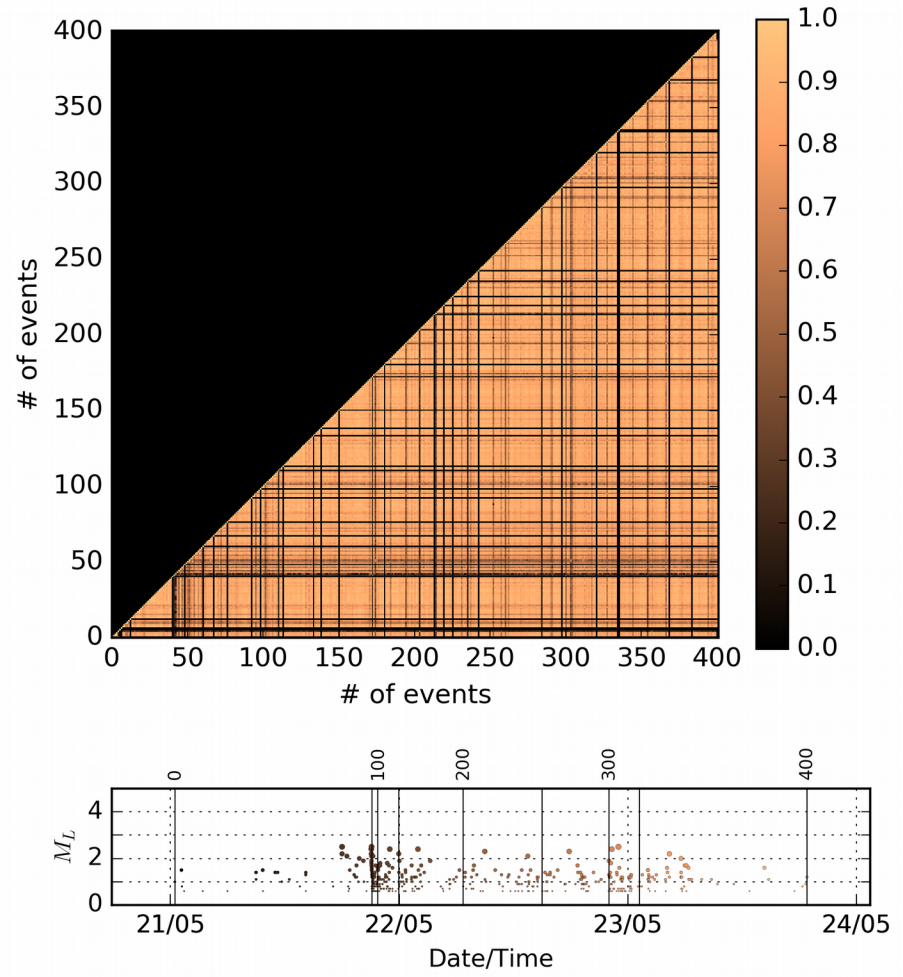


Cross-correlations in other applications

Similarity analysis





Cross-correlations - summary

Fast and easy method suitable for automatic data processing as well as for advanced analyses

Has its shortcomings – related to the stronger events

Valuable in fast relocations, picking (template matching), all kinds of waveform similarity analyses.

Thank you for your attention