SnT2023

CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

HOFBURG PALACE - Vienna and Online

19 TO 23 JUNE

Enhancing Signal Detection at IMS Seismometer Arrays

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Presentation Date: 20 June 2023

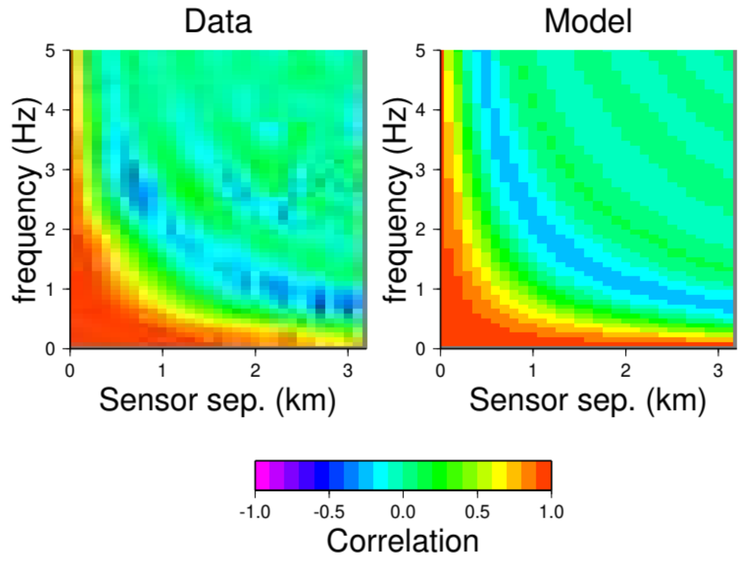
Overview

- Generalised *F* detector
  - Test dataset
- *fk* analysis of F detections
- Enhancing array signal detection - a framework

The generalised *F* detector

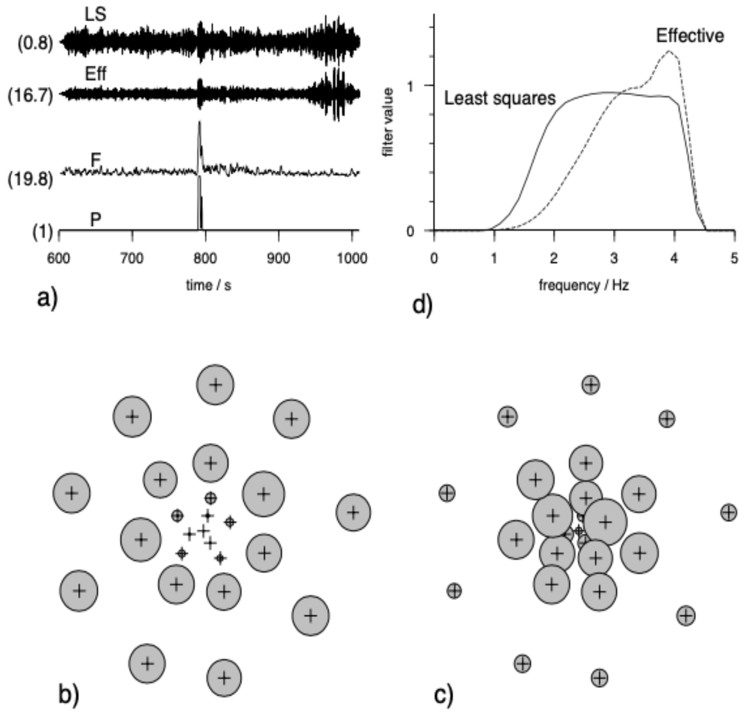
The generalised F detector (Selby 2008, 2011, 2013) is essentially a weighted-least-squares beamformer coupled with a statistical test for detection based on the non-central *F* statistic.

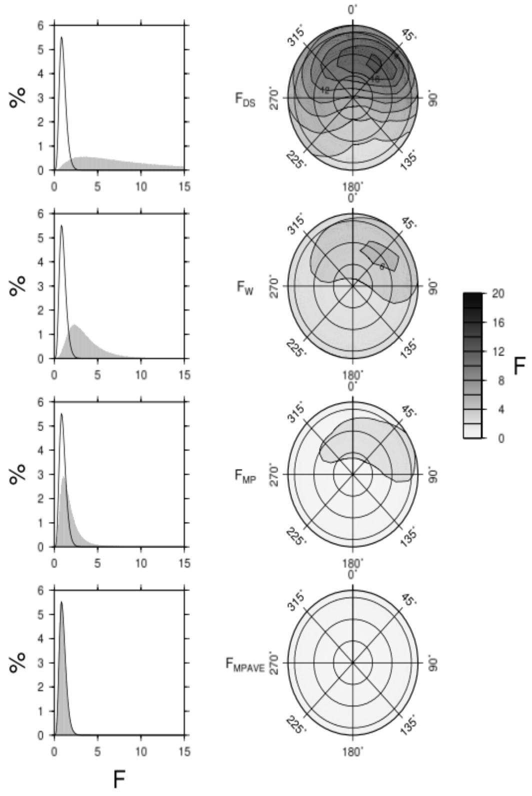
Compared to traditional STA/LTA detectors, detection of first *P* is enhanced while the number of unassociated detections is greatly reduced.



- *A priori* model used to account for spatial noise correlation.
- Continuously updated noise power spectrum used to account for temporal noise correlation.

- Calculates a set of complex frequency-dependent channel weights for each beam in a pre-defined beamset.





- Weighted background noise then fits a non-central *F* distribution.
- Enhanced numbers of genuine detections for first *P* at many arrays.

Test dataset

https://swp.ctbto.org/web/swp/genf-detector-testing-data

- Generalised *F* detector (*genF*) test dataset:
  - Test period first 14 days of 2022.
  - For IMS primary and auxiliary arrays not including AKASG, GEYT, HFS, NOA and PDYAR.
- Excellent presentations at WGB59 Waveform Expert Group:
  - Initial analysis of the Generalised *F* detector test dataset (Stuart Nippress, UK NDC, AWE).
  - GenF detector status update (Christos Saragiotis & Helmuth Breitenfellner, CTBTO).
- Additional presentations:
  - Generalised F detector testing (Selby, AWP meeting October 2022).
  - Generalised F detector testing and slowness-azimuth measurements. (Selby, WGB60 Waveform Expert Group).

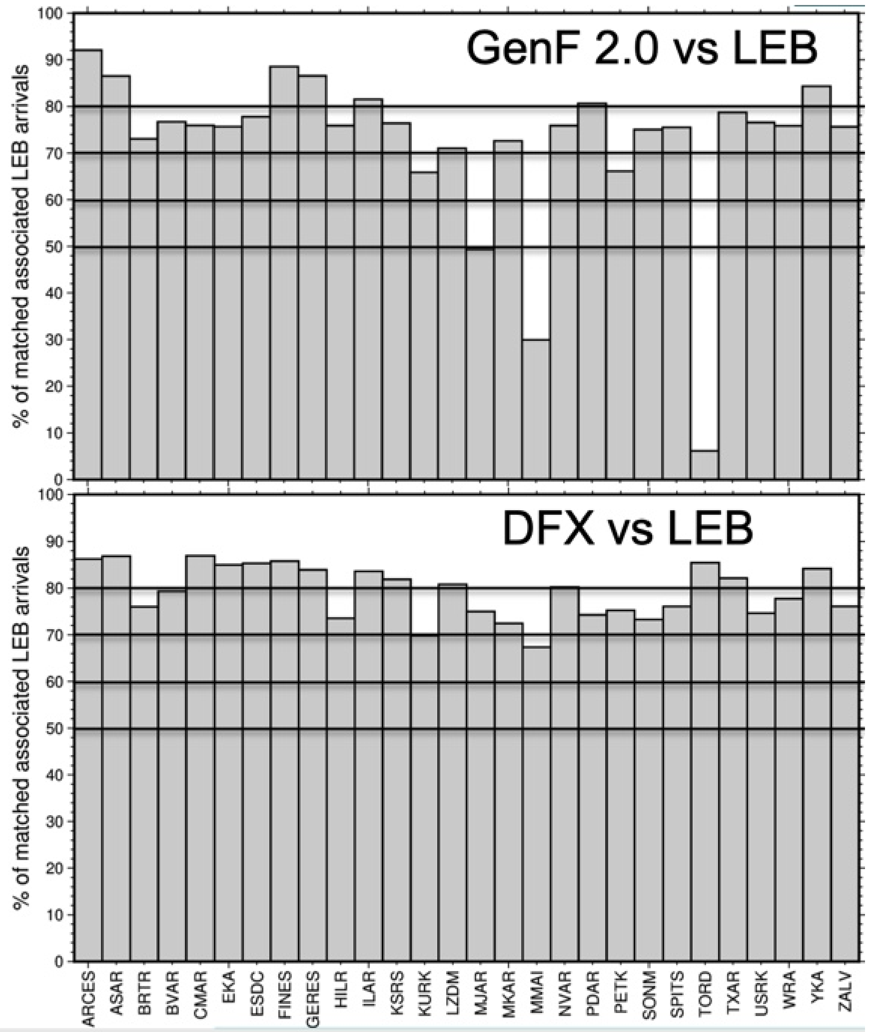
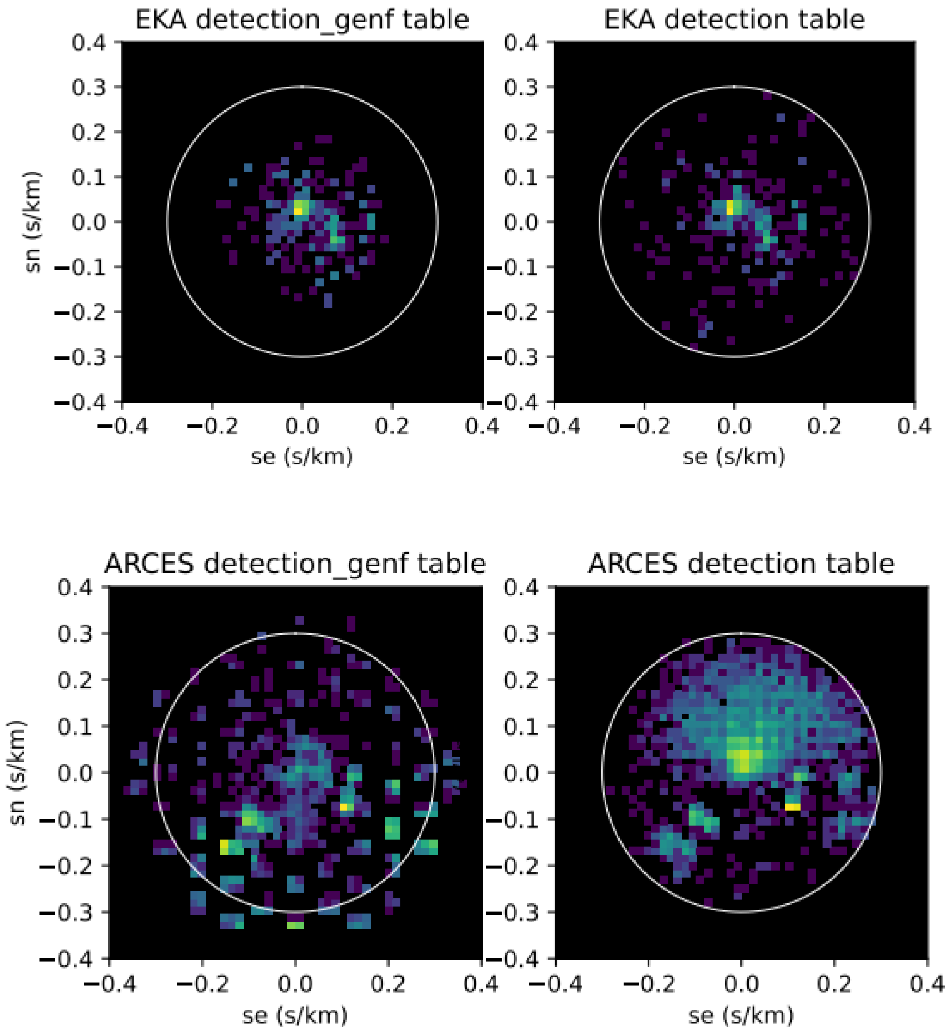


Figure from Nippress, WEG at WGB59.

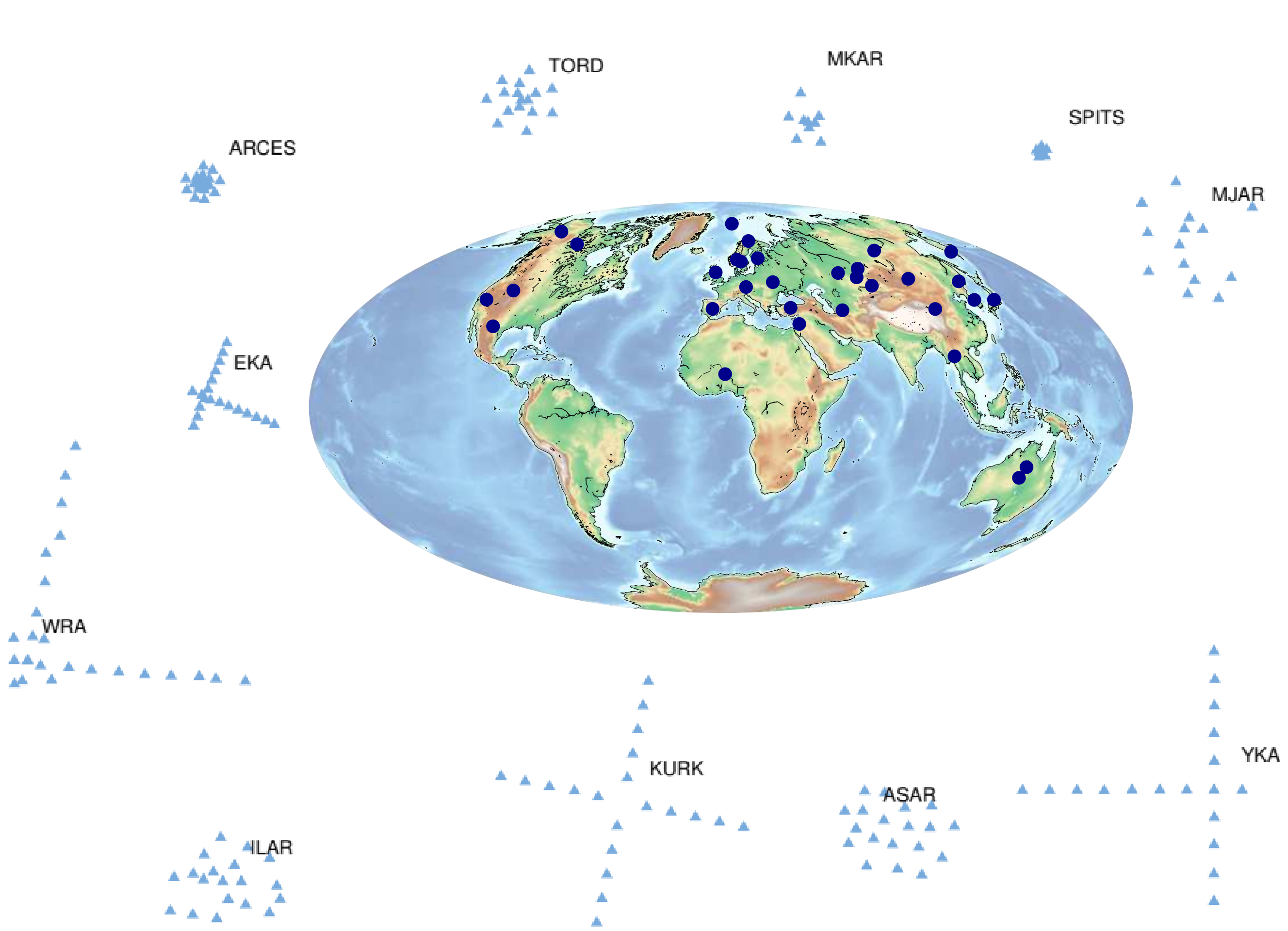
fk analysis

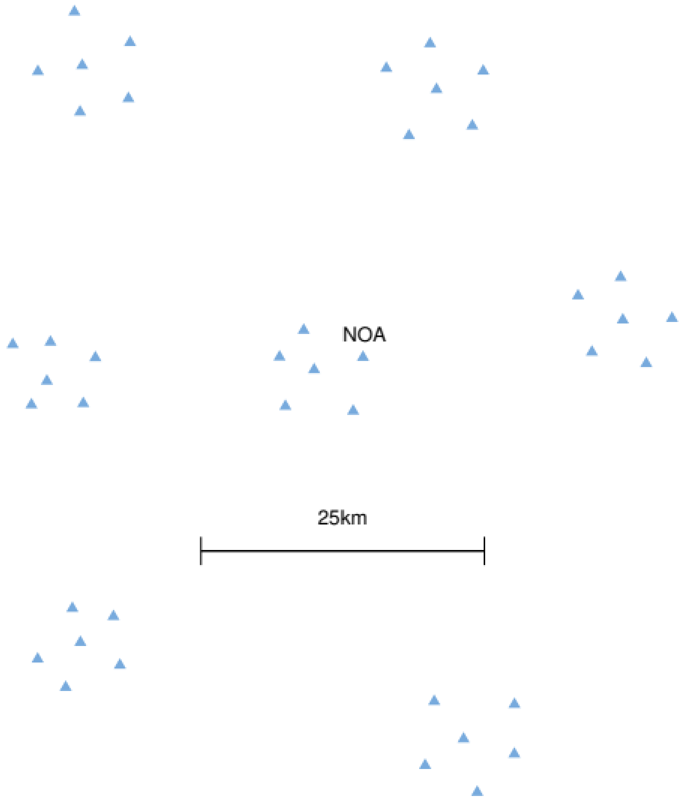
- *fk* analysis of genF detections.
  - *fk* process does not use *genF* noise model.
  - Consequently introduces errors at some arrays (e.g. ARCES).
- Possible solutions:
  - Use *genF* detection beam for azimuth and slowness and generate other parameter used by the association algorithm.
  - Develop *fk* tool using genF noise model.
  - Develop *fk* tool using beam-recipe approach.
- Other *fk* improvements:
  - Consider array designs and signal and noise models to tailor *fk* analysis to each array.



Also consider array design, signal and noise models for signal detection, regardless of algorithm.

IMS seismometer arrays

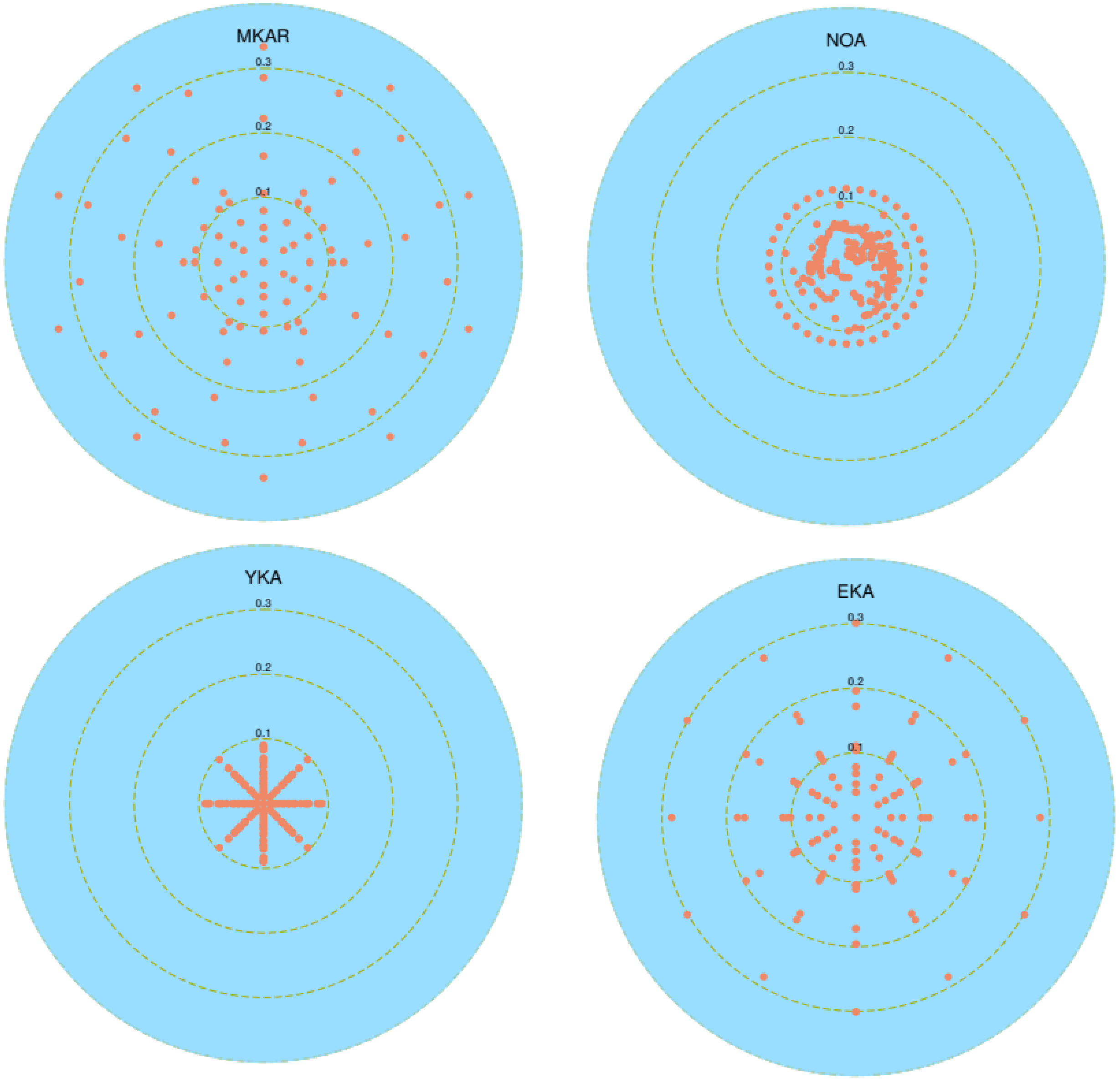




- IMS seismometer arrays:
  - Variety of apertures
  - Variety of designs
  - Various number of elements
  - Various signal and noise characteristics

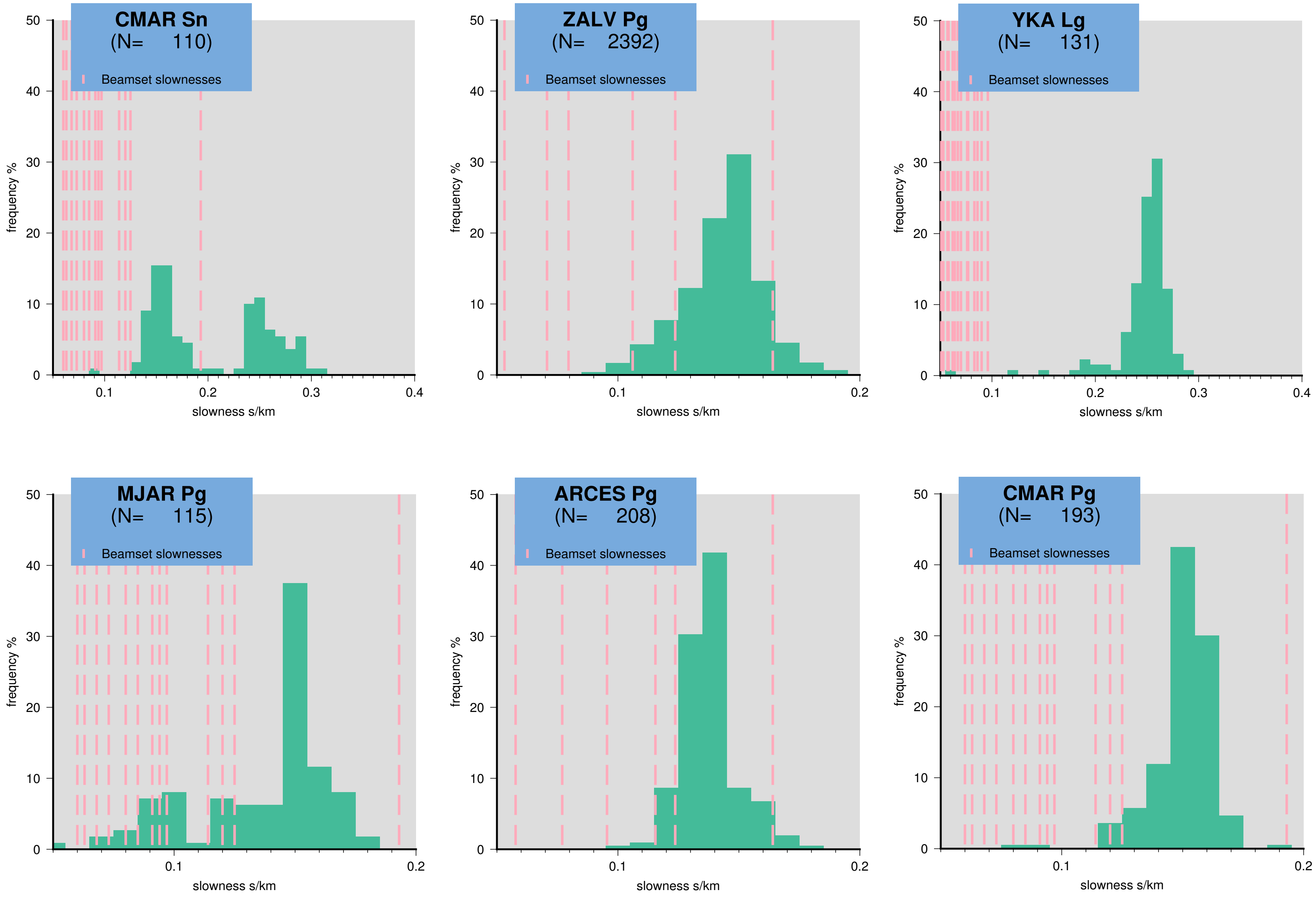
Beamsets

- “Traditional” array signal detectors use predefined azimuths and slownesses (“beamset”).
- Beamsets used by IDC are a mixture of array-specific designs and defaults.
- Beamsets should be based on array response function and signal and noise characteristics.
- Each detection beam is a *signal hypothesis* and we should take account of likely uncertainties when detecting.



Regional & local signal slownesses

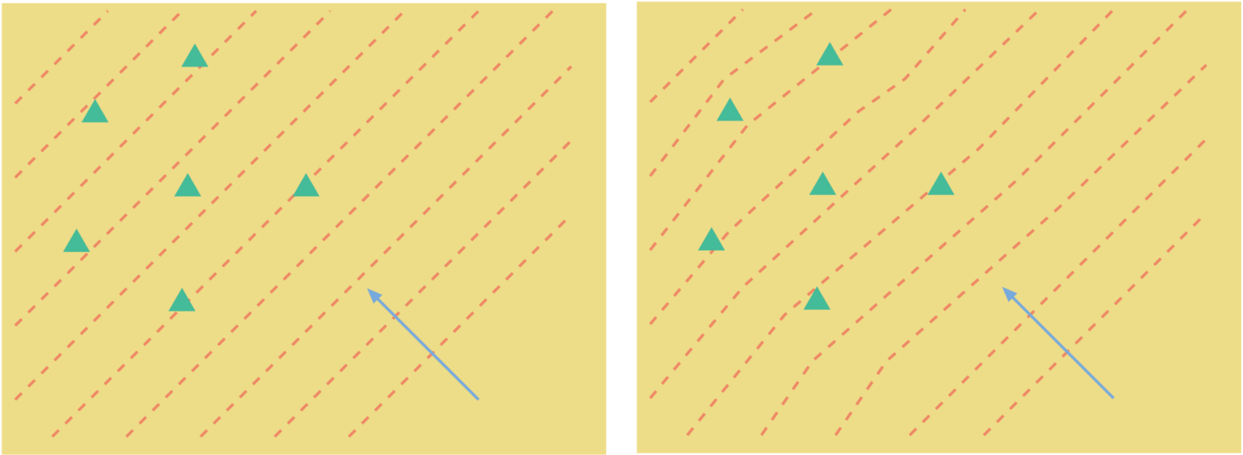
- Apparent speeds of regional and local phases (Pn, Pg, Sn, Lg) vary with array.
- Array beamsets often do not have beams with appropriate slownesses to detect regional phases.

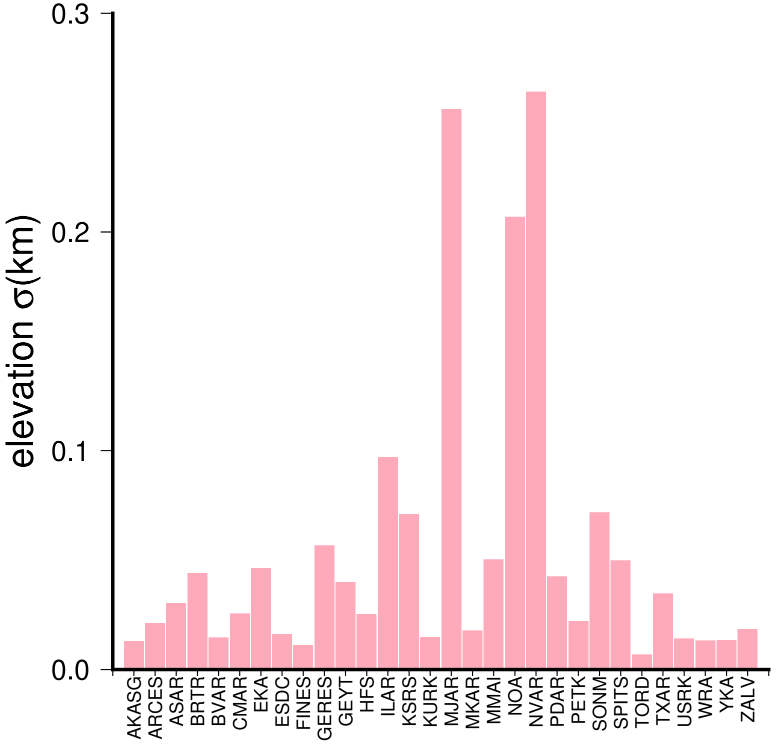


Histograms of REB observed regional phase slownesses for 2021 and 2022.

Arrival time variations

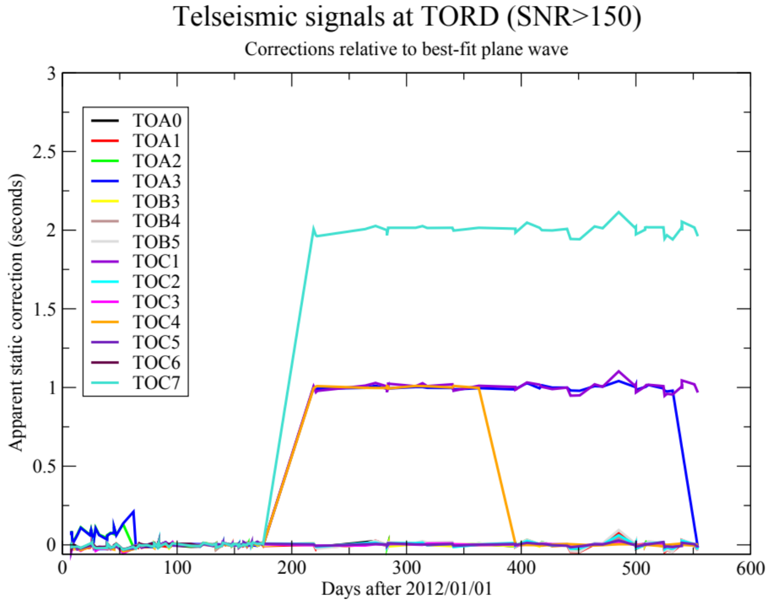
- Plane wave assumption.
- Geological variations.
- Frequency, azimuth and slowness-dependent arrival time variations across array.





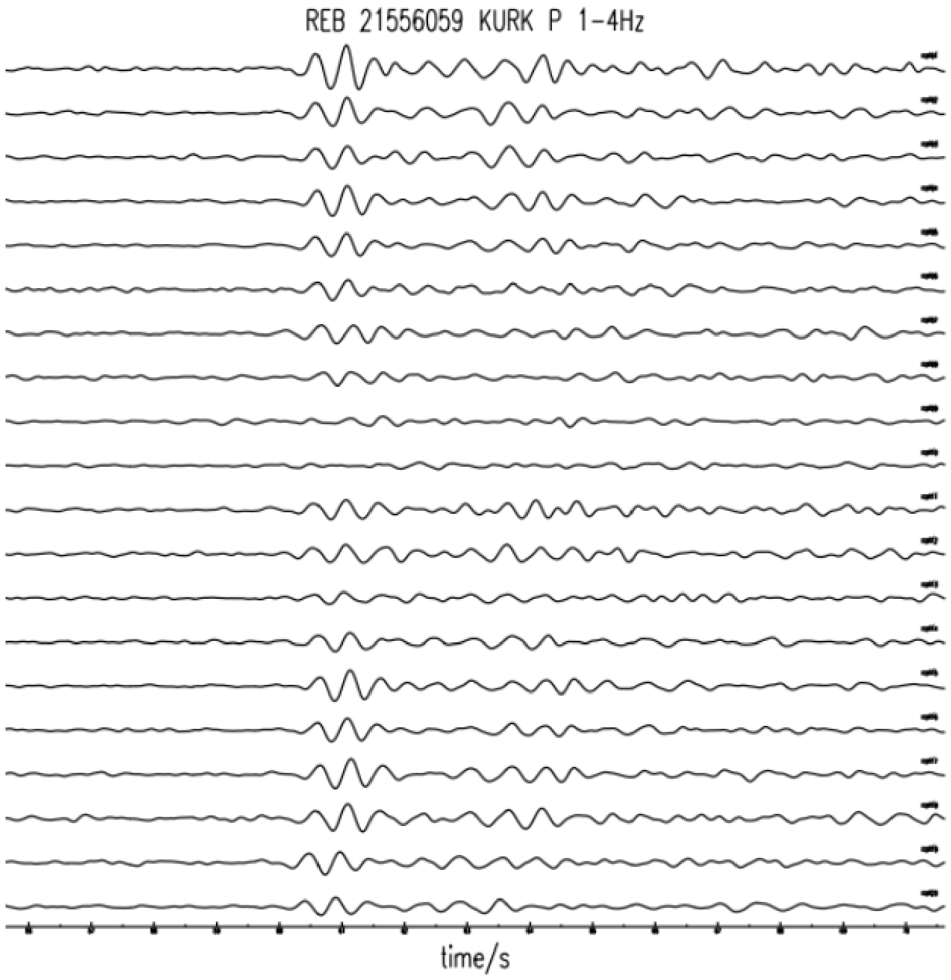
Left: topographic variations (especially MJAR, NOA, NVAR).

Right: Need to beware of clock errors (e.g. TORD 2012).



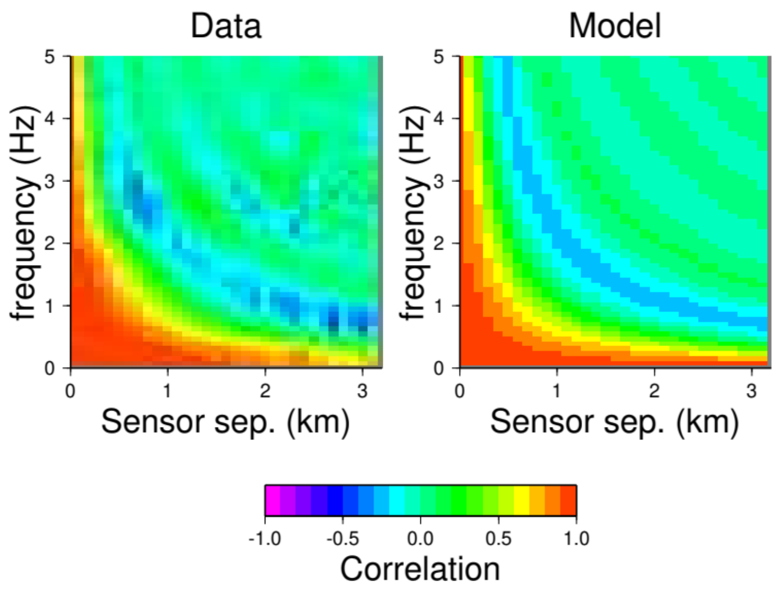
Amplitude variations

- Equal-amplitude signal assumption.
- Geological variations.
- Frequency, azimuth and slowness-dependent amplitude variations across array.
- Note:
  - Sensor calibrations.
  - Signal-to-noise ratio.

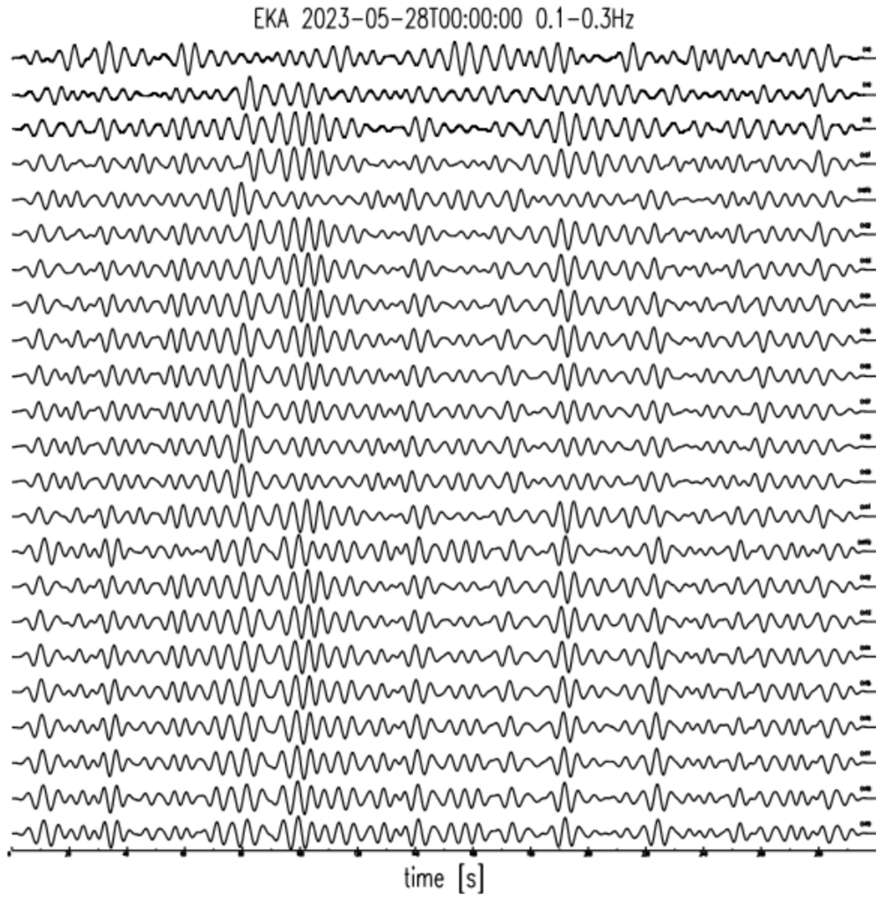


Noise models

- Spatial or temporal correlation.
  - Noise power spectrum.
  - Inter-element correlations.
- Frequency-dependence.
- Seasonal dependence.
- Parameterisation.
  - Simple and robust?



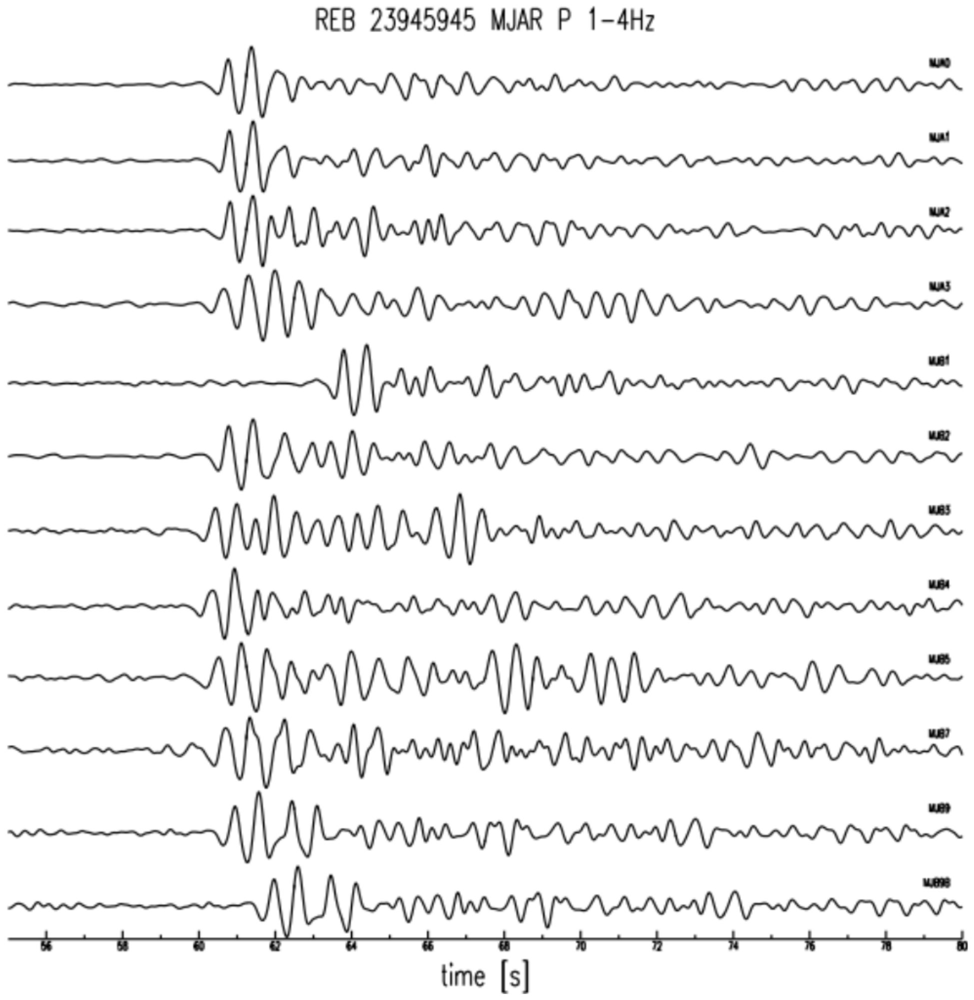
Observed and model noise correlation at ARCES.



Noise observed at EKA.

Signal models

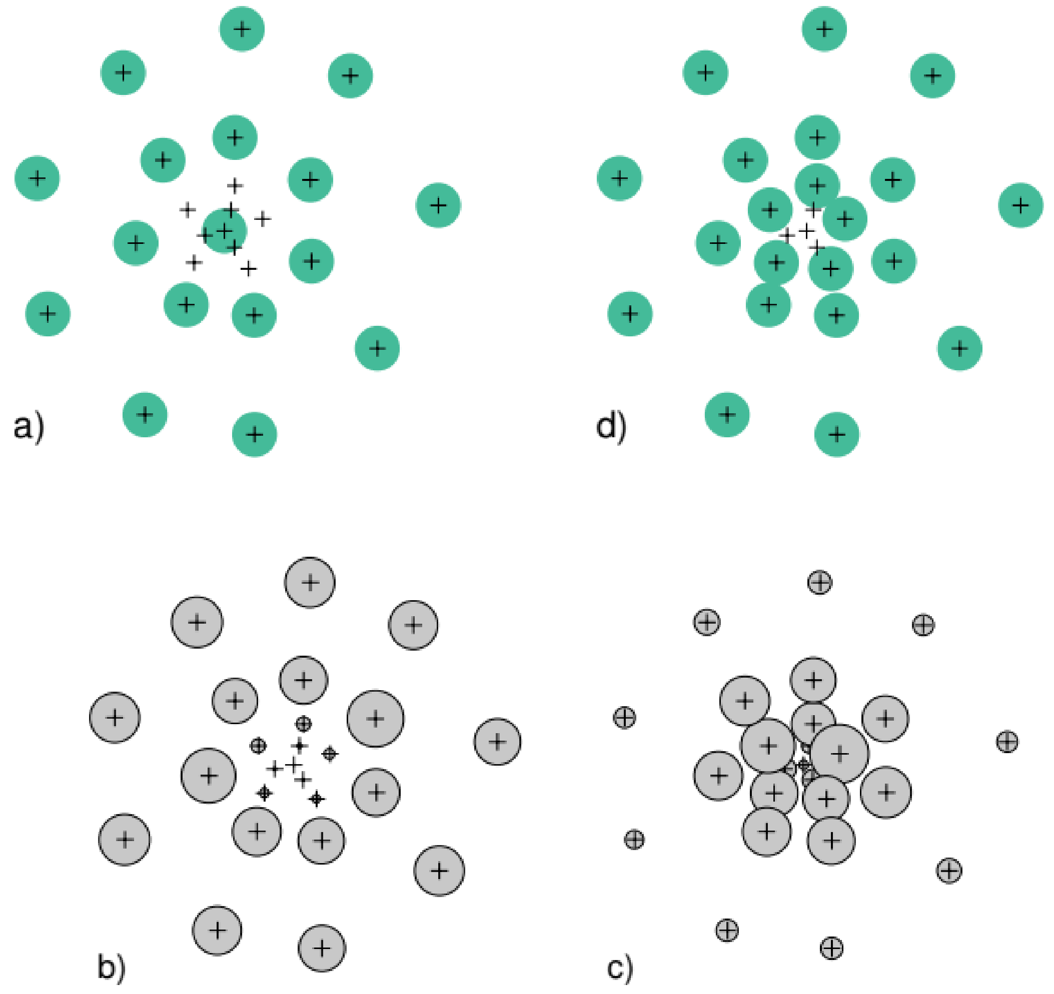
- After amplitude and time corrections.
- Inter-element correlations.
- Variation with element separation.
- Frequency, azimuth, slowness dependent?
- Phase dependent (e.g. P or S).



Right: Teleseismic P waveforms at array MJAR show considerable variation across the array.

Channel selection

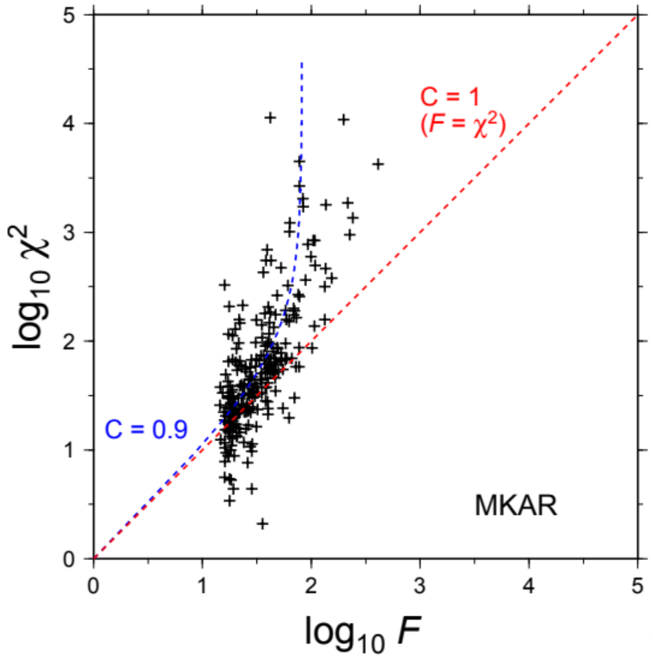
- Existing IDC processing uses element selections for certain arrays.
- Detectors such as *genF* use noise models to weight elements.
- Adding signal model may change these weights.

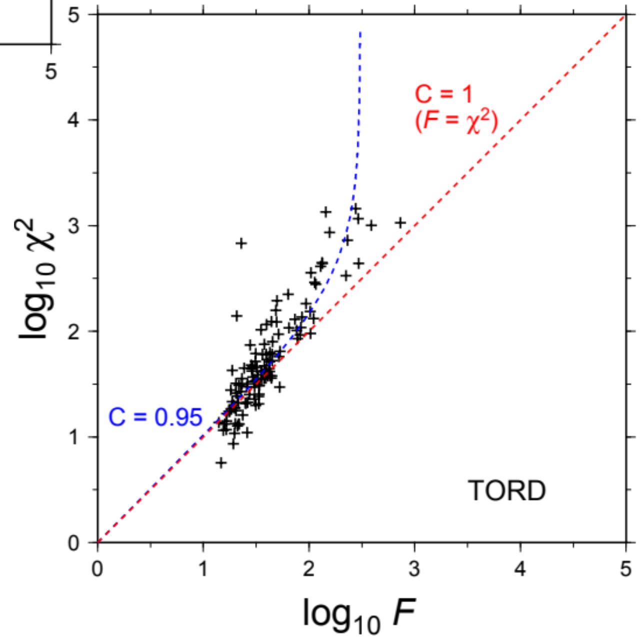


Right a) and d): IDC weights for ARCES array, 1-3Hz and 3-6Hz respectively. b) and c) genF weights at 2Hz and 4Hz (Selby, 2008). For a) and d) the weights are either 1 (green circle) or 0 (no circle), in b) and c) the circle diameter is proportional to the weight. '+' symbols show locations of all elements.

Detection statistics

- Incorporate signal and noise models into detection statistics:
  - Enhance detections.
  - Increase thresholds and reduce false detections.
  - Compare different statistics directly.
  - Refine predicted values of existing statistics.
  - Choose preferred statistics.





Right: Comparison of beam power and F statistic for signals at the MKAR and TORD arrays. C is the (estimated) proportion of coherent to total signal power. Selby (SnT 2015).

“Network detection”

Using information external to individual array:

- Source models → detection frequency band.
- Global t^* distribution → detection frequency band.
- Amplitude-distance curve → equal-magnitude detection.
- Relate beamset to geographic coverage → combined detection at multiple arrays.
- Use knowledge of array network sensitivity.
- Perhaps do without signal detection thresholds at all – use the network to detect events.
- Characterise clutter - real signals that should be detected but can be discounted.

Conclusions

- IMS seismometer arrays have a variety of sizes and designs and signal detection approaches should account for these.
- Improved signal and noise models, tailored to specific arrays, will enhance our capability to distinguish signal from noise.
- This framework should allow detection statistics to be more usefully interpreted and compared.
- Global, or network approaches can use our knowledge of the Earth and seismicity to enhance detection.
- Care should be taken not to bias detection capability.