SnT 2025 CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE

Automatic event detection and location using 3C array and denoising by Principal Component Analysis (PCA)

P3.5-340

C. Labonne, E. Rouzaud, M. Freire, Y. Cano

Introduction – How to fully exploit 3C array ?

- To detect and characterize small magnitude events, even those with long propagation distances, seismic arrays are perfectly adapted tools with their high detection capabilities.
- Fully 3-component (3C) seismic arrays (such as ARCES array in Norway) offer the possibility to use the coherency of the horizontal components in addition to the vertical one !
- But 3C arrays are still afflicted by coherent noise and incoherent noise.
- **How to effectively separate Signals Of Interest (SOI) from coherent noise(*) and incoherent noise with array data ?**

Methodology – Array denoising using PCA

Principal Component Analysis – a simple and effective method to decorrelate SOI and noise*/noise by identifying the "directions" :

- where the variance is greatest
- where there is significant information.

Two steps of denoising:

1. coherent noise* removal

- Selection of a 'noise' learning window
- Window of 1 hour preceding the analyzed time
- Elimination of periods likely to contain events
- Projection orthogonal to the first main direction (i.e. the most coherent noise)

➢ Reduce the number of detections (microseismic noise disappears)

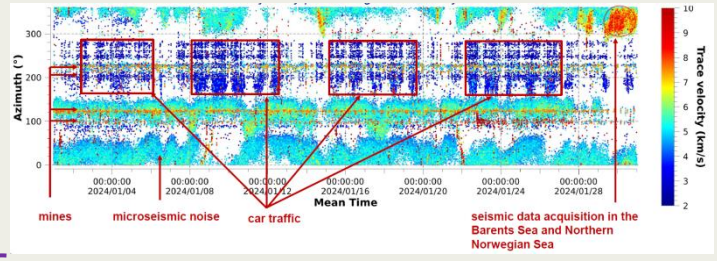
2. incoherent noise removal

- "as we go along" analysis
- Projection onto the principal component
- Concatenation of denoised signals

➢ New detections appears

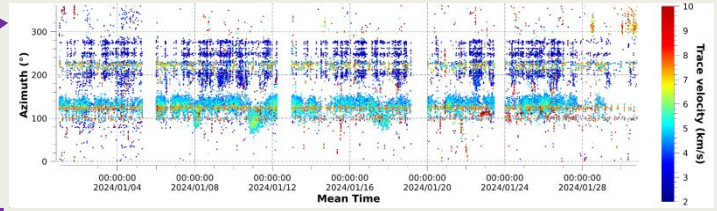
Results

- Improvement at the scale of the array phase detection:
  - More consistent detections (lower consistency meaning higher coherence, larger frequency band and higher number of pixels)
- Improvement for event detection
  - + 53% when denoising using 1C-ARCES array
  - + 51% without denoising using 3C-ARCES array
  - + 65% when denoising using 3C-ARCES array
- Improvement in event location



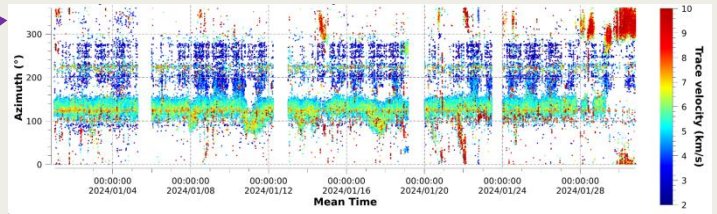
➢ ~164 000 detections
➢ 867 events

1. coherent noise* removal



➢ ~38 000 detections

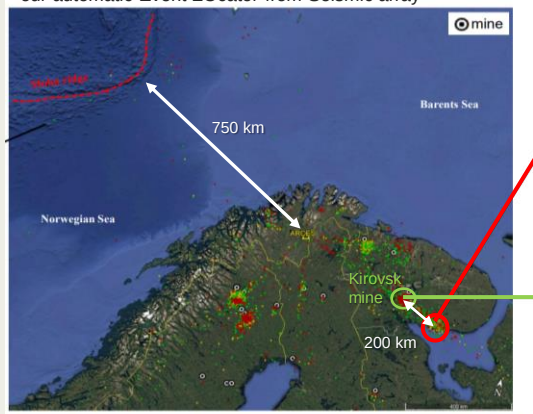
2. incoherent noise removal



➢ ~170 000 detections
➢ 1178 events (3 days missing)

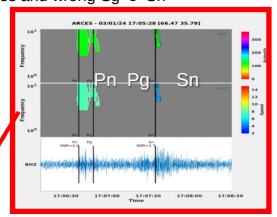
Number of coherent phase detections and events detected over a period of one month.

ELOS – our automatic **E**vent **LO**cator from **S**eismic array

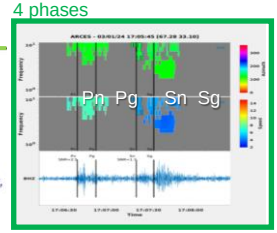


Map of detected events (dots) over one month of data, red corresponds to elos3c, yellow to elos1C and green to elos1C with denoising process.

Without denoising (mislocated event)
Only 3 phases and wrong Sg ➔ Sn



With PCA denoising
4 phases



Conclusions

Summary – we demonstrated the benefits of denoising array data for array processing :

- Phase detections are more consistent, S-waves are more visible
- More events detected and better located !

In progress – application to arrays with lower number of sensors (starting with FINES 15 sensors, next: standard IMS arrays with only 9 sensors)

Next step –

- Better exploit the spectral matrix : quantify the number of sources by looking at the eigen values
- Assessing potential improvements for teleseismic events detection
- Quantify improvements for event detection when using template matching

If needed, each part is detailed in the next slides

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- Fully 3-component (3C) seismic arrays (such as ARCES array in Norway) offer the possibility to use the coherency of the horizontal components in addition to the vertical one !
- But 3C arrays are still afflicted by coherent noise and incoherent noise.
- **How to effectively separate Signals Of Interest (SOI) from coherent noise(*) and incoherent noise with array data ?**

ARCES array – 25 three-component sensors deployed over 3 km²

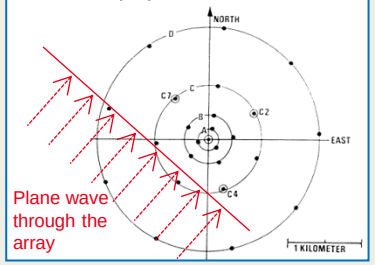
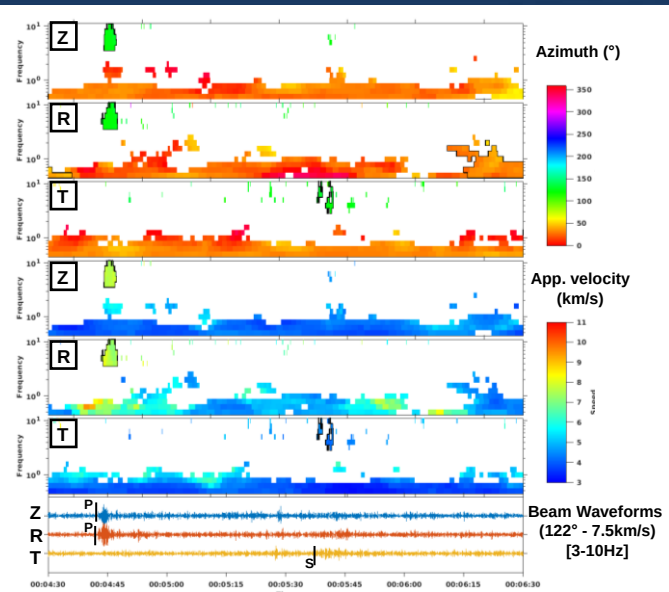
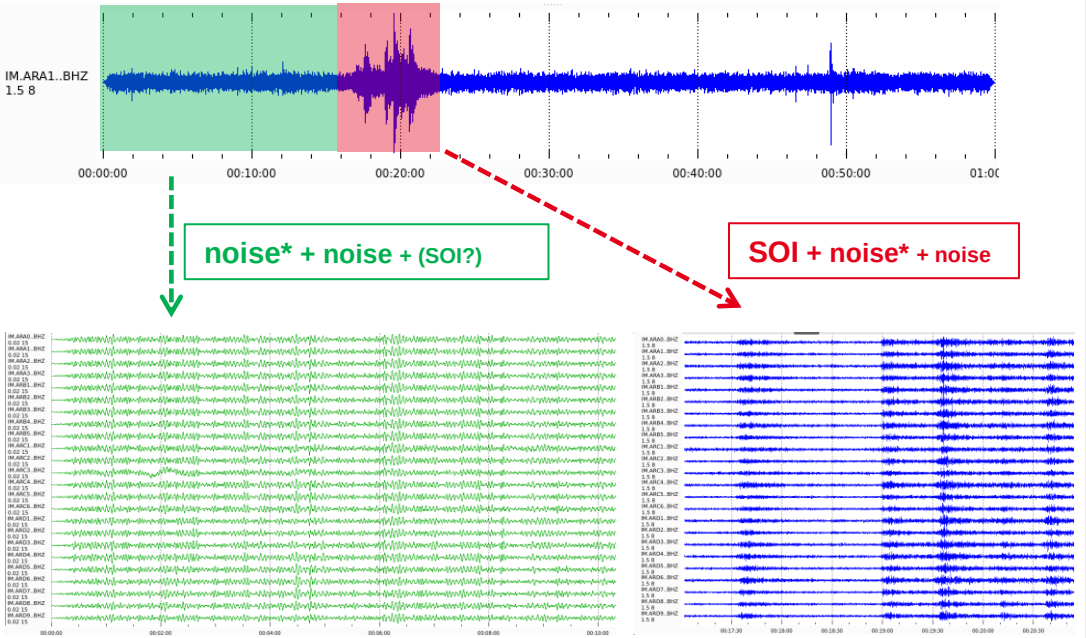


Figure : Example of a small magnitude event detected and located using 3C-array data from only ARCES seismic array: event from Kirovsk mine located at ~400km. PMCC results obtained using the vertical component (Z) or the horizontal components (R-radial or T-transverse). The top part presents the azimuth of coherent detections, the middle the apparent velocity, and the bottom the array beam waveforms obtained for each component. The S wave is only visible on T component !





➢ Time window dominated by low frequency coherent noise (e.g. microseismic noise)

➢ Time window dominated by mine events

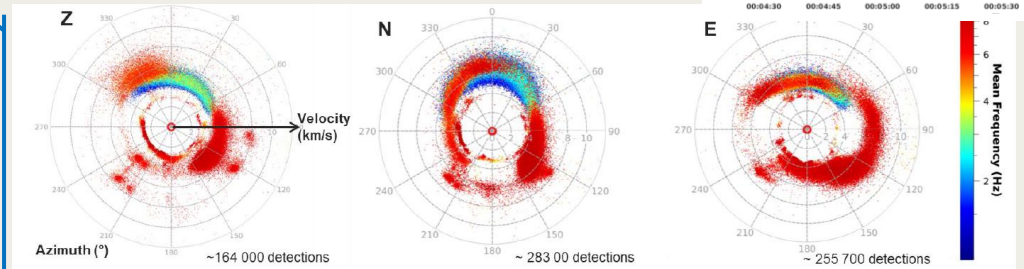
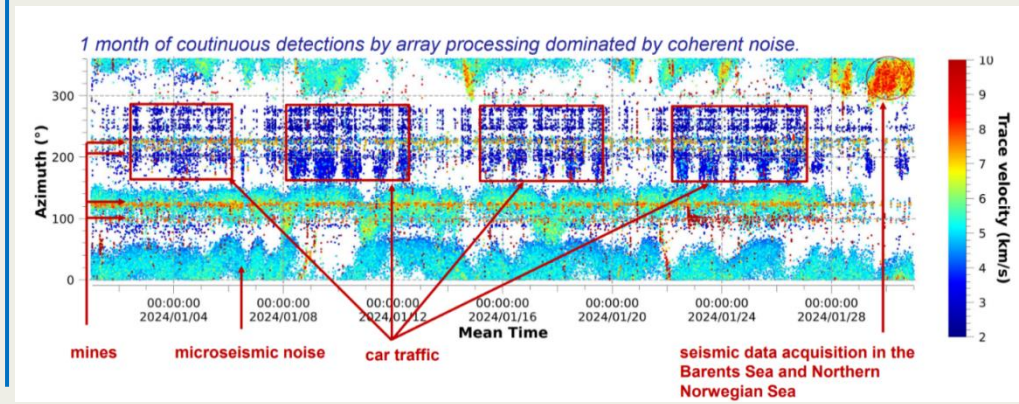


Figure to illustrate the complementarity of the horizontal (North and East) and vertical components.



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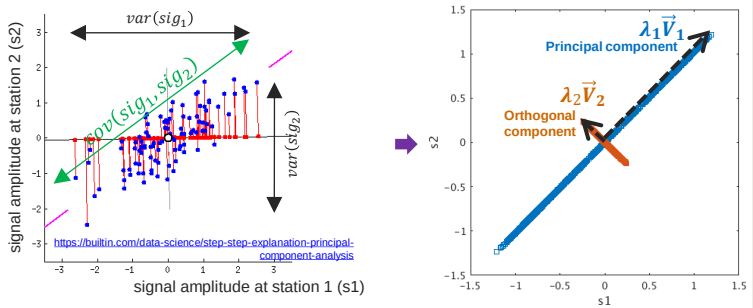
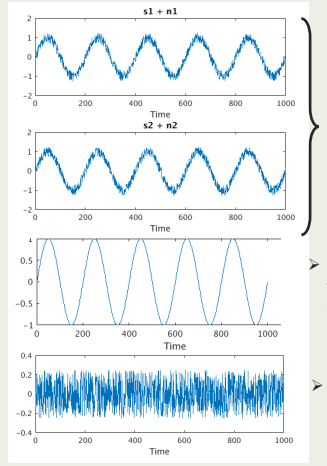
- where the variance is greatest

Figure to illustrate PCA principle with 2 stations only



$$M_{cov} = \begin{pmatrix} var(sig_1) & cov(sig_1, sig_2) \\ cov(sig_1, sig_2) & var(sig_2) \end{pmatrix} = P \begin{pmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{pmatrix} P^{-1}$$

$$P = (\vec{V_1}, \vec{V_2})$$



raw signals at station 1 and 2

➢ Signal 1 projected on the first component ($\vec{V}_1$)
Coherent part of the signal

➢ Signal 1 projected orthogonally to the first component ($\vec{V}_2$)
Incoherent part of the signal

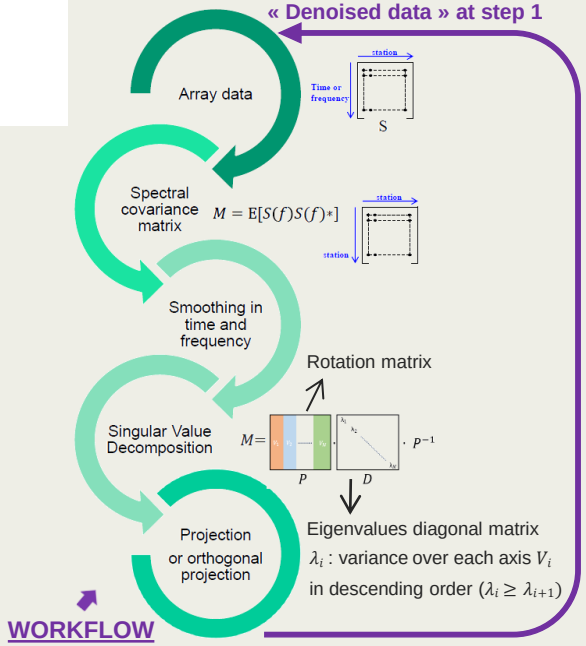


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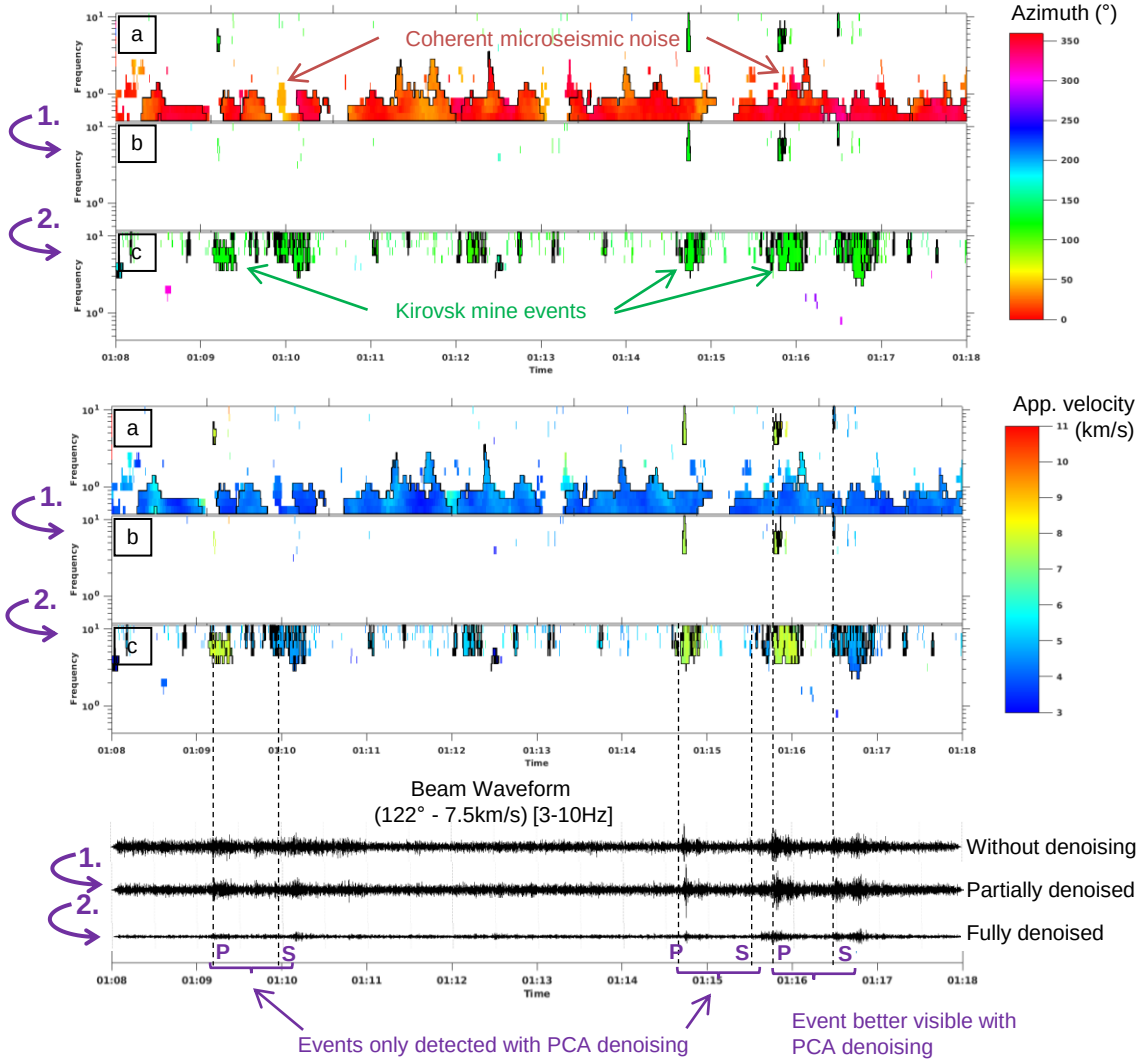
Figure: PCA denoising example using ARCES array. PMCC results obtained on raw data (a), partially denoised data (b), and fully denoised data (c). The top part presents the azimuth of coherent detections, the middle the apparent velocity, and the bottom the array beam waveform.



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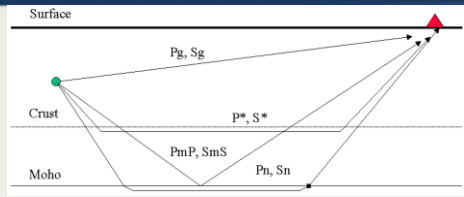

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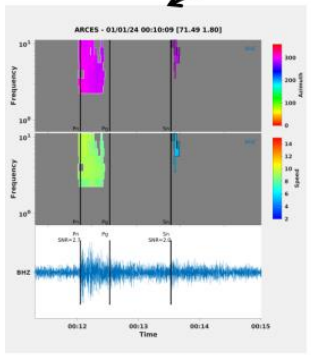
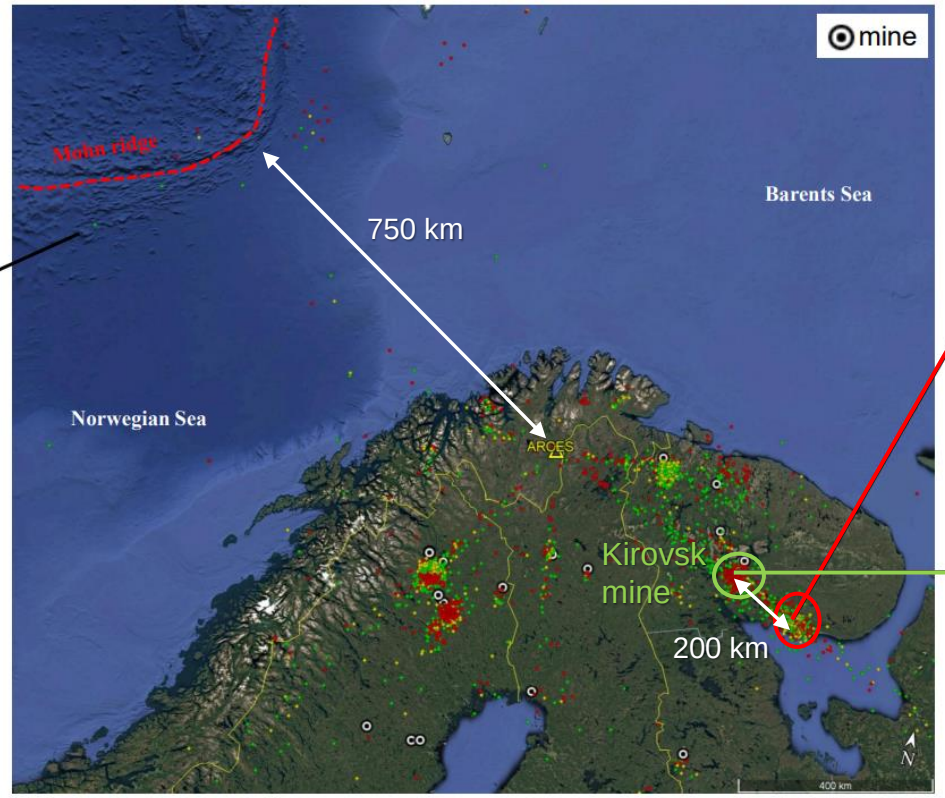


New event detected along Mohn ridge

ELOS (our automatic **E**vent **LO**cator from **S**eismic array)



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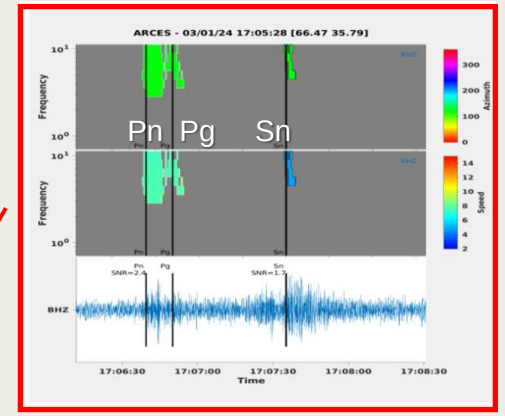
Without denoising

Only 3 phases and wrong Sg ➔ Sn



With PCA denoising

4 phases