

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

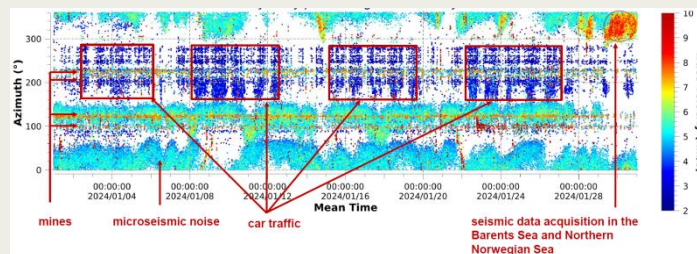
- Selection of a ‘noise’ learning window
- Window of 1 hour preceding the analyzed time
- Elimination of periods likely to contain events
- Projection orthogonal to the first main direction (i.e. the most coherent noise)
- Reduce the number of detections (microseismic noise disappears)

2. incoherent noise removal

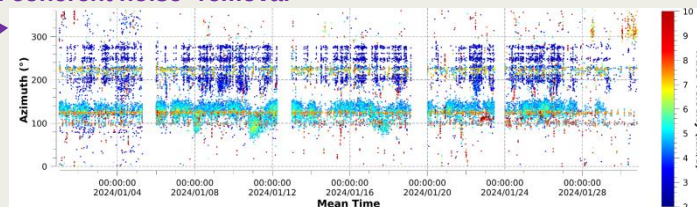
- “as we go along” analysis
- Projection onto the principal component
- Concatenation of denoised signals
- New detections appears

Results

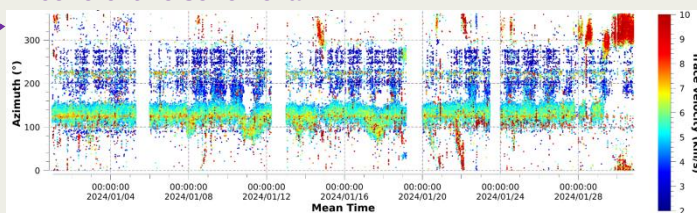
- Improvement at the scale of the array phase detection:
 - More consistent detections (lower consistency meaning higher coherence, larger frequency band and higher number of pixels)
- Improvement for event detection
 - + 53% when denoising using 1C-ARCES array
 - + 51% without denoising using 3C-ARCES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



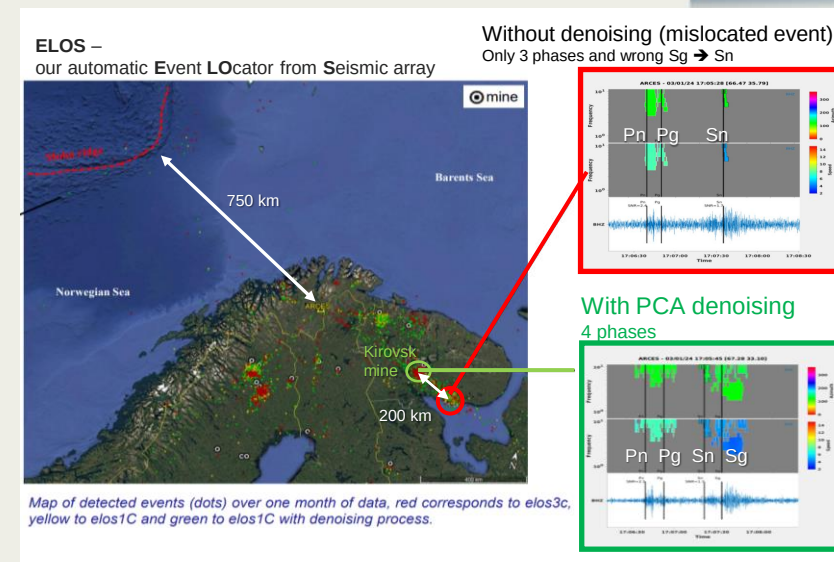
1. coherent noise* removal



2. incoherent noise removal



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



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

i If needed, each part is detailed in the next slides

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

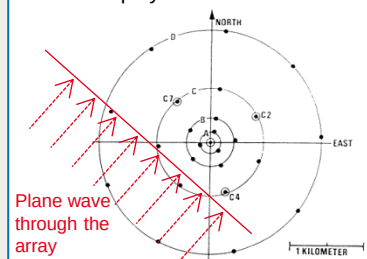


Figure : Example of a small magnitude event detected and located using 3C-array data from only ARCES seismic array: event from Kirovsk mine located at ~400km. PMCC results obtained using the vertical component (Z) or the horizontal components (R-radial or T-transverse). The top part presents the azimuth 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 !

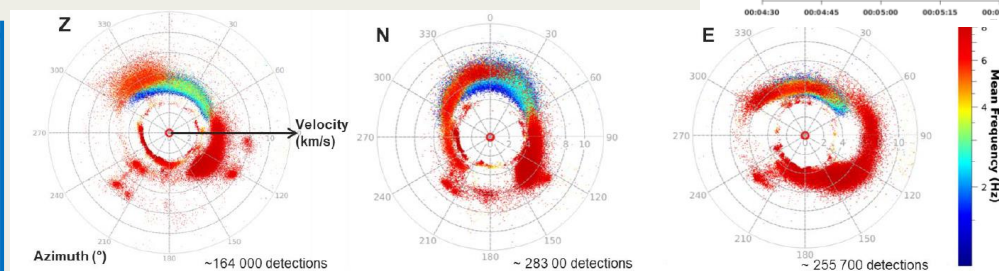
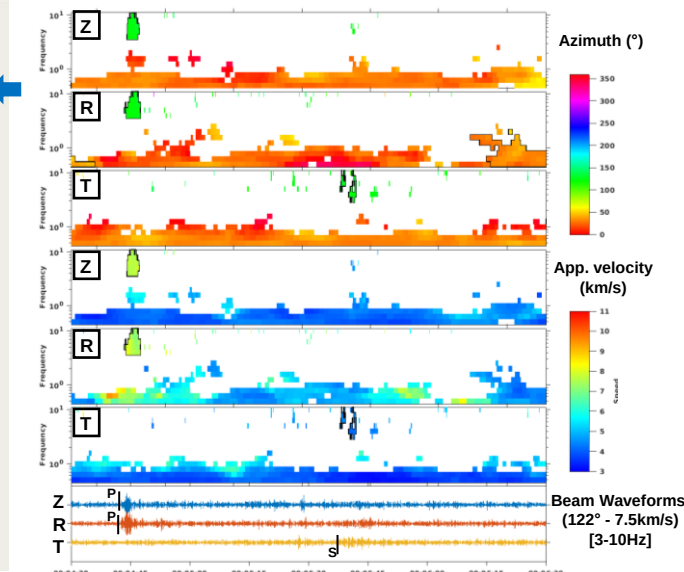
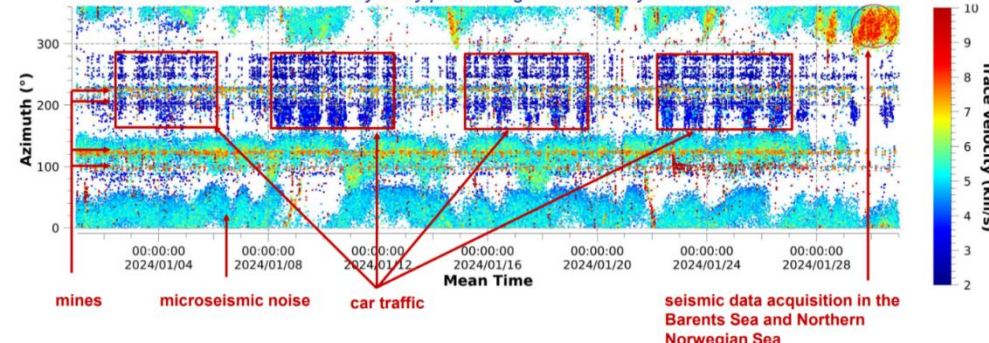


Figure to illustrate the complementarity of the horizontal (North and East) and vertical components.

1 month of continuous detections by array processing dominated by coherent noise.



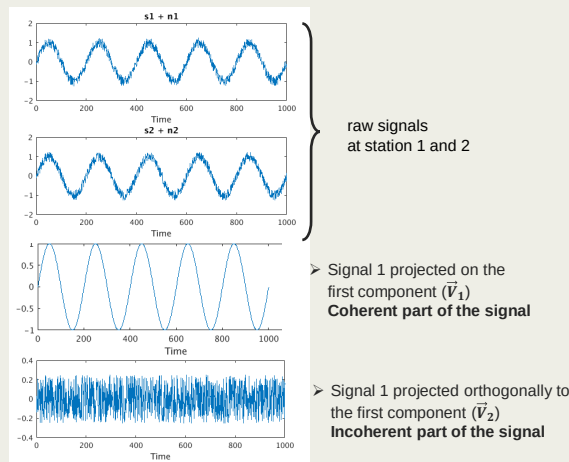
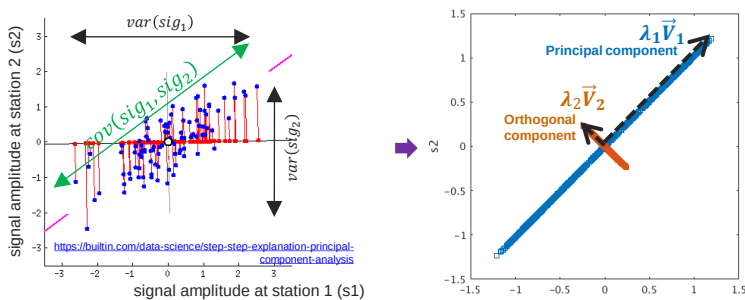
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Methodology – Array denoising using PCA

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

- where the variance is greatest

Figure to illustrate PCA principle with 2 stations only



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

$$P = (\vec{V}_1, \vec{V}_2)$$

Two steps of denoising:

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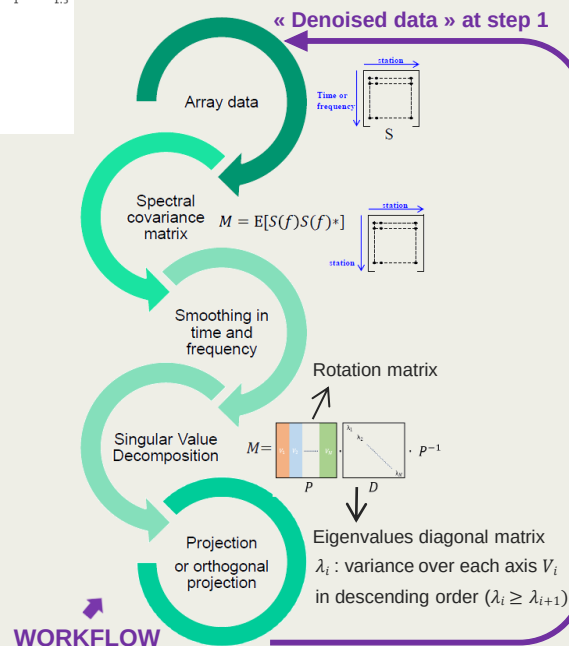
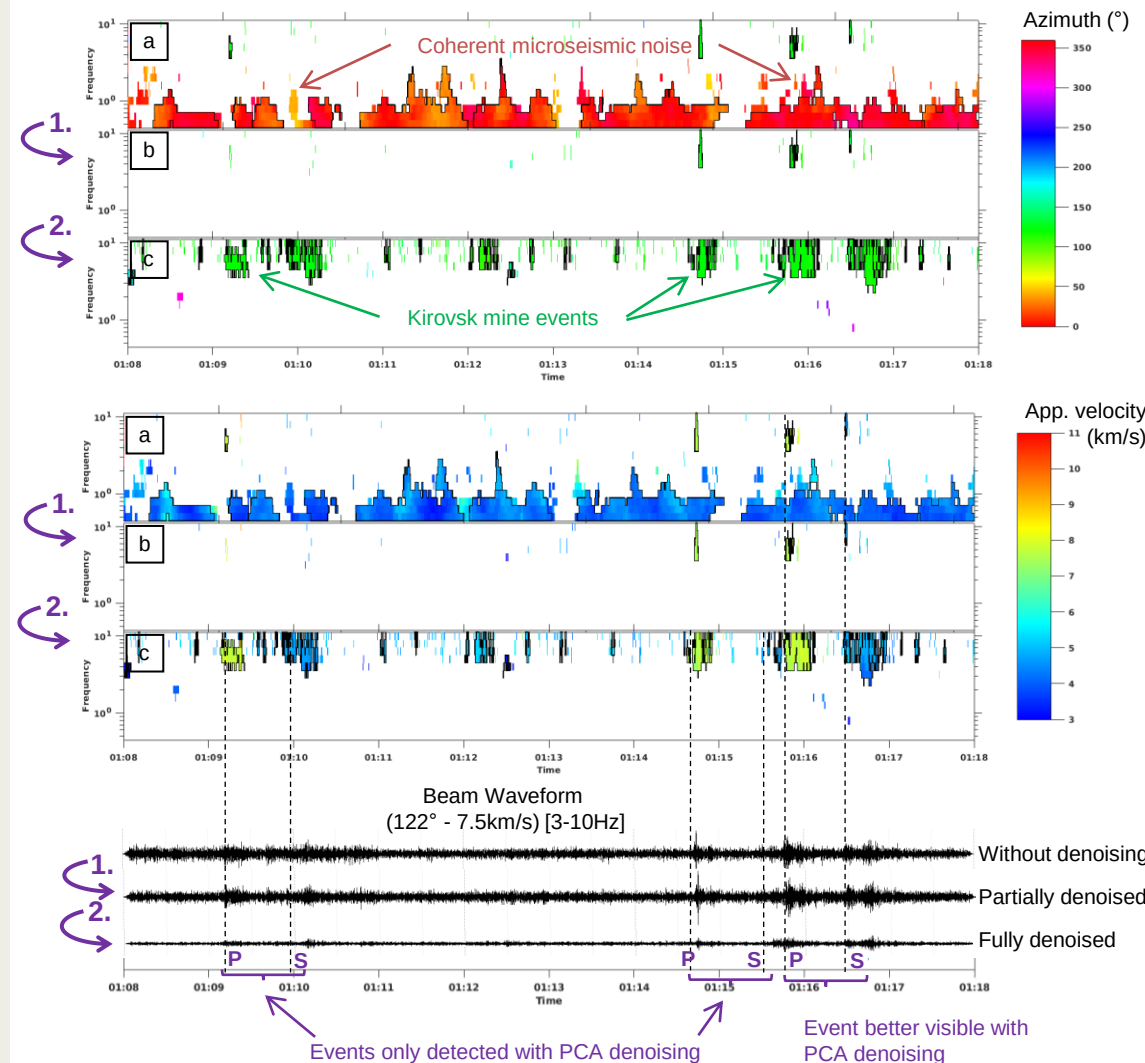


Figure: PCA denoising example using ARCES array. PMCC results obtained on raw data (a), partially denoised data (b), and fully denoised data (c). The top part presents the azimuth of coherent detections, the middle the apparent velocity, and the bottom the array beam waveform.



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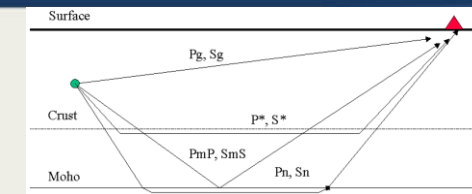
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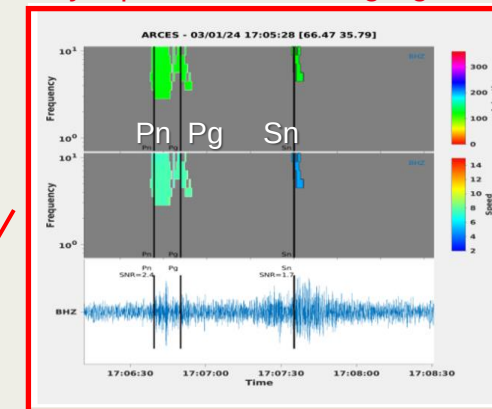
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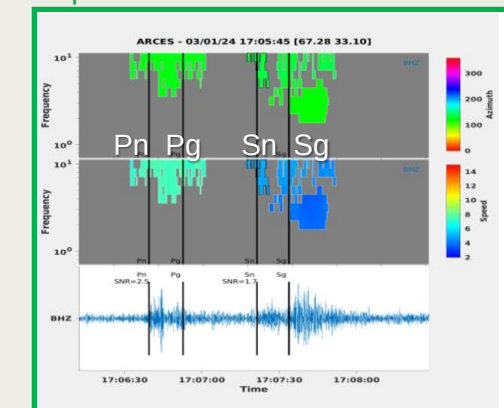
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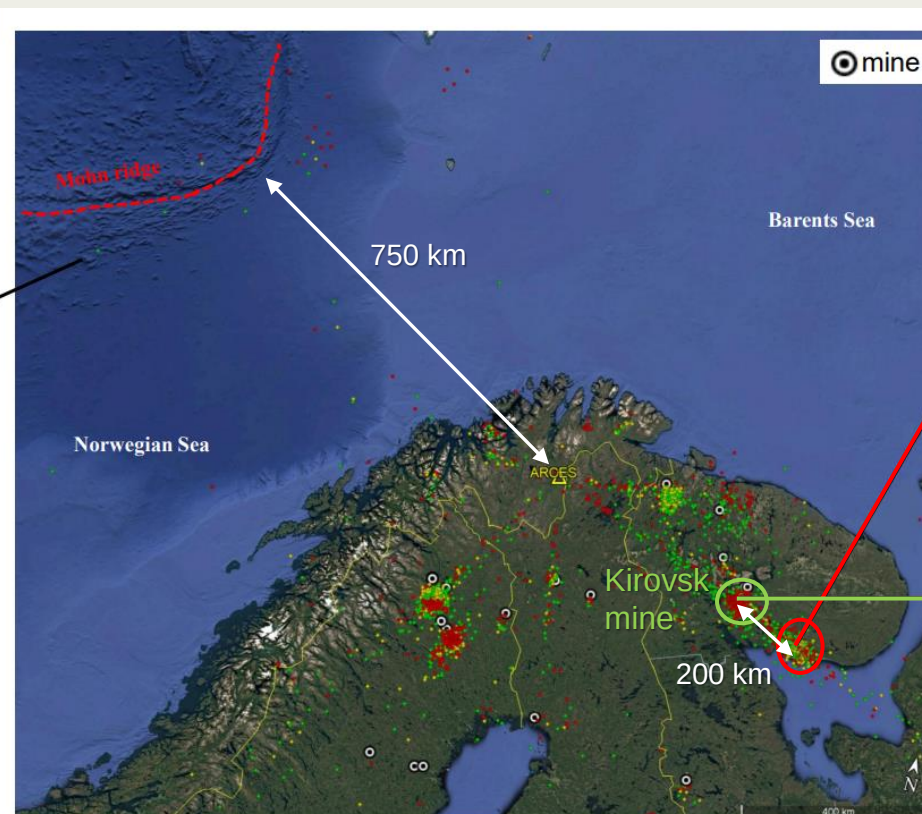
Without denoising
Only 3 phases and wrong Sg → Sn



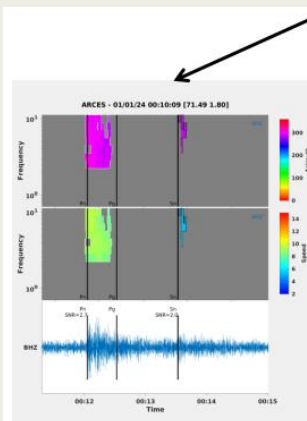
With PCA denoising
4 phases



ELOS (our automatic Event LOcator from Seismic 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.



New event detected along Mohn ridge