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Detection, Localization and Characterization of the Seismicity: Deep Learning Methods for Accuracy Improvements of Regional Seismic Bulletins

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INTRODUCTION

We present results on the methodological use of multiple automatic deep-learning algorithms to detect, pick, locate and characterize the seismicity by using the regional seismic networks diversity

METHODS/DATA

Integrative automated protocol using Deep-Learning (CNN) methods on multi-instrumented sites. Applications from anthropic seismic monitoring, to regional natural seismicity, through microseismic swarms activity

START

RESULTS

+ Operational automated protocol of picking, phase association, earthquake location and event discrimination

+ Anthropic seismicity detection and discrimination

+ Gain up to 0.5 of magnitude of completeness

+ hypocenter accuracy location improvement

CONCLUSION

Our global automatic protocol, which takes advantage of different deep learning-based methods and causal approaches, has been applied to different tectonic and instrumental contexts and has demonstrated its efficiency in providing extensive new seismic and labelled catalogues

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INTRODUCTION

The CEA/DIF/DASE and OMP/IRAP laboratories rely on a large network of seismic sensors transmitting information in real time by satellite to the various institutes where seismologists study each seismic event to determine its exact location, determine its origin and its type and, if necessary, trigger the early warning system.

This complex mass of information to be collected and processed is now growing exponentially, thanks to the general increase in storage capacity and advances in data transmission. For example, CEA/DIF/DASE continuously collects data in real time from more than 650 sensors around the world, a figure that will continue to grow in the coming years as the number of sensors increases. Every day, this information is added to the CEA's databases, which analyze and reference nearly 700,000 seismic events and store more than 30 years of digital signals (i.e. nearly 100 TB).

It is now essential to benefit from the development of new algorithms to process and analyze these huge amounts of data. Among the multiple task to achieve, the detection, location and characterization of the seismic events is of prime importance.

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OBJECTIVES

- Through the development and use of multiple methods, including new advances in deep learning-based approaches, we aim to build an automated and operational protocol for processing and analyzing seismic data in order to detect, locate and automatically characterize seismic events.

- We applied our off-the-shelf protocol to different geological and instrumental contexts, at different scales, and for different studies with various scientific objectives to test the reliability of the automatically generated comprehensive catalogues.

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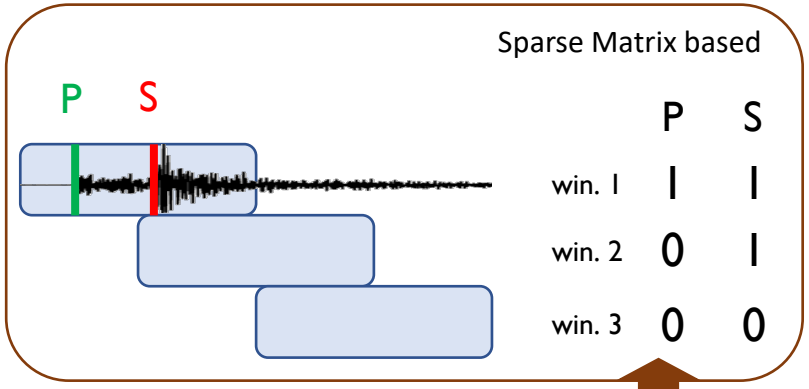
METHODS

Integrative automated protocol: Deep-Learning-based approach

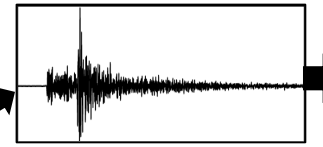


Automatic implemented protocol

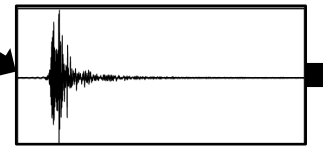
Coupled deep learning based approaches

Derode, et al., 2023b

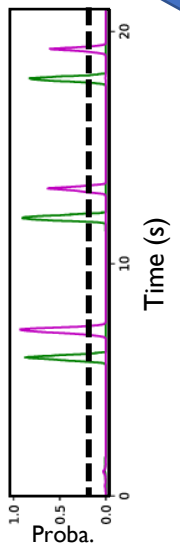
Phase Detection PHASENET → **Phase Association PANEAR** → **Location NONLINLOC** → **Event Discrimination DISCRIEQQ**

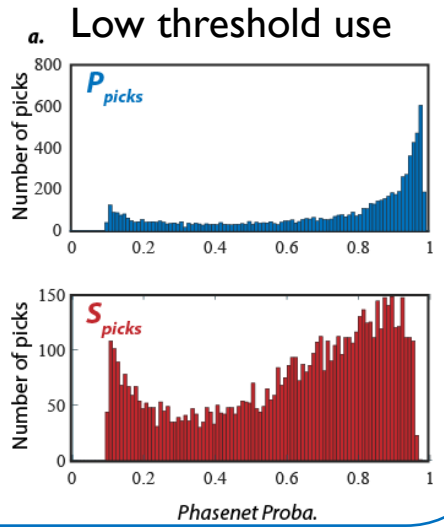


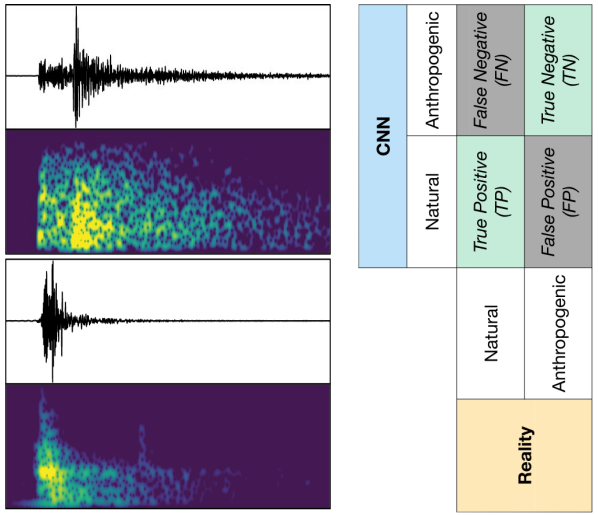
Natural Seismicity



Anthropic Seismicity







Comprehensive labelled regional catalogue

Hourcade et al., 2023

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RESULTS

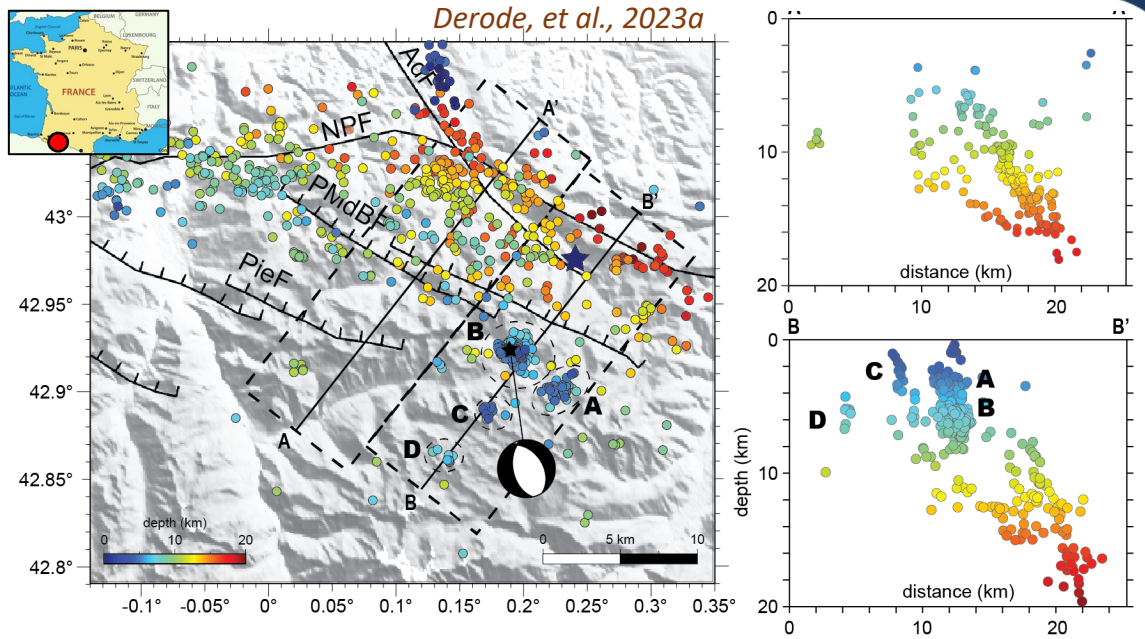
Protocol application to monitor and study local seismicity

French Pyrenees: Campan valley
Temporary seismic crisis monitoring

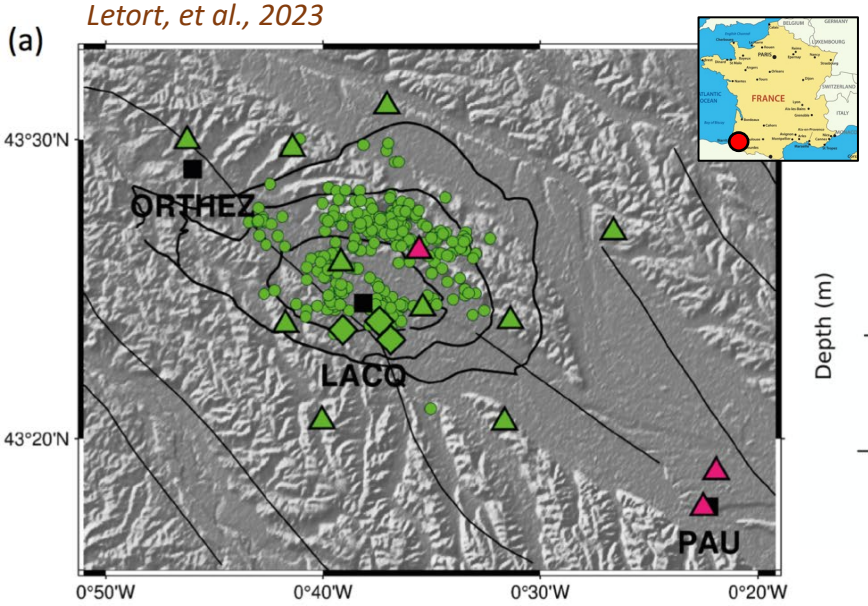
- Strict Phase Association (Grid Search + PANear)
- 1D velocity model readjustment
- Strict NLL reloc.

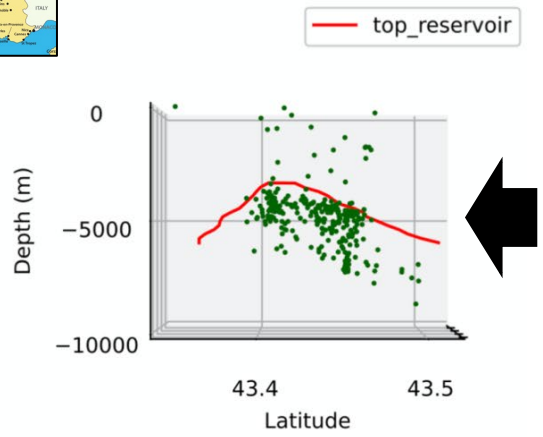
~ 800 automatically detected and well-located events
+ Complete protocol adapted to study regional natural fluid-induced micro-seismicity

Derode, et al., 2023a



Letort, et al., 2023





French Pyrenees: Lacq gas field
Induced seismicity monitoring

- Small temporary network (10kmx10km) for continuous monitoring

+ Depth accuracy strongly increased
+ Quick and reliable information on seismicity induced by anthropic fluid-injections

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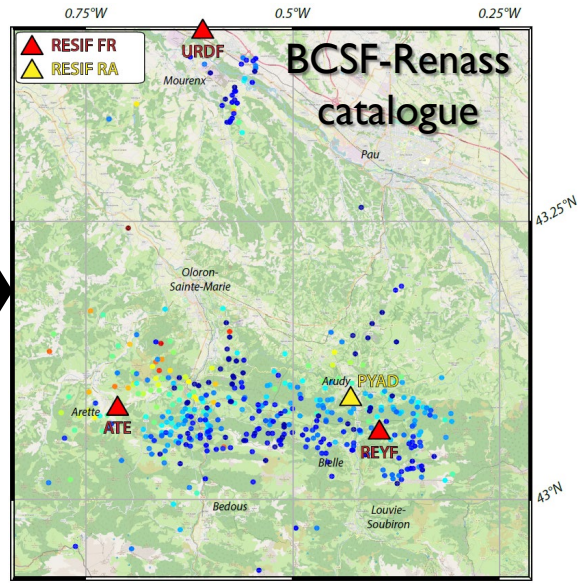
RESULTS

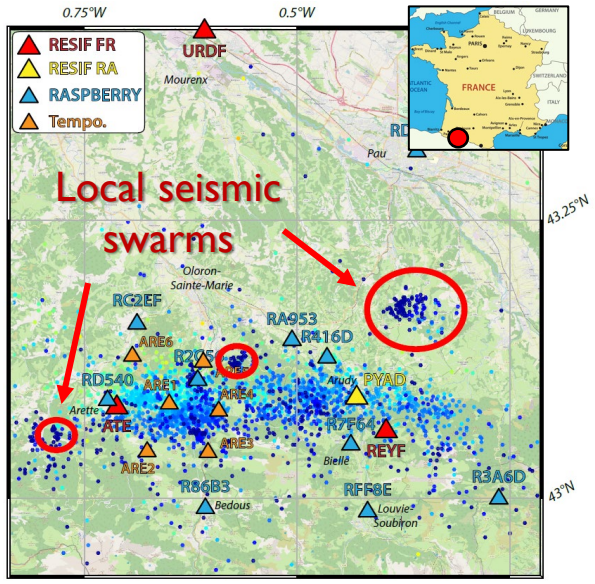
Protocol application to build extensive regional seismic catalogues

French Pyrenees: Arette valley
Multi-instrumental integration

- Vel. (BB) and Acc.(SM) permanent network + temporary seismic antenna + low cost network (rasp.)

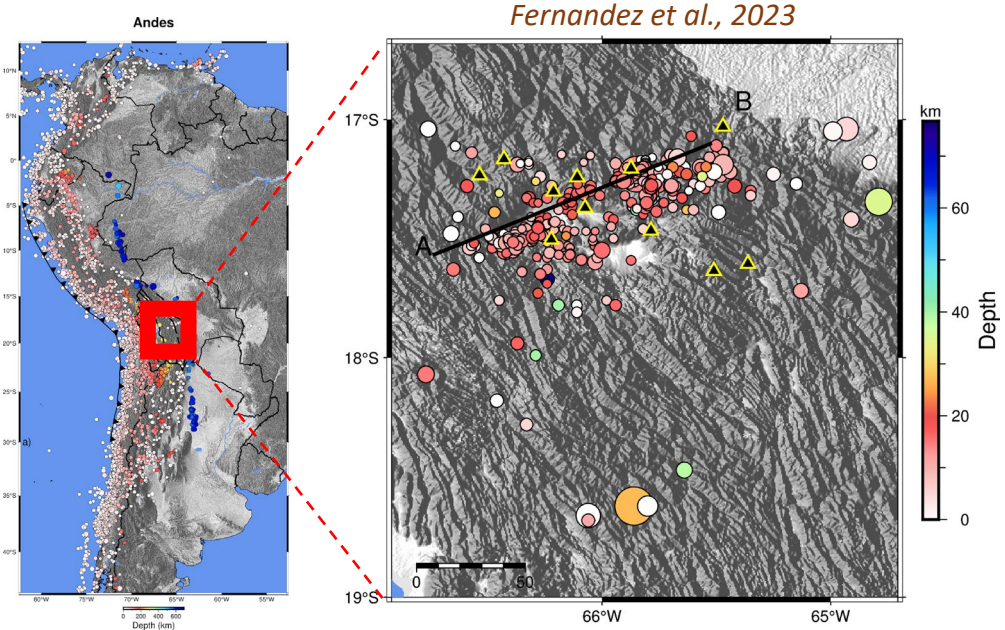
~ 5x more detected events ($M_{comp\_fin} = M_{comp\_init} - 0.5$)
+ Improvement of the location by adding multiple S-picks
+ Automatic Quarry-blast detection and location





Derode, et al., 2021

Fernandez et al., 2023



Bolivia: Cochabamba valley
Regional seismotectonic study

- Regional seismic array (100kmx100km)

+ New detected events, lowering magnitude of completeness at 0.9 (M_L)
+ Optimization of hypocenter locations
+ Swarms and clusters highlight

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CONCLUSION

- Our global automatic protocol, which takes advantage of different deep learning-based methods and causal approaches, has been applied to different tectonic and instrumental contexts and has demonstrated its efficiency in providing extensive new seismic and labelled catalogues.

- The implemented protocol has been used at local and regional scales, with different and heterogeneous seismic instrumentation and network geometries, for local microseismicity or anthropogenic seismicity monitoring, as well as for multi-instrumentation sites or regional tectonic studies.

- Our new methods of rapid regional phase association and deep learning-based event discrimination coupled with the efficiency of the PhaseNet and NonLinLoc algorithms can represent substantial improvement for operational seismic survey institutions .

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