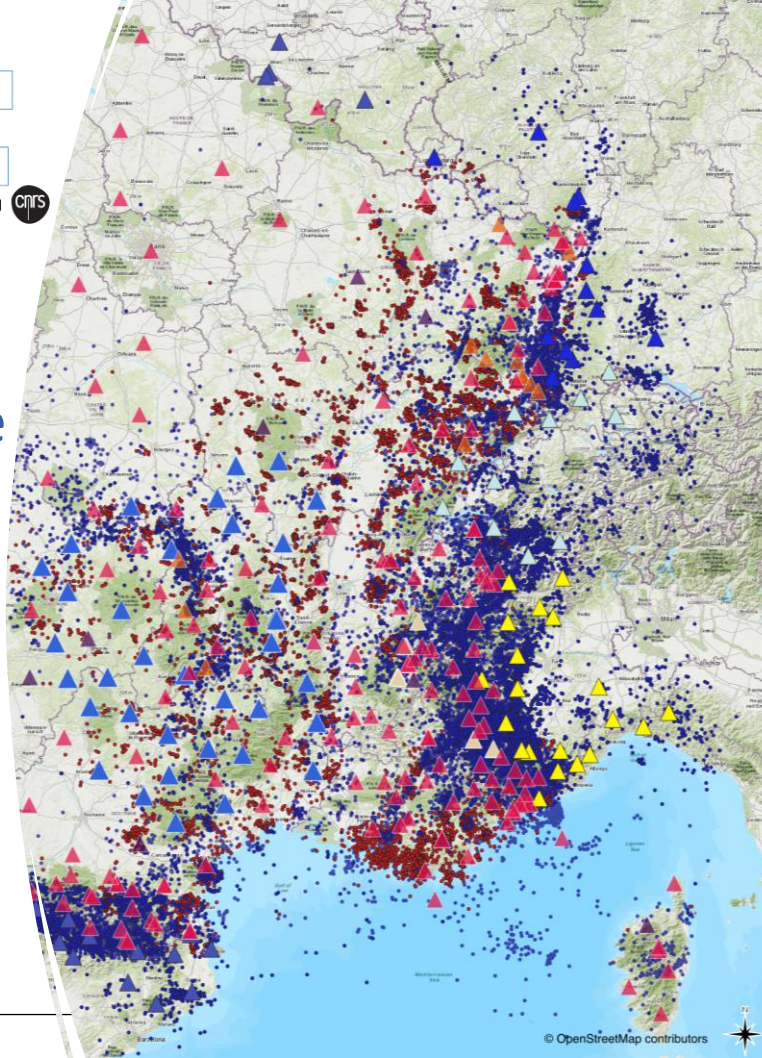




Deep learning en sismologie workflow pour l'analyse multi-échelles, de l'Hexagone aux essaims

2eme rencontres Epos-France
Sète, 18-21 novembre 2025

Marc Grunberg (marc.grunberg@unistra.fr),
Sophie Lambotte, Remi Dretzen

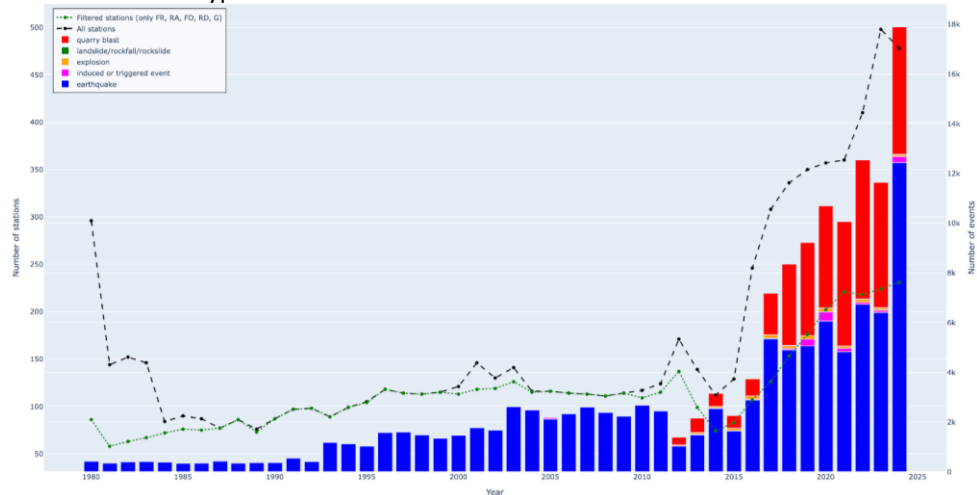


BCSF-RéNass Service National d'Observation CNRS/INSU

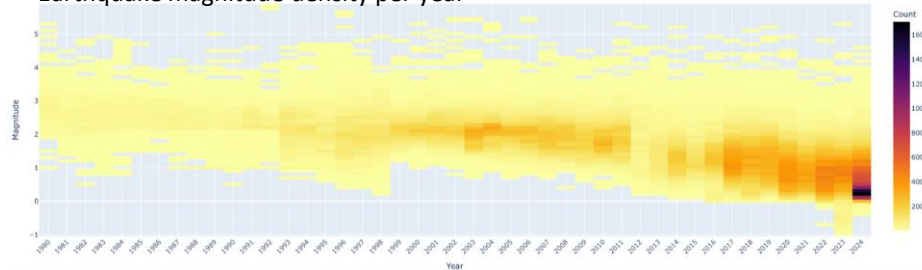


Carte des stations sismologiques utilisées par le
BCSF-RéNass en 2025

Annual event types and station count

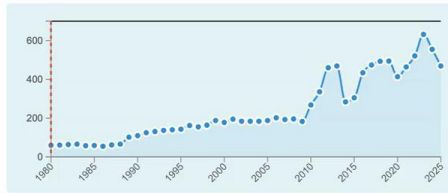


Earthquake magnitude density per year



Evolution des stations sismologique 1980-2025

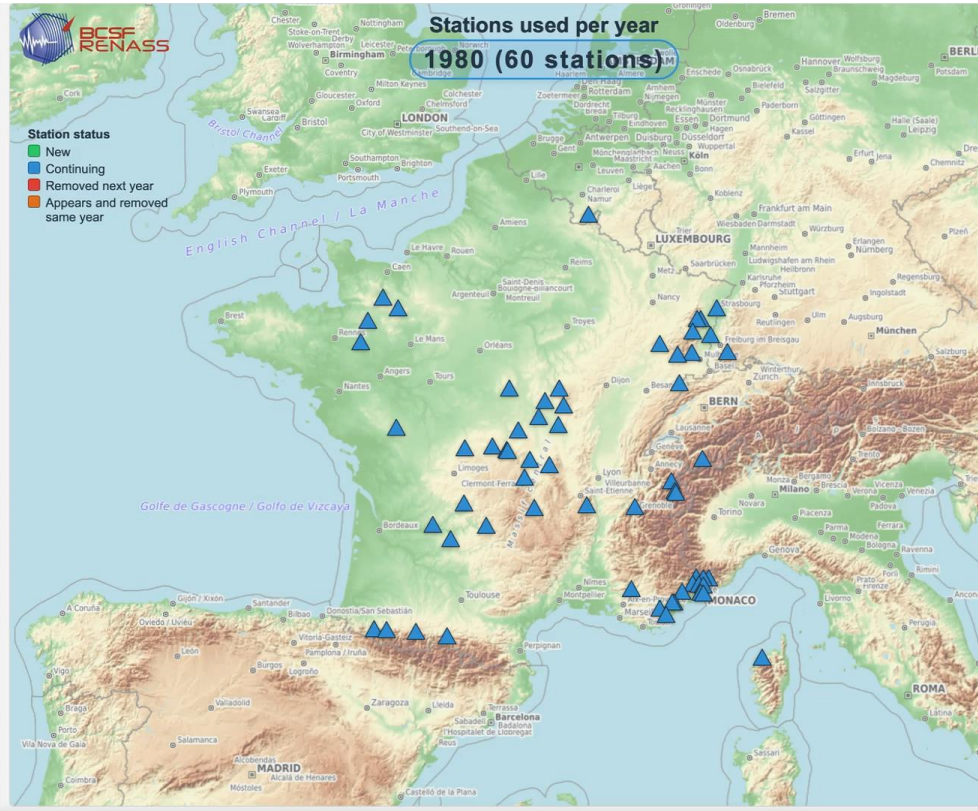
Evolution of the total number of stations (used)



New stations per year (used)



Stations removed per year (not used)

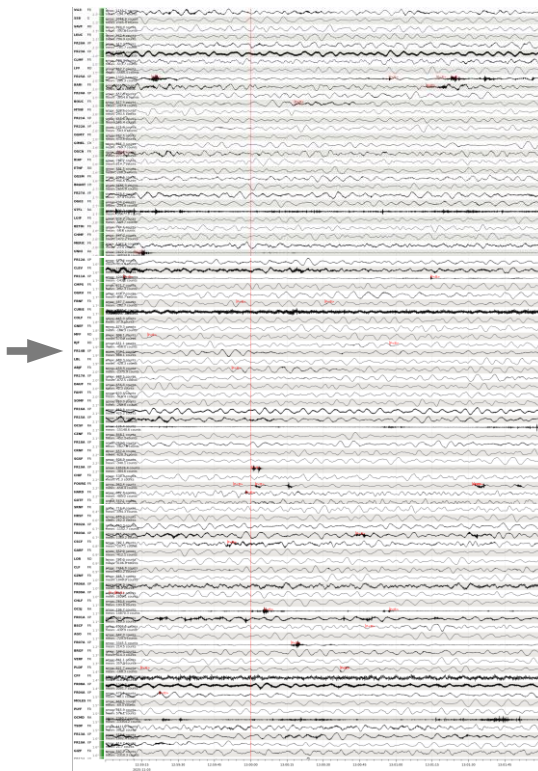


Data Input

- Waveforms
- Bulletins

Seismicity Workflow

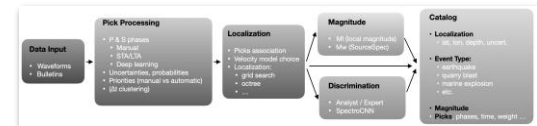
Data Input



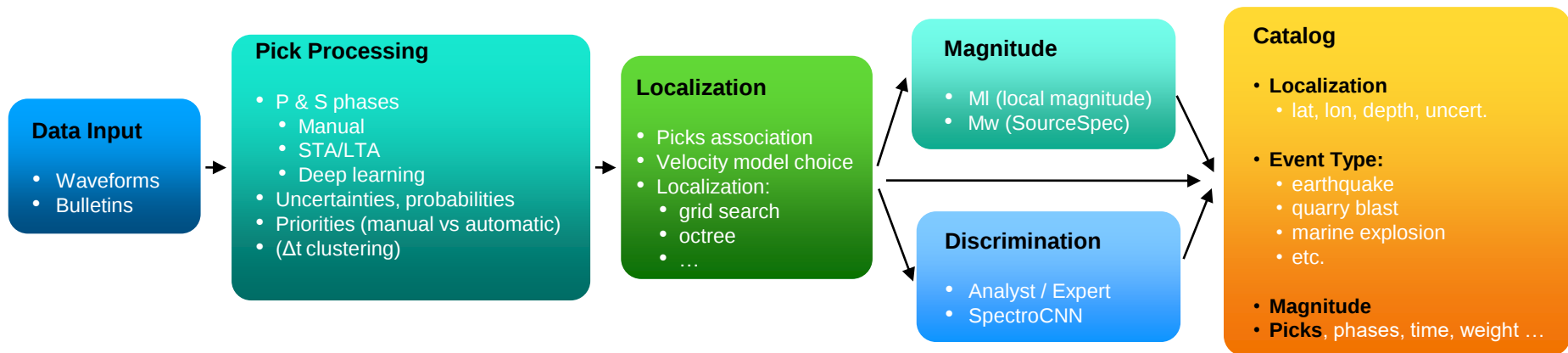
Centre de données
de l'EOST, data center
de l'Unistra



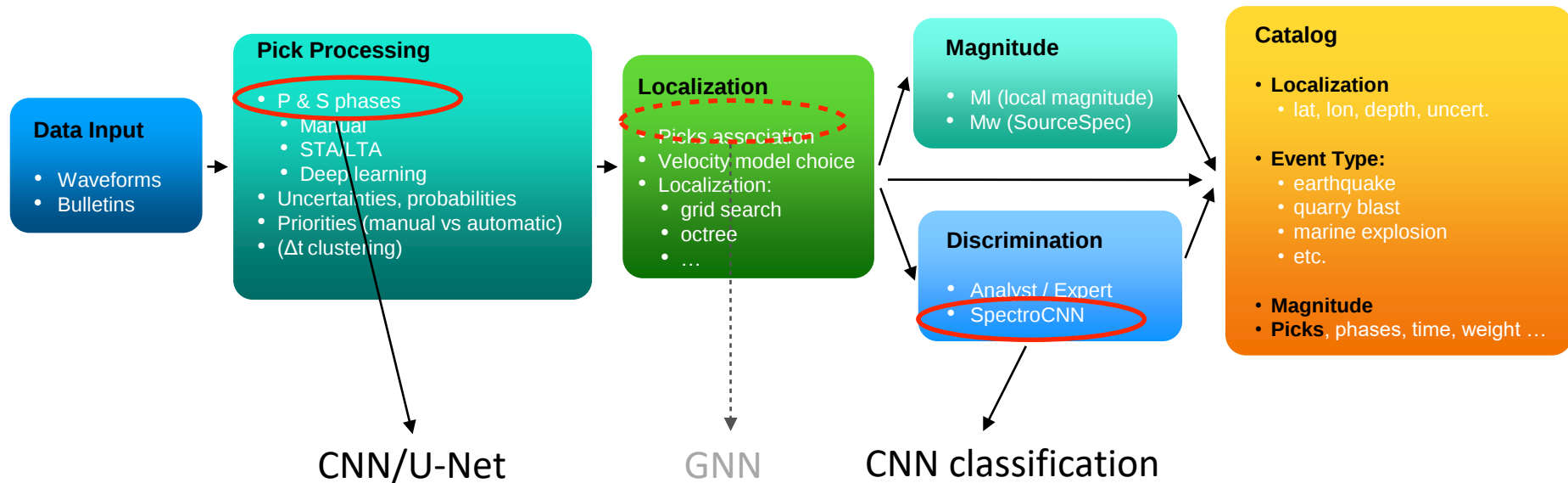
File system
Webservice



Seismicity Workflow



Seismicity Workflow



CNN: convolution neural network

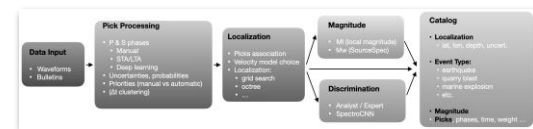
GNN: graph neural network

Pick Processing

- P & S phases
 - Manual
 - STA/LTA
 - Deep learning
- Uncertainties, probabilities
- Priorities (manual vs automatic)
- (Δt clustering)

Seismicity Workflow

Pick Processing



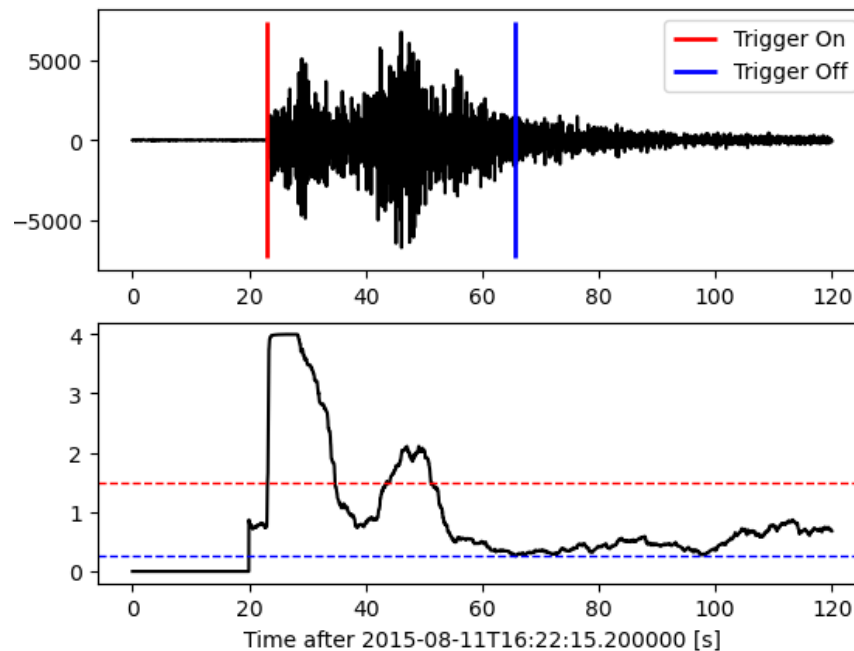
Earthquake Detection STA/LTA

Standard trigger algorithm.

Two moving time windows :

- a short-time average window (STA)
- a long-time average window (LTA)

The **STA** measures the 'instant' amplitude of the seismic signal and **watches for earthquakes**. The **LTA** takes care of the current average **seismic noise amplitude**.

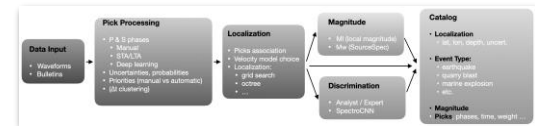


Pick Processing

- P & S phases
 - Manual
 - STA/LTA
 - Deep learning
- Uncertainties, probabilities
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- (Δt clustering)

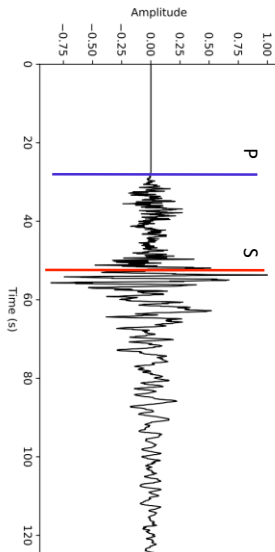
Seismicity Workflow

Pick Processing

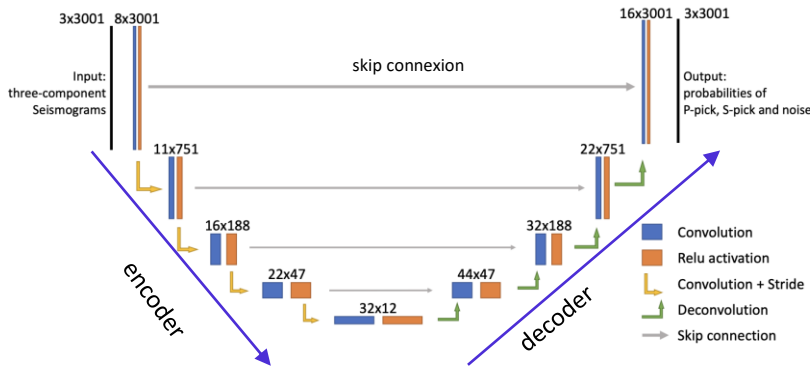
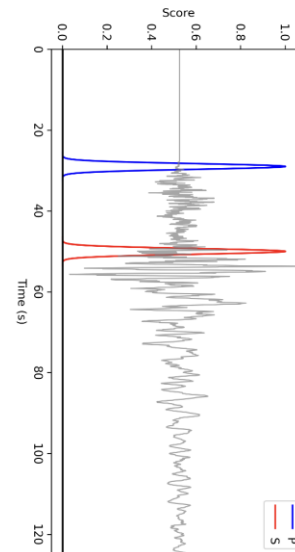


PhaseNet (Zhu et al. 2018) from modified U-net architecture (Ronneberger et al. 2015)

Input waveform



Target characteristic function

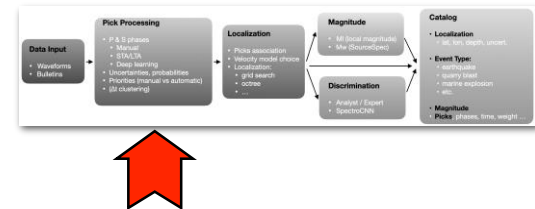


Pick Processing

- P & S phases
 - Manual
 - STA/LTA
 - Deep learning
- Uncertainties, probabilities
- Priorities (manual vs automatic)
- (Δt clustering)

Seismicity Workflow Pick Processing

Training new PhaseNet models



We trained 2 models :

- Using Pytorch / **SeisBench** (Woollam et al. 2022)

1. BCSF-Renass for mainland France

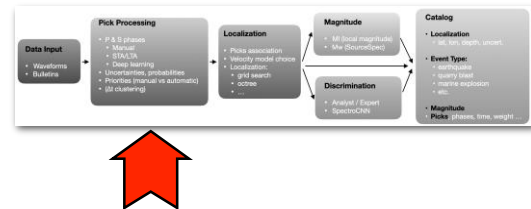
2. Induced seismicity analysis (geothermal activities)

Pick Processing

- P & S phases
 - Manual
 - STA/TA
 - Deep learning
- Uncertainties, probabilities
- Priorities (manual vs automatic)
- (Δt clustering)

Seismicity Workflow Pick Processing

Training new PhaseNet models



1. BCSF-Renass for daily analysis

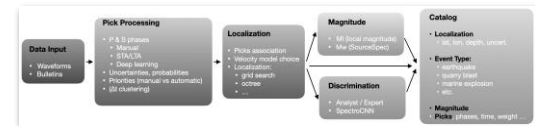
- Training from scratch (unsuccessful transfer learning)
- From **2016.01.01-2024.05**
- Dataset:
 - **55.740** events (EQ + QB)
 - **519.214** (both P&S)



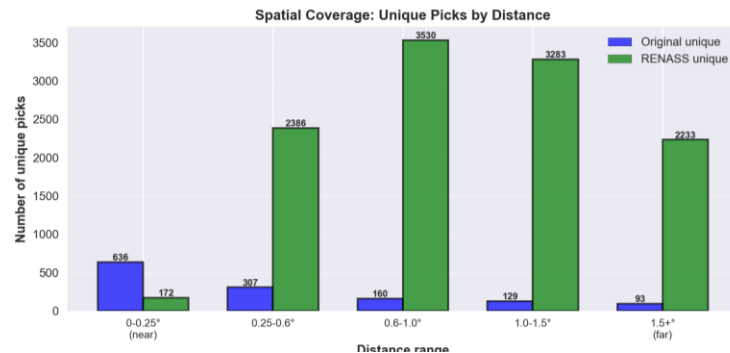
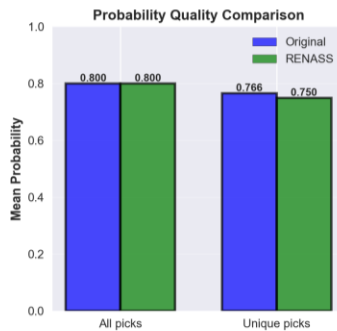
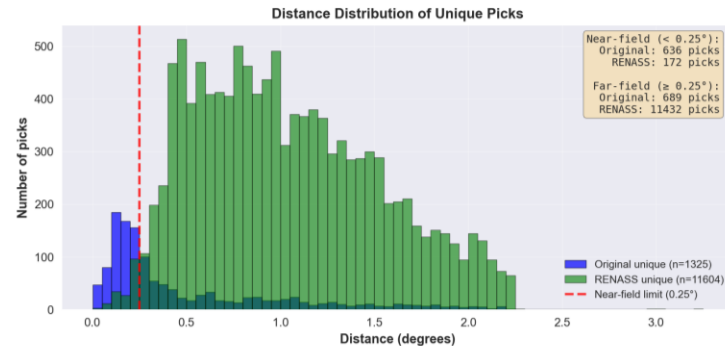
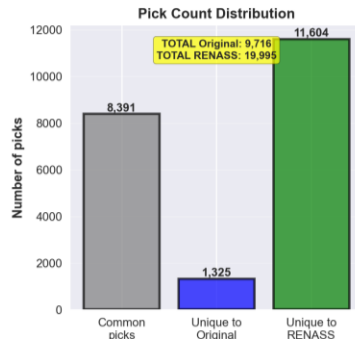
Pick Processing

- P & S phases
 - Manual
 - STA/TA
 - Deep learning
- Uncertainties, probabilities
- Priorities (manual vs automatic)
- (Δt clustering)

Seismicity Workflow Pick Processing



Training new PhaseNet models: BCSF-Renass

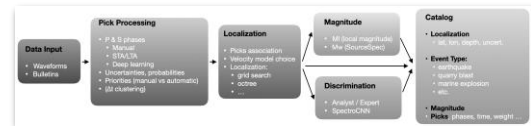


Pick Processing

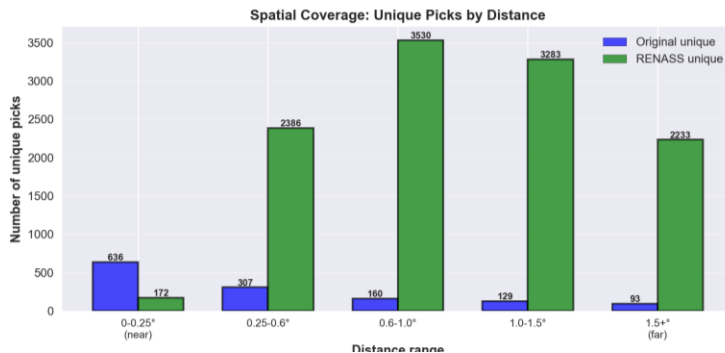
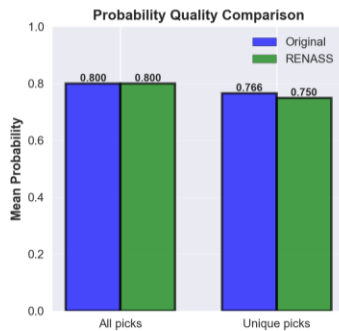
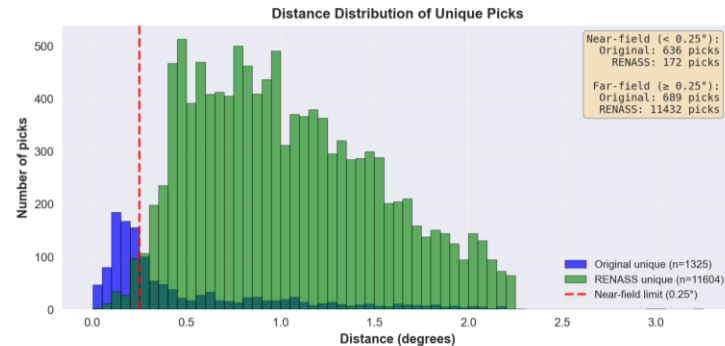
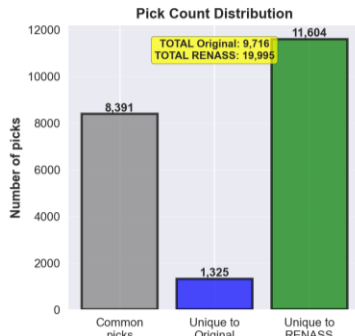
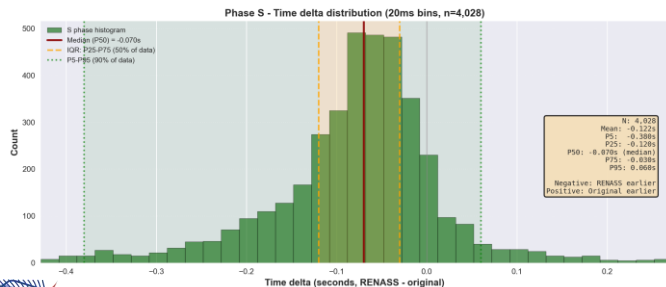
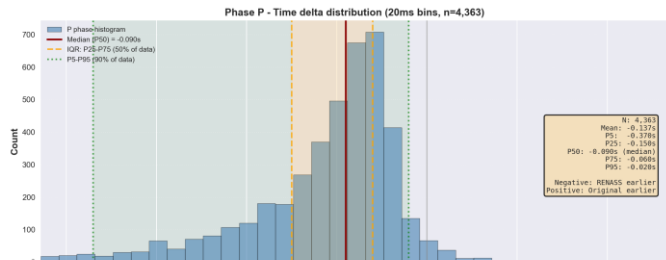
- P & S phases
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Seismicity Workflow

Pick Processing



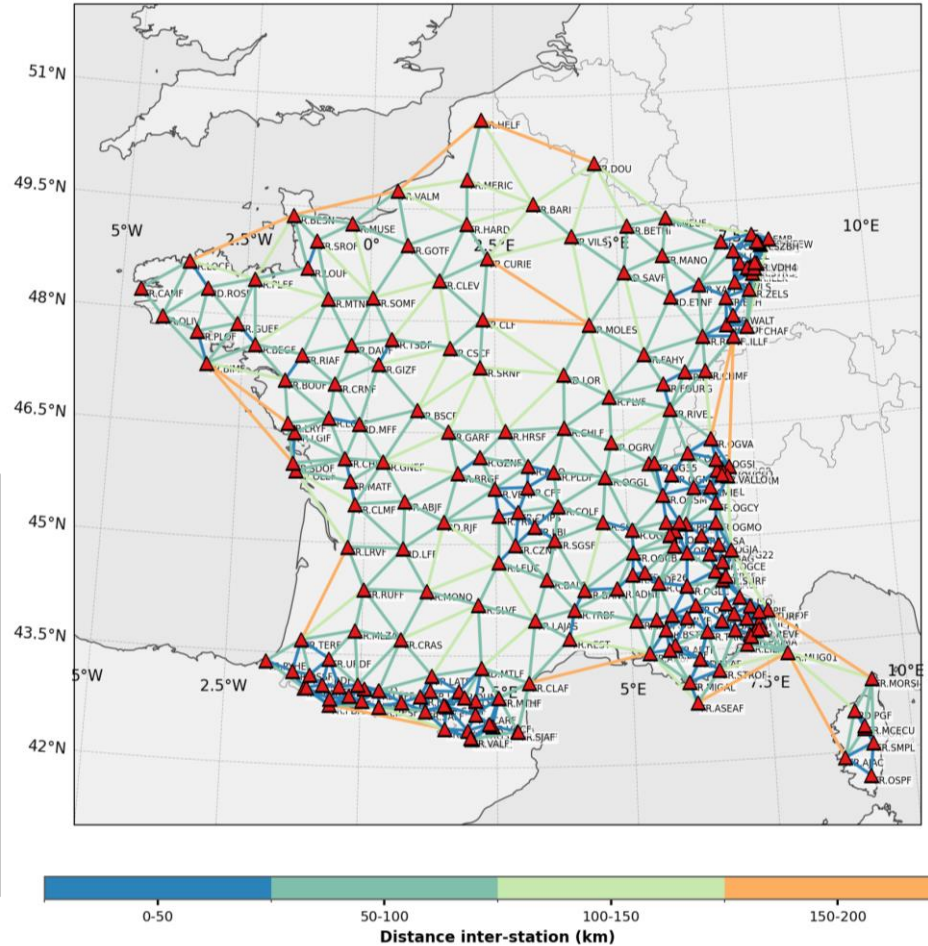
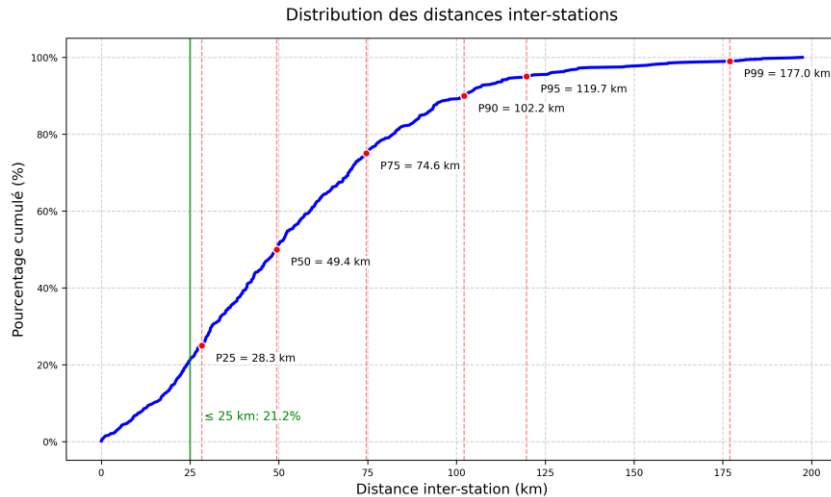
Training new PhaseNet models: BCSF-Renass



Delaunay mesh of seismic stations (FR, RD)

Mean distance: 54.9

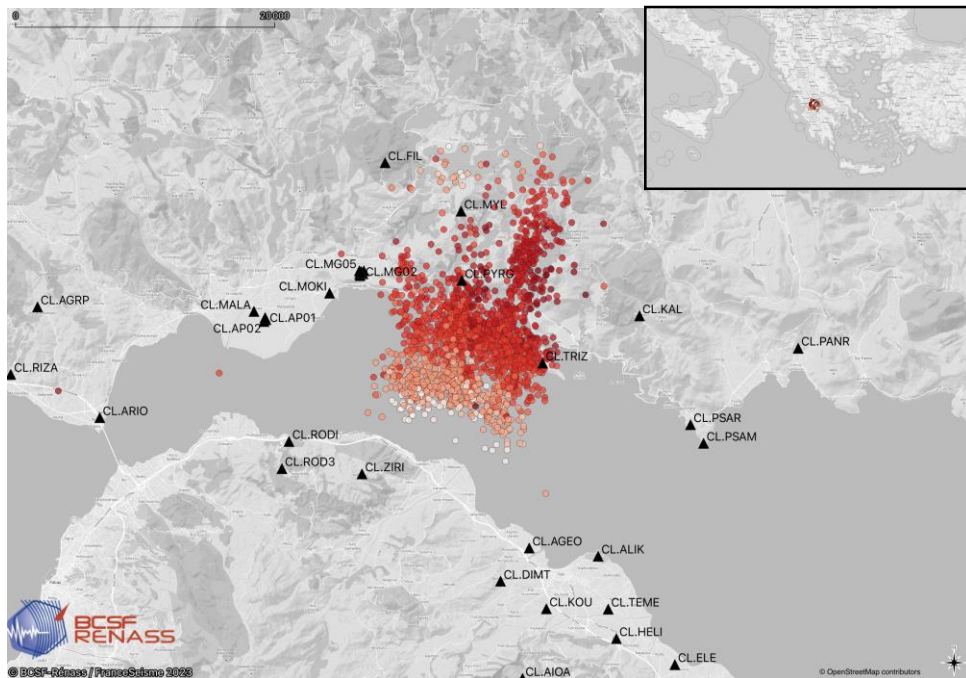
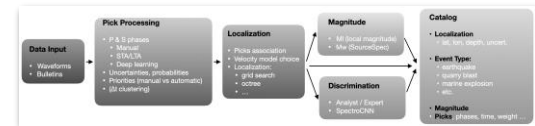
Median distance: 49.4 km



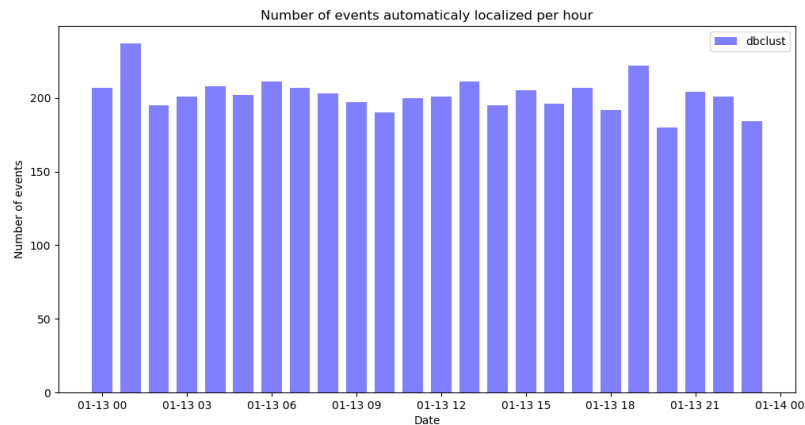
Localization

- Picks association
- Velocity model choice
- Localization:
 - grid search
 - octree
 - ...

Corinth Earthquake Swarm Localization (stress test !)



~5000 earthquakes in one day !
13/01/2021



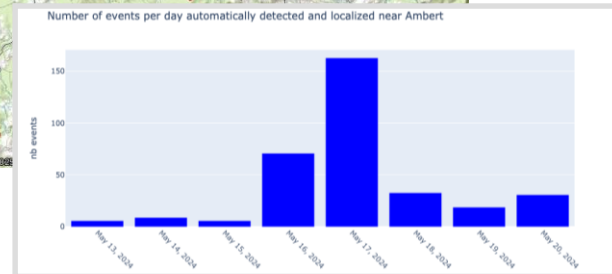
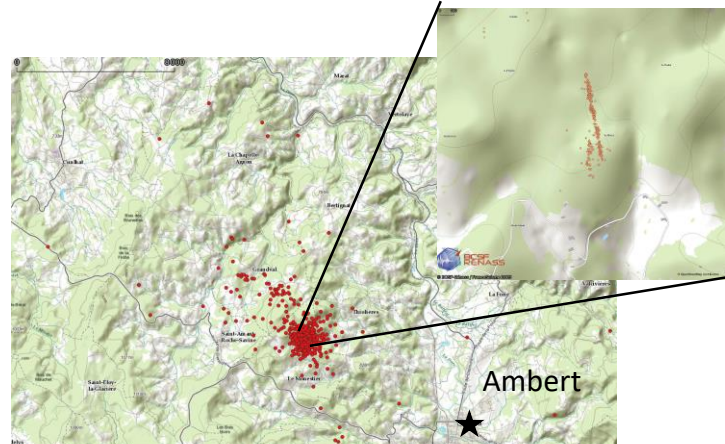
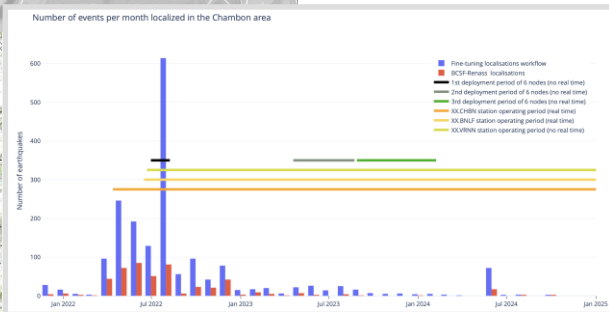
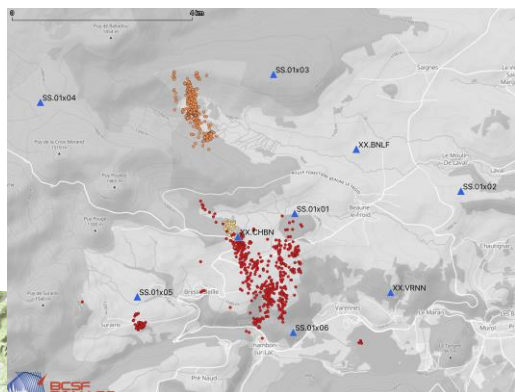
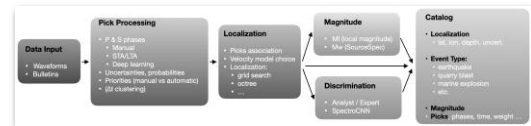
Localization

- Picks association
- Velocity model choice
- Localization:
 - grid search
 - octree
 - ...

Swarm Localization

Chambon (2021.12-2025.01)

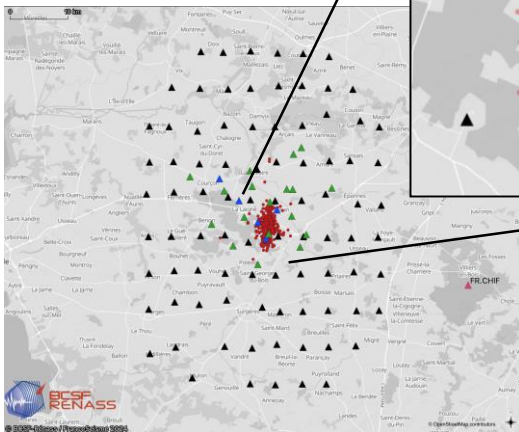
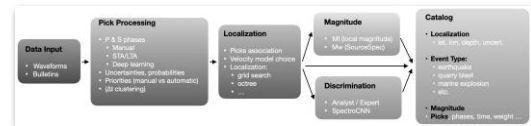
Ambert (2023.01-2024.09)



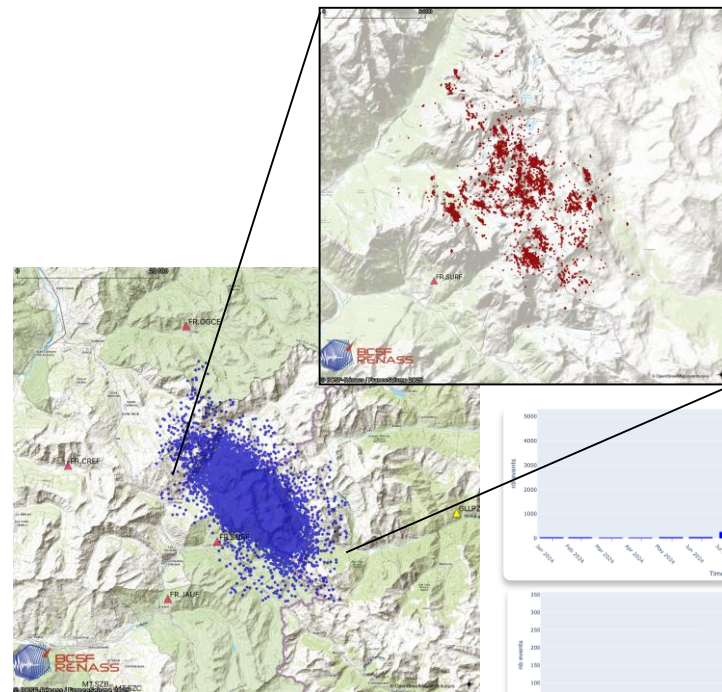
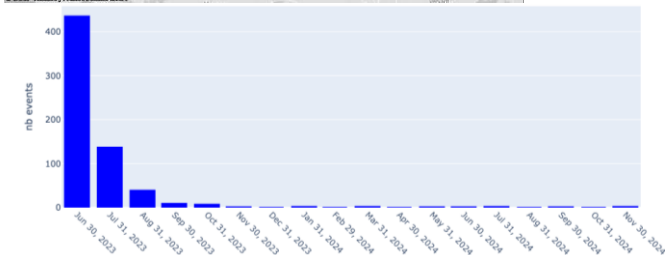
Localization

- Picks association
- Velocity model choice
- Localization:
 - grid search
 - octree
 - ...

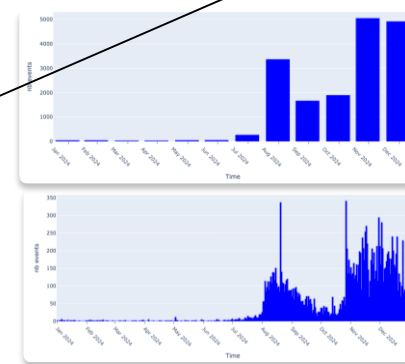
Swarm Localization



Lalaigue
(16.06.2023 MLv 5.3)



Ubaye 2024.01-2024.12

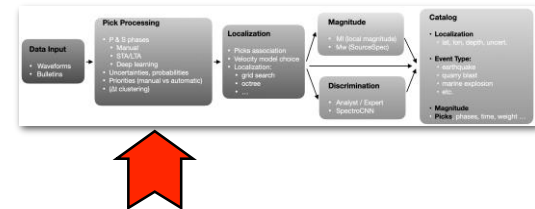


Pick Processing

- P & S phases
 - Manual
 - STA/TA
 - Deep learning
- Uncertainties, probabilities
- Priorities (manual vs automatic)
- (Δt clustering)

Seismicity Workflow Pick Processing

Training new PhaseNet models

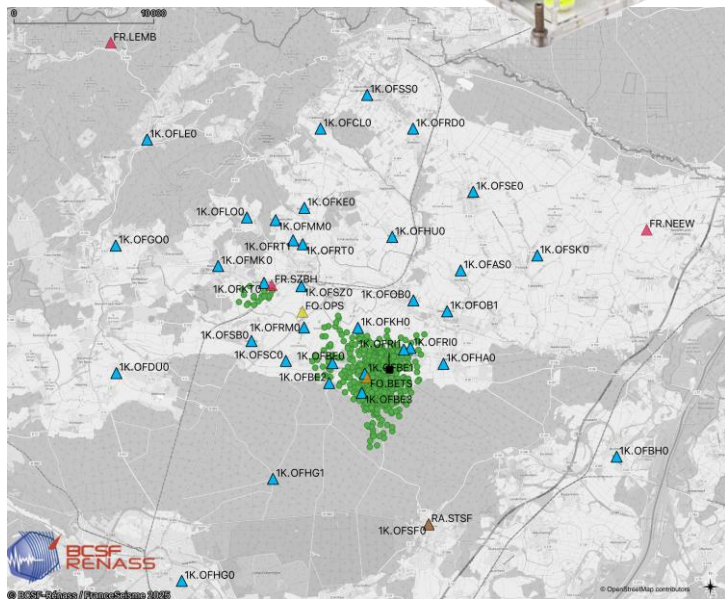


2. Induced seismicity analysis

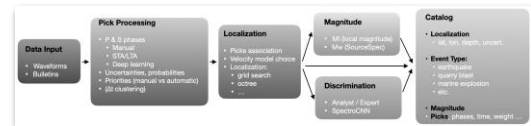
- Stimulation 2013 Rittershoffen dataset (ESG, EOST, KIT)
 - 1031 events
 - 12895 picks
- Strasbourg induced seismicity 2019-2022 (BCSF-Renass)
 - 583 events
 - 9530 picks



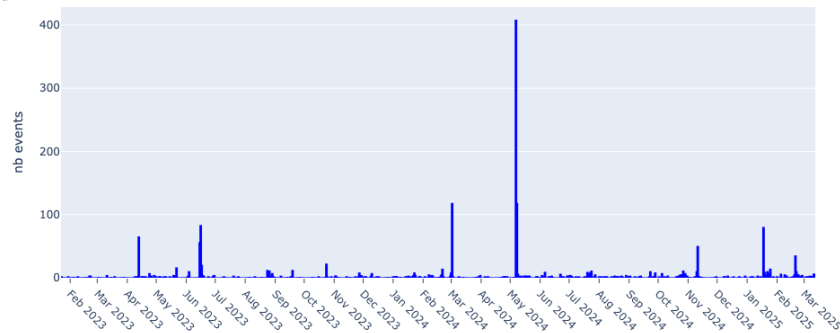
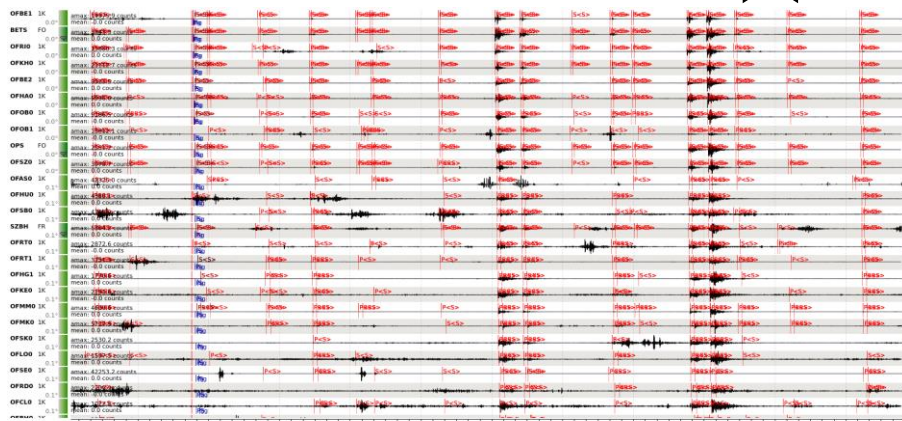
- Picks association
- Velocity model choice
- Localization:
 - grid search
 - octree
 - ...



Maps of the (~ 1550) seismic events from 2023 to 2025-08-14 located using deep learning method



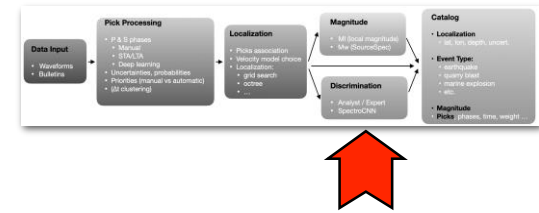
6 min time window: 20 induced events



Discrimination

- Analyst / Expert
- SpectroCNN

Seismic Event Classification Earthquake vs Quarry Blast



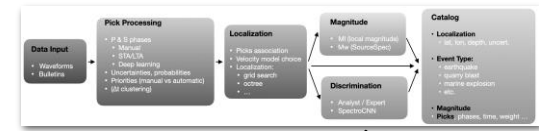
SpectroCNN3D - CNN architecture with ECA (Efficient Channel Attention)

Discrimination

- Analyst / Expert
- SpectroCNN

Seismic Event Classification Earthquake vs Quarry Blast

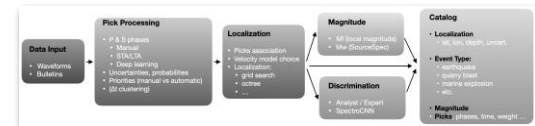
SpectroCNN3D - CNN architecture with ECA (Enhanced Channel Attention)



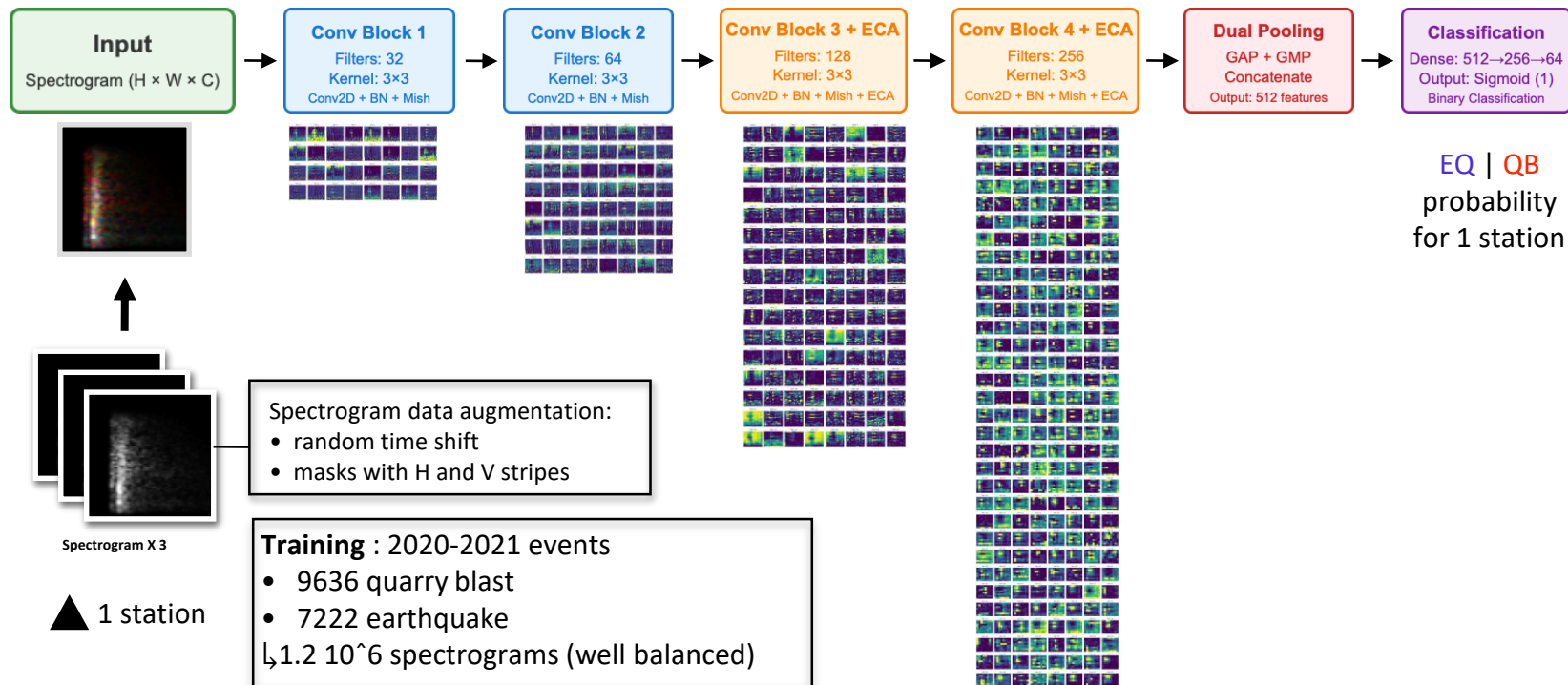
Discrimination

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Seismic Event Classification Earthquake vs Quarry Blast



SpectroCNN3D - CNN architecture with ECA (Efficient Channel Attention)

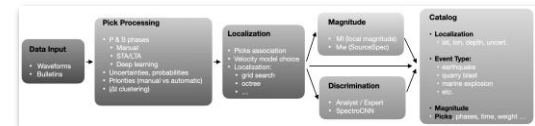
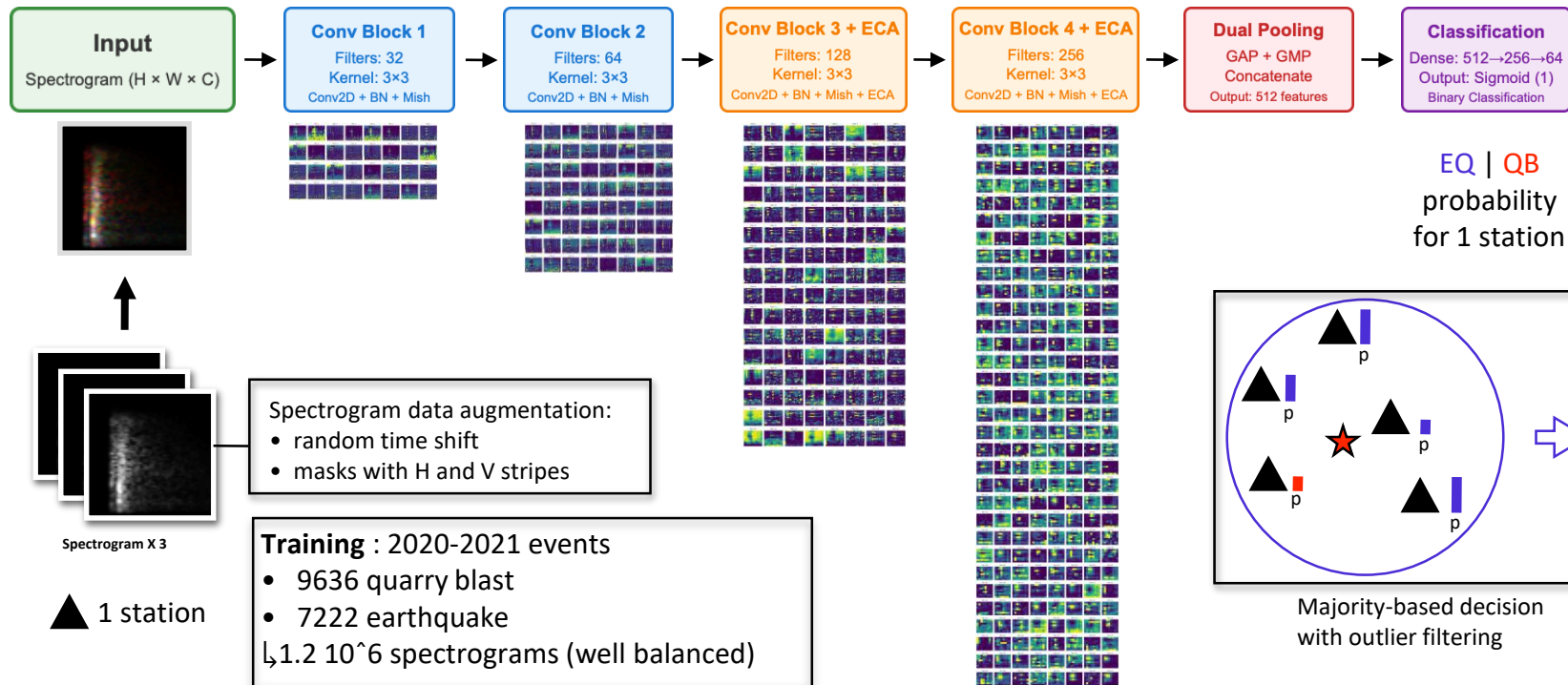


Discrimination

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Seismic Event Classification Earthquake vs Quarry Blast

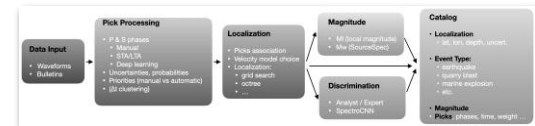
SpectroCNN3D - CNN architecture with ECA (Enhanced Channel Attention)



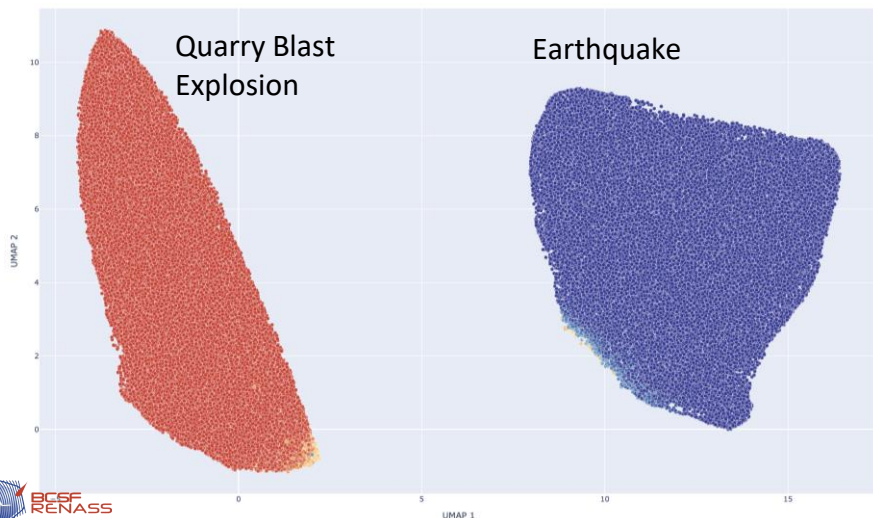
Discrimination

- Analyst / Expert
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Seismic Event Classification Earthquake vs Quarry Blast



SpectroCNN3D - CNN architecture with ECA (Efficient Channel Attention)



2D **UMAP** projection of **feature map**
highlighting the separation between EQ and QB classes

Validation: 6 months 2023, 4394 events

Majority-based decision
with outlier filtering

Station confusion matrix

Event confusion matrix

		Predicted	
		EQ	QB
Real	EQ	16040	2735
	QB	1927	23890

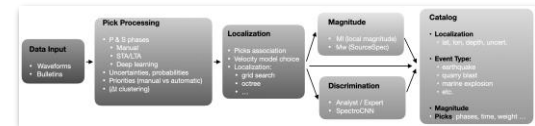
		Predicted	
		EQ	QB
Real	EQ	2005	14
	QB	11	2389

Very high overall **events** classification rate ($\approx 99\%$)

Discrimination

- Analyst / Expert
- SpectroCNN

Score-CAM Attention Maps for Earthquake vs Quarry Blast Classification



Attention maps were computed on 1,000 earthquake and 1,000 quarry blast spectrograms using **Score-CAM** (Score-Weighted Class Activation Mapping; Wang et al., 2020).

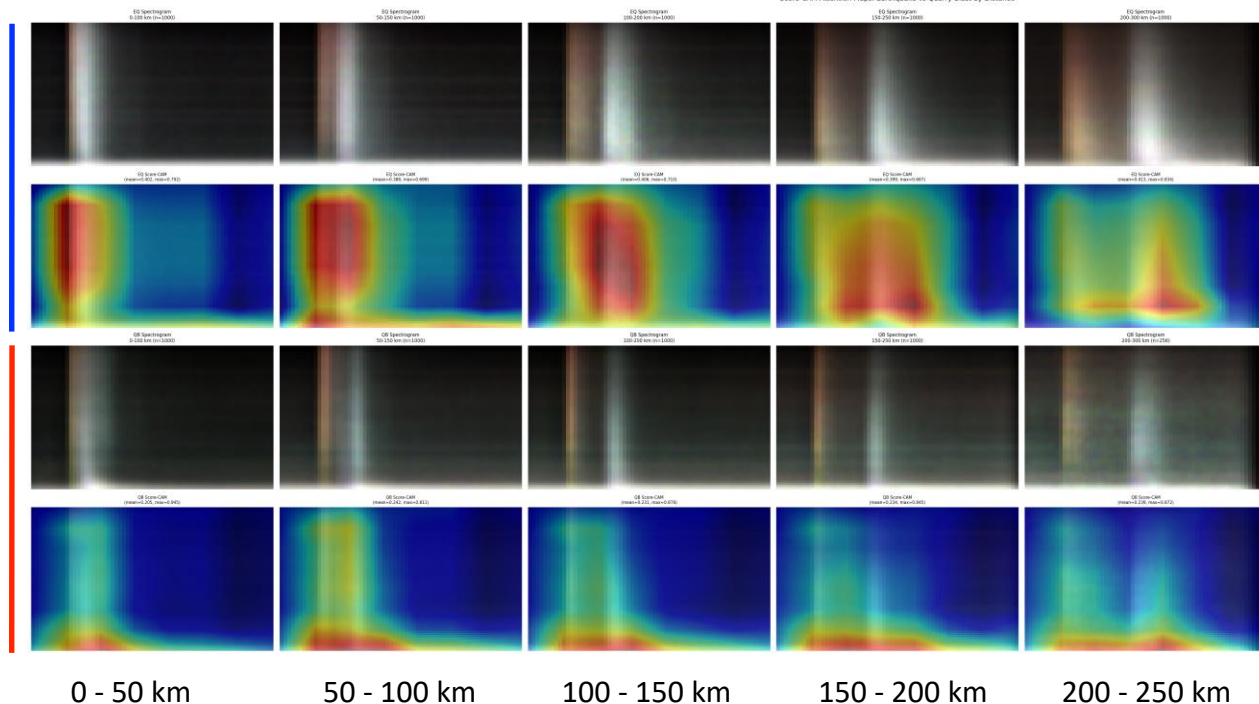
Score-CAM generates class-discriminative **saliency** by weighting activation maps according to the model's confidence when each feature map is individually used as a spatial mask.

This **highlights the time-frequency regions that most strongly influence the classifier's decision** for each class.

EQ

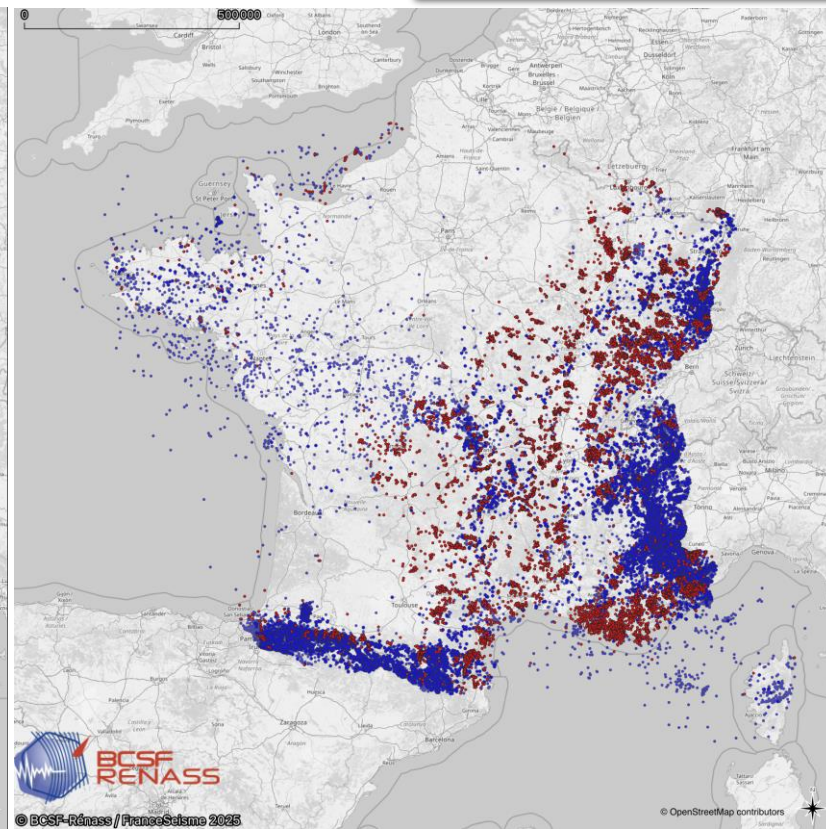
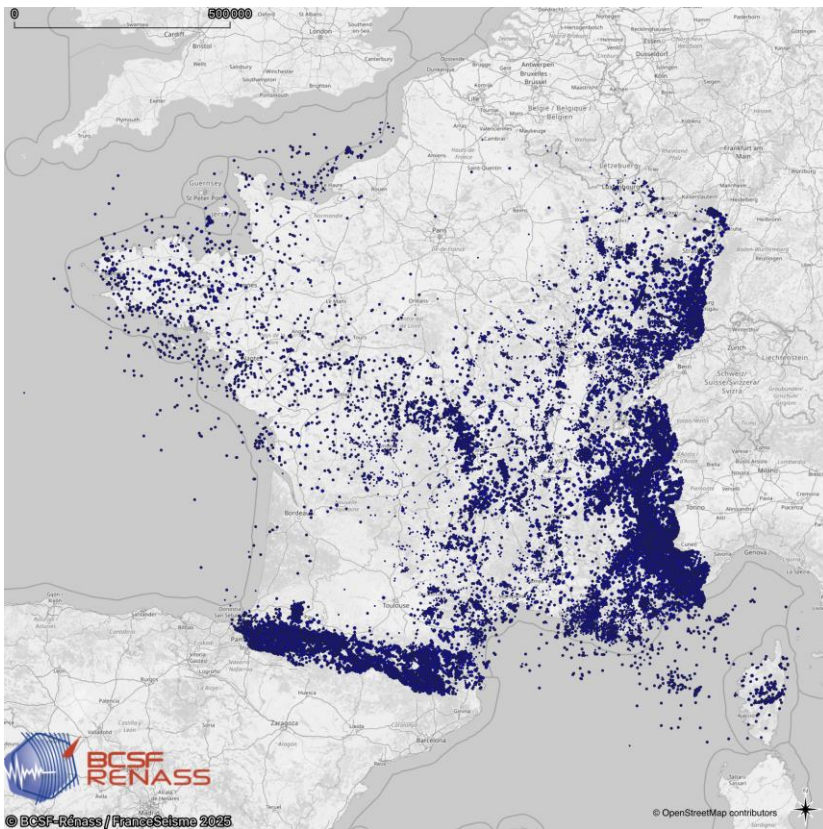
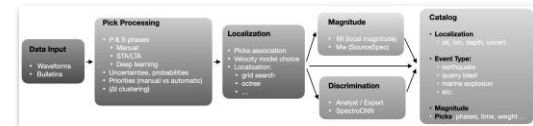
QB

Score-CAM Attention Maps: Earthquake vs Quarry Blast by Distance



2010-2018 seismicity catalog, using **deep learning** to **pick** and **discriminate**

~63.000 events : 43.000 earthquakes / 20.000 **quarry blasts**



Conclusion

- Forte croissance du nombre de **capteurs permanents** depuis 2010 (IR RESIF/Epos-France)
- Déploiement régulier de **réseaux denses** lors de campagnes de mesure (nodes)
- Développement de la **sismologie citoyenne** (capteurs low-cost chez l'habitant, en Alsace et à Lacq)

→ Explosion du volume de données à traiter

 Développement et usage de méthodes en IA

