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Quake Prediction on Etna: A Multi-Parametric Deep Learning Approach

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Master's Degree in Data Science

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Introduction

Objective
Short-term quake prediction

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Approach
ML vs DL models

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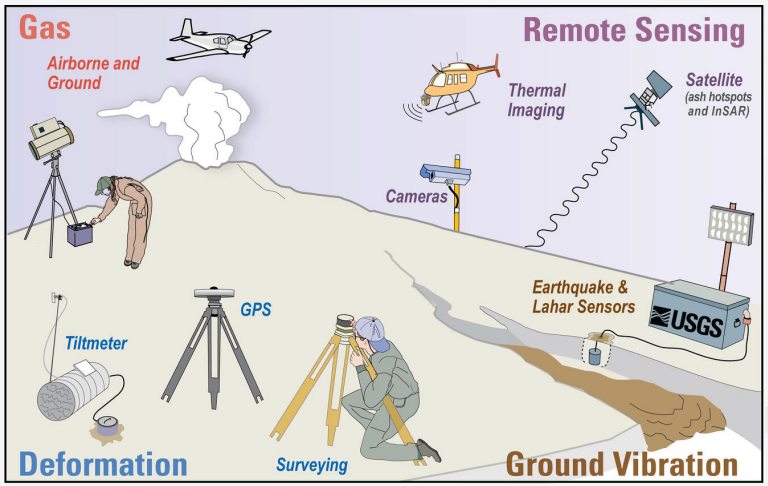
Context
Monitoring & risk

Dataset

- INGV-OE
- 2017–2019
- Multi-parametric
- Mixed sampling rates
- Alignment preprocessing



Dataset Overview

Geophysical

- Volcanic Tremor (ESPC)
- Ground Deformation
- Seismicity
- Surface Heat Flux

Geochemical

- Gas Fluxes: CO_2, SO_2, HCl
- Gas Ratios: CO_2/SO_2, $^3He/^4He$

Temporal Structure

Units: Tremor (m/s) · Tilt (µrad) · Seismicity (counts, ML) · Heat Flux (W) · Gas Fluxes (t/day)

Data Preprocessing

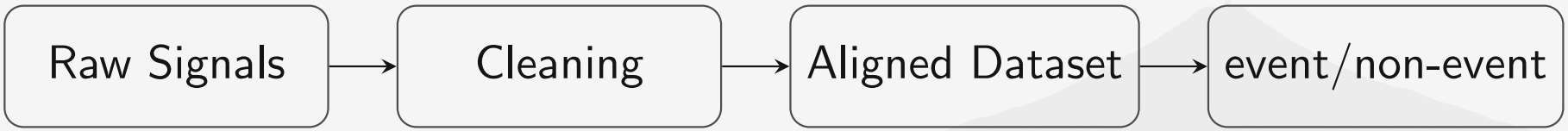
Standard

- Date/column standardization
- Numeric formatting
- Time ordering
- Duplicate handling

Signal-Specific

- ESPC: anomaly filtering
- Clinometry: temporal alignment
- Seismicity: magnitude harmonization
- Gas: signal normalization

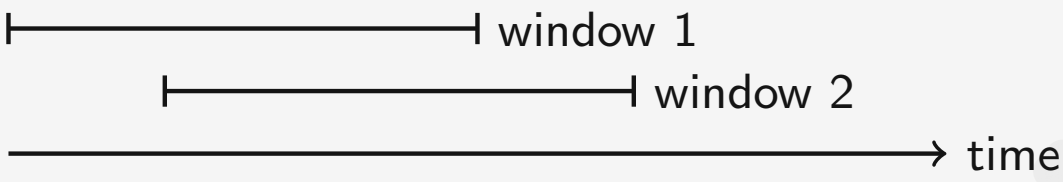
Classification Pipeline



Feature Engineering & Evaluation Protocol

Feature Engineering:

- Hourly resampling
- Short-gap interpolation
- Z-score + clipping
- Sliding windows: 96h, stride 1d
- Target label: event if ML $\geq$ 2.0 occurs within next 24h



Evaluation:

- Accuracy, Precision, Recall, F1-score
- Threshold tuned for high recall
- Confusion matrix, PR curve, training curve (LSTM)

Proposed Models

Random Forest (RF)

LSTM

Random Forest

Configuration:

Reinforced RF (geophysical & geochemical)

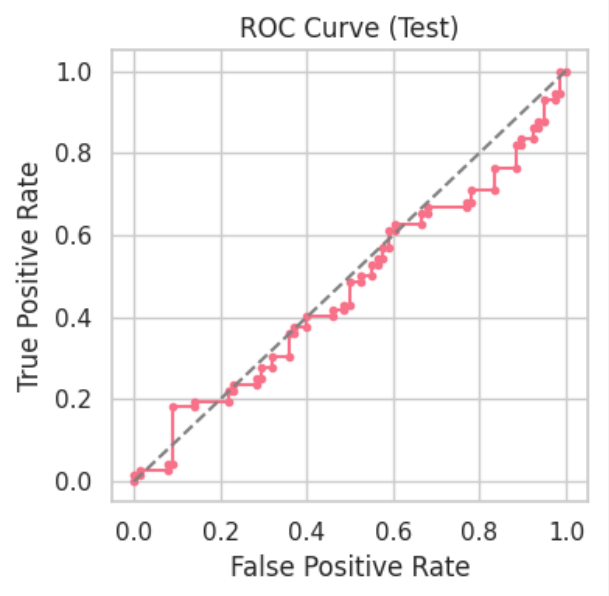
Performance Metrics:

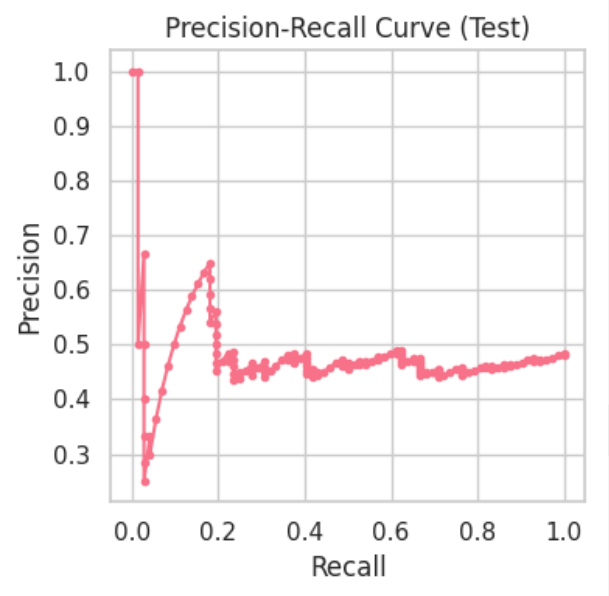
- Accuracy: 0.87
- Precision: 0.81
- Recall: 0.92
- F1-score: 0.86

Key Features:

tremor amplitude, tilt rate, SO_2 flux variability

Static model, high recall and interpretable feature importance.





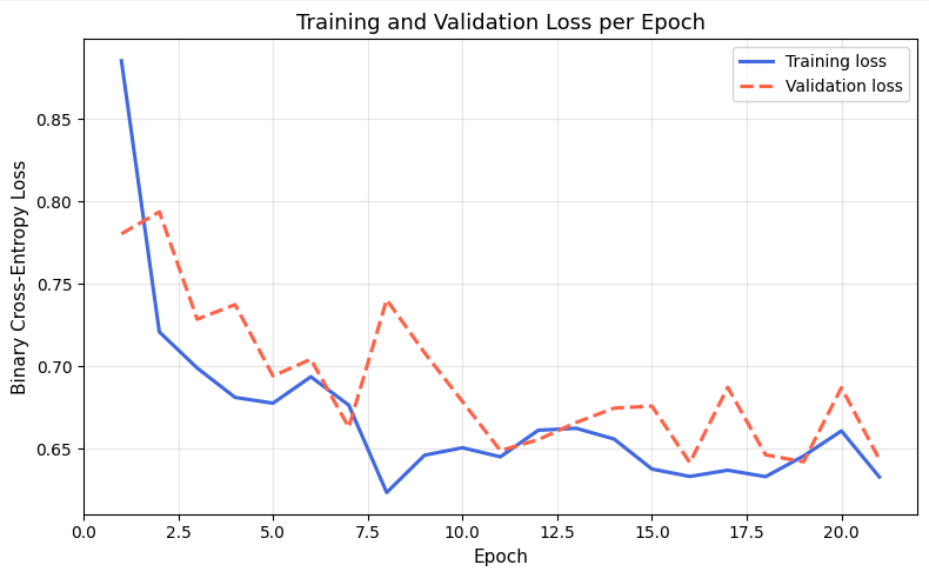
Univariate LSTM

Configuration:
Univariate LSTM (tremor)

Performance Metrics:

- Accuracy: 0.77
- Precision: 0.73
- Recall: 0.65
- F1-score: 0.68

Sequential model captures temporal patterns in tremor amplitude.



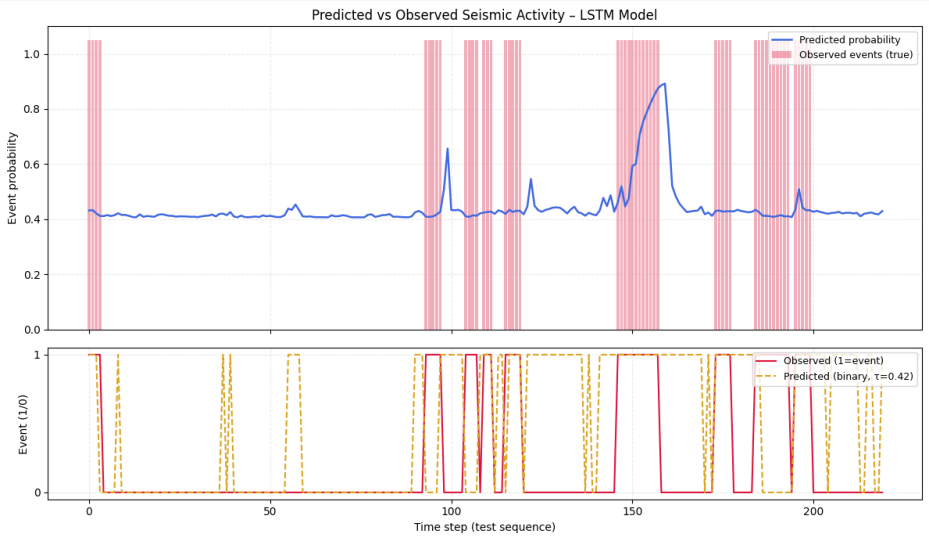
High-Sensitivity Mode

Configuration:
LSTM High-Sensitivity
Threshold $\tau = 0.35$

Performance Metrics:

- Precision: 0.33
- Recall: 0.90
- F1-score: 0.49

Prioritize early detection, increasing false negative.



Multi-LSTM

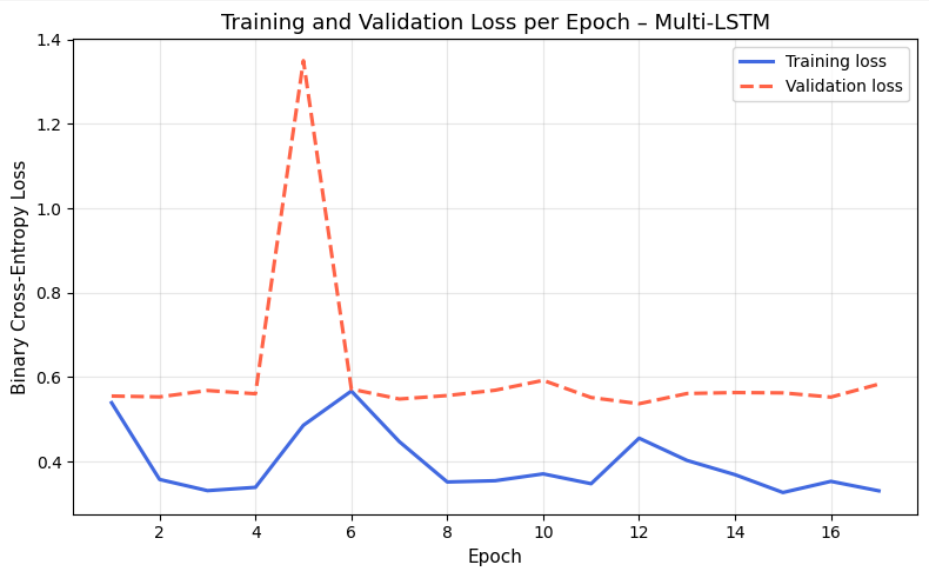
Configuration:

tremor, tilt, seismicity, SO_2/CO_2 fluxes

Performance:

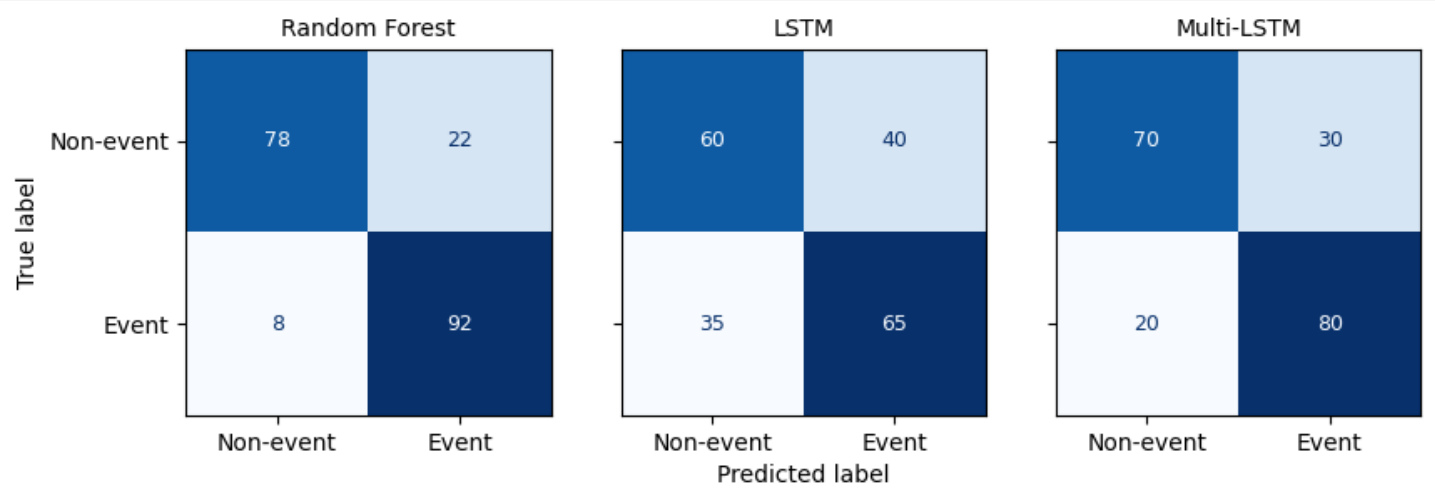
- Accuracy: 0.78
- Precision: 0.74
- Recall: 0.83
- F1-score: 0.78

Captures cross-domain patterns, balanced trade-off between recall and precision.



Model Comparison

Model	Accuracy	Precision	Recall	F1-score
Random Forest	0.87	0.81	0.92	0.86
LSTM	0.77	0.73	0.65	0.68
Multi-LSTM	0.78	0.74	0.83	0.78



- Random Forest: good overall accuracy, static baseline.
- Univariate LSTM: add temporal awareness, misses some events.
- Multi-LSTM: leverages multi-sensor integration and temporal dynamics.

Conclusions & Future Work

- Multi-LSTM boosts early-warning sensitivity, detecting signals that precede seismic unrest.

- Future work:
  - Extend the dataset and monitored observables
  - Explore CNN-LSTM, transformer, and attention-based architectures
  - Integrate explainable AI (SHAP values, saliency maps)
  - Deploy real-time probabilistic alert systems

Machine learning does not replace volcanological expertise, but strengthens early-warning systems by extracting subtle, multi-sensor precursors from complex data streams.

Thank you
for your attention!

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