P2.2-580

Probabilistic Source-Type Analysis for Seismic Event Classification

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INTRODUCTION AND MAIN RESULTS

This work presents a probabilistic framework for seismic event classification from moment tensors. Uncertainties are represented as probability densities on source-type diagrams, and modeled with Gaussian mixtures around canonical source types (explosions, earthquakes, collapses, CLVDs). This is applied to North Korea and USA nuclear tests, earthquakes, and collapses, with implications for decision pipelines.

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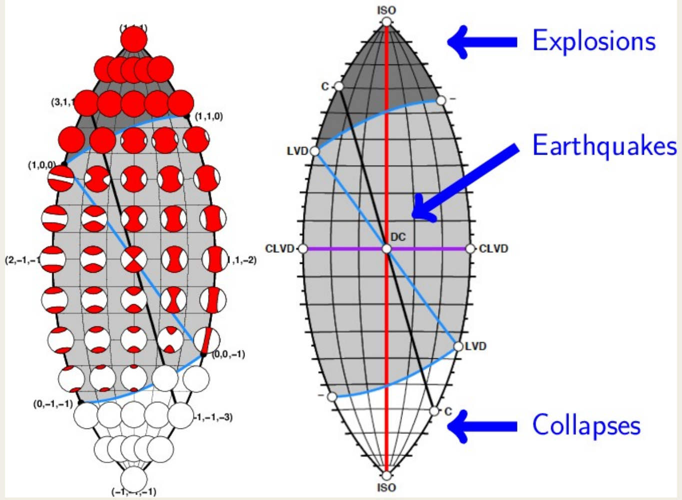
Introduction

What is the probability that a given seismic events is a nuclear explosion, an earthquake, or a collapse? How confidently can we make such determinations, and how can they inform verification workflows? We present a method that estimates these probabilities using moment tensor posteriors and translates them into operationally meaningful classifications

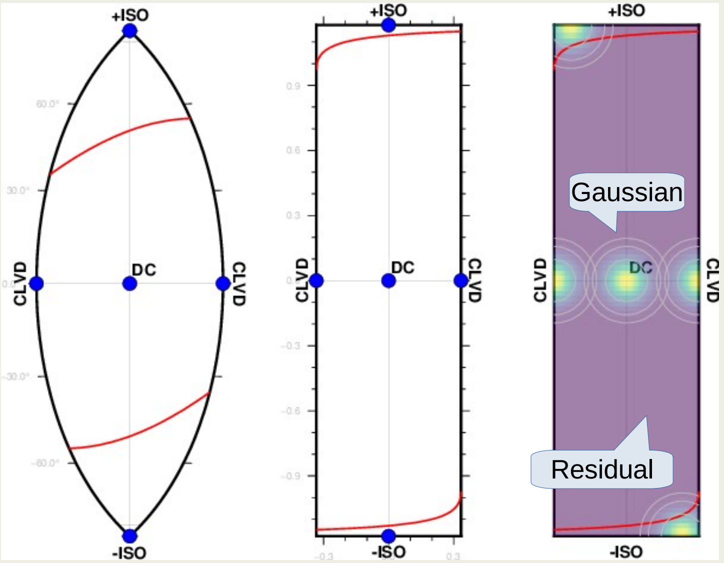
Moment tensors and source-type diagrams

Seismic sources such as nuclear explosions and earthquakes are routinely modelled with moment tensors, which map into diagrams such as the Tk plot or source-type lune. These representations naturally separate mechanisms and provide a basis for classification.



Probabilistic Classification Method

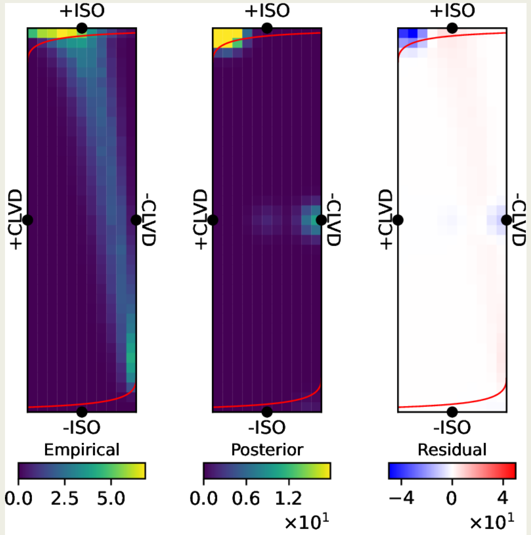
We introduce a probabilistic framework that classifies seismic sources based on the posterior probability density of the moment tensor. Each posterior is modeled as a Gaussian mixture over source-type regions: explosions (+ISO), collapses (–ISO), earthquakes (DC), and CLVD. Probability mass outside these defined regions is assigned a residual term, signaling model mismatch or atypical events.



While the source-type lune provides physical insight, computations are performed on an equivalent rectangular (v,w) Cartesian grid for numerical integration.

Results

The framework is applied to nuclear tests at Punggye-Ri (DPRK) and the Nevada National Security Site (USA), alongside regional earthquakes and collapses. It enables robust probabilistic classification using moment tensor posteriors and is designed for integration into verification pipelines.



2017 DPRK Nuclear Test

```
P(explosion )= 58.35 %
P(earthquake)=  4.54 %
P(collapse  )=  4.01 %
P(+CLVD     )=  0.00 %
P(−CLVD     )= 18.64 %
P(Residual  )= 14.47 %
```

Main Takeaways

- Classifies seismic sources by integrating posterior probability over defined source-type regions.
- Compatible with additional discriminants (e.g., P/S ratios, depth, magnitudes, location) in operational monitoring pipelines.
- Enables threshold-based, reproducible decision-making with confidence levels

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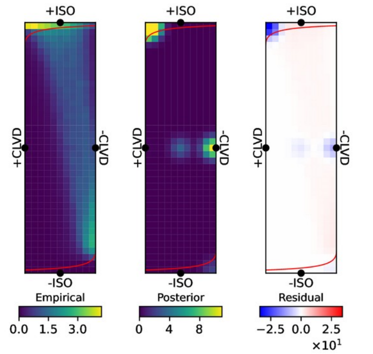
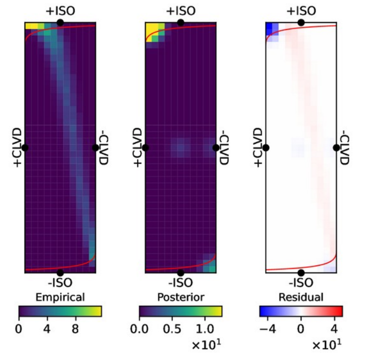
DPRK nuclear tests from 2006–2017, a collapse on 2017, and the 2016 Gyeongju earthquake in S. Korea

NNSA nuclear tests HOYA, COSO, Earthquakes Little Skull main & aftershock



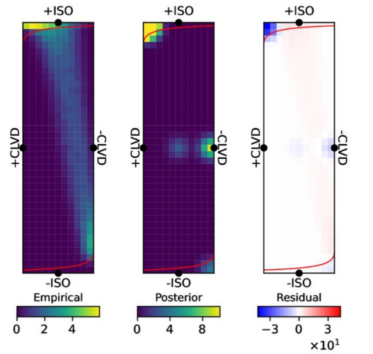

```
EVID 20061009013528000 MODEL MDJ2 Depth 001

P(explosion ) =  51.45 %   [Ratio=1.90, KL=18.6]
P(earthquake) =   9.14 %   [Ratio=0.49, KL=18.7]
P(collapse  ) =   2.80 %   [Ratio=0.42, KL=21.4]
P(+CLVD     ) =   0.30 %   [Ratio=0.03, KL=22.4]
P(-CLVD     ) =  21.50 %   [Ratio=1.07, KL=18.4]
P(Residual  ) =  14.81 %
```



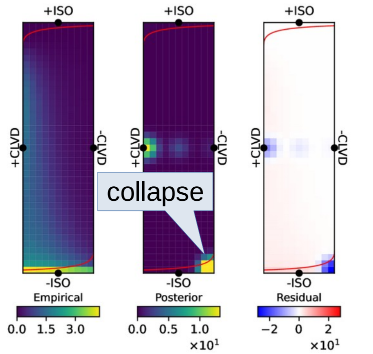

```
EVID 20090525005443123 MODEL MDJ2 Depth 001

P(explosion ) =  82.06 %   [Ratio=4.18, KL=15.9]
P(earthquake) =   4.97 %   [Ratio=0.58, KL=19.7]
P(collapse  ) =   9.70 %   [Ratio=0.96, KL=21.7]
P(+CLVD     ) =   0.00 %   [Ratio=0.00, KL=23.4]
P(-CLVD     ) =   3.27 %   [Ratio=0.70, KL=19.9]
P(Residual  ) =   0.00 %
```



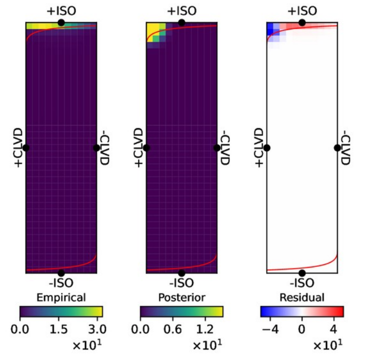

```
EVID 20130212025751272 MODEL MDJ2 Depth 001

P(explosion ) =  64.84 %   [Ratio=2.38, KL=17.7]
P(earthquake) =   7.60 %   [Ratio=0.48, KL=19.1]
P(collapse  ) =   5.33 %   [Ratio=0.60, KL=21.5]
P(+CLVD     ) =   0.01 %   [Ratio=0.00, KL=22.9]
P(-CLVD     ) =  17.09 %   [Ratio=1.01, KL=18.8]
P(Residual  ) =   5.12 %
```



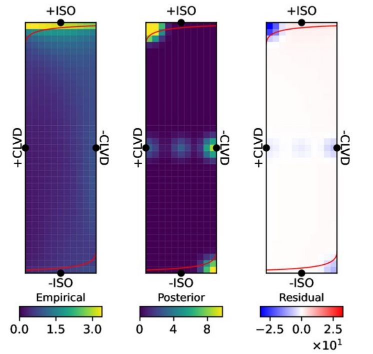

```
EVID 20170903033831810 MODEL MDJ2 Depth 001

P(explosion ) =   0.22 %   [Ratio=0.04, KL=22.7]
P(earthquake) =   7.66 %   [Ratio=0.42, KL=18.8]
P(collapse  ) =  41.99 %   [Ratio=1.65, KL=18.9]
P(+CLVD     ) =  26.27 %   [Ratio=1.14, KL=18.4]
P(-CLVD     ) =   1.85 %   [Ratio=0.11, KL=22.1]
P(Residual  ) =  22.01 %
```



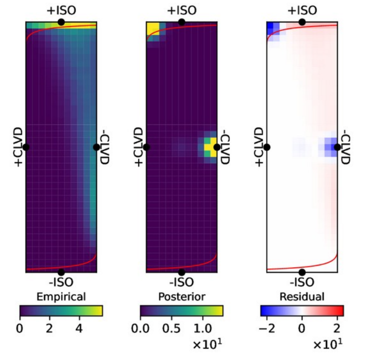

```
EVID HOYA MODEL wes Depth 001

P(explosion ) =  99.44 %   [Ratio=10.07, KL=7.8]
P(earthquake) =   0.03 %   [Ratio=0.01, KL=25.6]
P(collapse  ) =   0.22 %   [Ratio=0.03, KL=25.6]
P(+CLVD     ) =   0.00 %   [Ratio=0.00, KL=25.7]
P(-CLVD     ) =   0.31 %   [Ratio=0.04, KL=25.6]
P(Residual  ) =   0.00 %
```



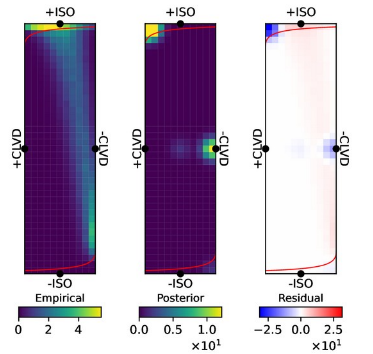

```
EVID COSO MODEL wes Depth 001

P(explosion ) =  48.67 %   [Ratio=1.93, KL=18.1]
P(earthquake) =   7.55 %   [Ratio=0.40, KL=19.0]
P(collapse  ) =  13.81 %   [Ratio=0.64, KL=21.0]
P(+CLVD     ) =   5.36 %   [Ratio=0.28, KL=21.1]
P(-CLVD     ) =  15.45 %   [Ratio=0.71, KL=19.6]
P(Residual  ) =   9.16 %
```



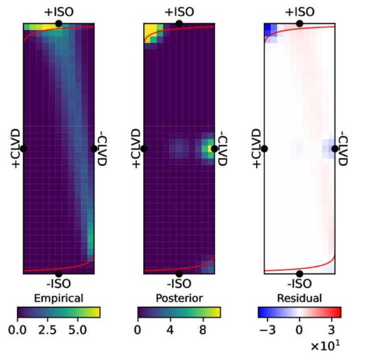

```
EVID 20160106013000963 MODEL MDJ2 Depth 001

P(explosion ) =  35.50 %   [Ratio=1.40, KL=19.6]
P(earthquake) =   2.70 %   [Ratio=0.22, KL=19.8]
P(collapse  ) =   0.39 %   [Ratio=0.06, KL=23.0]
P(+CLVD     ) =   0.02 %   [Ratio=0.00, KL=23.3]
P(-CLVD     ) =  36.76 %   [Ratio=1.51, KL=18.1]
P(Residual  ) =  24.64 %
```



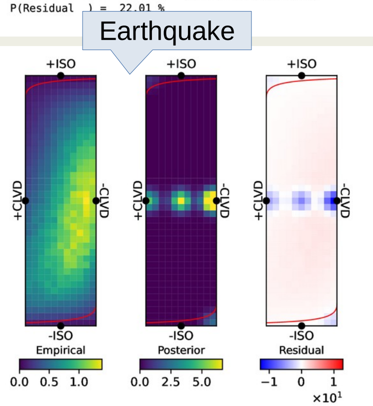

```
EVID 20160909003001385 MODEL MDJ2 Depth 001

P(explosion ) =  47.53 %   [Ratio=1.90, KL=18.5]
P(earthquake) =   4.48 %   [Ratio=0.34, KL=19.5]
P(collapse  ) =   2.28 %   [Ratio=0.31, KL=22.1]
P(+CLVD     ) =   0.02 %   [Ratio=0.00, KL=23.1]
P(-CLVD     ) =  24.19 %   [Ratio=1.25, KL=18.5]
P(Residual  ) =  21.50 %
```



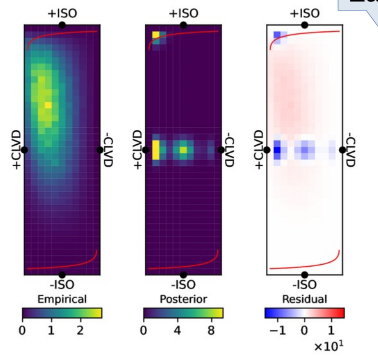

```
EVID 20170903033001760 MODEL MDJ2 Depth 001

P(explosion ) =  58.35 %   [Ratio=2.34, KL=17.7]
P(earthquake) =   4.54 %   [Ratio=0.39, KL=19.5]
P(collapse  ) =   4.01 %   [Ratio=0.47, KL=22.0]
P(+CLVD     ) =   0.00 %   [Ratio=0.00, KL=23.3]
P(-CLVD     ) =  18.64 %   [Ratio=1.15, KL=18.9]
P(Residual  ) =  14.47 %
```



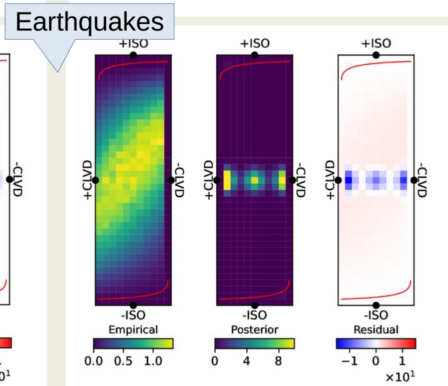

```
EVID 20160912113255770 MODEL MDJ2 Depth 013

P(explosion ) =   1.20 %   [Ratio=0.08, KL=22.3]
P(earthquake) =  18.21 %   [Ratio=0.91, KL=15.2]
P(collapse  ) =   3.11 %   [Ratio=0.23, KL=21.6]
P(+CLVD     ) =   8.82 %   [Ratio=0.50, KL=19.4]
P(-CLVD     ) =  24.96 %   [Ratio=1.22, KL=16.9]
P(Residual  ) =  43.70 %
```




```
EVID Little-Skull-Main MODEL wes Depth 010

P(explosion ) =   8.50 %   [Ratio=0.59, KL=20.8]
P(earthquake) =  21.91 %   [Ratio=1.08, KL=15.5]
P(collapse  ) =   0.02 %   [Ratio=0.00, KL=23.1]
P(+CLVD     ) =  23.05 %   [Ratio=1.26, KL=17.0]
P(-CLVD     ) =   3.10 %   [Ratio=0.24, KL=20.5]
P(Residual  ) =  43.42 %
```




```
EVID Little-Skull-Aftershock MODEL wes Depth 005

P(explosion ) =   0.29 %   [Ratio=0.03, KL=22.6]
P(earthquake) =  24.23 %   [Ratio=1.19, KL=13.8]
P(collapse  ) =   0.35 %   [Ratio=0.03, KL=22.7]
P(+CLVD     ) =  23.83 %   [Ratio=1.18, KL=17.3]
P(-CLVD     ) =  19.24 %   [Ratio=0.99, KL=17.8]
P(Residual  ) =  32.06 %
```

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