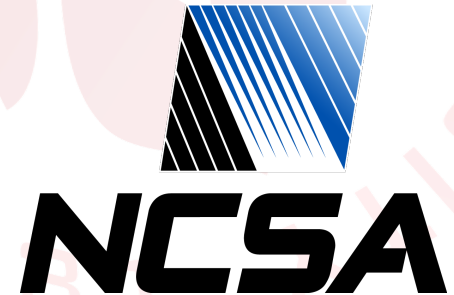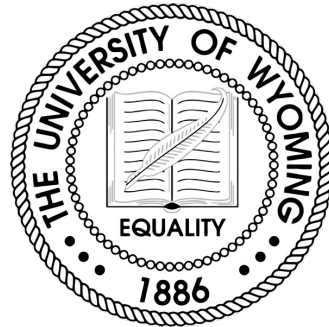# Towards autonomous earthquake monitoring using machine learning

李恩瑞(En-Jui Lee)[1], 廖勿渝[1], Po Chen[2], & Dawei Mu[3]

[1]*Department of Earth Sciences, National Cheng-Kung University, Taiwan*
[2]*Department of Geology and Geophysics, University of Wyoming, USA*
[3]*National Center for Supercomputing Applications, USA*

Natural disaster

- Large disaster ➡ casualties & economic losses
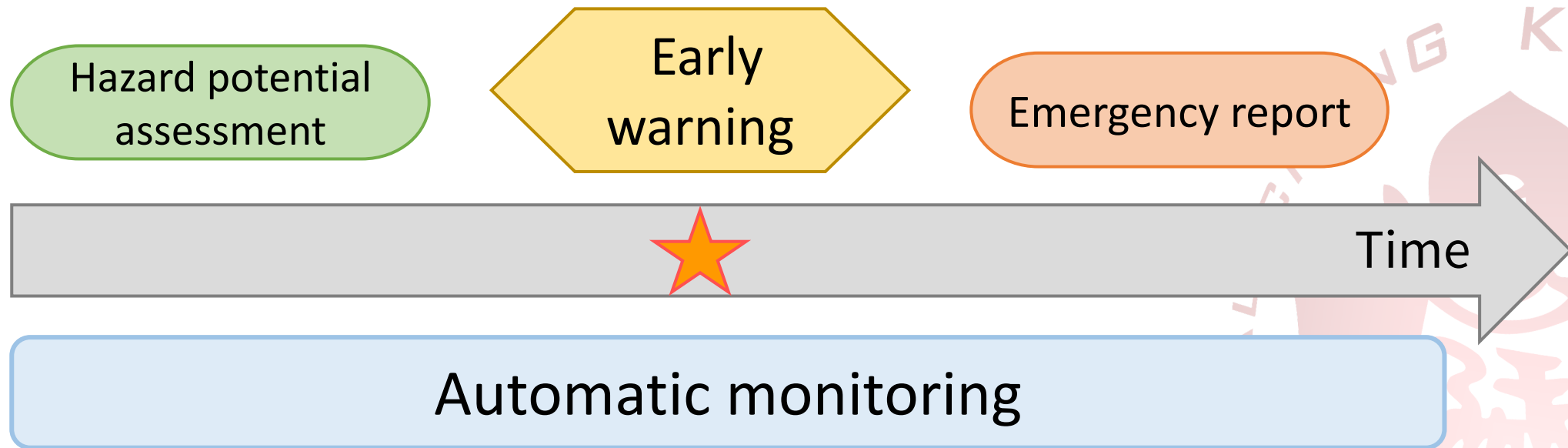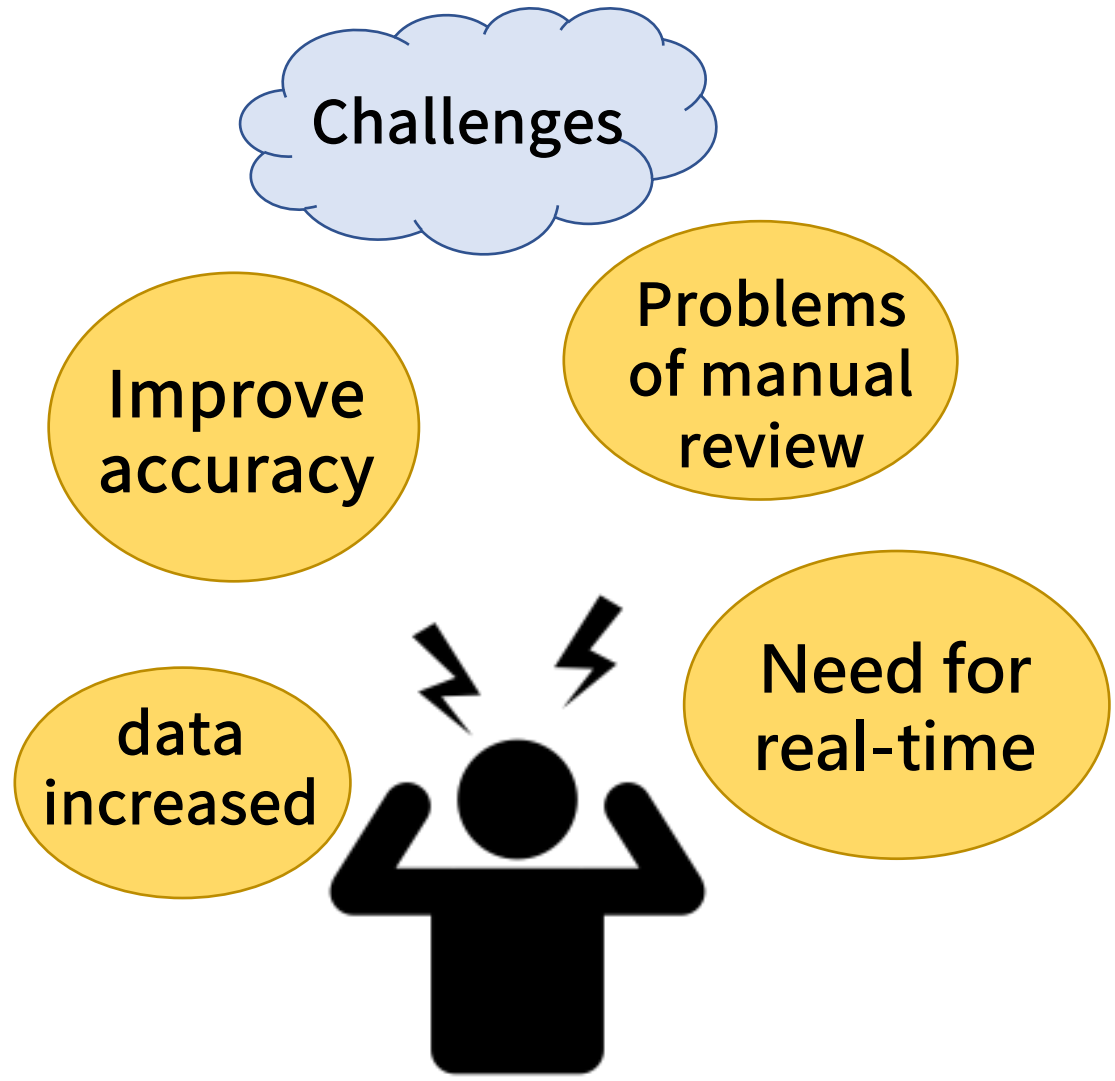- Taiwan ➡ Earthquakes, volcanic activity⋯

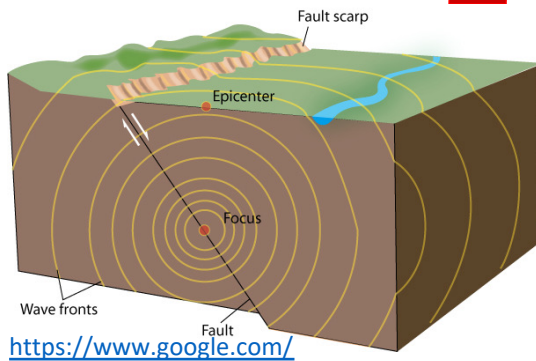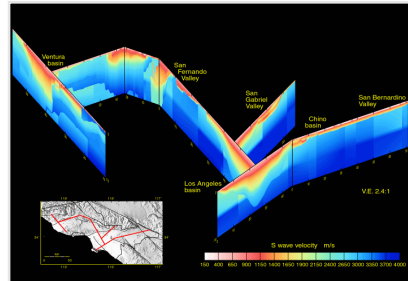1999 集集地震　　　　　2016美濃地震　　　　　2018花連地震

Disaster Prevention Strategy

Challenges

Improve accuracy

Problems of manual review

data increased

Need for real-time

GPU high performance computing

Advances of machine learning

Automatic monitoring process
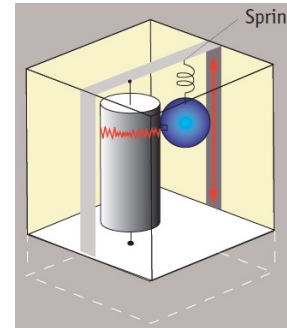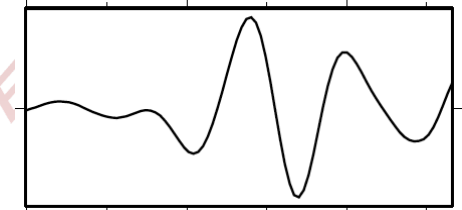
Seismological Framework

Forward modeling

Inversion

Source * Medium * Instrument = Observations

https://www.google.com/

3D velocity model, density, Q

Strong motion, SP, BB, OBS, Geophone ..

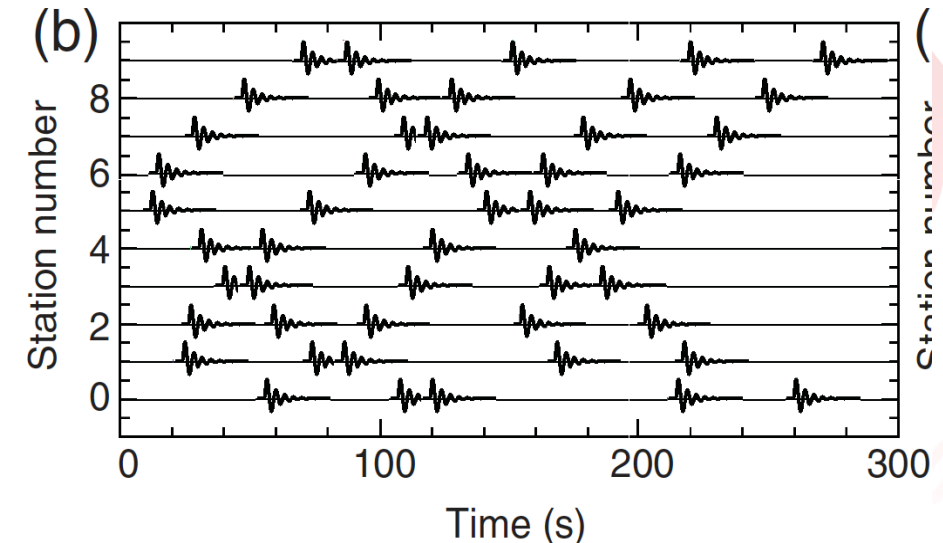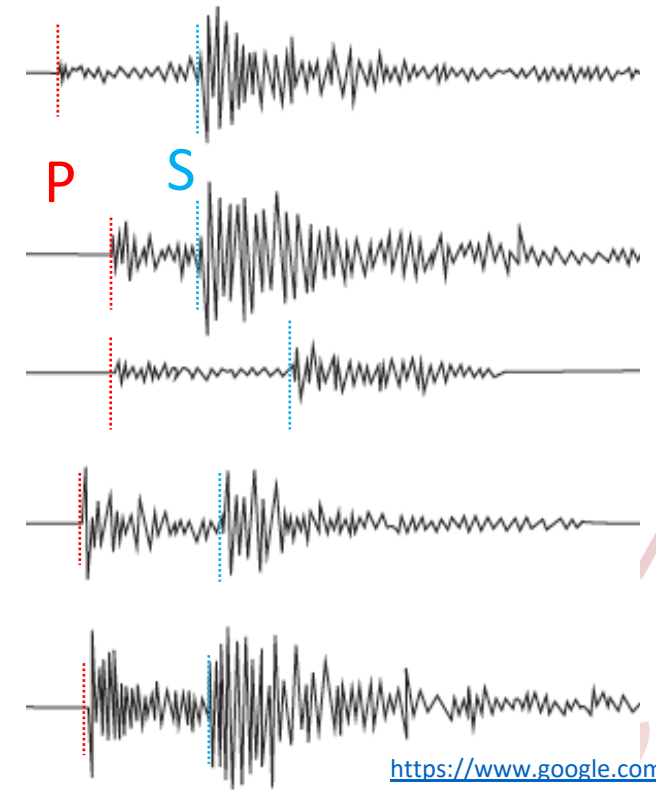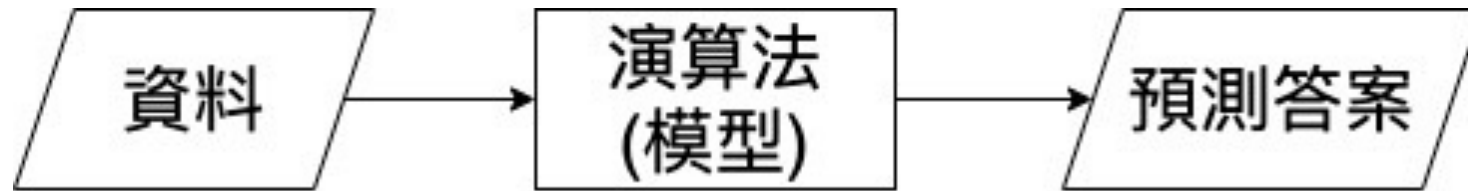Travel times, Amplitudes, Waveforms

Challenges of Earthquake Monitoring

- Earthquake location process
  - Detect earthquake
  - Pick P and/or S arrivals
  - Locate EQs
- Monitoring challenges
  - High seismic activity ➔ large and small EQs occurred closely
  - pick arrivals of all EQs
  - EQ phase association for all EQs

P   S

https://www.google.com/

(b)

Station number

0   100   200   300

Time (s)

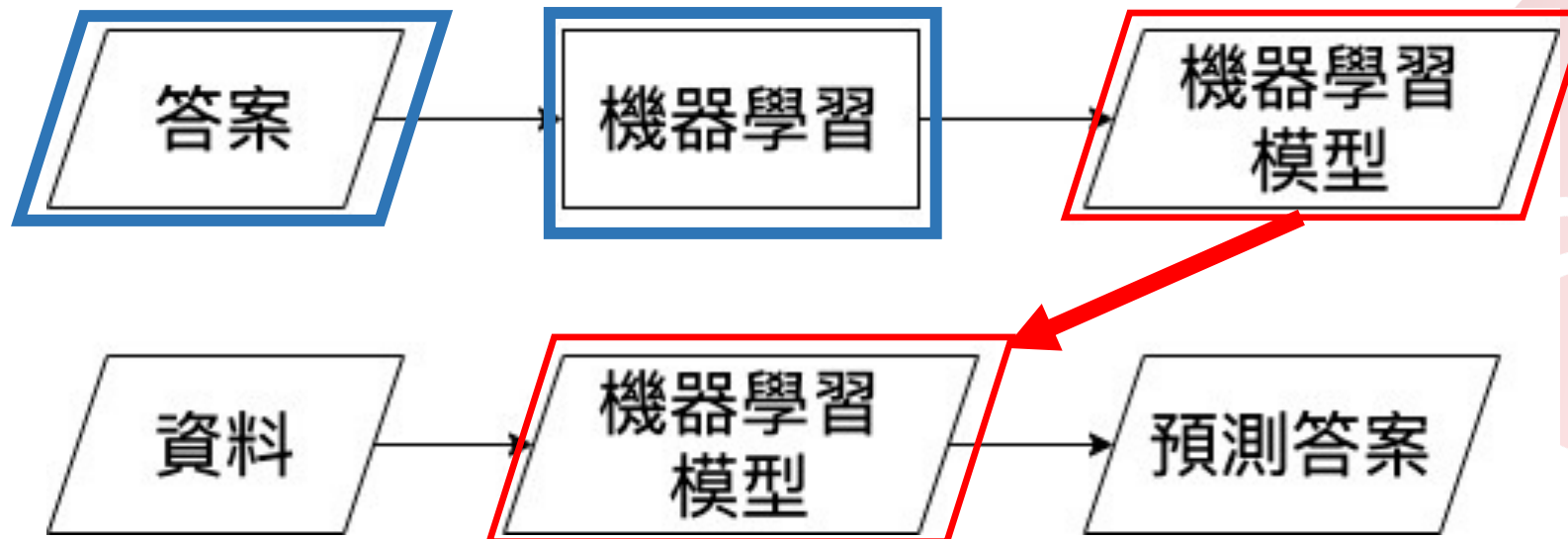https://www.seismosoc.org/publications/bssa/

Machine learning (ML)
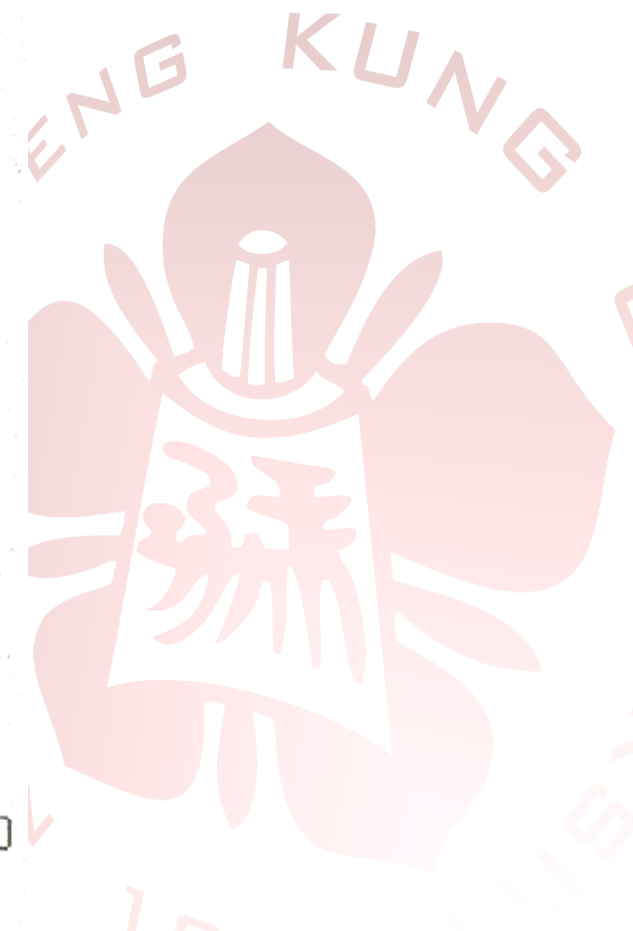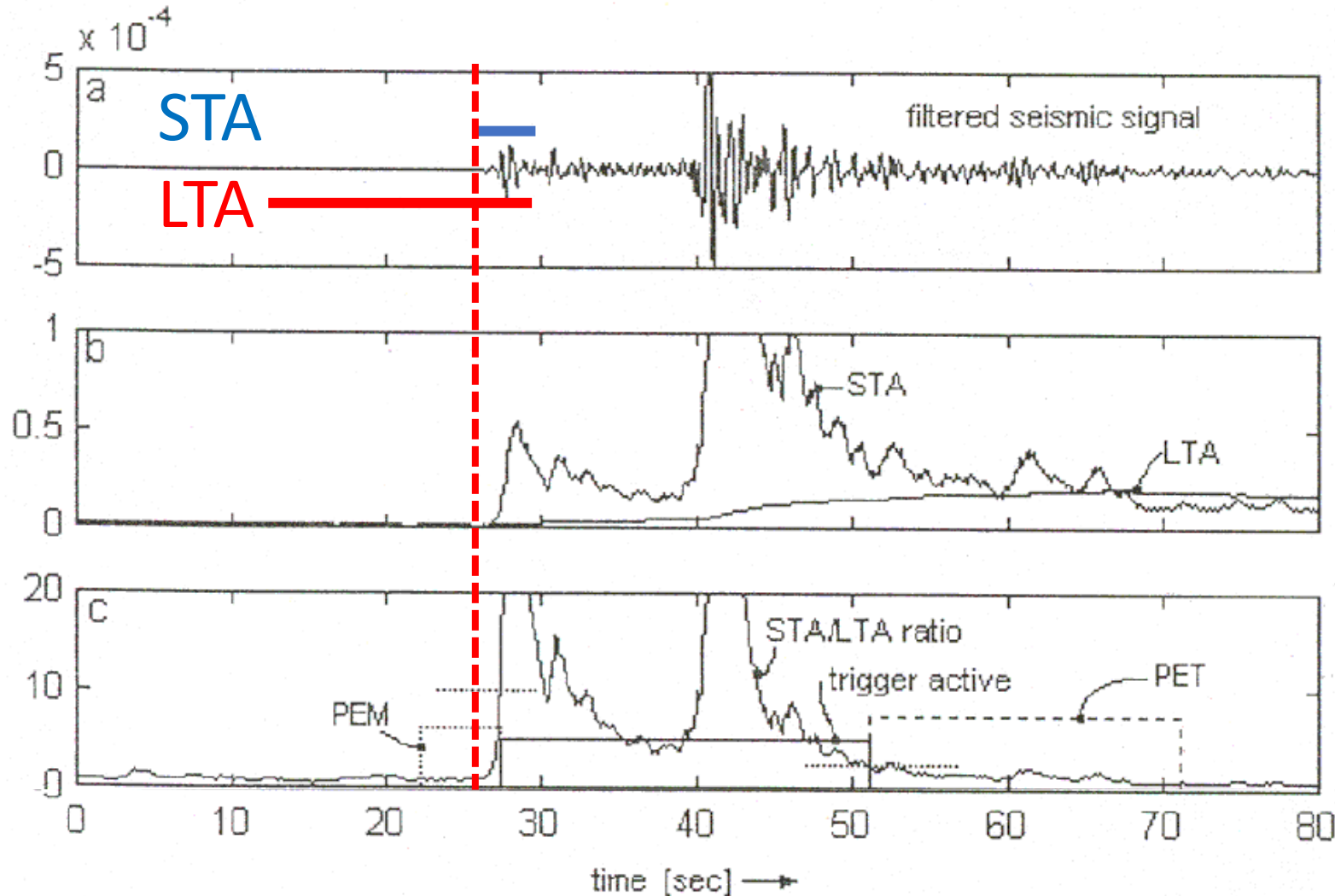
Traditional method

Machine learning methods

Traditional methods
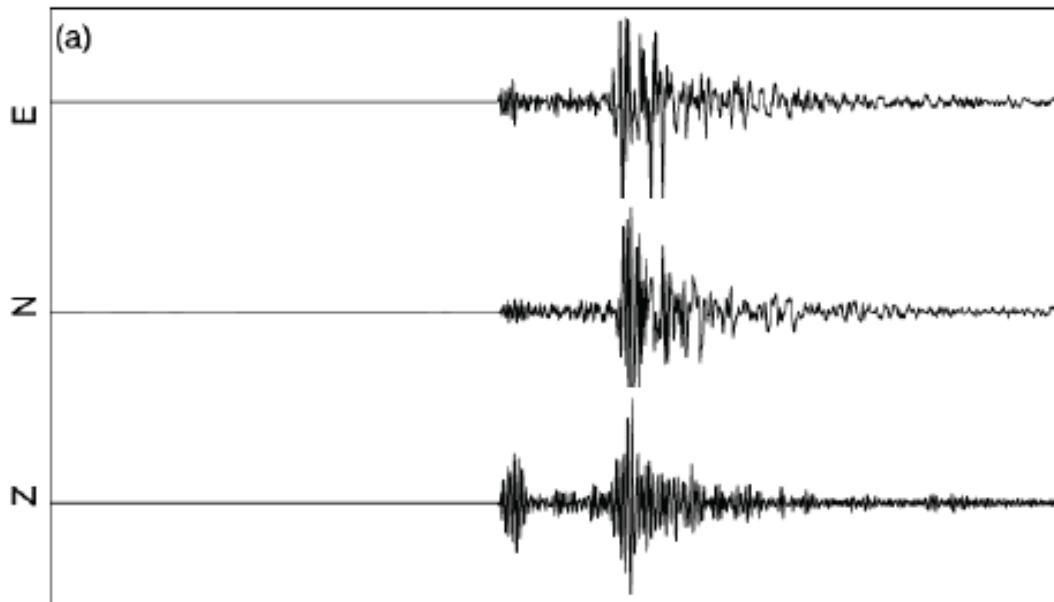
• Short-time-average (STA)/ long-time-average (LTA) & kurtosis

P & S phase picking

- Picking P & S arrivals
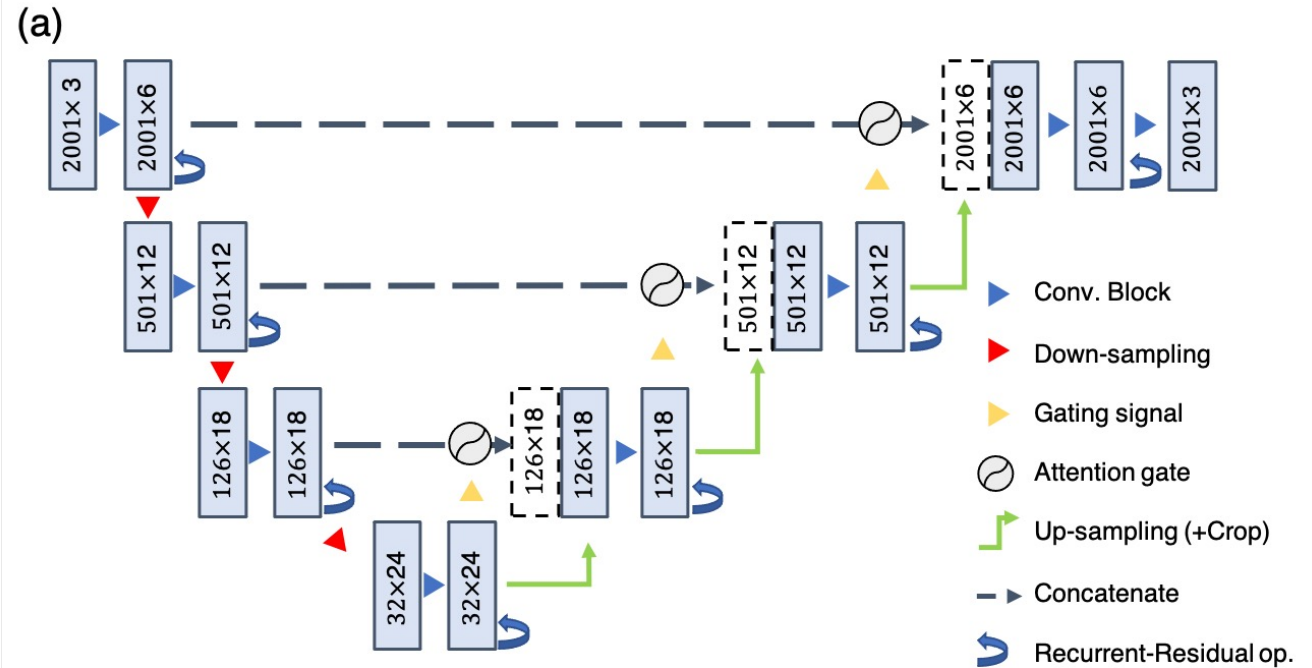- Attention ➔ P & S waves
- Waveform changes ➔ before and after the P and S arrivals

ARRU Phase picker

- ML can take different algorithms ➔ improve model performances
- U-Net
  - CNN-based encoder–decoder architecture
- Attention gates
  - Focus on P and S waves
- Recurrent-residual convolution units (RRCUs)
  - Strengthen contextual connections

Input & target functions

- Inputs
  - Earthquake recording
  - Noise and problematic recordings

- Phase picking
  - P, S, and others
  - Sum of PDFs = 1

- Earthquake(EQ) detection
  - EQ mask (P-S)
  - Others
  - Sum of PDFs = 1

(a)

Time (s)
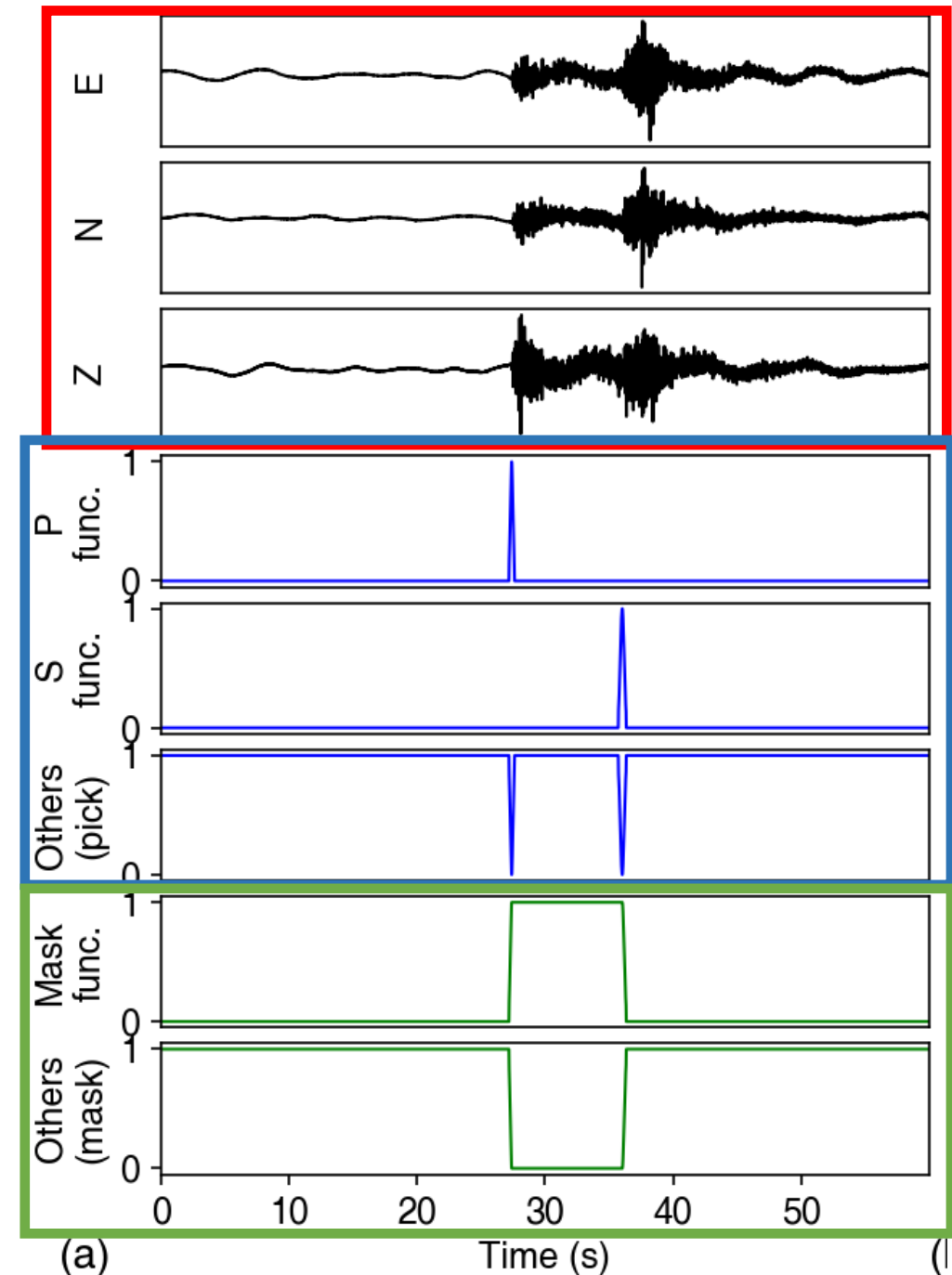
資料增強(Data augmentation)

- Increase the complexity of the data when training the model
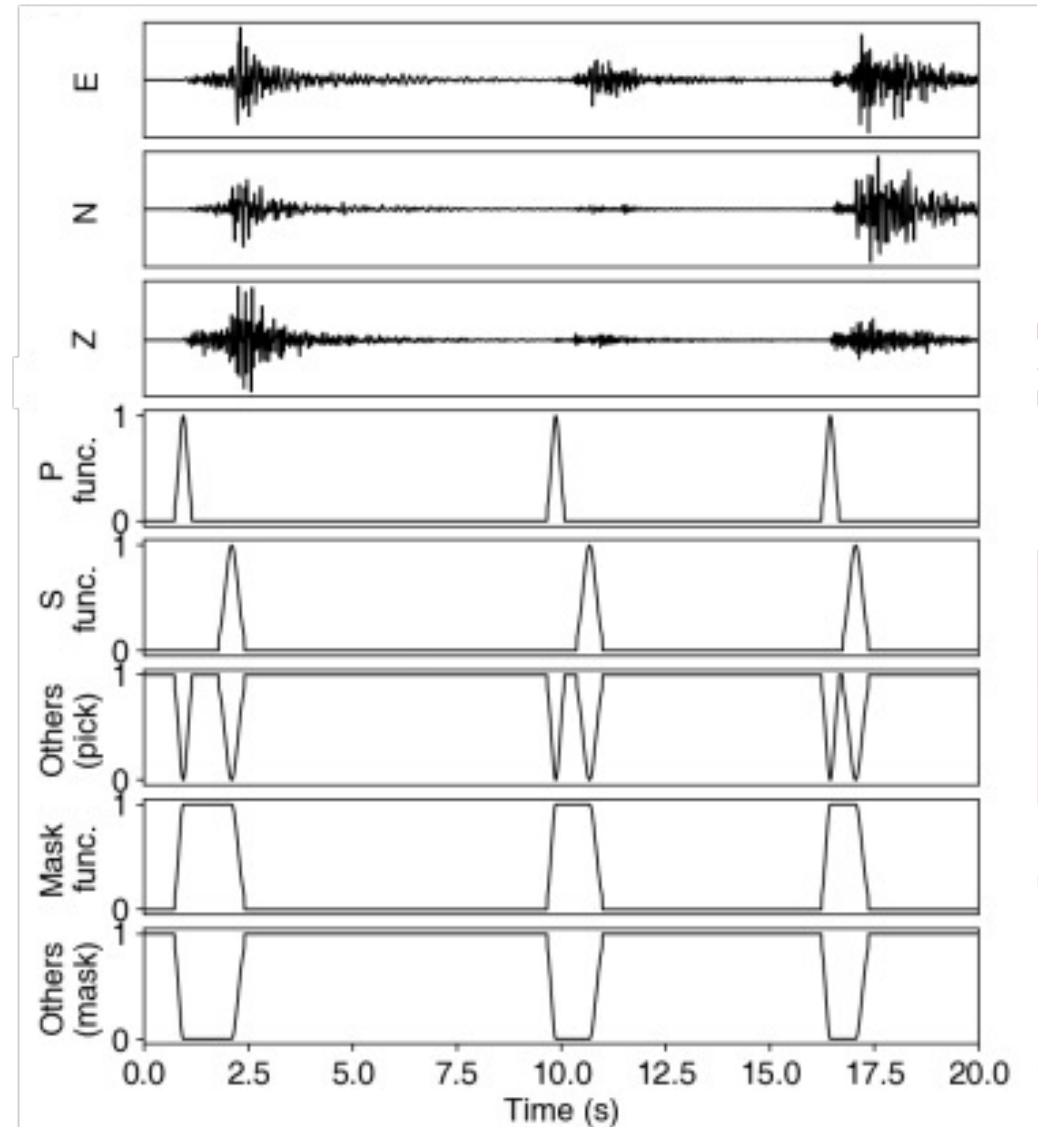- Improve the model to identify phases of multiple EQs
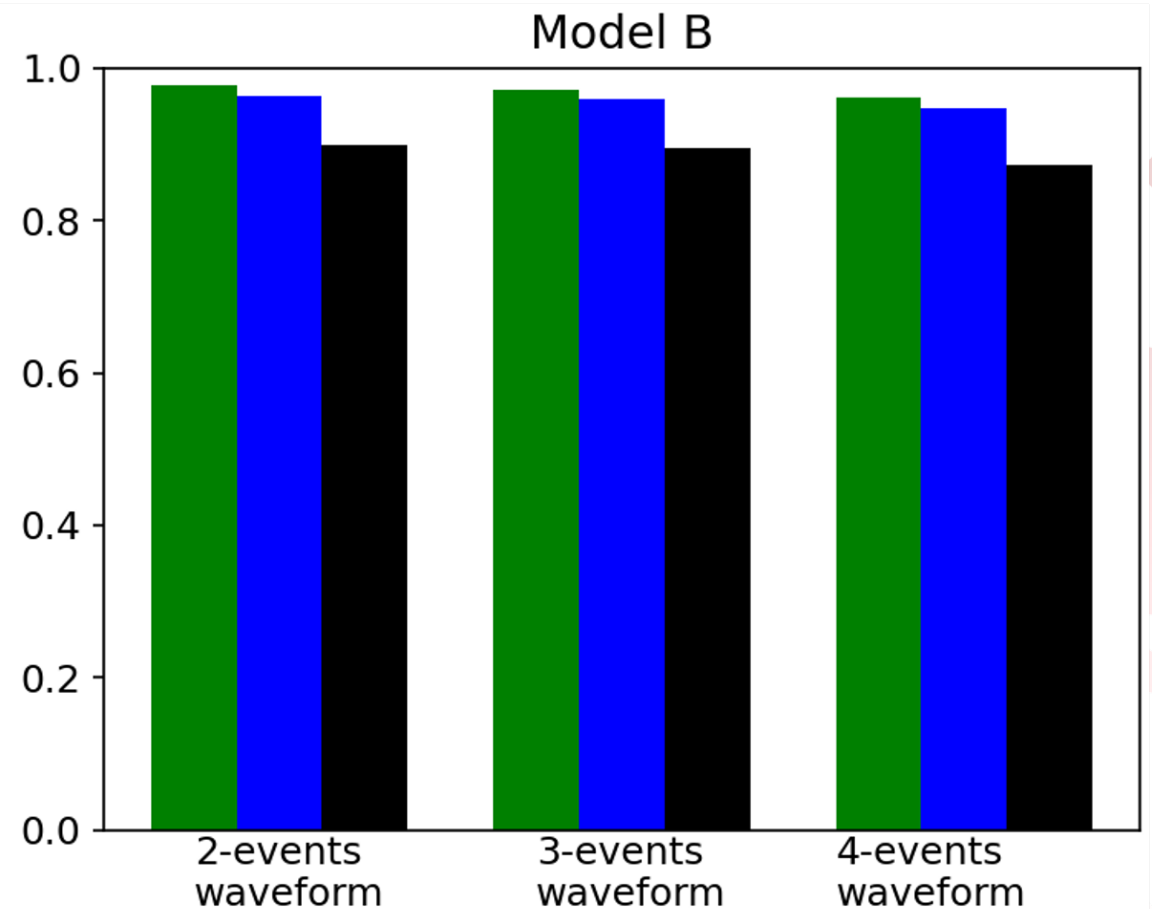

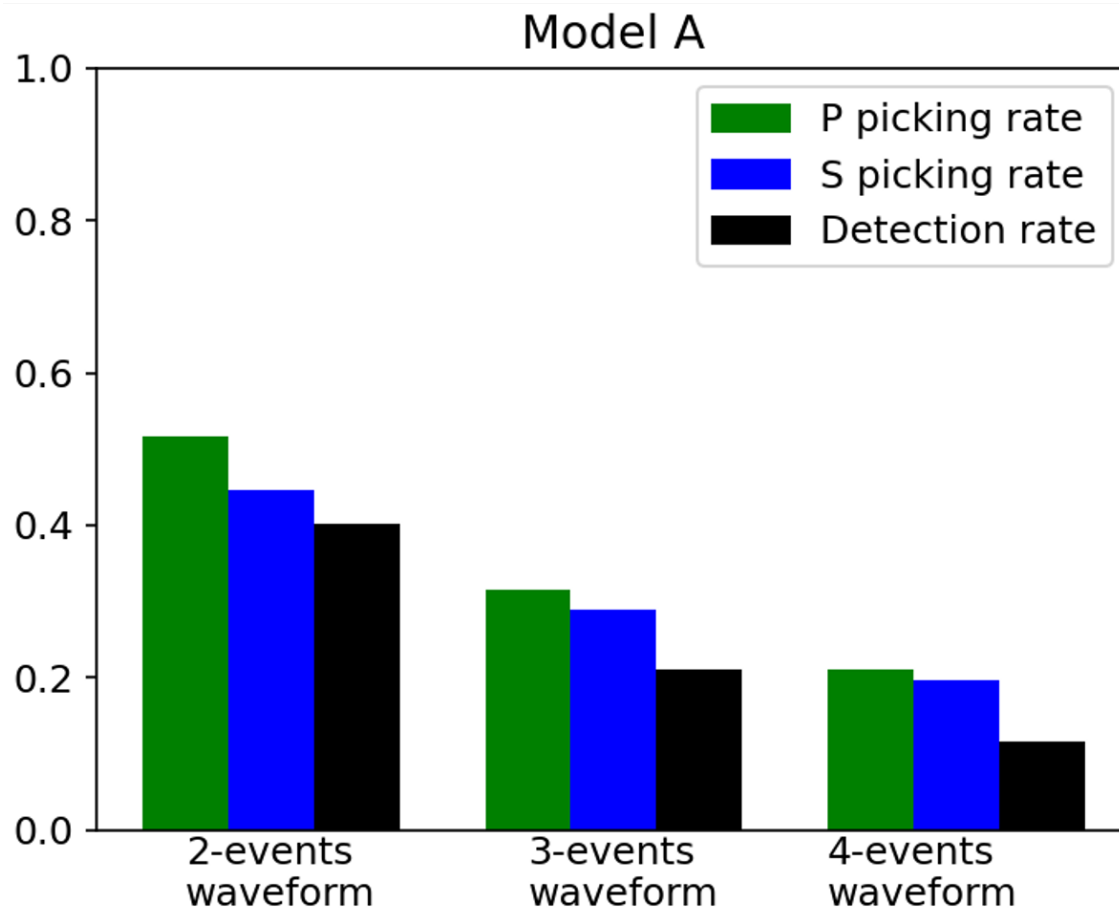Single Training Image → Self-mixed Image

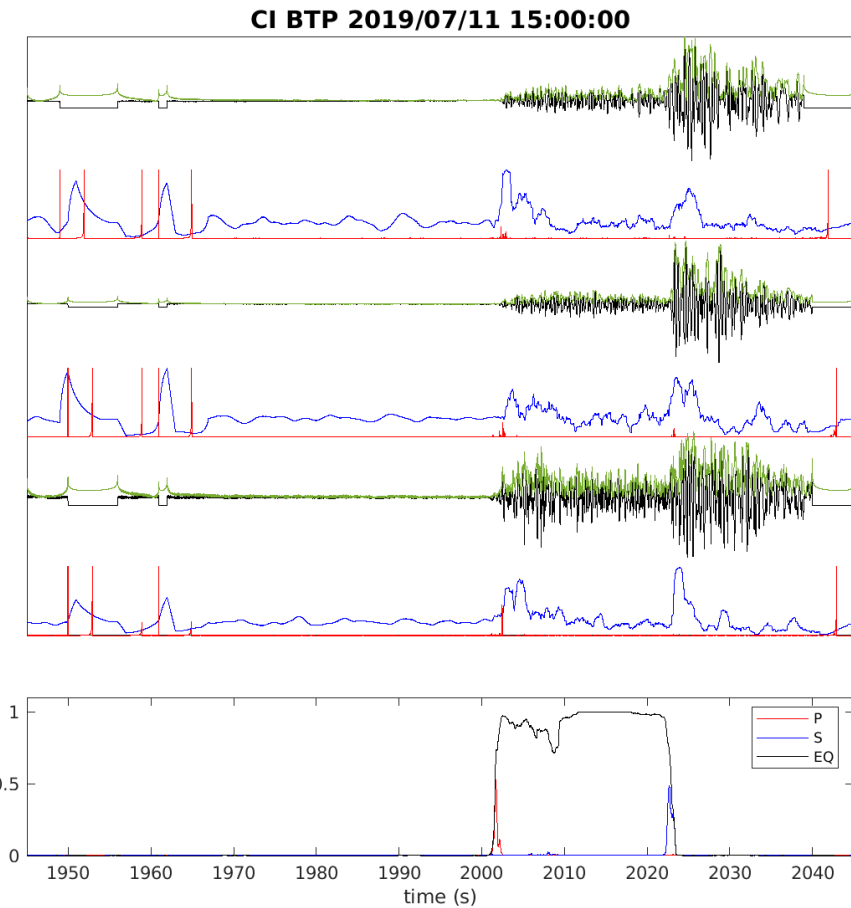# Model validation
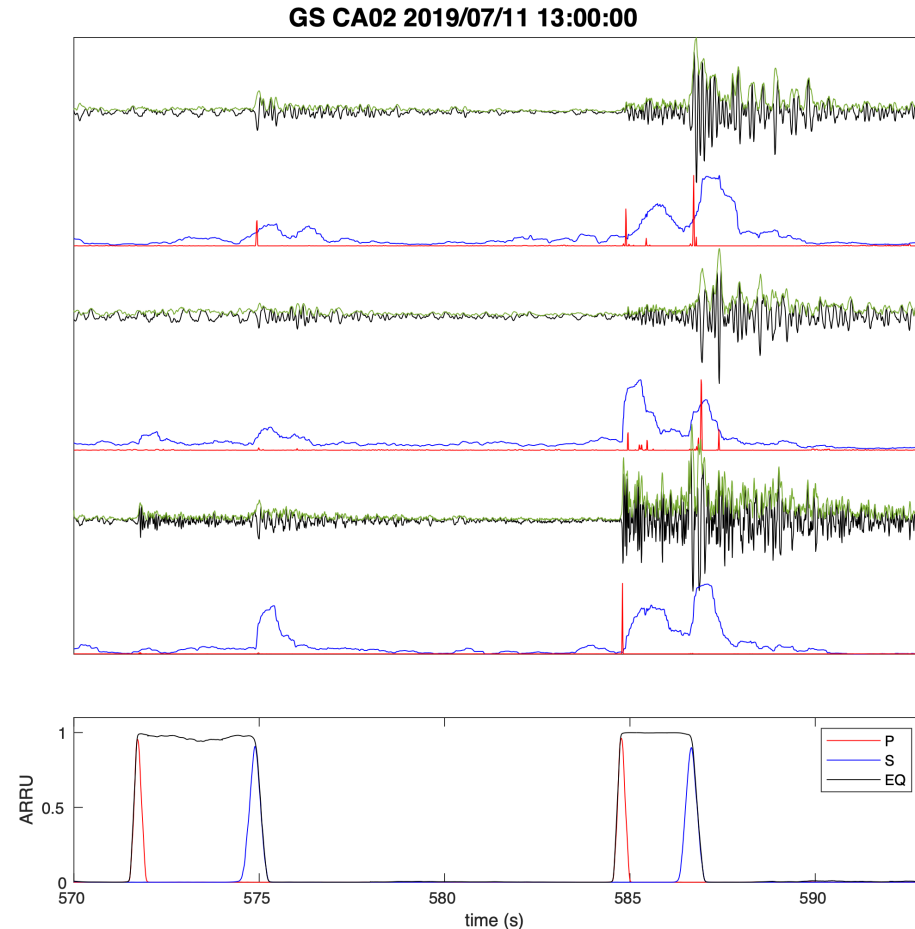
Testing dataset : > 200K
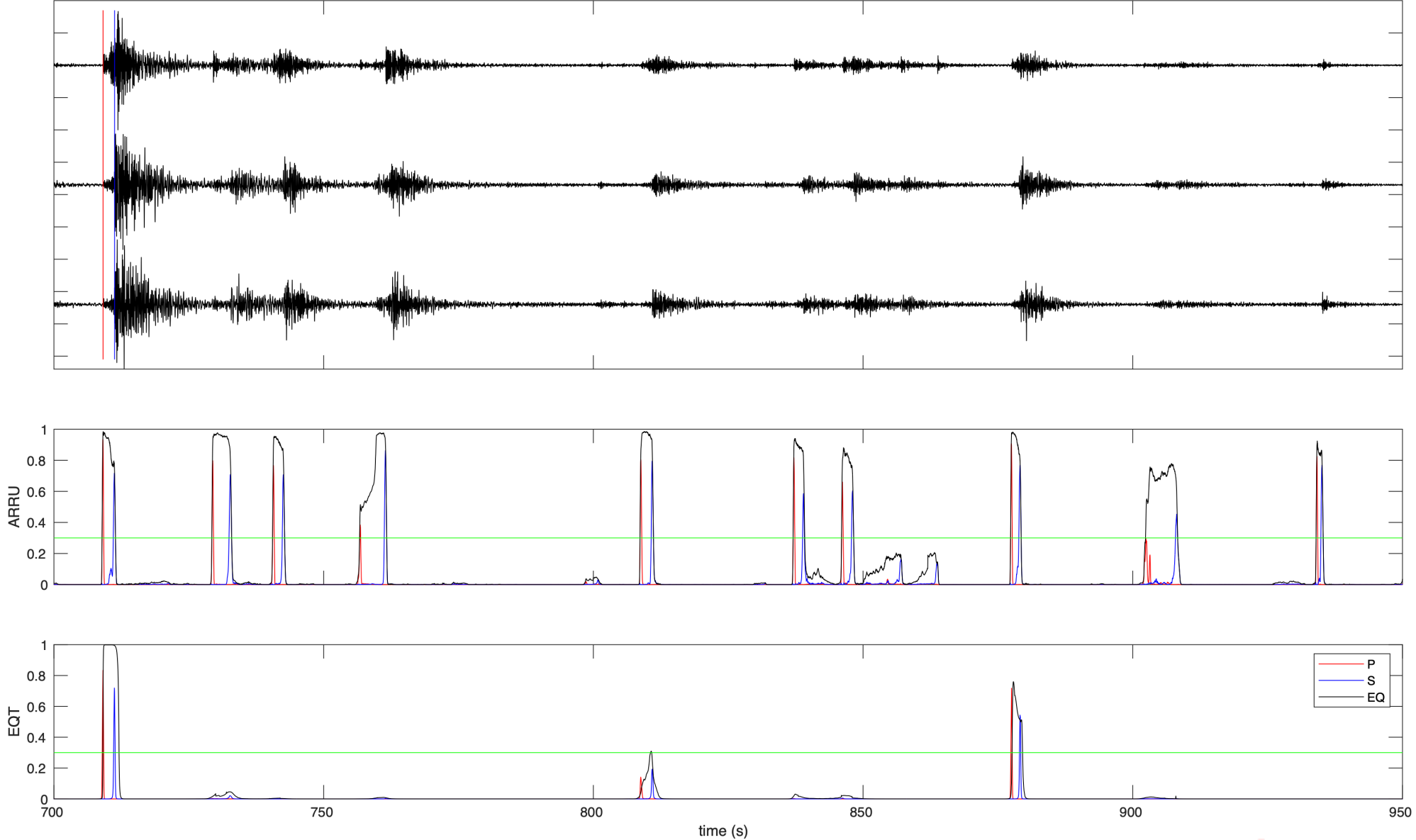Model A : 1 EQ event

Model B : 1~4 EQ events

ARRU VS. traditional methods

- Know the P and S waves
- less affected by Background noise
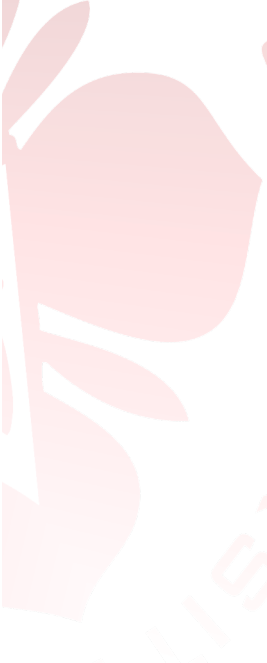- Quantified phase probabilities
- Learn about unexpected situations

GS CA02 2019/07/11 13:00:00

CI BTP 2019/07/11 15:00:00

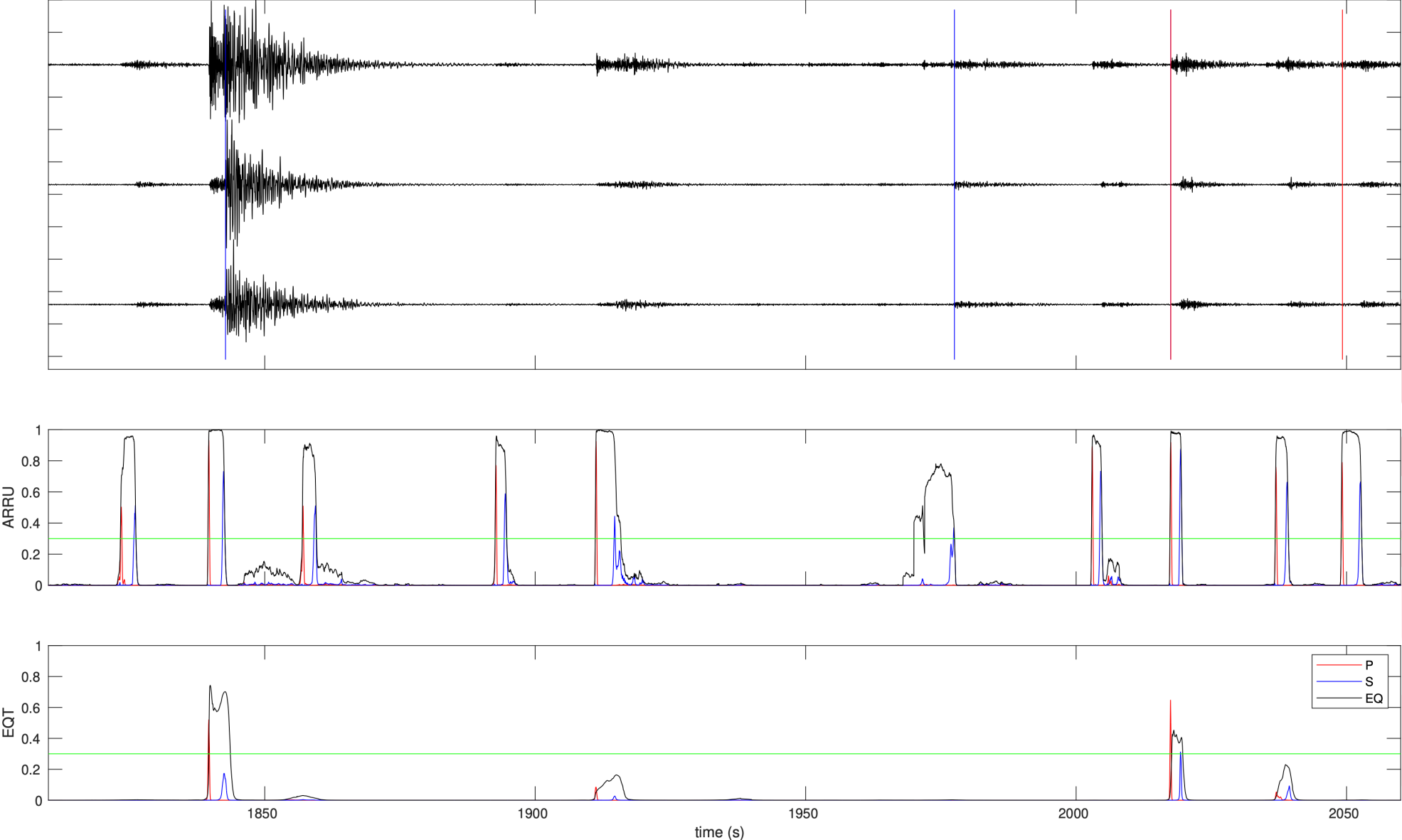# Comparison with other machine learning models

ZY SV03 2019/07/07 22:00:00

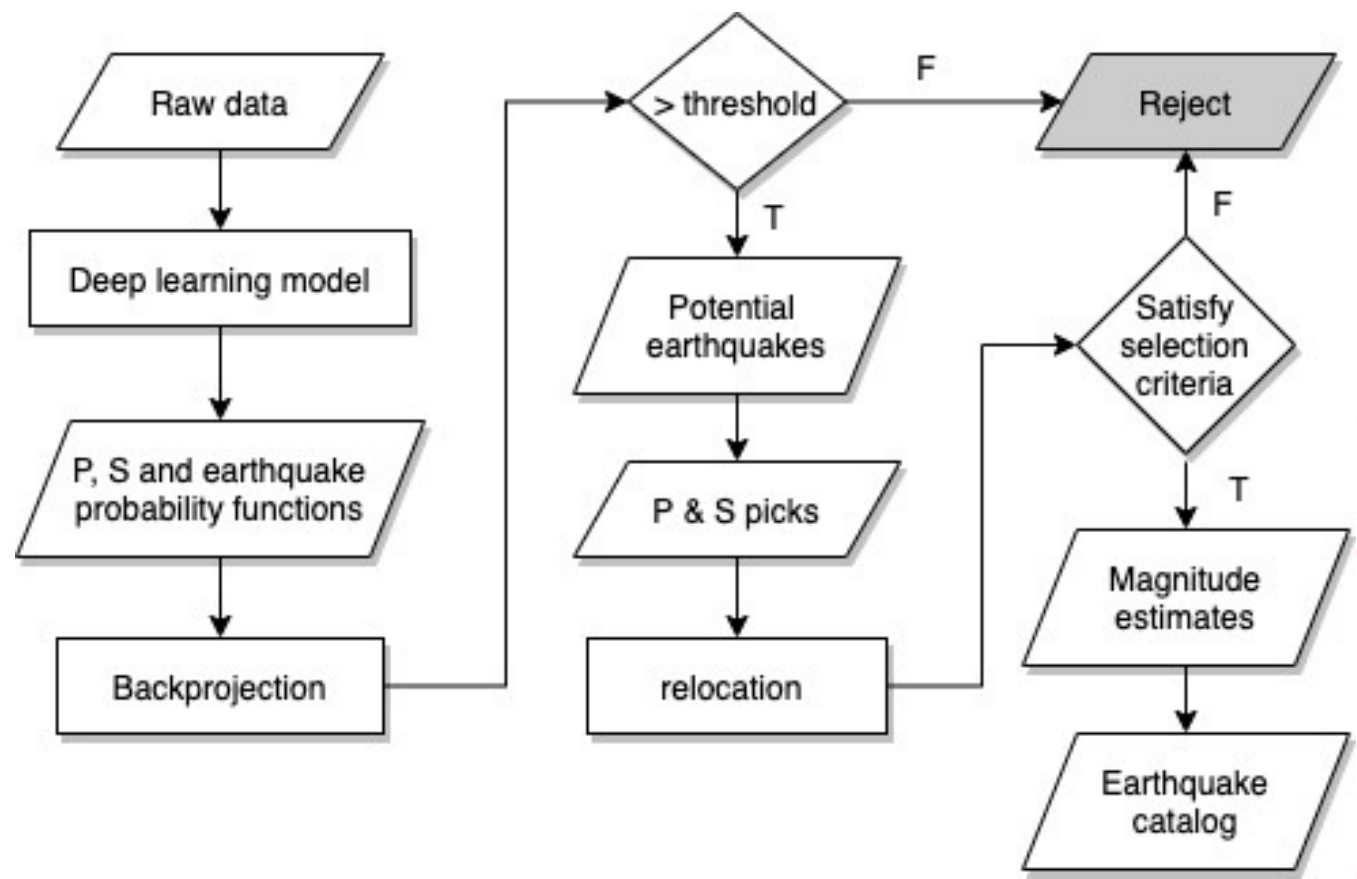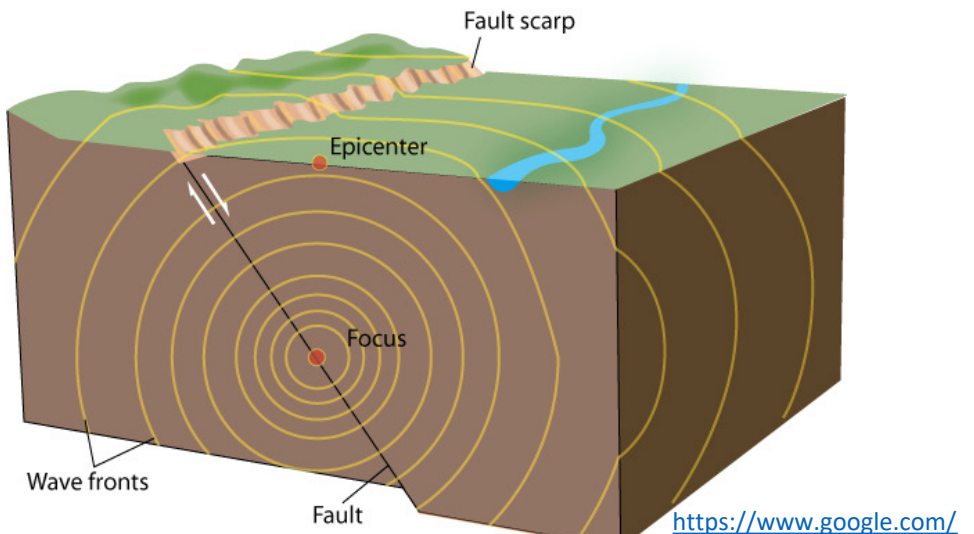# Comparison with other machine learning models

ZY SV03 2019/07/07 20:00:00

ARRU+backprojection ➔ Automatic EQ Location

- Backproject P & S PDFs ➔ epicenters
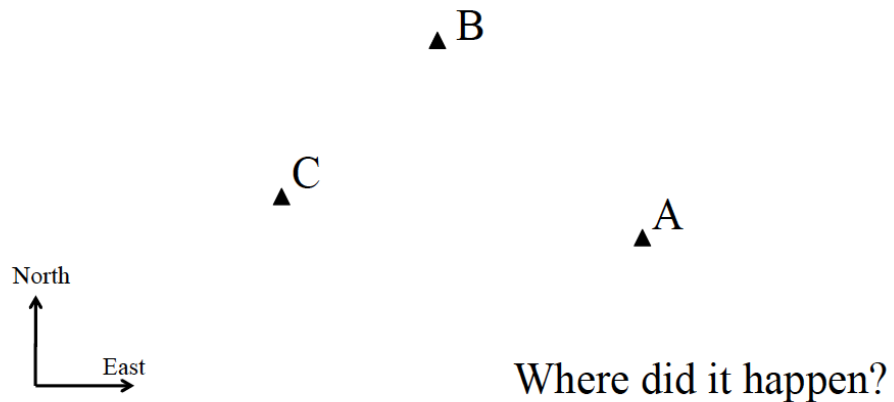

https://www.google.com/

Backprojection

From Peter M Shearer
http://igppweb.ucsd.edu/~shearer/SCECERI/
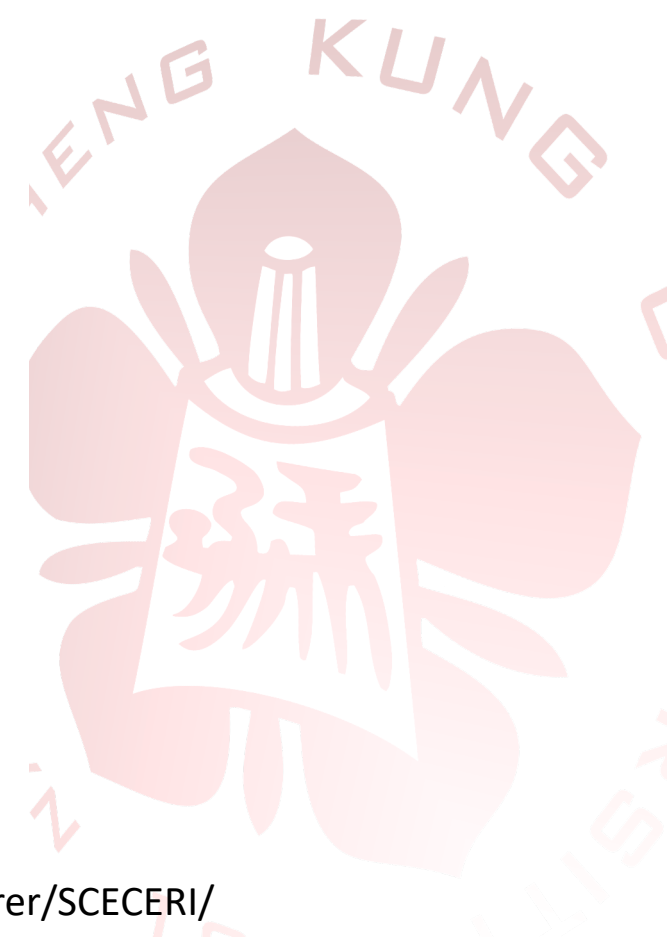
Backprojection

P-wave arrival times
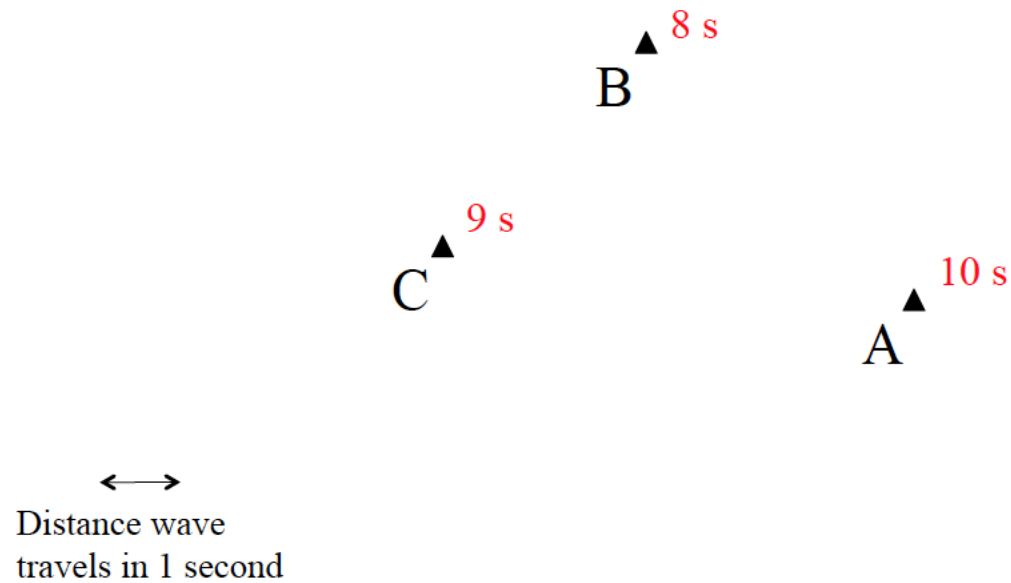
Backprojection

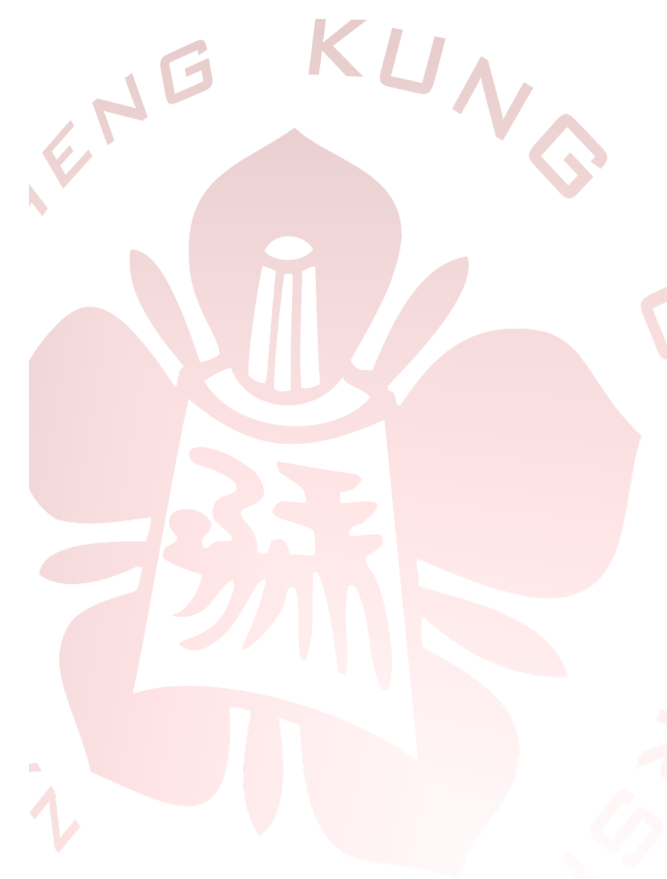Possible event locations at 8 s (red circles)

From Peter M Shearer
http://igppweb.ucsd.edu/~shearer/SCECERI/
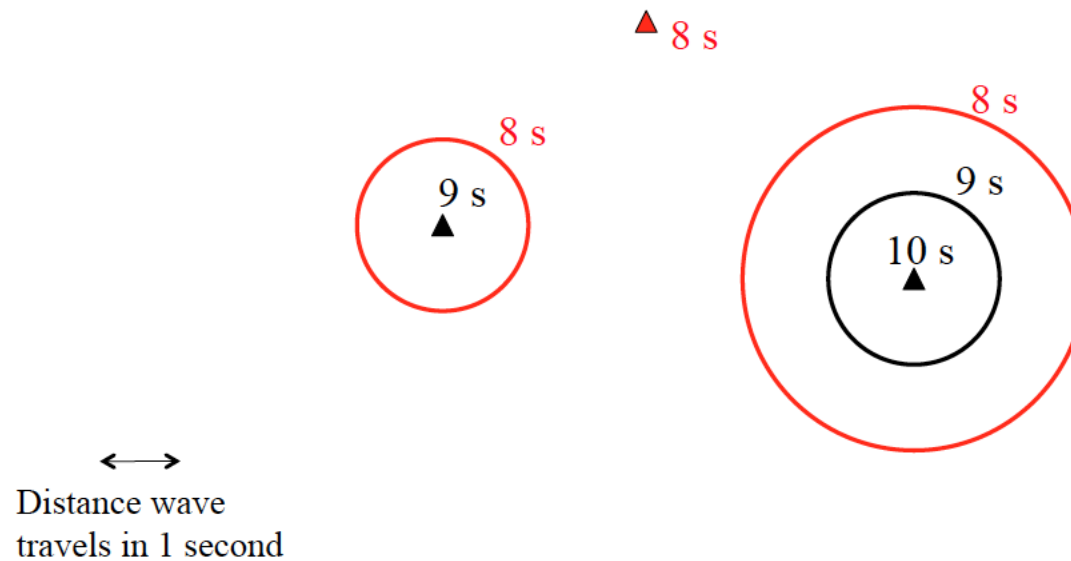
Backprojection

Possible event locations at 7 s (red circles)

Distance wave travels in 1 second

From Peter M Shearer
http://igppweb.ucsd.edu/~shearer/SCECERI/
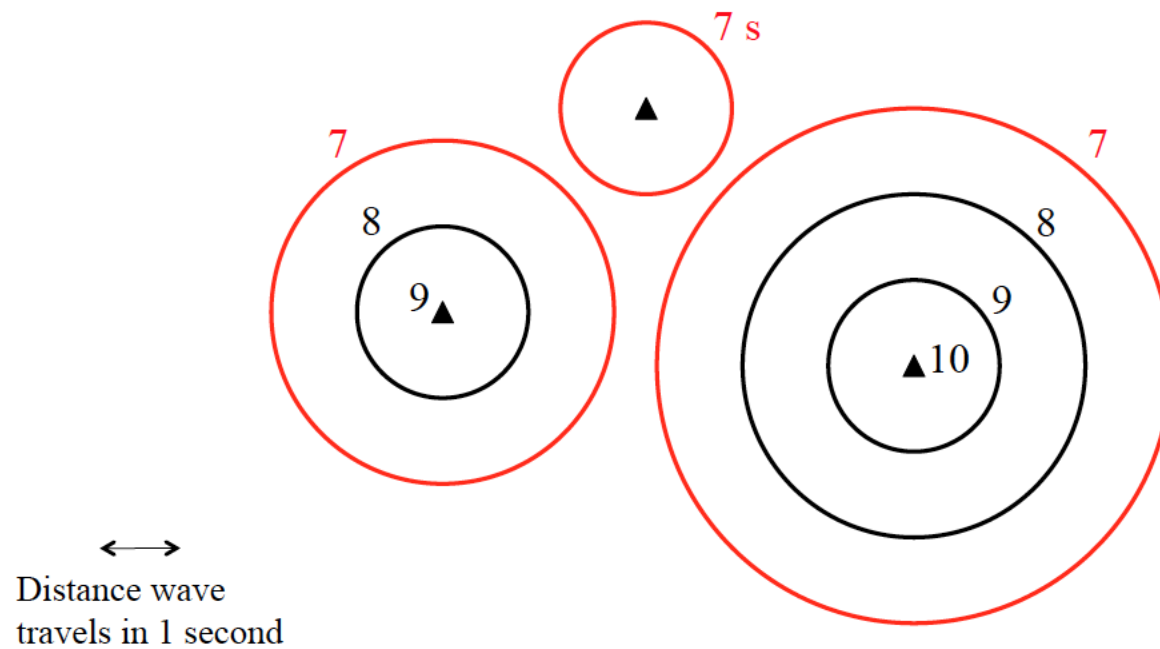
Backprojection

Possible event locations at 6.5 s (red circles)

6.5 s

6.5 s

6.5 s

▲8 s

▲9 s

Best-fitting location

▲10 s

↔ Distance wave travels in 1 second

From Peter M Shearer
http://igppweb.ucsd.edu/~shearer/SCECERI/
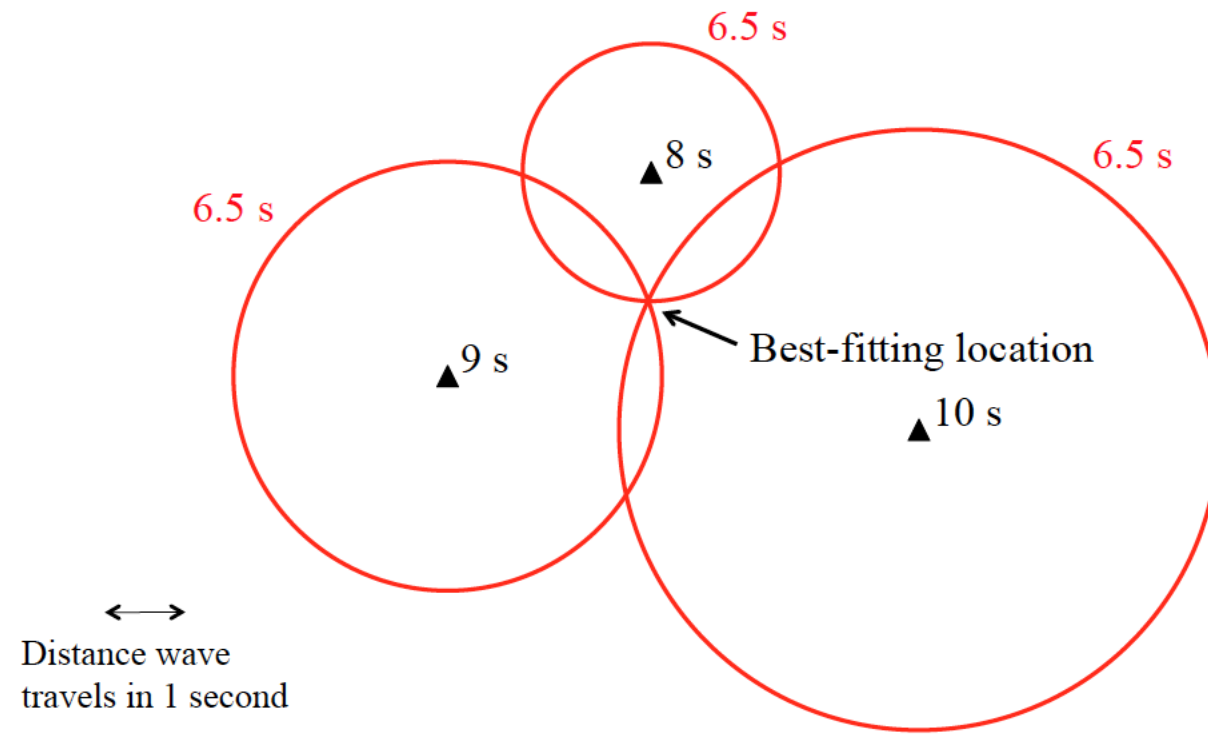
Backprojection

Earthquake!

Seismic waves recorded at three stations:

3 s — B

3.5 s — C

6 s — A

North / East

Where did it happen?
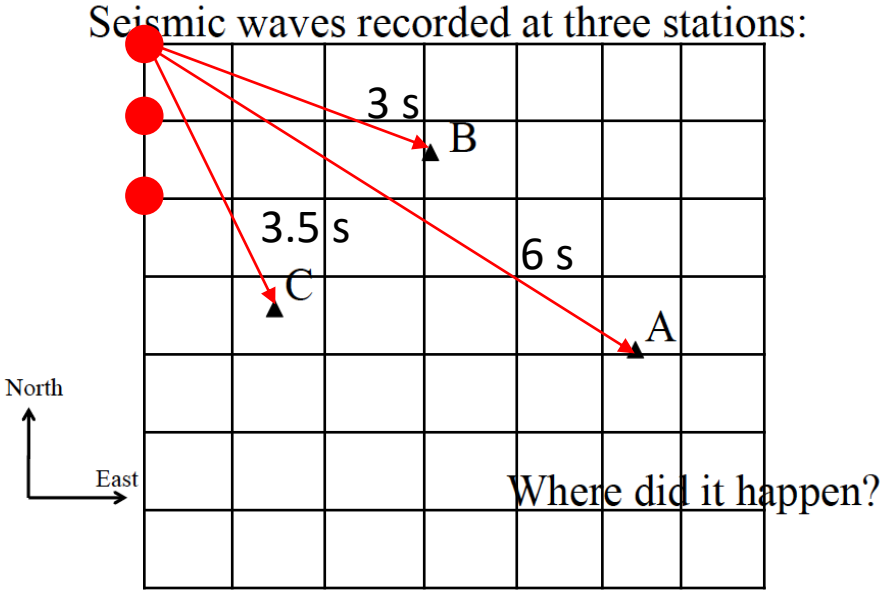
Measure seismic wave arrival times

Station A — 6 s — 10 s

B — 3 s — 8 s

C — 3.5 s — 9 s

time

From Peter M Shearer
http://igppweb.ucsd.edu/~shearer/SCECERI/
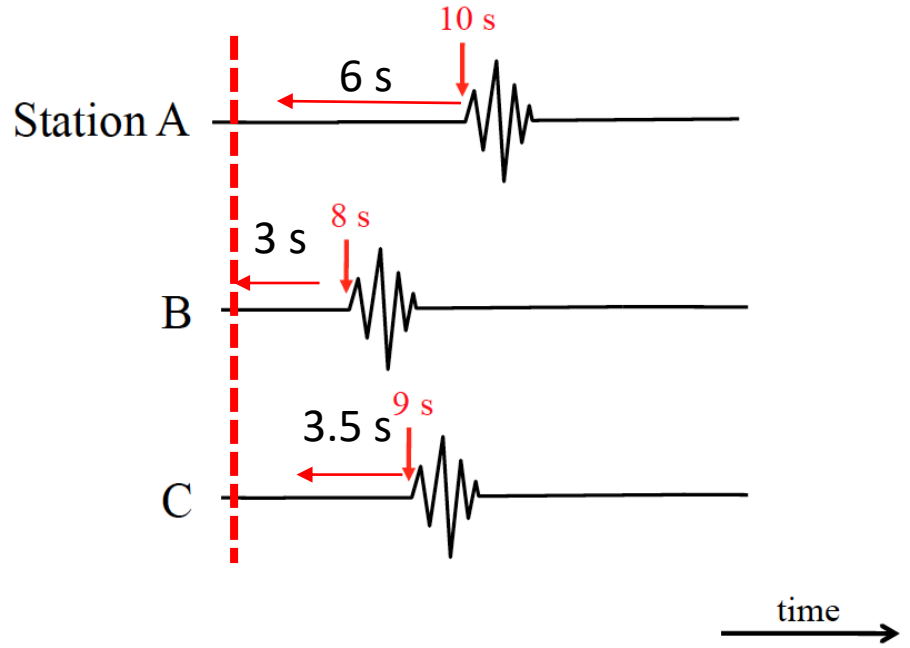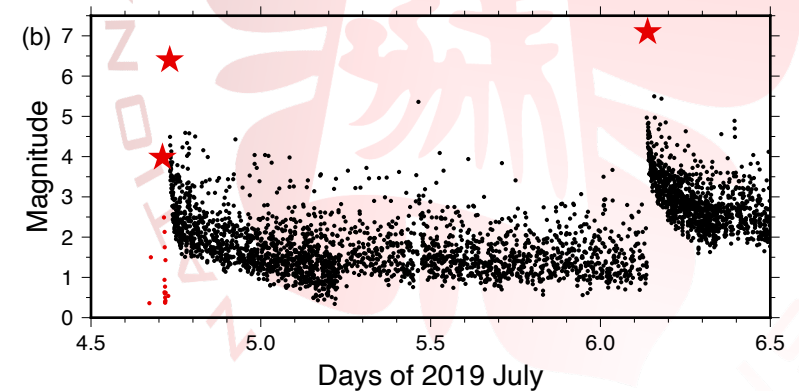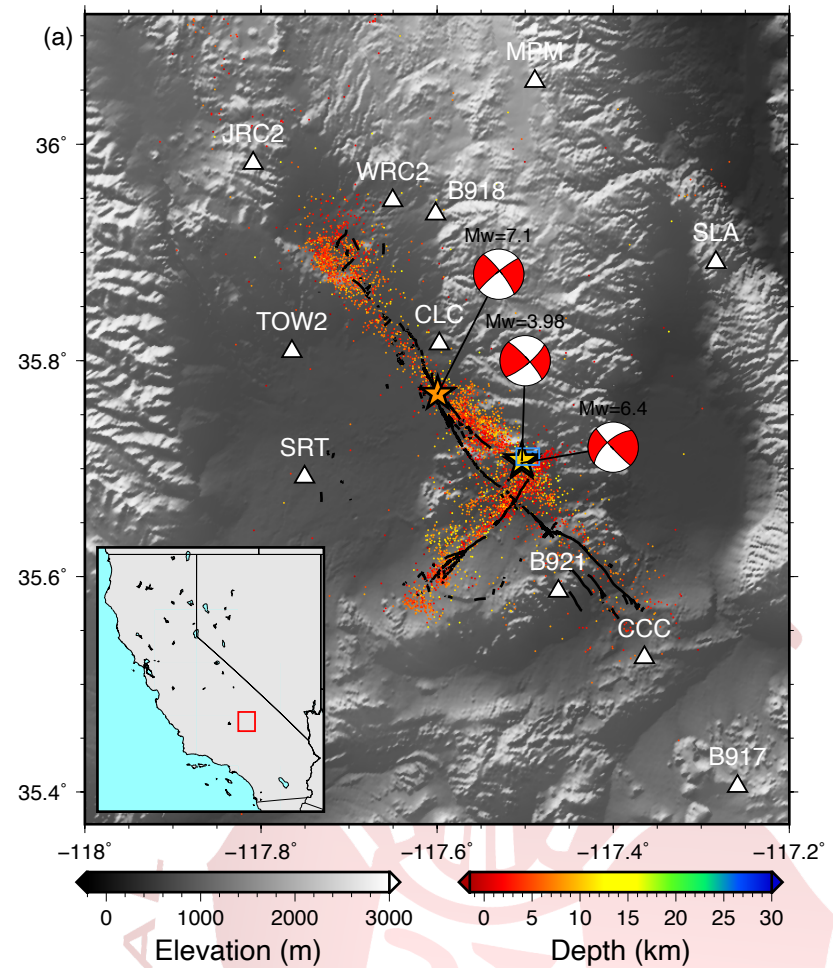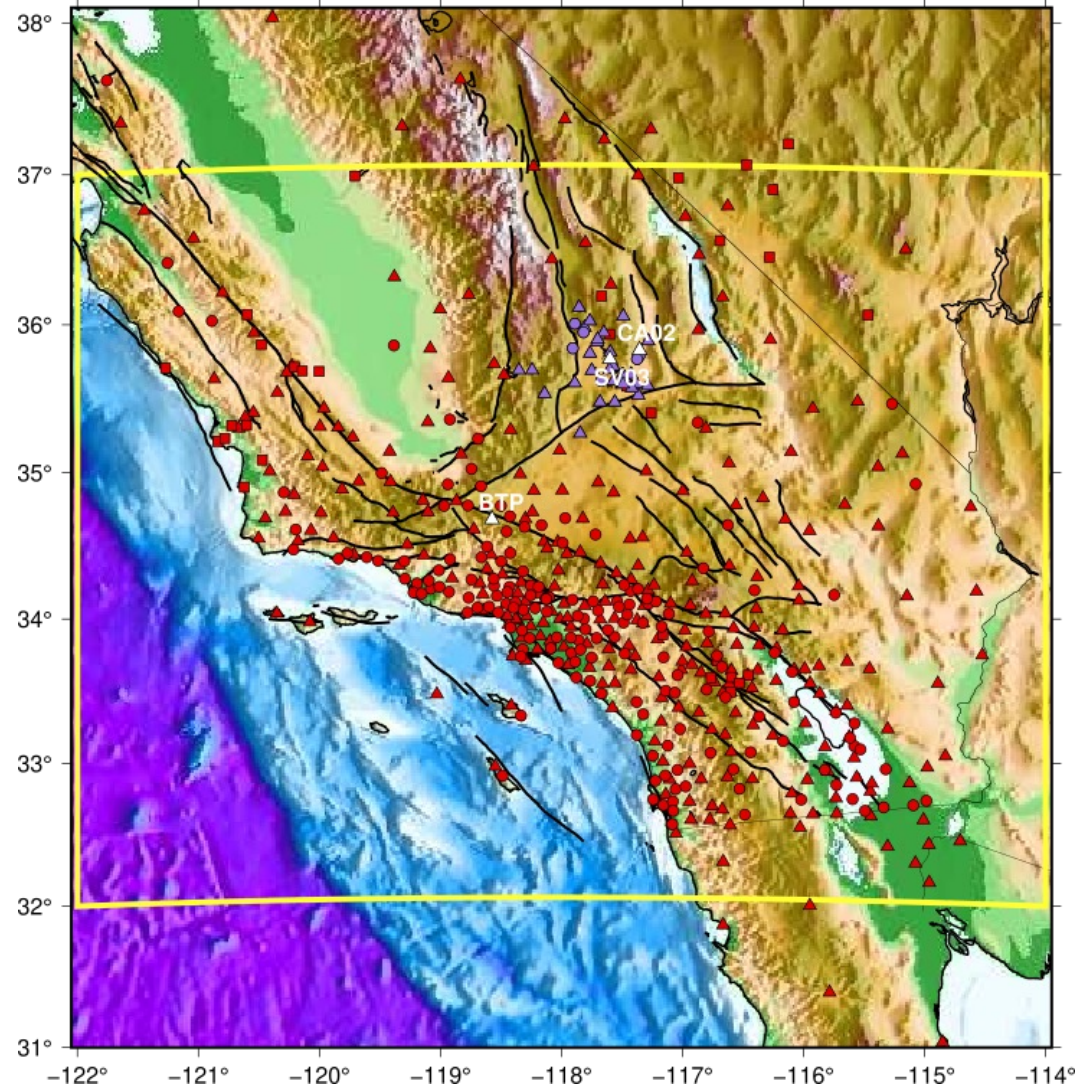
Backprojection

- Input functions
  - PDF of P & S

- Advantages
  - Time shifts by P or S arrivals
  - P-S pairs ➜ reject impossible pairs
  - Threshold values
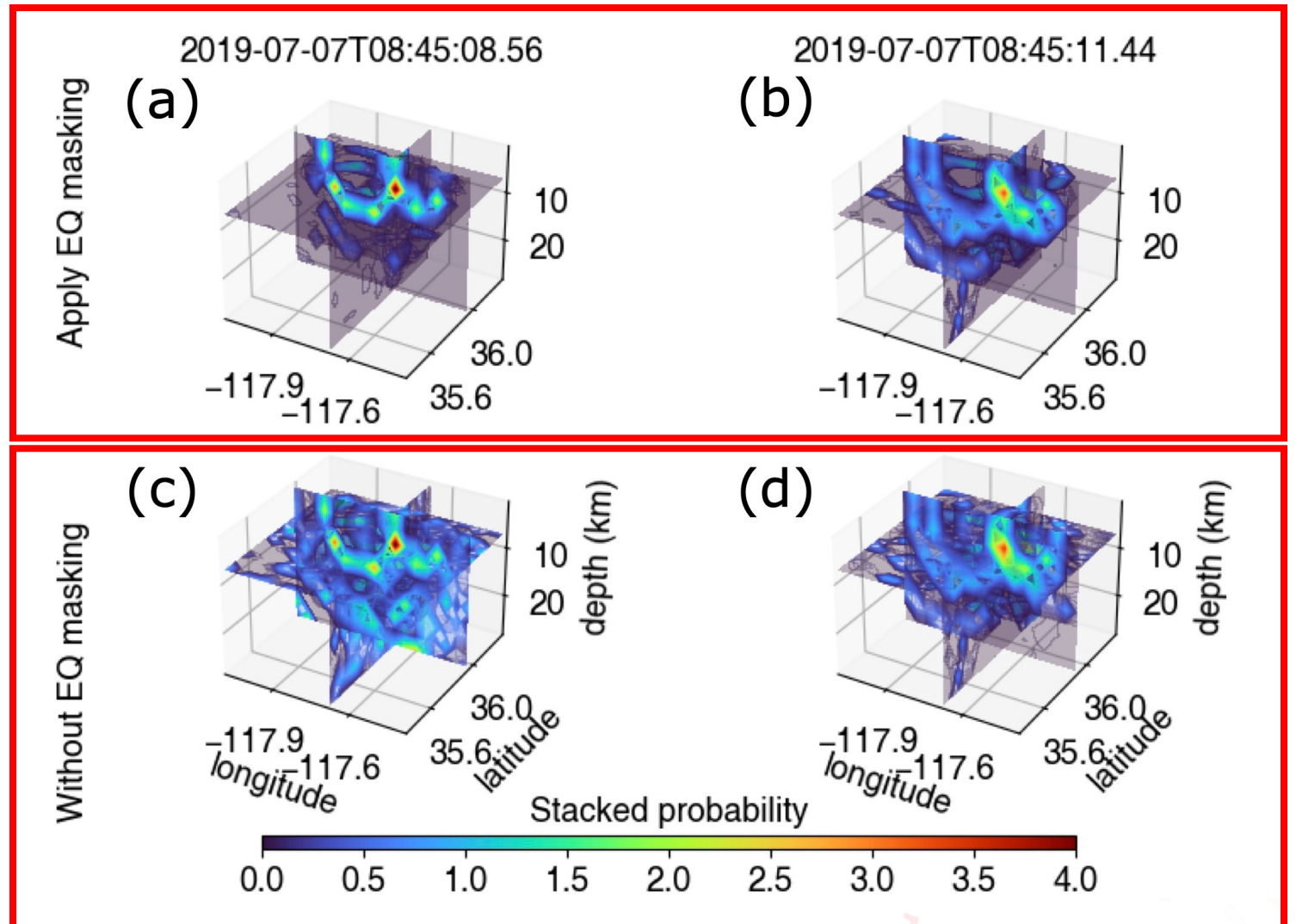
SC & 2019Ridgecrest

- > 500 stations
- Large area(about 500 × 600 km)
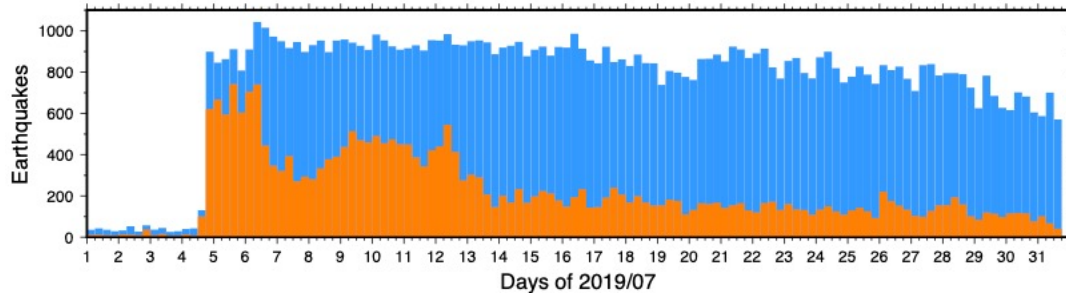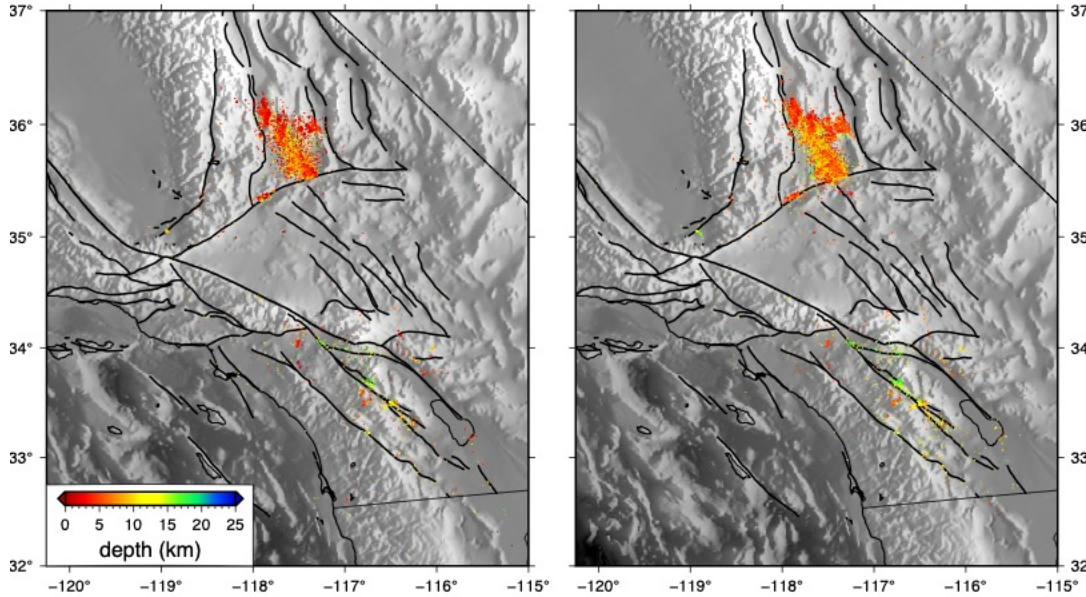- Ridgecrest EQ is the largest earthquake in 25 years

2019 Ridgecrest

- 3 times as many as SCEDC catalog
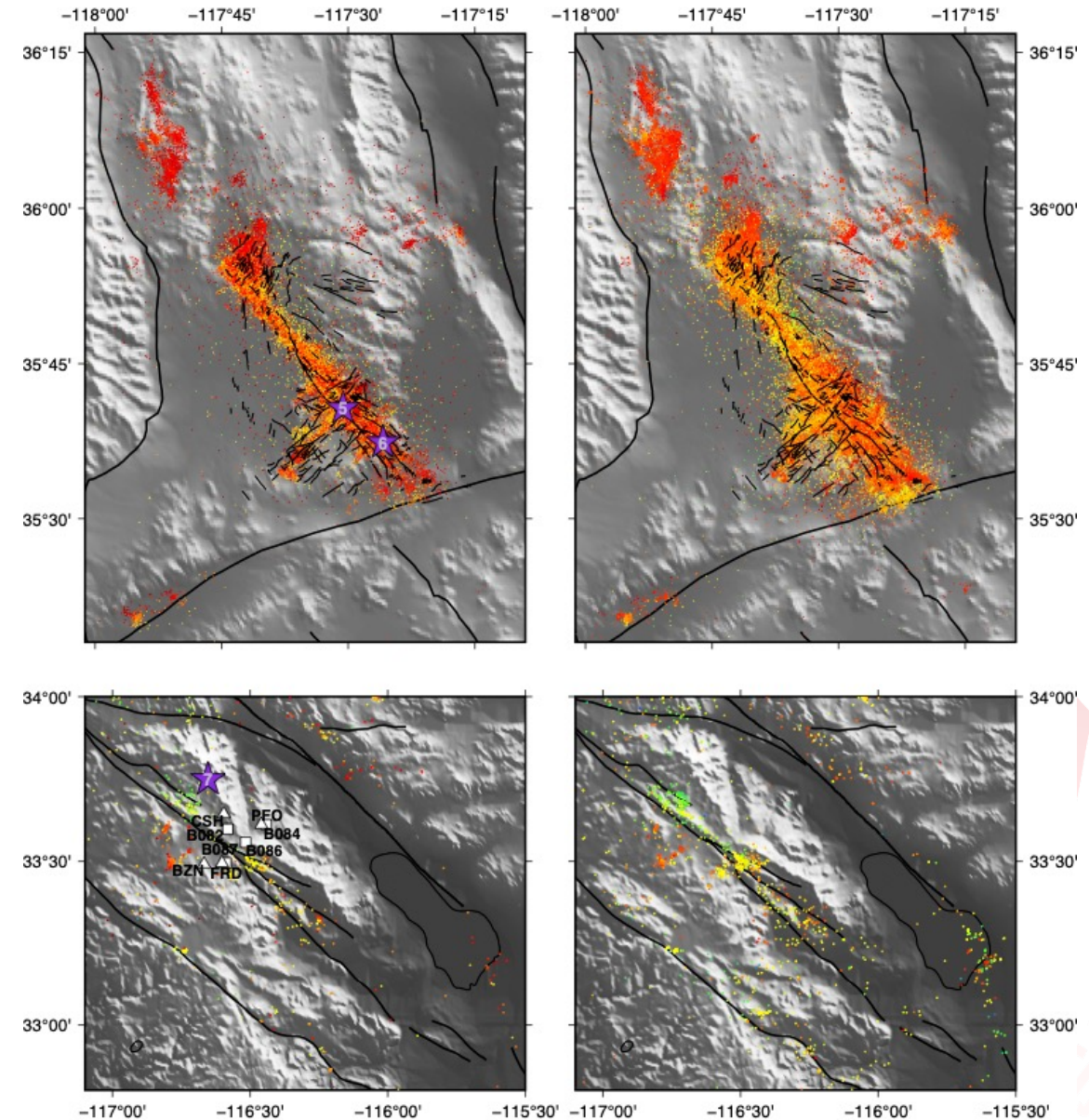- More complete earthquake catalog

ARRU+BP

- Earthquakes ➜ close epicenter and time
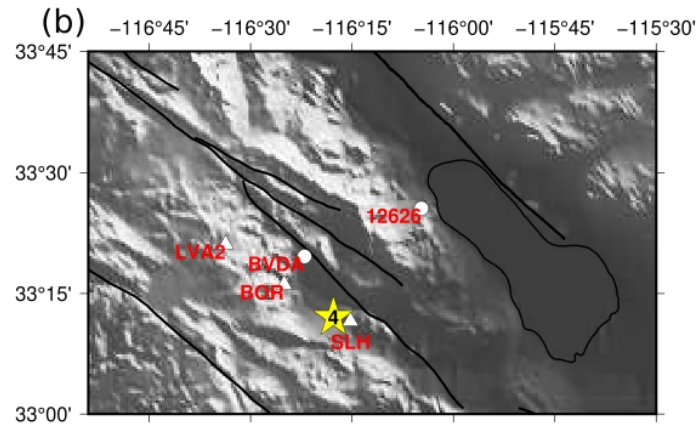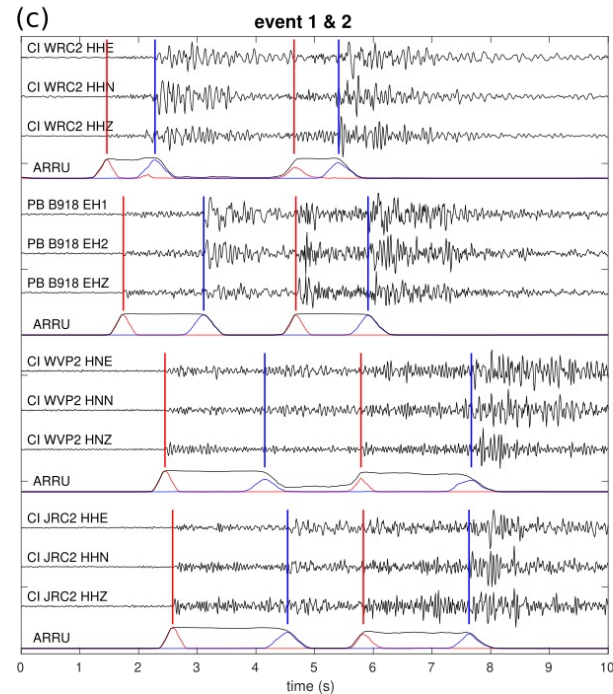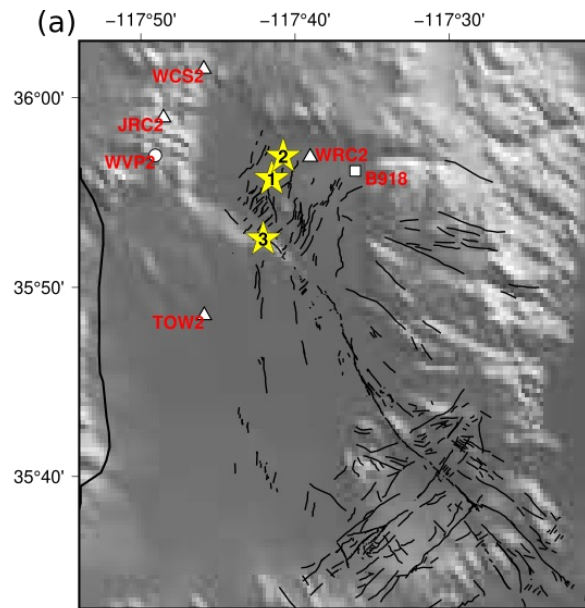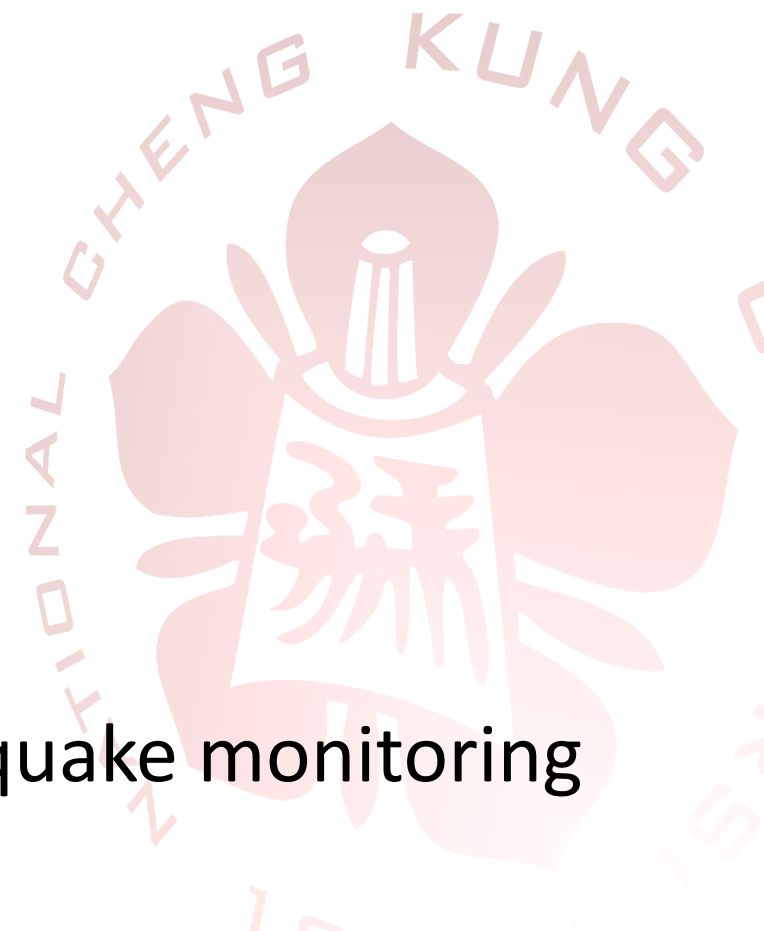- Almost simultaneously (<0.1s) earthquakes
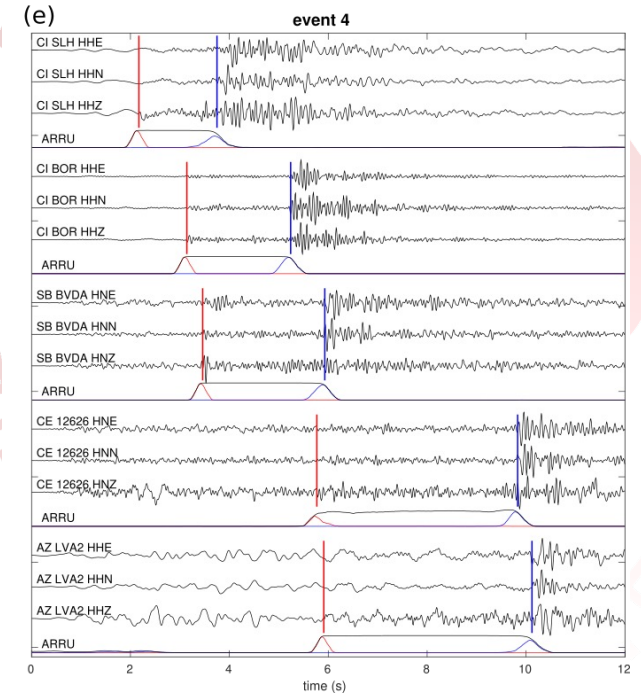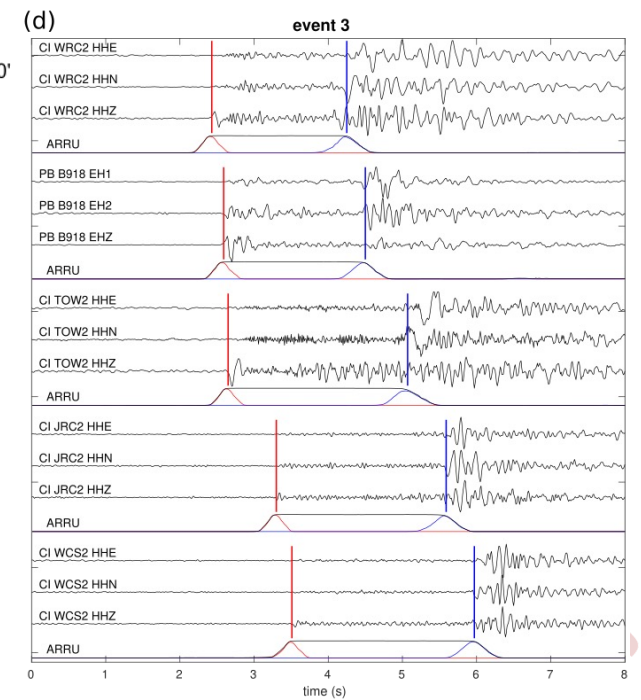
Summary

- Improved ML model
  - Machine learning algorithms
  - Data augmentation
- ARRU phase picker
  - Detect earthquakes & pick P and S arrivals
  - Phases of multiple earthquakes
  - Continuous seismic recordings
- ARRU + Backprojection ➔ Automated earthquake monitoring

Chi-Chi Earthquake

The new techniques can provide
near real-time information
for preparing our community
for the next big earthquake.

復國中

台北東星大樓

Thank You !!

http://admdmt.ccu.edu.tw