Detection and discrimination of small earthquakes and explosions around North Korean Nuclear Test Site

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- Small seismic event detection & Identification
  Examples: 12 May 2010 (M ~1.5) and 11 Sept. 2016 (M ~1.8)
- Newly available local data and methods.

Temporary 16-station Dongbei Network (Northeast, China) deployed during July 2004 through August 2010 are made available for us to use by Dr Kip-Yip Chun of formerly at Univ. of Toronto, Canada.

Borehole installation of Korea Meteorological Administration (KMA) provide complementary data to IMS in the region.

Small Seismic Event Detection

Nuclear Test Ban Monitoring Regime for seismic events: Key

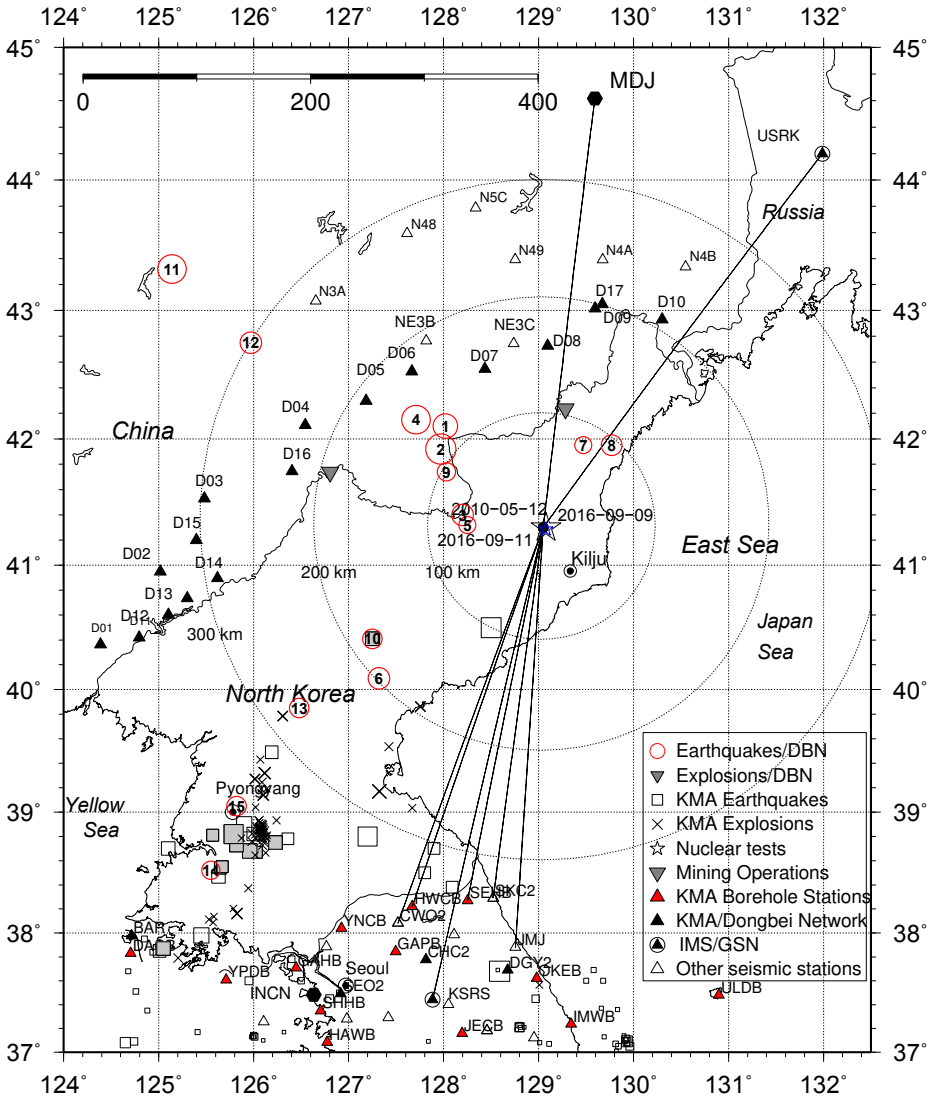
Detection,

Location,

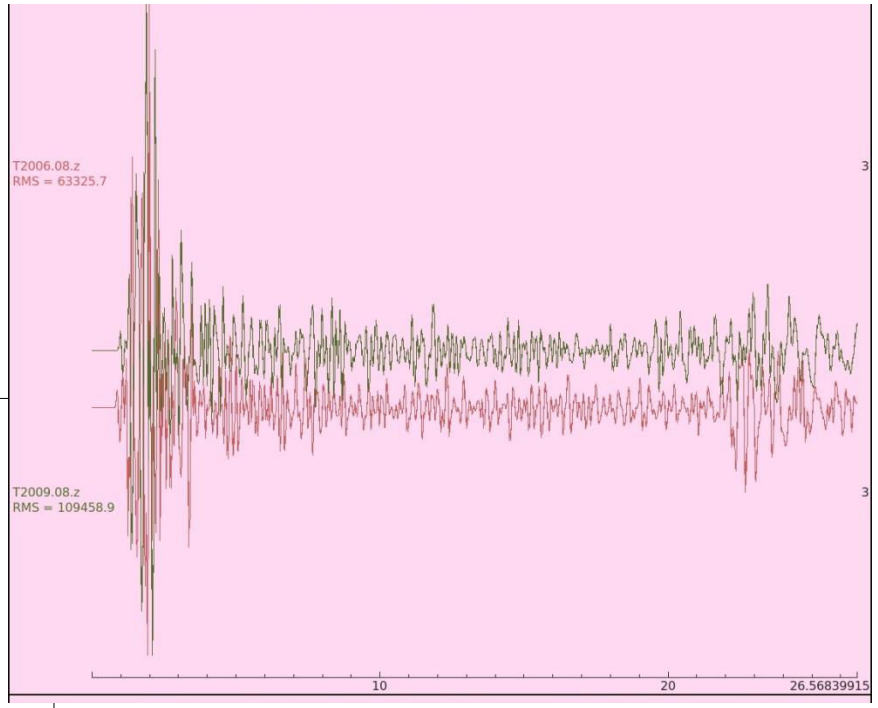
Identification

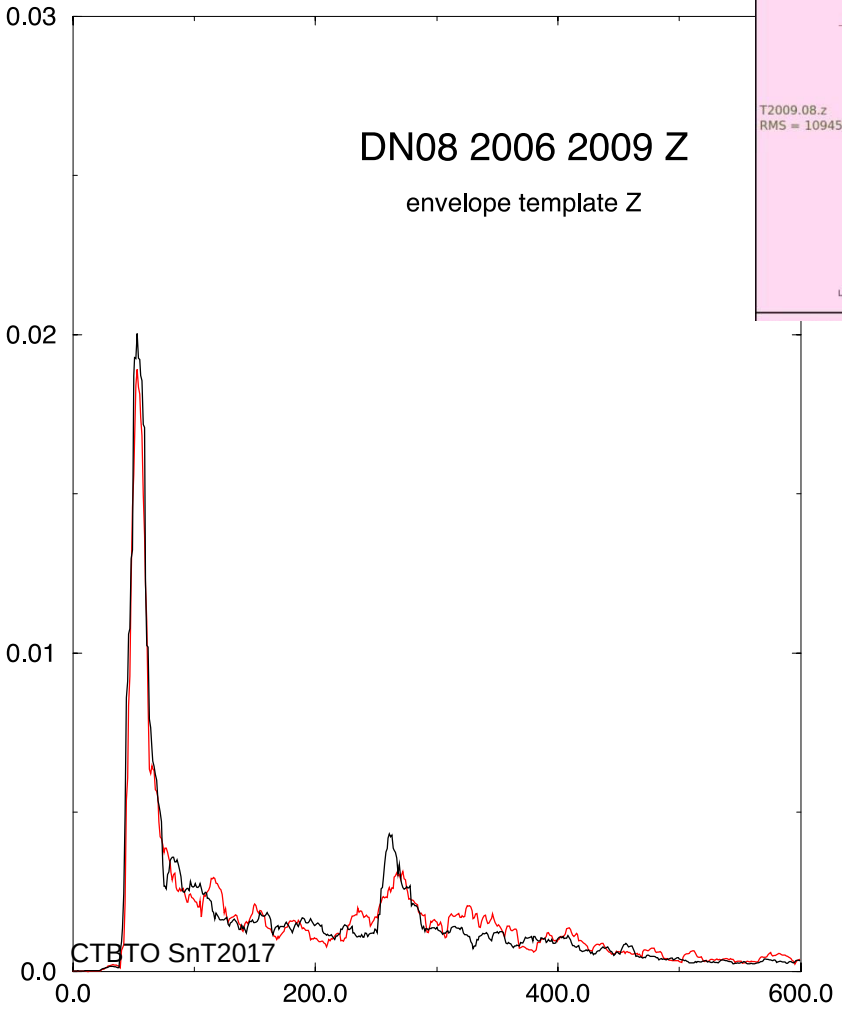
CTBT Regime: Small Seismic Event Detection with Local Data

- Visual inspection multi filtering
- Short-term/Long-term Average
- Array processing / Beam form
- Waveform X-correl. w template
- Envelope template detector



Small event detection using template envelope detector on Dongbei network data.





Envelope Detector

-1-sec RMS amplitude, and 0.1 s offset smoothing ~1.0 sec. [$1/n \sum x^2)^{1/2}$]

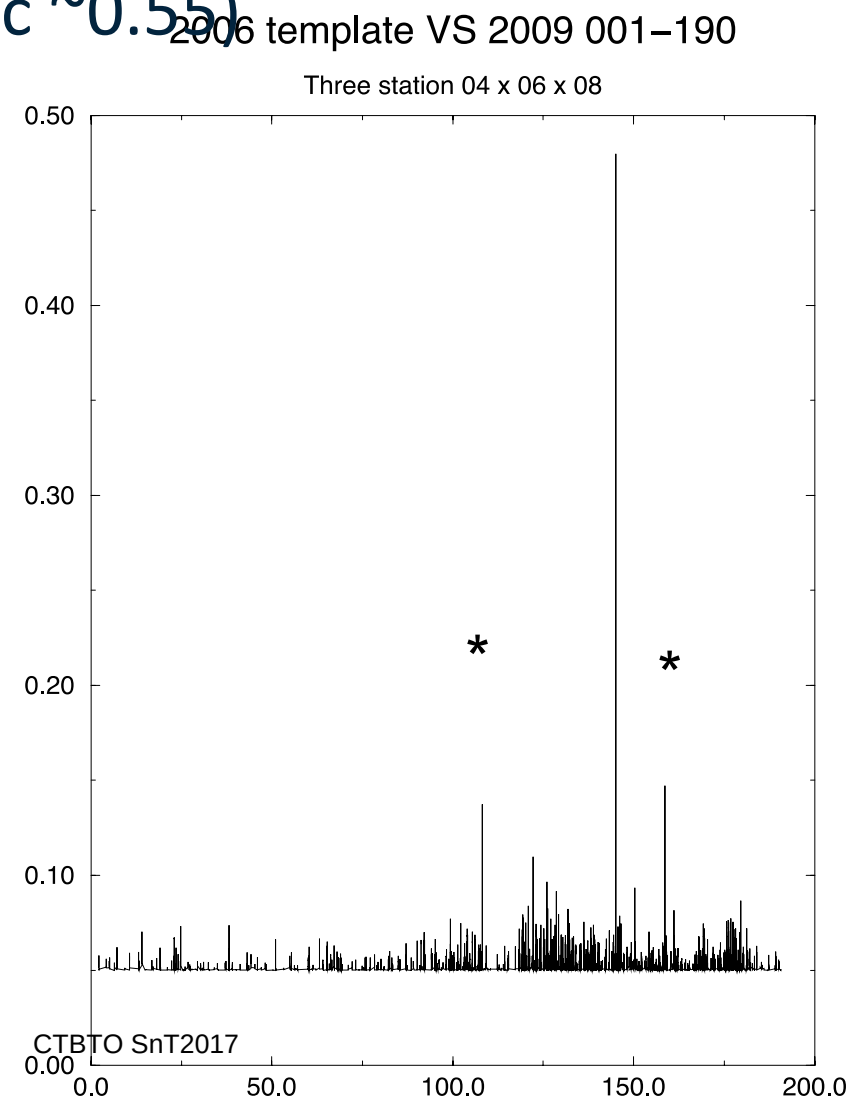
-60-sec long template trace is used, 60s/0.1 = 600 samples

Used in Episodic Tremor detection in Cascadia in Western North America and in Japan.

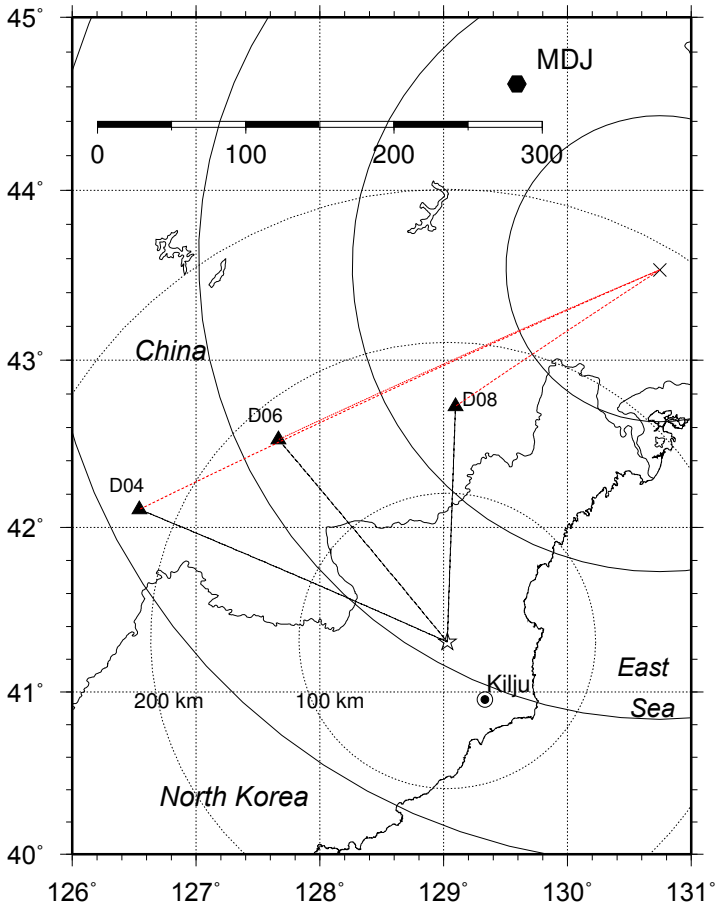
Area between two envelopes is zero for perfect correlation.

Event detection around North Korean Test Site: w **Dongbei**

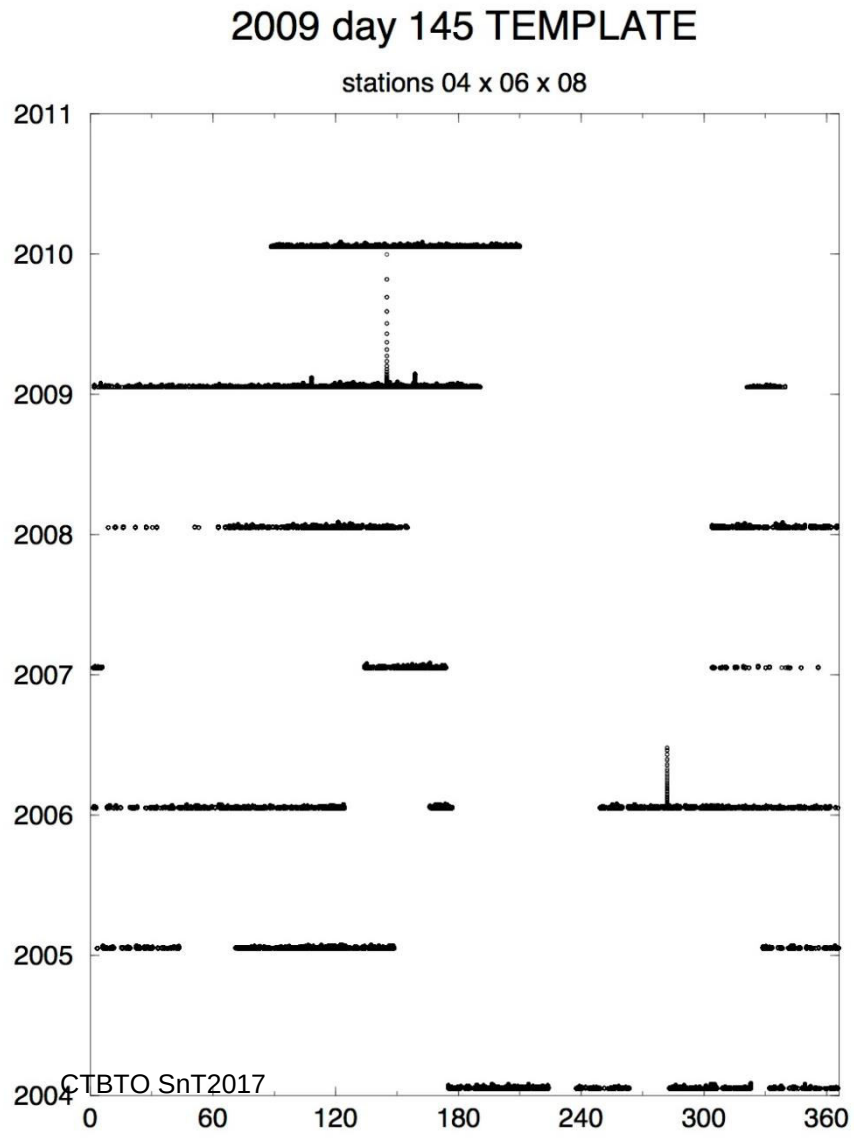
Using 3-station pairs of 2006 UNE as template envelope detector, we found 3-4 events with cc ~0.15 (each cc ~0.55)

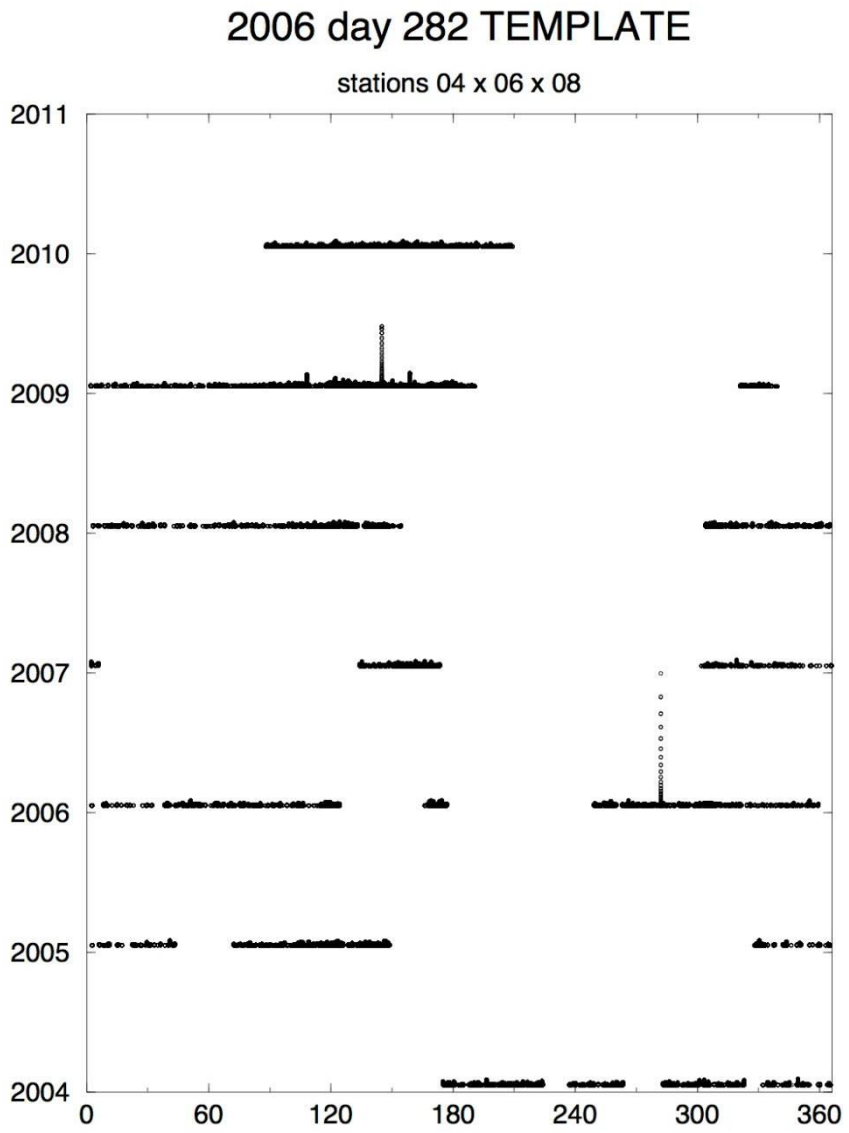


For the 6 months in 2009, 3 deep focus earthquakes (h=560-580 km).

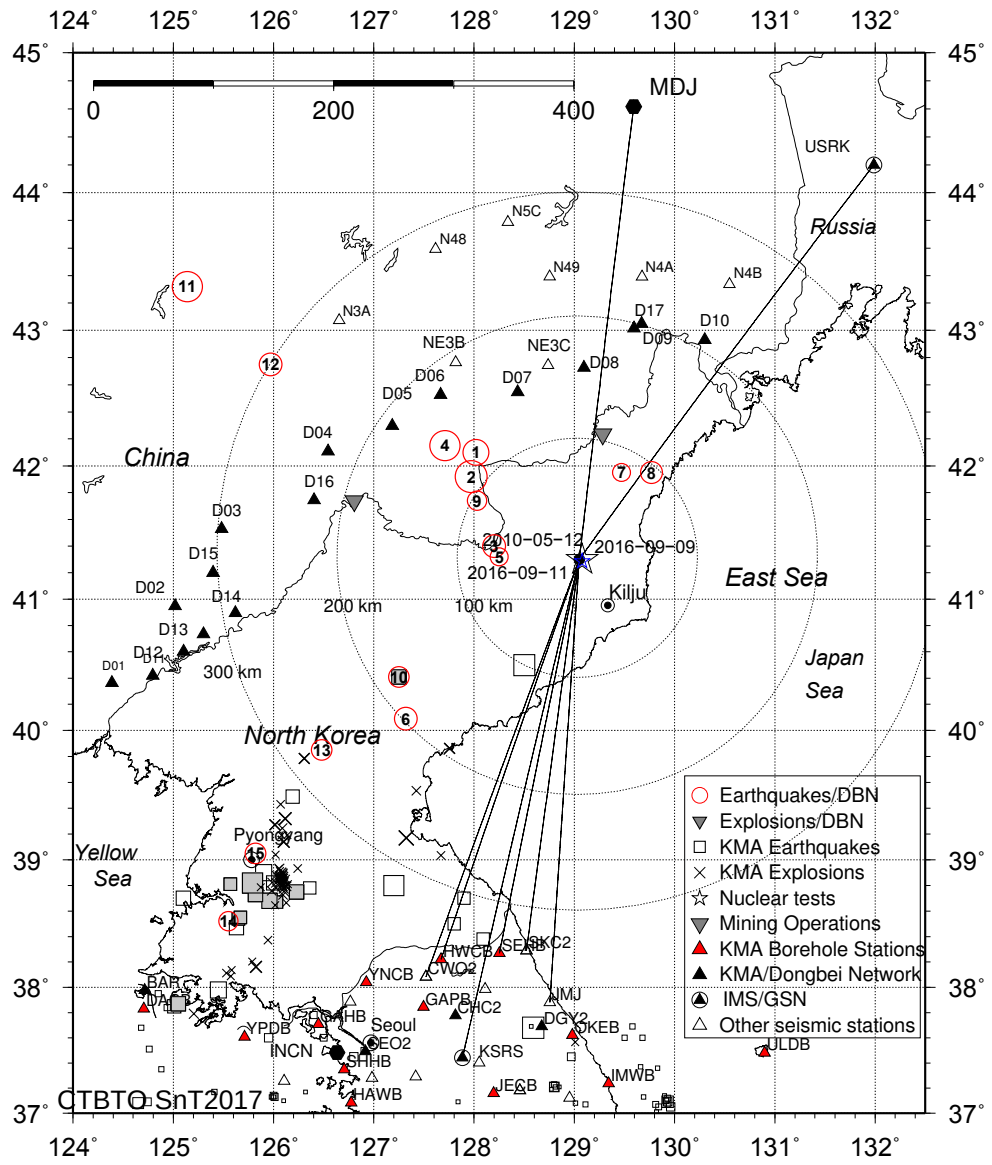


For 7 year of Dongbei Network data (2004-2010) – vertical records from 3 stations produced no new local events, so far. Few deep focus earthquakes (h=580 km) & 2 UNEs. More template envelope events?





Identifying Small Seismic Events around NKTS



Identify small seismic events:
- Earthquakes,
- Industrial explosions,
- UNEs etc.

Using observed seismic records

-Signal type: P, S or Surface waves

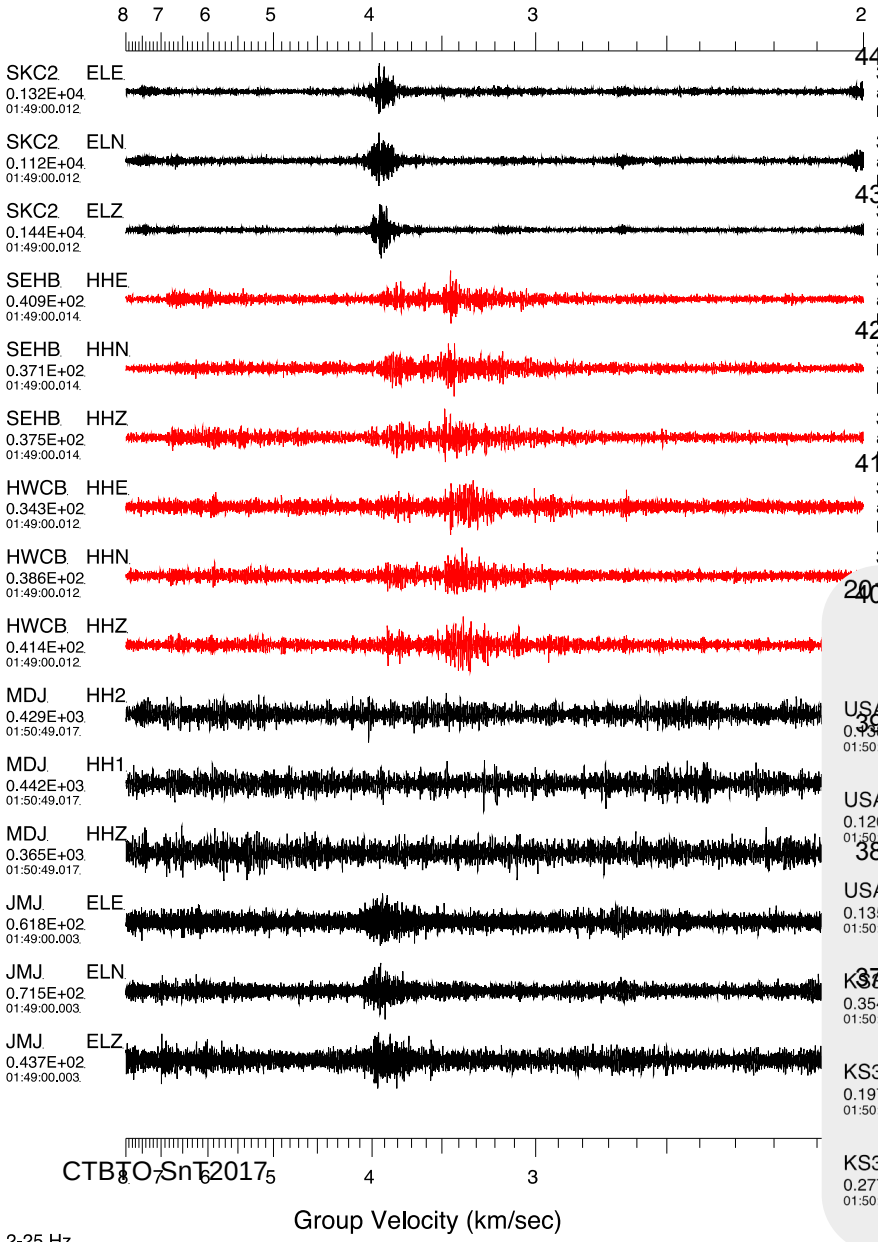
-Components: Vertical-, horizontal- or 3-component

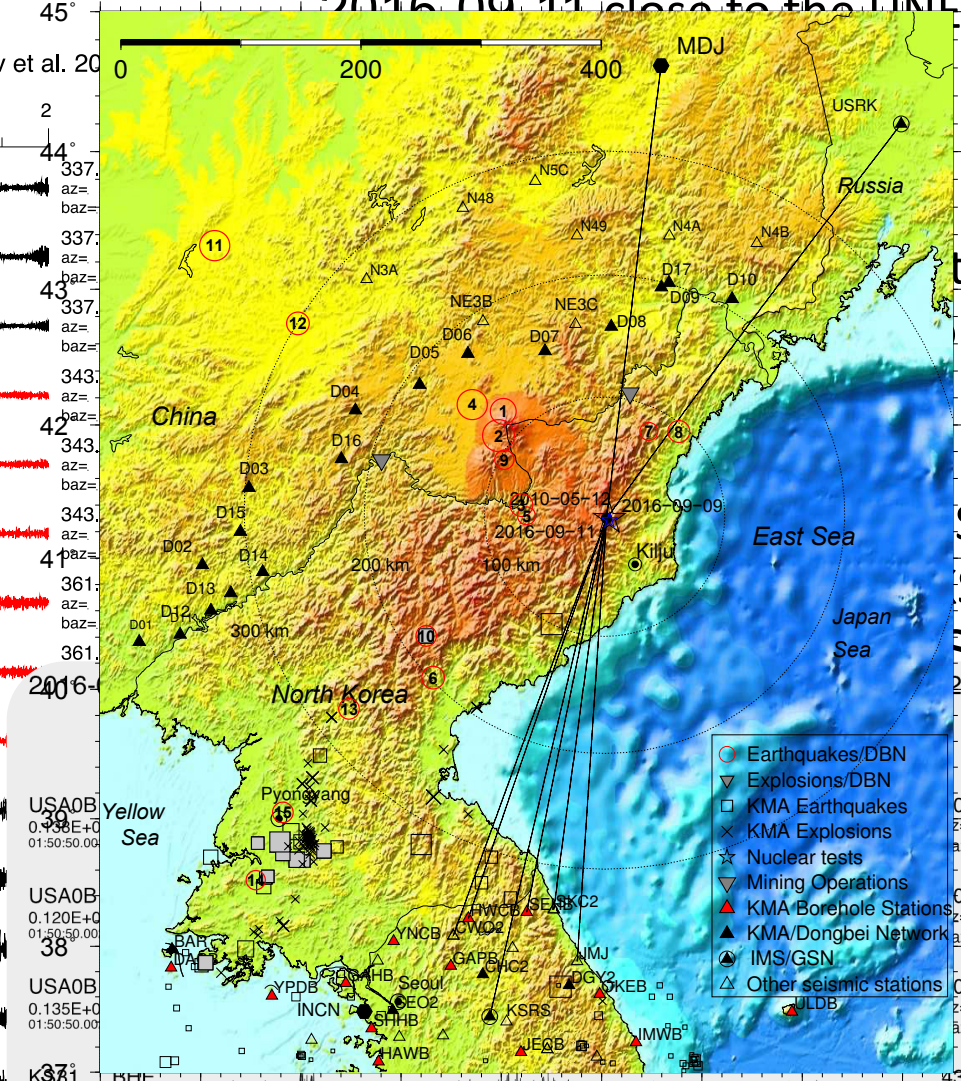
-Frequency/period: High – or Low-frequency bands.

Records at KMA stations from 2016-09-11

An event of M_L 1.8 occurred on 2016-09-11 close to the UNE on the ... 9

2016-09-11, 01:50:49.8, 41.299°N, 129.049°E, h= 0 km, ML=1.8, (Bobrov et al. 20...





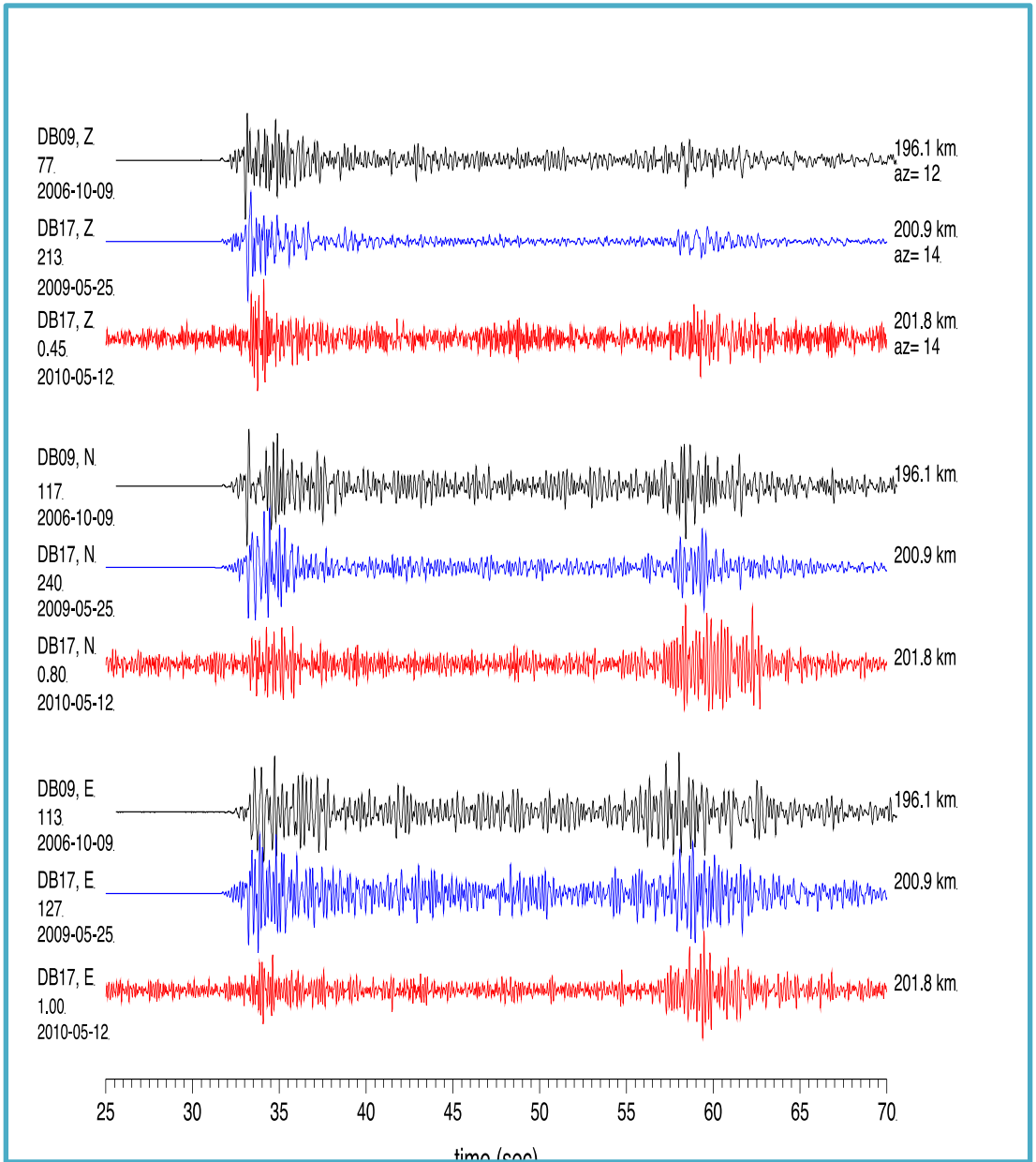
Records from 12 May 2010 event at Dongbei Network

3-component at DB17

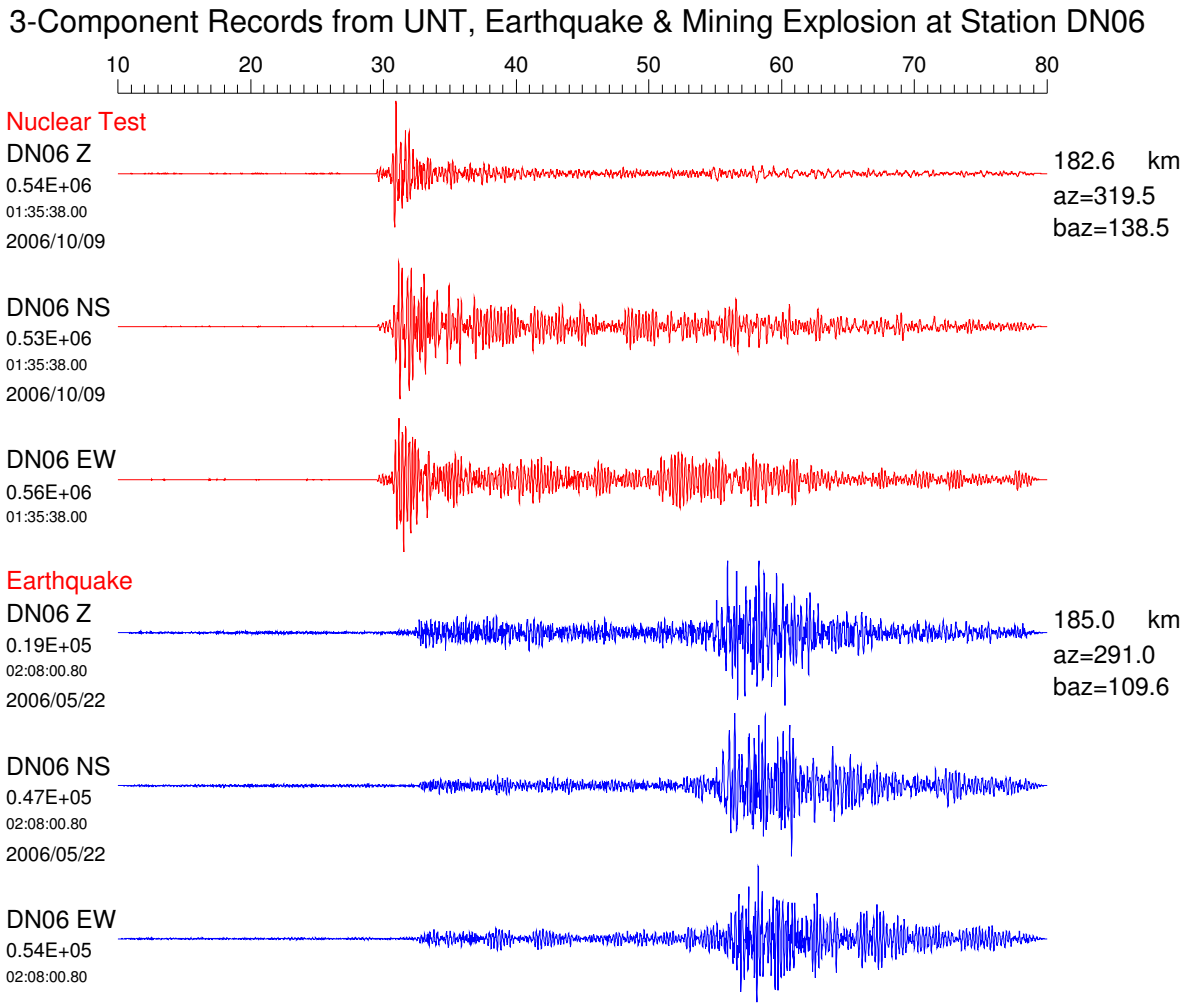
UNE 9 Oct 2006
UNE 25 May 2009
12 May 2010

On horizontal records, 12 May event show a weak P and strong S

UNE shows S waves on horizontals – scattered energy.



P / S Spectral Amplitude Ratios as Discriminant



P- and S-wave from

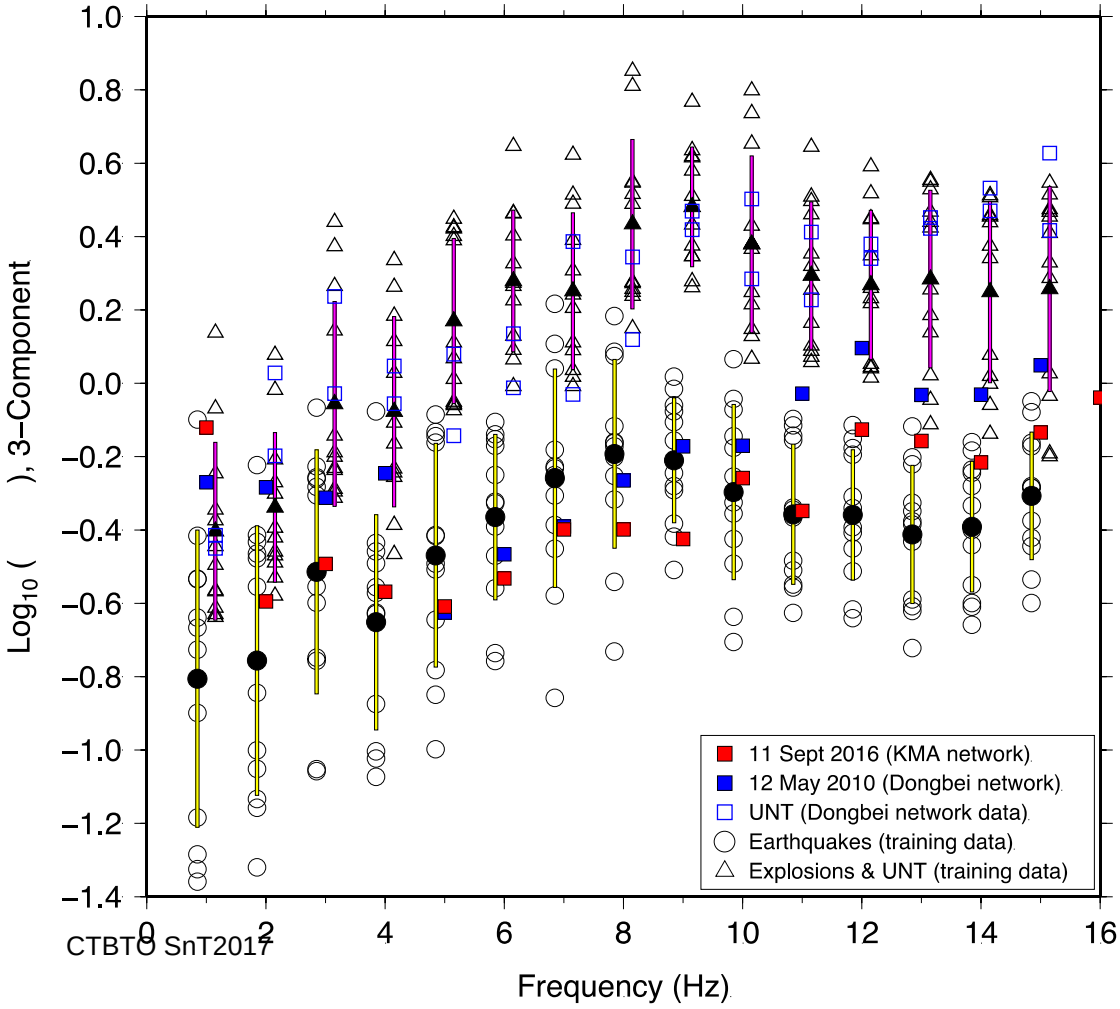
Explosions, strong P waves on all 3 components, but weak S

Earthquakes, Show strong S waves on all 3 component, but weak P

Frequency is a key parameter.

3-component spectral ratios

P/S amplitude ratios of 12 May 2010 event (blue squares)
11 Sept. 2016 event are plotted with (red squares)



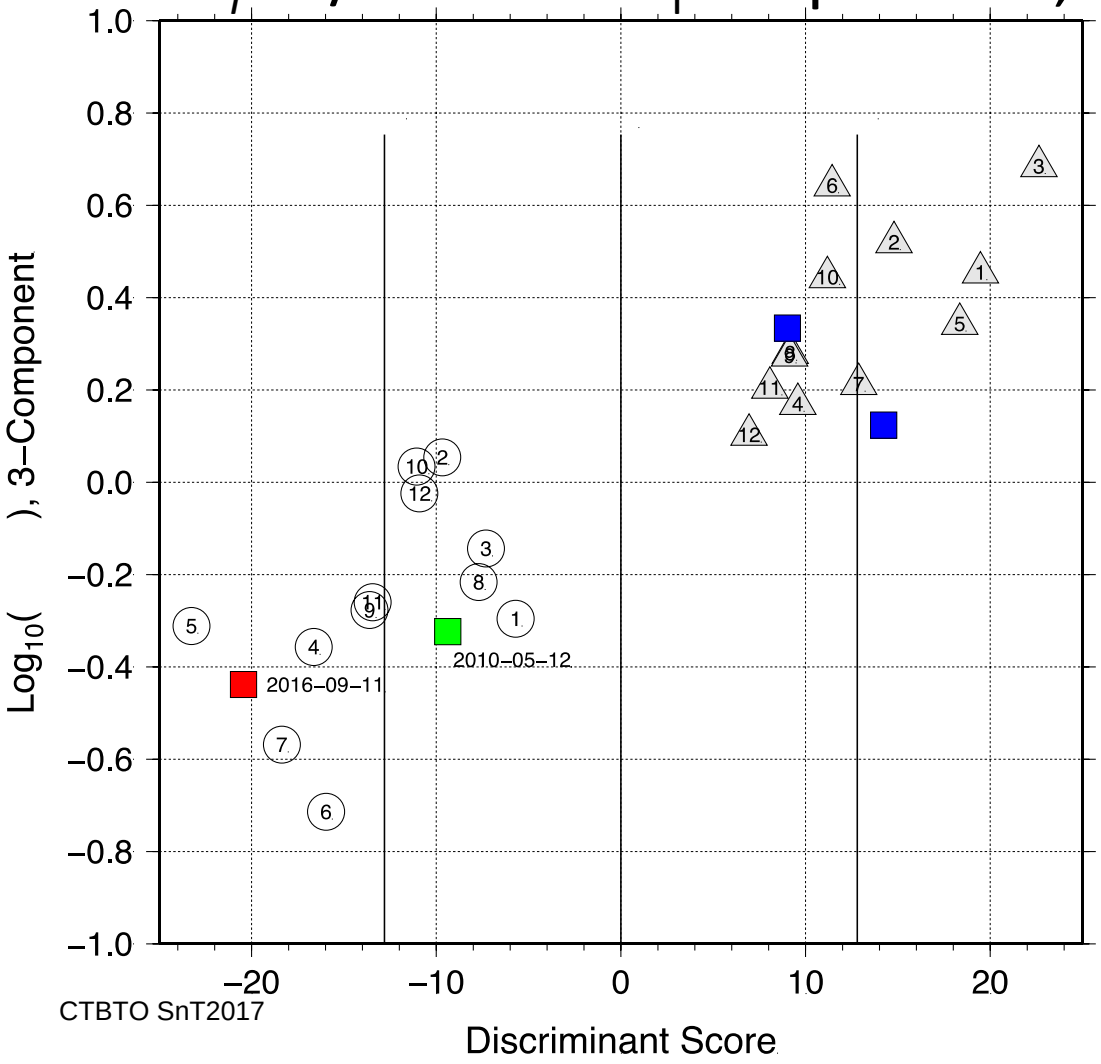
Most difficult part is to assemble "***training data***" or ***Sample Data***.

Explosions and Earthquakes with ground truth information to form Training Data.

Using P/S spectral amplitude ratios of sample data – we develop LDF (Linear Discriminant Function) –

$$D(r) = -4.33+14.43r_1-16.77r_2-12.04r_3+45.91r_4$$

where r_i =P/S ratio at r_i frequencies, 6, 7, 8 & 9 Hz.



Mahalanobis distance, $\Delta^2 = 25.6$, Separation of two population means, Eq (earthquakes) and Ex (explosions).

Using LDF, we can classify new unknown events in the region

Two unknown events - 2016-09-11 and 2010-05-12 are classified as “earthquake” with 0.57% total misclassification probability.

Thank you.