Evaluation of a seismic event, 12 May 2010, in North Korea

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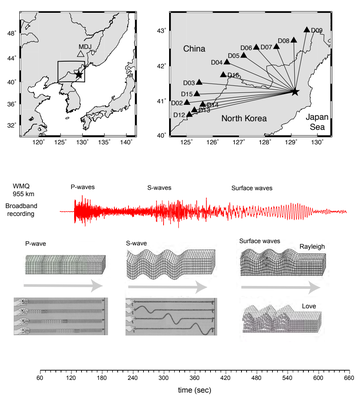
Background, and summary of our methods/results

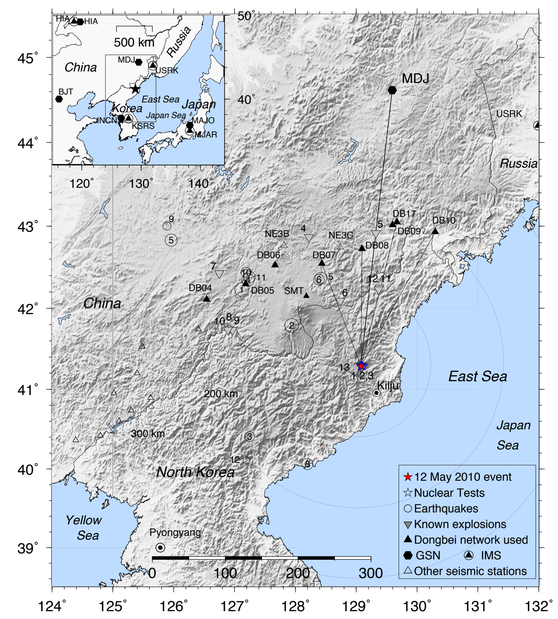


Depicts different seismic waves (for a Soviet UNE recorded in China)

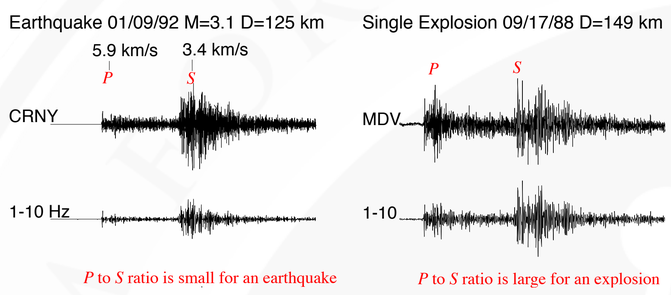
Claims of a small nuclear explosive test in North Korea, conducted in May 2010 and additional to those generally recognized, were first published by Lars-Erik De Geer in 2012, on the basis of radionuclide evidence. Several papers have supported his claim from this evidence.

Additionally, in 2015, Zhang and Wen found seismological evidence that on May 12, 2010, a very small seismic event (magnitude ~ 1.5) occurred at the North Korea nuclear test site. They too claimed, unambiguously, that it was from a nuclear explosion. In this project, we have found and analyzed seismograms for the May 2010 event. We used an open station, MDJ, in China, and the temporary Dongbei network, shown here in maps on the left (above depicted waves).

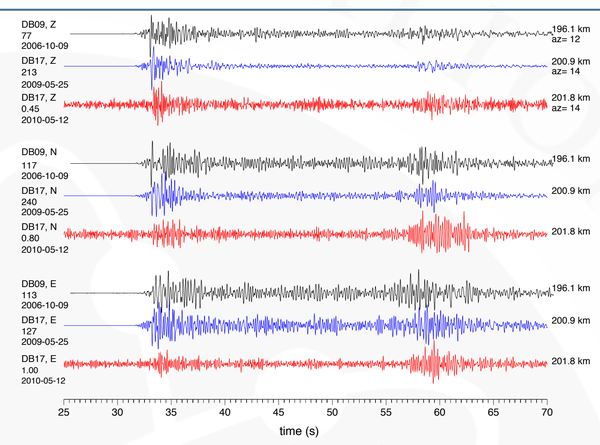
We developed training seismograms of twelve earthquakes and twelve explosions, located in the map on the right, as recorded by station MDJ. We then developed an objective procedure to discriminate between these two types of seismic signal, using Dongbei data. **We conclude that the seismic event of interest was a very small earthquake.** Our work indicates that the North Korean nuclear test site can be monitored for explosions down to a few tons of explosive yield.



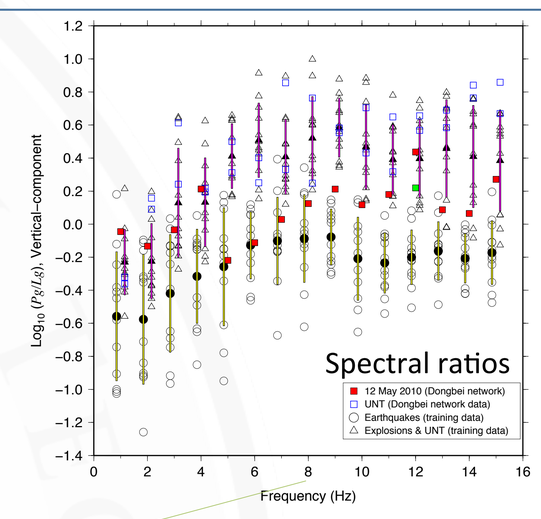
Earthquake and explosion seismograms—note the different *P/S* ratio for these two types of source; examples of our data in the present case, for known explosions of 2006 & 2009 and the problem event; and our first measurements of spectral ratios (made only on the vertical component).



Type examples of *P*-waves and *S*-waves from a small earthquake and a small explosion. *P/S* (eq) < *P/S* (ex)

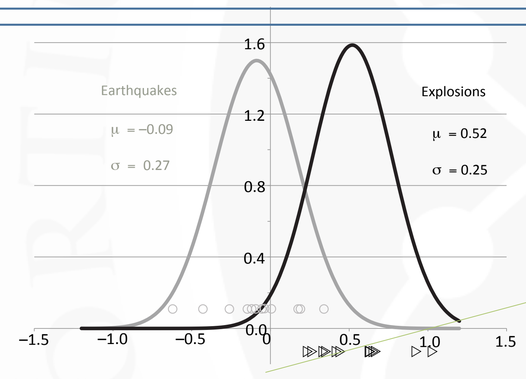


Three-component records (Z, N, E) at a Dongbei station for 2006 and 2009 explosions and for the problem event.



Development of the Mahalobis technique for this application.

Mahalanobis developed his methods principally in biology, e.g. to identify butterflies, but they have been applied more widely.



The log(*P/S*) values, **measured at 8 hz from vertical component waveforms** at station MDJ for two training sets, are shown as *circles* (earthquakes) and *triangles* (explosions), together with the normal (gaussian) probability density functions inferred from these two data sets. Note two length scales; the gaussian widths, and the distance between the means (explosions, earthquakes).

The amount of separation is quantified by the dimensionless ratio Δ given by the difference between the two means divided by the standard deviation of the gaussians.

With a measurement only at one frequency (8 hz), the mean values for earthquakes and explosions are separated by less than two standard deviations. There is considerable overlap.

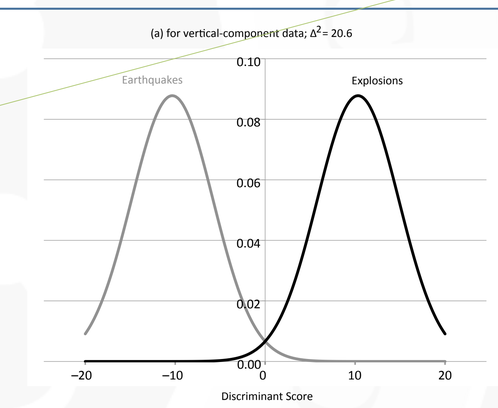
Classification theory was extensively developed in the 1930s by

Prasanta Chandra Mahalanobis

Using measurements of $\log_{10}(P/S)$ at multiple frequencies, we define a linear discriminant function of a vector **r** of $\log_{10}(P/S)$ measurements, namely

$$D(\mathbf{r}) = \boldsymbol{\lambda}^T [\mathbf{r} - (\boldsymbol{\mu}_{Eq} + \boldsymbol{\mu}_{Ex}) / 2] \quad \text{where}$$

$\boldsymbol{\mu}_{Eq}$ and $\boldsymbol{\mu}_{Ex}$ are mean values of **r** for the earthquake and explosion training sets, $\boldsymbol{\lambda} = \boldsymbol{S}^{-1} (\boldsymbol{\mu}_{Ex} - \boldsymbol{\mu}_{Eq})$ and $\boldsymbol{S}$ is the covariance matrix of the data.

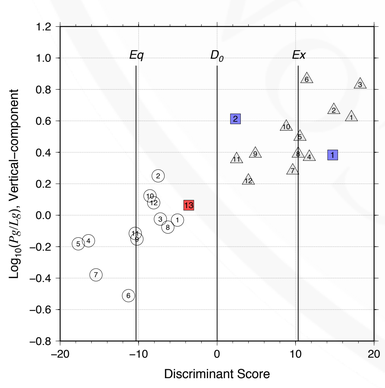


Probability distributions for the linear discrimination function which best-separates the earthquake and explosion populations, using MDJ data. Shown here, are the underlying gaussians for **vertical components** recorded for our two training sets (earthquakes, explosions).

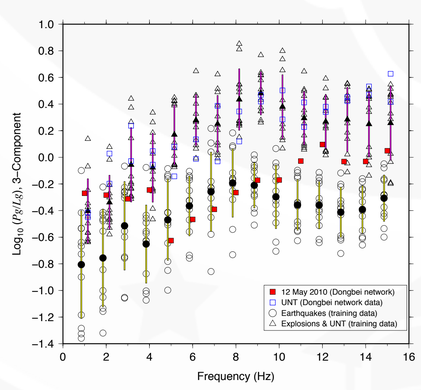
Earthquakes have a negative score, and explosions are positive. The chance of misclassification (the area under one Gaussian that is mainly under the other), is only 1.15% in this case.

Objective results

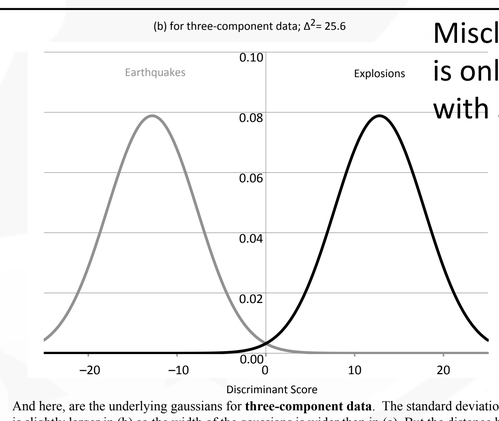
The first Figure shows the score for training sets (12 eq, triangles; 12 ex, circles) using vertical data at MDJ. Squares are from Dongbei data; nuclear explosions of 2006 2009, and the problem event of 2010.



The problem event, in red, is earthquake-like.

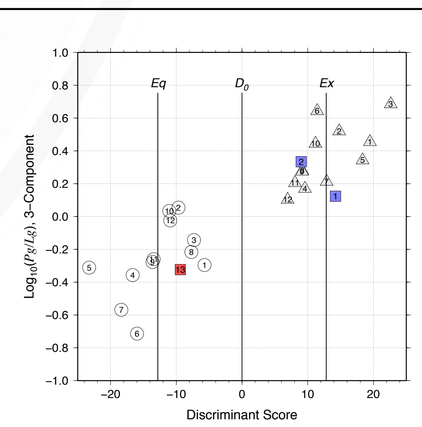


We can do even better with 3-component data.



And here, are the underlying gaussians for **three-component data**. The standard deviation, Δ, is slightly larger in (b) so the width of the gaussians is wider than in (a). But the distance between the means, which equals Δ^2, is greater in (b) than in (a), providing better classification capability.

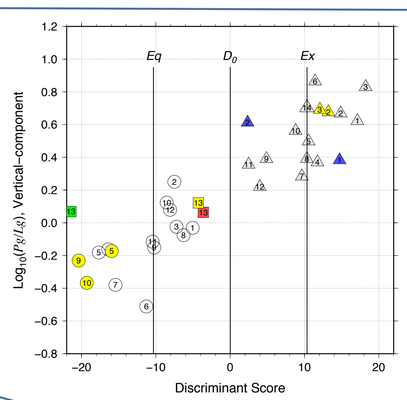
Misclassification is only 0.57% with 3-C data.



When we use 3-component data, there is better clustering of known events (see above right); and the problem event, in red, is even more clearly earthquake-like.

A final Figure, and concluding remarks.

An event suited to on-site inspection (CTBT, post EIF)?



Our final Figure is similar to the one immediately above it, but we have added several points. Those in yellow, are derived from the 2015 paper of Zhang and Wen, made at their best station (SMT, in a borehole at a distance of only 120 km from the North Korea test site–see the map, top right). These values are for three earthquakes, for two known nuclear explosions, and for the 12 May 2010 event, at the frequencies needed to evaluate the discriminant score we have used for vertical component data. The known earthquakes and explosions fall appropriately into their respective populations. The 12 May 2010 event falls among the earthquakes. Also shown is a green square for the problem event, derived from an additional station (NE3C) for the event of interest. It is an outlier among the earthquakes, but on the side away from being explosion-like.
At magnitude around 1.5, the 2010 event has signals about 300 times smaller than those of the (small) nuclear test of 2006.
A paper giving further details is now in press with the Bulletin of the Seismological Society of America (first issue for 2017). A preprint is available via https://dl.dropboxusercontent.com/u/32478215/BSSA-D-16-00111_accepted.pdf

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