Automatic computation of MSVMAX magnitudes at the French National Data Center

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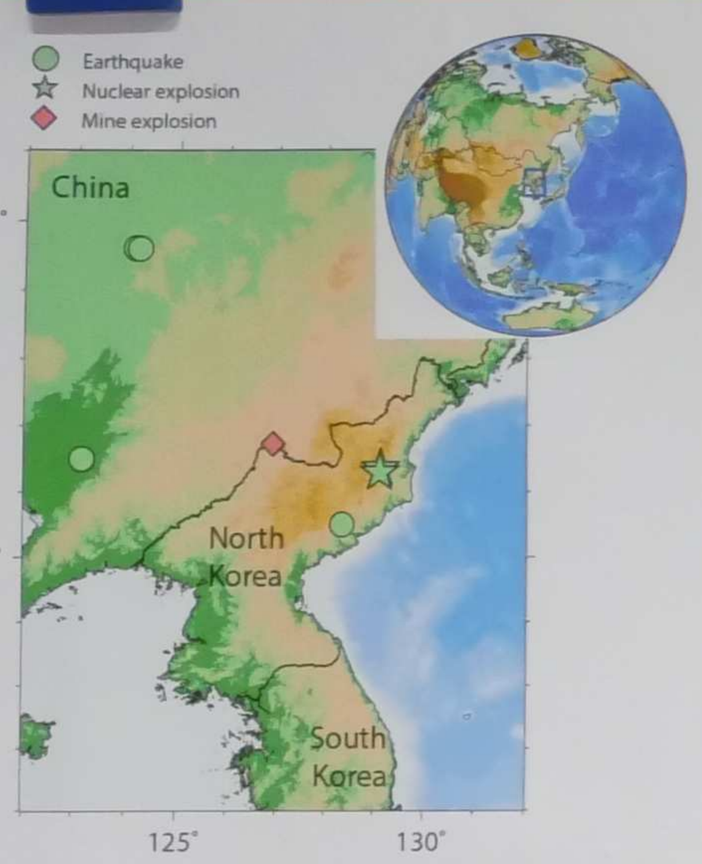
ABSTRACT

One robust and rapid discriminant between tectonic and treaty-relevant events is based on the discrepancy between seismic wave magnitudes: the surface wave magnitude (MS) and the body-wave magnitude (mb). A better alternative is to consider the MSVMAX, a frequency varying MS between 8 and 40 s period. Such approach opens up the limited frequency range and helps improve event detectability and characterization. Studies led the French National Data Center to develop and implement an operational tool to calculate the MSVMAX on Rayleigh and Love waves. Such tool is now running in an automatic mode and quickly returns magnitude information for events within a region of interest. This operational software is being used to process seismic data from different networks and sensor types, select time windows of interest based on the wave propagation according to an Earth velocity model, and apply several tests (azimuth and wave polarization) before providing a weighted MSVMAX value. It can also access a seismic database, which makes it a very valuable tool. We present this newly designed operational tool with illustrations on selected events of interest. Its high value for event discrimination is shown and the performance of available discrimination laws is discussed.

SELECTED DATASETS

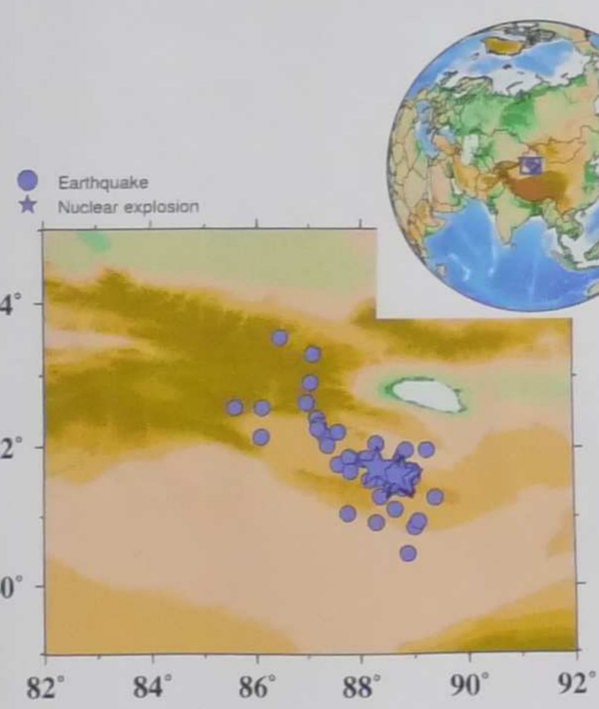


Three regions of interest

- Korean Peninsula (300 km around 41°N/129°E)
- Lop Nur (40°N<lat<43°N and 86°E<lon<90°E)
- Europe (SnT 2015)

Interest

Discrimination of seismic events of different nature (earthquakes, nuclear explosion, mine explosions, chemical explosions, etc)



Events

- Implementation of a database of referenced and well characterized seismic events (IDC screening database, ISC catalogue, FR-NDC database, bibliography)
- Events between 2002 and 2018, except for Lop Nur (since 1990) in order to be able to compare with past nuclear tests in the region.
- Magnitude >= 2.8
- Depth < 500 km
- Types of identified events: earthquake, nuclear explosion, chemical explosion, mine explosion
- A total of 61 events in the Korean Peninsula and 54 in the Lop Nur region

Data

- All available seismic waveforms (and their instrumental responses) in a 25° radius around the epicenters from the IRIS database
- IDC stations: 13 for Lop Nur, and 11 for the Korean Peninsula
- ~ 90 Go of data for the Korean Peninsula only
- Exponential number of data

Only the largest events can be screened out with the MSVMAX approach

MSVMAX DEFINITION

MS VMAX was proposed by Russel (2006) and Bonner et al. (2006) as a new approach to calculate the surface magnitude (MS) of a seismic event.

Objectives

- ✓ Extend the distance range of MS measurements
- ✓ Extend the definition of MS_{20s} by allowing a broader range of frequency bands at which the magnitude can be measured
- ✓ Calibrate a new MS definition relatively to MS 20s
- ✓ Application to both Rayleigh and Love waves

Initial definition by Russel (2006)

At 20 s period, this definition is equivalent to Von Seggern (1977) and Rezapour (1998)

Amplitude — Distance (°) — Period (s)

$$M_{s(b)} = \log(a_b) + \frac{1}{2}\log(\sin(\Delta)) + 0.0031\left(\frac{20}{T}\right)^{1.8}\Delta - 0.66\log\left(\frac{20}{T}\right) - \log(f_c) - 0.43,$$

$$f_c \le \frac{0.6}{T\sqrt{\Delta}}.$$

Developments at the French NDC

- ✓ 17 narrow bandpass filters between 8 and 40 s period
- ✓ Calculations made on both Rayleigh and Love waves
- ✓ Determination of the maximum amplitude to define the MSVMAX
- ✓ Use of specific tests (polarization, azimuth, signal-to-noise ratio, etc) for both Love and Rayleigh waves
- ✓ Use of short-period sensors, broadband sensors, network of sensors (beam)

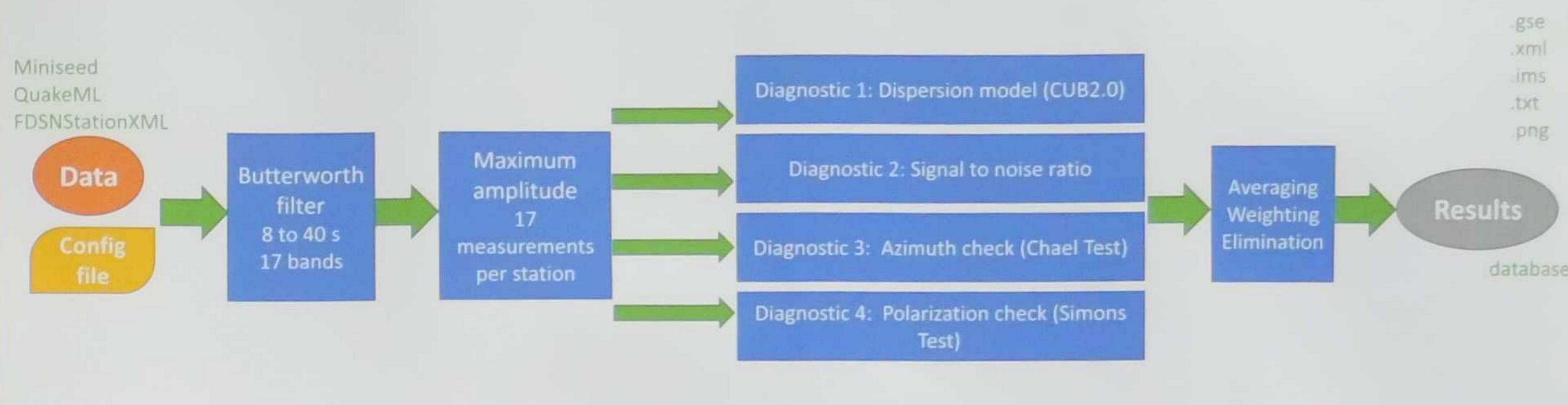
→ Increase the chance of having a useful MS magnitude at short/long distances and for a wider magnitude range

→ Increase the chance of event characterization in the screening procedure

AN OPERATIONAL TOOL

Industrialization of the code: DTK-BERYL

- Written in C++ / Qt (original code written in Fortran 77 and developped in 2013-2014)
- Automation of the calculation chain: mb, mb_{IDC}, MS_{20s}, MSVMAX (Rayleigh and Love)
- Standard I/O (FDSNStationXML, miniseed, QuakeML)
- Flat files or connected to IDC database
- Based on DTK-GEOLIB API*



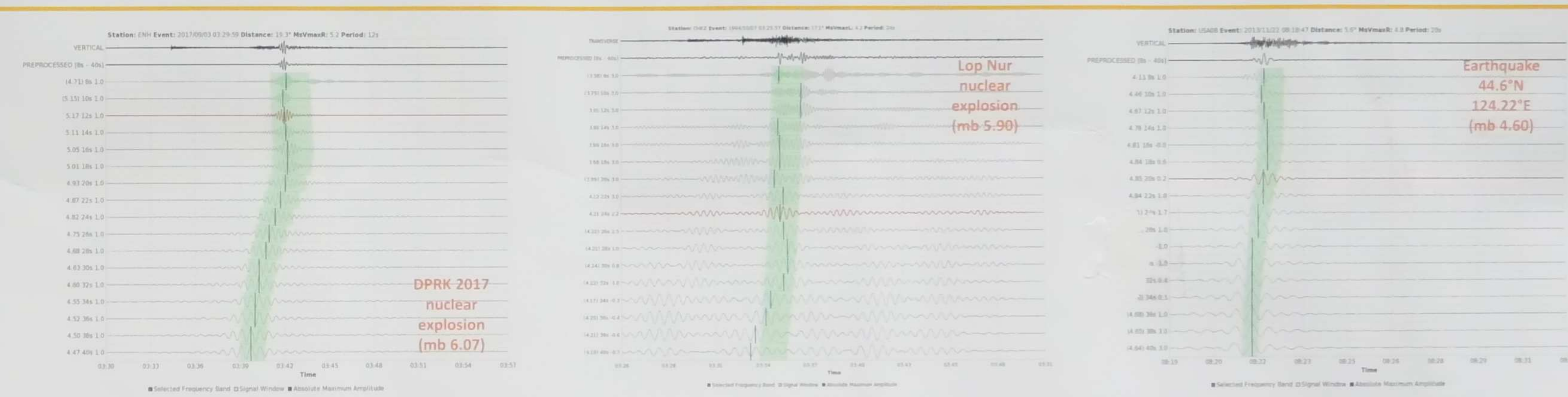
Calculation chain for MSVMAX

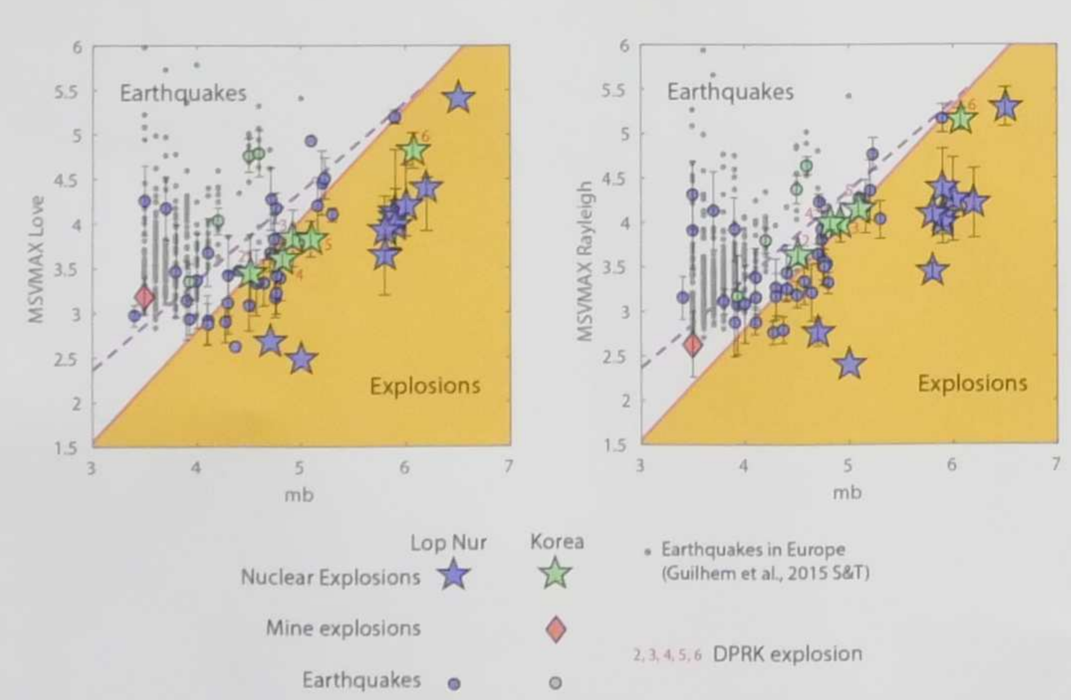
RESULTS AND DISCRIMINATION LAWS

Examples of graphical outputs for three events: DPRK 2017 nuclear explosion (left), Lop Nor nuclear explosion in 1994 (middle), and 2013 earthquake in 2013 China (right)

The figures show the unfiltered seismograms and the filtered seismograms in the 17 passbands. The green areas indicate the time period for surface wave picking according to the CUB2.0 model (Shapiro and Ritzwoller, 2002). The blue bars show the time of the maximum wave amplitude for each passband.

The red seismograms show the passband providing the maximum amplitude, and by consequence, the maximum MS value.

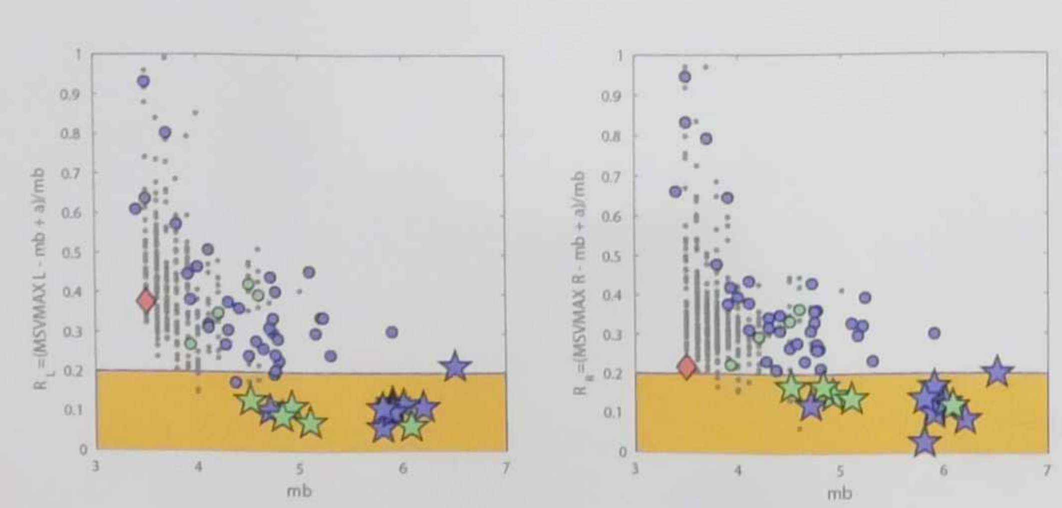




Comparison of MSVMAX Love (left) and Rayleigh (right) waves with mb for the three datasets (Korean Peninsula, Lop Nur, and Europe)

Error bars for the MS values are given.

The orange line separating the Earthquake zone to the Explosion zone is the standard IDC screening line (MS=1.25mb-2.2), while the purple dashed line shows the screening line defined by Selby et al. (2012, MS=mb-0.64).



Comparison of MSVMAX Love (left) and Rayleigh (right) waves with mb for the three datasets (Korean Peninsula, Lop Nur, and Europe) using Svancara's approach (Svancara, 2013)

The discrimination is made on a R parameter defined as :

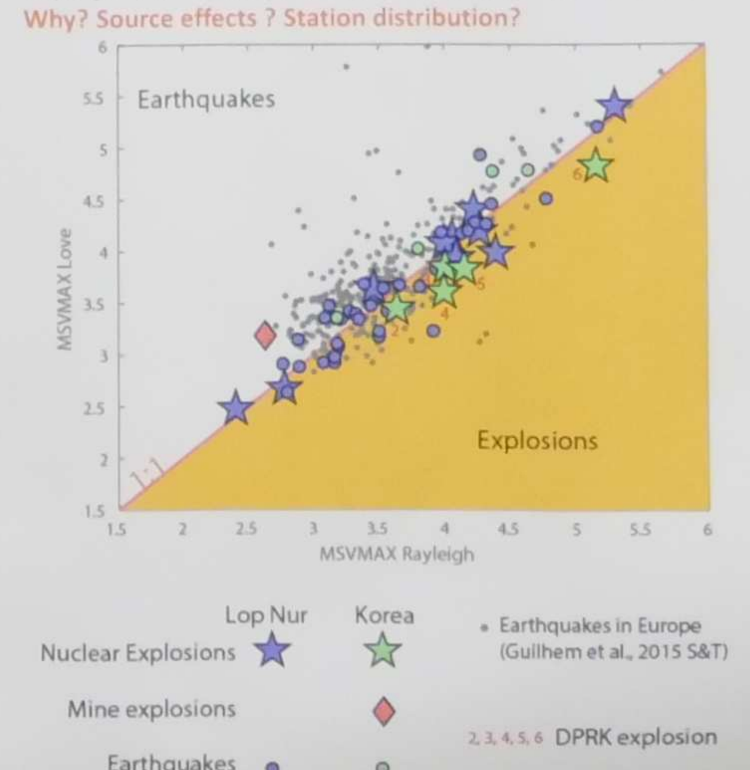
R = (MS – mb + a)/mb

where *a* is 1.63 for the Korean Peninsula events.

Here, we use the same *a* value for European events but we adjusted it to 2.5 for Lop Nur region in order to obtain a single R discriminant.

Comparison of MSVMAX Love and Rayleigh waves for the three datasets (Korean Peninsula, Lop Nur, and Europe)

The DPRK explosions show a discrepancy in the Love wave amplitudes compared to the Rayleigh wave amplitudes. This pattern is opposed to the one observed for earthquakes in the region. Such result is common to the analysis of the seismic activity in Europe where 80% of the events (dominantly earthquakes) have larger MS Love than MS Rayleigh. However, the contrast Love wave versus Rayleigh wave is not confirmed for Lop Nur events. In this region, the MS Love and MS Rayleigh are similar for both explosions and earthquakes. Why? Source effects ? Station distribution?



- Event screening is rapidly done by comparing the MSVMAX values (Rayleigh and Love waves) and the mb magnitudes.
- Several empirical relationships are available to help discriminate explosions from earthquakes.
- Some are better than others, depending on the wave type.

→ Considering both Rayleigh and Love waves together can also help for event screening.

→ The French NDC is currently working on combining these two types for event discrimination [(1+a) MSL – a MSR]

DISCUSSION

MSVMAX is an operational tool used at the French NDC
DTK-BERYL

Recent developments have been made in order to use flat files or database as inputs and a series of formats as outputs

The mb:MSVMAX discriminant works well for events in Europe and Lop Nur, but also for the Korean Peninsula, under some conditions:

- IDC screening line: MS=1.25mb-2.2 helps to separate earthquake population to explosion population for the three studied regions
- Svancara (2012) also helps to screen out events
- Selby's relationship provides a large false alarm rate (too conservative) – Difficult for an operational use

It appears that MSVMAX measured on Love waves provides a better discriminant factor than Rayleigh waves.

- True for DPRK nuclear tests
- How can we explain the lack of Rayleigh wave energy compared to Love wave's for Lop Nur earthquakes?

References

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PUTTING AN END TO NUCLEAR EXPLOSIONS