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Using spectral ratios to discriminate between low-magnitude earthquakes, explosions and mining events in Canada

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Abstract

Many regions in Canada contain a mixture of natural seismicity of variable depth, low-magnitude explosions (arising from construction and/or mining activity) and mining-induced events. Their correct classification is critical for seismic monitoring and for ensuring that anthropogenic events do not inflate seismic hazard estimates. Recently, local- to regional-spectral ratio discriminants across multiple phases and frequency bands have successfully been used in Canada to improve the accuracy and efficiency of event screening, particularly at low magnitudes (M < 3) where other explosion discriminants often fail. This work will present results from two case studies where spectral ratio discriminants have been used with varying degrees of success. In a test study in the New Brunswick, Canada, both high-frequency Pg/Lg and low-frequency Lg/Rg spectral ratios consistently discriminated between small (M < 2) blasts and earthquakes. In the mining-rich district of Sudbury, Canada, successful discrimination was possible for roughly 80 % of a test sample of M2 to M3 blasts and rockbursts. However, no single spectral ratio consistently provided adequate discrimination, and optimal spectral ratios needed to be calculated/tuned for particular stations.

Introduction

Current procedures for event discrimination at the Canadian National Data Centre are largely qualitative and accurate discrimination relies on the experience of the analyst.

Amplitude ratios have been extensively used and researched for the discrimination of chemical, mining and nuclear explorations from natural earthquakes, with the most widely used discriminant comparing P to S phase amplitudes. A P/S amplitude ratio exploits the fundamental difference between source mechanisms whereby an earthquake is expected to radiate the majority of its energy as S waves while explosions will radiate mostly P waves. However, the P/S discriminant has not been found to be universally valid in all regions and for all event types. Moreover, previous discrimination work has largely focused on M > 4 events recorded at regional to teleseismic distances and debate still exists as to how effective the discriminants are for smaller magnitudes and at local-to-regional distances.

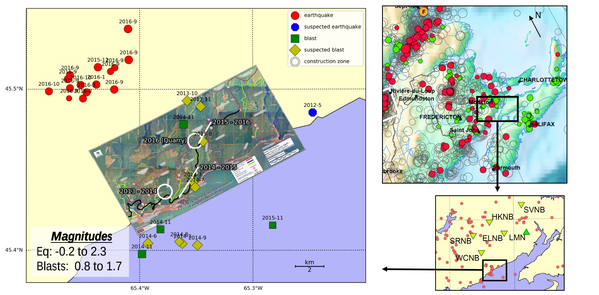
The work presented here, outlines a procedure for the selection of discriminants based on a multivariate analysis of different phase and frequency spectral ratios and investigates whether these ratios can discriminate between 1) low magnitude (M < 2) explosions and shallow (depth < 3 km) earthquakes and 2) mining explosions and rockbursts occurring in the Sudbury, Canada region.

Ex 1: Road Construction - 1

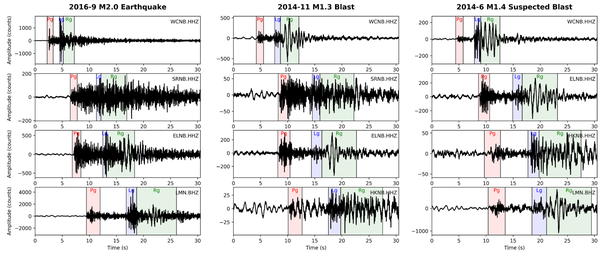
Between September 19 and October 5, 2016, a shallow low-magnitude earthquake swarm (M<2) occurred near the Big Salmon River (BSR) in southern New Brunswick, Canada. The region has a total of six seismic stations ranging in distances from 15 km to 85 km and the fifteen events were primarily between M1 to M2 and were located in a region roughly 5 km by 5 km where no previous earthquake activity had been registered.

South-west of the BSR swarm (approximately 5 km to 15 km) four confirmed blasts (M0.8 to M1.7) and 9 suspected blasts and 1 suspected earthquake (majority M0.7 to M1.4, one M2.3) occurred in the preceding 3 years.

Ex 1: Road Construction - 2



Map of the regional seismicity, station locations and the location of the BSR earthquakes, blasts and suspected events. Approximate areas of construction related to the eastward extension of the Fundy Parkway are also indicated.



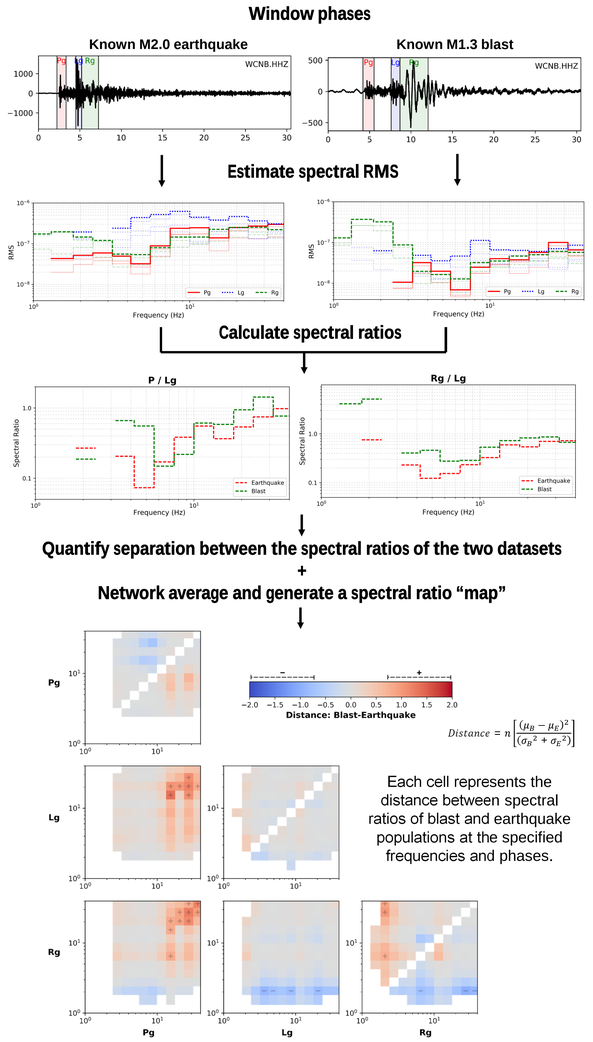
For station WCNB and at broadband frequencies (first row in figure above), the earthquakes have a larger Lg (Lg = Sg and Lg) than Pg and little Rg, while the blasts have an Lg and Pg of similar amplitude and their waveforms are mostly dominated by a large Rg. For the suspected blasts, the large Lg would lead one to believe it was an earthquake while the large Rg would suggest it was a surface blast. For this reason, a more comprehensive and quantitative analysis which considers all stations, phases and filters is required.

Methodology

The waveforms for each component are windowed (using picked phases and average phase velocities), the windowed data is tapered and fast Fourier transformed and the resulting amplitude spectra is lightly smoothed. An RMS amplitude is then calculated within eight logarithmically spaced narrowband windows per decade (13 windows from 1 to 40 Hz). The single-component RMS amplitudes are then vector-summed to provide a three-component station-phase amplitude. For each station and component, an equivalent process was performed on a corresponding noise window prior to the event signal, allowing for a signal-to-noise ratio (SNR) to be calculated (a minimum SNR of 1.5 was imposed).

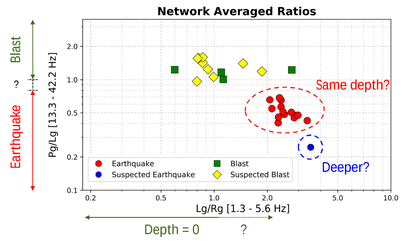
Spectral ratios are then calculated between each narrowband window and phase. With three phases and thirteen narrowband windows there is a total of 786 unique discriminants. In order to quantify the discriminating power of each ratio, the Mahalanobis distance between the two populations is calculated and displayed in a “spectral ratio map”. Spectral ratios which have large distances indicated on the map correspond to discriminants which are sensitive to the event type and could potentially be used to classify future suspected events.

Ex 1: Methodology & Results - 3



“Suspected blasts” group with known blasts and are likely to be blasts.

“Suspected earthquake” likely to be a earthquake (but separate source).

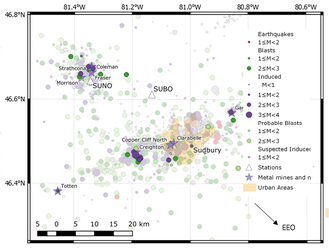


Ex 2: Blasts vs. Rockbursts

Mining explosions and rockbursts are recorded on a weekly basis within the mining region of Sudbury, Ontario Canada. Event types are typically determined by seeking event confirmation from the mining operators.

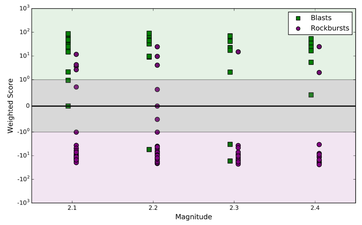
Right: events recorded in Sudbury in 2018 (opaque) and in previous years (semi-transparent).

Bottom: spectral ratio maps for confirmed M2 – 2.5 blasts (n=49) and rockbursts (n=85) for a local and regional station.



By combining the top 20 station-phase-frequency discriminants, roughly 80% of the test sample of events (n=134) could be correctly classified as either a blast or rockburst:

Right: Weighted score calculated by combining spectral ratio discriminants. Scores above 10 indicate blasts while scores below -10 indicate rockbursts. Scores in-between (grey band) represents events which fail to be classified. Over 80% of the test-events are correctly classified



Conclusion

Local to regional spectral ratio discriminants across multiple phases and frequency bands have successfully been used in Canada to improve the accuracy and efficiency of event screening, particularly at low magnitudes (M < 3) where other explosion discriminants often fail.

In a test study in New Brunswick it was found that broadband high-frequency Pg/Lg and low-frequency Lg/Rg was able to correctly discriminate small (M<2) shallow earthquakes and blasts related to road construction. In another example in Sudbury, Canada, spectral ratios were able to correctly classify 80% of the tested events, but the discriminants needed to be tuned for specific stations.

See also:

Kolaj, M., (2018) Discriminating between low-magnitude shallow earthquakes and road construction blasts near Big Salmon River, New Brunswick, Canada. *Seismological Research Letters*, 89(5), 1966-1976.

Questions/comments?
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