Automatic event detection and picking of P-wave arrivals

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ABSTRACT

We have presented a procedure for detecting a microseismic event and locating the arrival time of the first P-wave. This algorithm was investigated using synthetic data and data from Turtle Mountain, Alberta. The method worked very well in locating the synthetic event; detecting it at the exact time in which it was situated. However, when faced with a microseismic event recorded by 6 receivers on Turtle Mountain, the algorithm only detected half of the channels to within 5 ms of the manual pickings, while the other half were detected to within 20 ms.

INTRODUCTION

Accurate and dependable picking of the first P-wave arrival is of immense significance in event location and recognition. Manual reviewing of seismograms and phase picking is extremely time-consuming and subjective, as similarly qualified persons will pick onsets at different times.

There are a number of techniques currently employed for identification and picking of seismic waves using single- or three-component recordings. The most common approach used at present is an autoregressive technique used in conjunction with the Akaike information criteria method to detect P and S phases (Sleeman and Eck, 1999; Leonard and Kennett, 1999; Leonard, 2000). Here I present a simpler algorithm for detection of first P-wave arrivals involving computations of the L2 norm for a short- and long-term moving time window. Initially I consider automatic picks according to this algorithm using synthetic data and then using data from Turtle Mountain, Alberta.

DETECTION AND ONSET TIME METHOD

The detection of microseismic events is based on separating seismic events from ambient noise. Since a seismic event and background noise differ in character and frequency content it is possible to distinguish them on a seismogram. Microseismic events are characterized by impulsive onsets, high frequency, exponential envelope, and decreasing signal frequency with time, while background signals are distinguished by its low amplitude, low frequency, signature (Lee and Stewart, 1981).

We take advantage of these characteristics of microseismic events by using the notion of short-term and long term 'averages' of the incoming signal amplitude. If the amplitude of the incoming signal is denoted by $A(t)$, where t is time then the short-term 'average' at time τ, $\alpha(\tau)$, is defined as

$$\alpha(\tau) = \sqrt{\sum_{k=-n_1}^{0} \left(A(t_k)\right)^2}\ , \tag{1}$$

where n_1 is the length of the time window for the short-term 'average' divided by the sample rate of the data. Similarly, the long-term 'average' at time τ, β(τ), is defined as

$$\beta(\tau) = \sqrt{\sum_{k=-n_2}^{0} \left(A(t_k)\right)^2}\ , \tag{2}$$

where n_2 is the length of the time window for the long-term 'average' divided by the sample rate of the data. These calculations are actually the L2 norms evaluated over the specified windows.

The long-term average (LTA) characterizes the slow trend of signal energy, while the short-term average (STA) is more responsive to a sudden increase in energy (Oye and Roth, 2003). The ratio of STA/LTA is used as a measure of the signal-to-noise ratio (SNR). When the ratio STA/LTA exceeds a user-defined threshold a detection time is assigned to the specific geophone. In a seismic monitoring system once a number of geophones are triggered an event is considered detected and the system would proceed to compute the location of the event, the hypocenter.

The lengths of the STA and LTA time windows are dependent upon the distance between the receivers as well as the average distance to the seismically active region (Oye and Roth, 2003). The STA is usually longer than a few periods of the typically expected seismic signal, and the LTA is longer than a few periods of typically irregular seismic noise fluctuations.

For a relatively large signal-to-noise ratio, which is normally the case for microseismic data, our procedure used to detect microseismic events also evaluates the first P-wave arrival.

AUTOMATIC EVENT DETECTION AND PICKING USING SYNTHETIC DATA

To determine the effectiveness of my automatic event detection and picking method I contrast its values with known event times using synthetic data. Our synthetic microseismic event consists of an exponentially decaying sine wave

$$y(\tau) = \sin(80\pi\tau)\exp(-10\tau)\,, \tag{3}$$

where the dominant frequency is 40 Hz, and the sample rate is 5 ms. This signal is illustrated in Figure 1. A random noise signal with a specified signal-to-noise ratio of 10 is added to this waveform (see Figure 2a).

Consider the case where we have positioned this microseismic signal at 7.505 seconds. According to the procedure described above using a threshold trigger value of 0.8, a LTA of 0.8 seconds, and a STA of 0.3 seconds, we are able to detect the synthetic seismic event at 7.505 seconds with an STA/LTA value of 0.94231 (see Figure 2). From Figure 2c, we observe the background signal to have an STA/LTA ratio range between 0.7 ~0.5.

To investigate the effect of the STA time window length we ran the same procedure with STA values of (0.2 and 0.1) seconds, see Figures 3 and 4. As the STA window time was decreased from 0.3 to 0.2 and 0.1 seconds, keeping the LTA value constant at 3.0 seconds, we saw the STA/LTA ratio of the background signal decrease to between 0.55~0.45, and to 0.45~0.25, yet the time at which the event was triggered remained the same at 7.505 seconds, with the trigger values slightly decreasing to 0.922269, and 0.90704, respectively. Since our signals period is 25 ms, even an STA of 100 ms is still sufficient.

Overall, this procedure works very well with our synthetic data, however, adaptation to real data may pose difficulties.

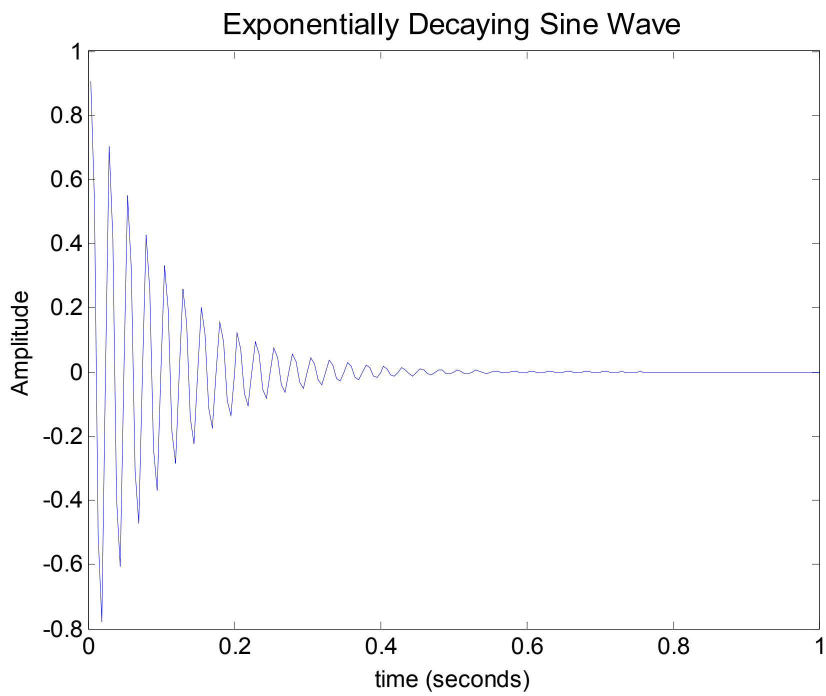

FIG. 1. Synthetic microseismic event signal prior to addition of background noise.

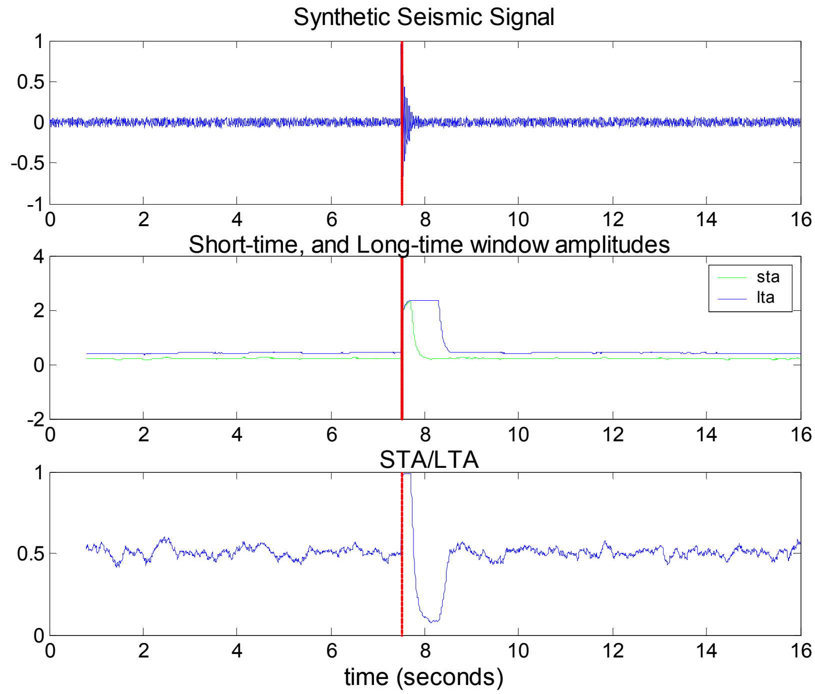

FIG. 2. (A) The synthetic microseismic event recording using STA of 0.3 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

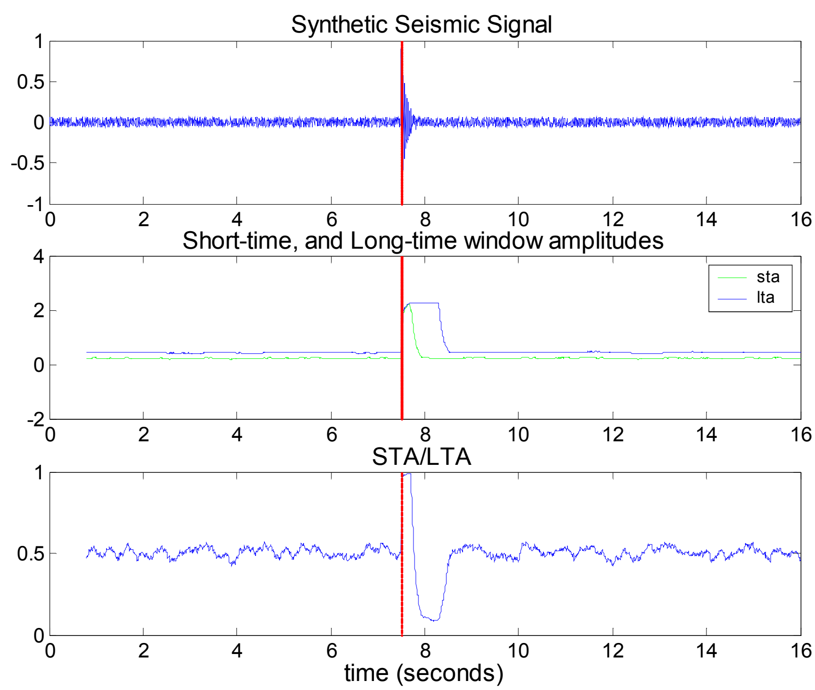

FIG. 3. (A) The synthetic microseismic event recording using STA of 0.2 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

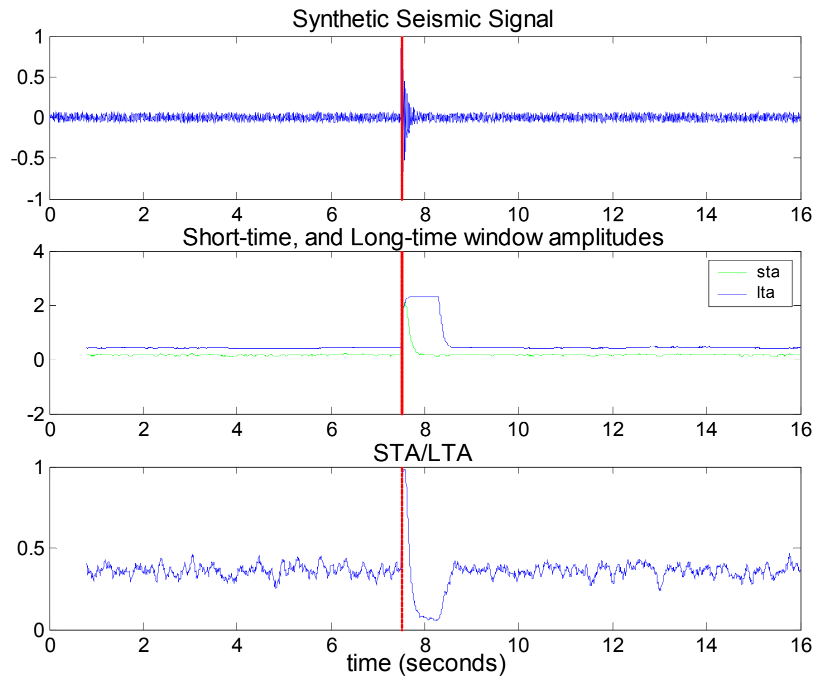

FIG. 4. (A) The synthetic microseismic event recording using STA of 0.1 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

AUTOMATIC EVENT DETECTION AND PICKING USING MICROSEISMIC DATA ACQUIRED AT TURTLE MT., ALBERTA

Seismic monitoring took place between 1983 and 1992 on Turtle Mountain, where 347 local events were identified (Bingham, 1996). Turtle Mountain is home to the Frank Slide, which took place on April 29th, 1903, destroying the town of Frank. Geologic instability of the mountain is blamed for the slide, and continues to cause concern in the region. Here I use one of the local events recorded to test our event detection and P-wave arrival algorithm.

The event I have used was recorded on the 103rd day of 1991, at 09:12:12.390, by 6 stations with single vertical-component geophones. The data was sampled at 5 ms. Using the procedure described previously with a trigger value of 0.945, and a LTA of 3.0 seconds, and a STA as indicated in Table 1 we are able to detect the microseismic event, and the P-wave arrival times on each channel.

Table 1. The manual and automatic picks for a microseismic event with various STA values.

Channel number	#1	#2	#3	#4	#5	#6	STA (sec)	Average difference
Manual picks (sec)	7.933	7.970	7.960	8.240	8.210	8.247	N/A	
Automatic picks (sec)	7.935	7.950	7.955	8.265	8.215	8.26	0.5	0.012
Automatic picks (sec)	7.935	7.950	7.955	8.255	8.215	8.255	0.6	0.009
Automatic picks (sec)	7.935	7.945	7.955	8.255	8.215	8.255	0.7	0.010

From Table 1 we see that the best value of STA is 0.6 seconds, as it has the least deviation from the manual picks. Figures 5 through 10 display the results for all 6 channels using a STA of 0.6 seconds. Channels 1, 3 and 5 have been picked automatically to within 5 ms or less of the manual picks, while the other three channels are within 20 ms or less.

These results are satisfactory as only half of the channels have an uncertainty in the range of what is considered appropriate for manual picking (Oye and Roth, 2003). It is important to emphasize that the trigger level, LTA, and STA were adjusted manually during this process to acquire the best possible results. Knowledge of what these quantities should remain at for an automatic system would require extensive research on the characteristics of seismic events, as well as, background signals that would occur in the region, prior to the systems initiation.

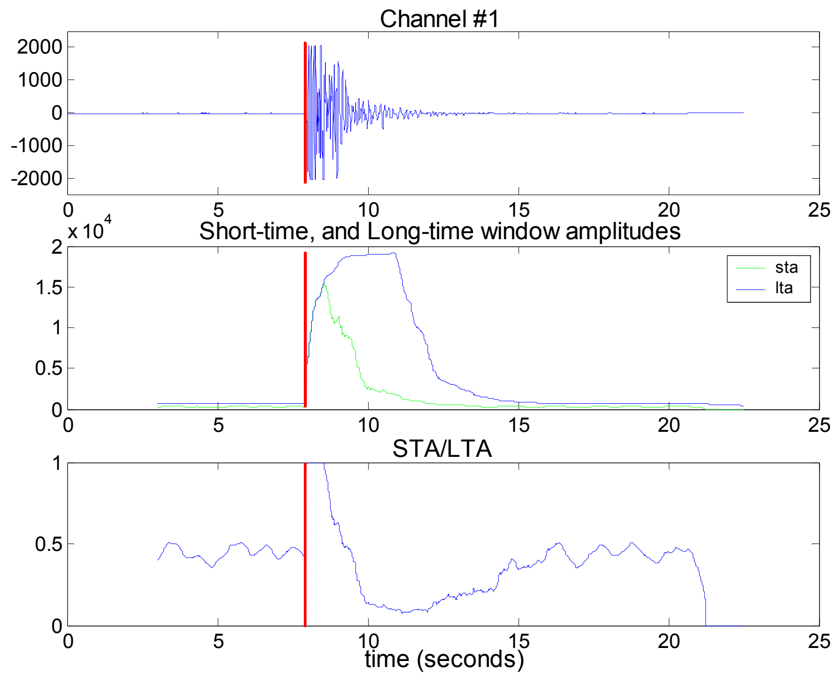

FIG. 5. (A) The microseismic event recording on Channel #1 using STA of 0.6 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

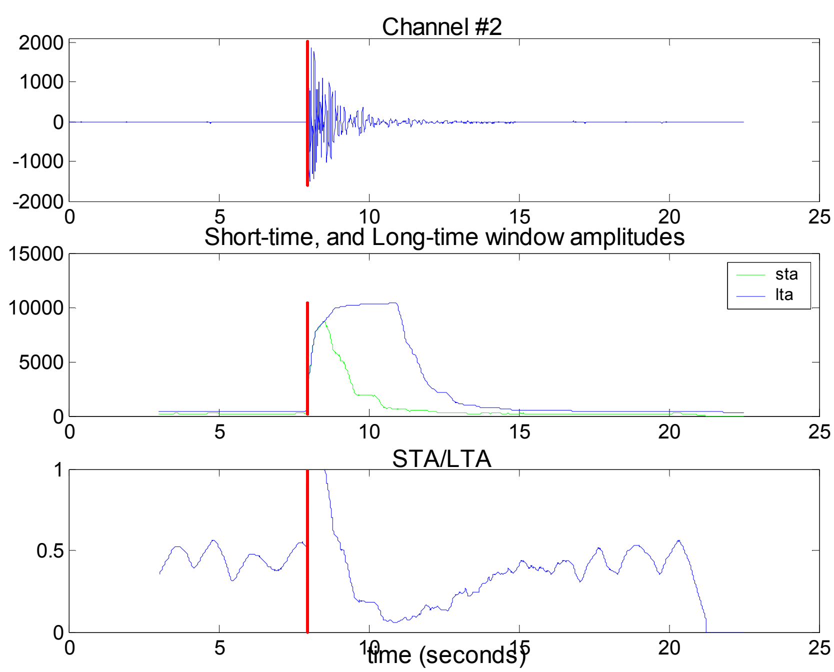

FIG. 6. (A) The microseismic event recording on Channel #2 using STA of 0.6 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

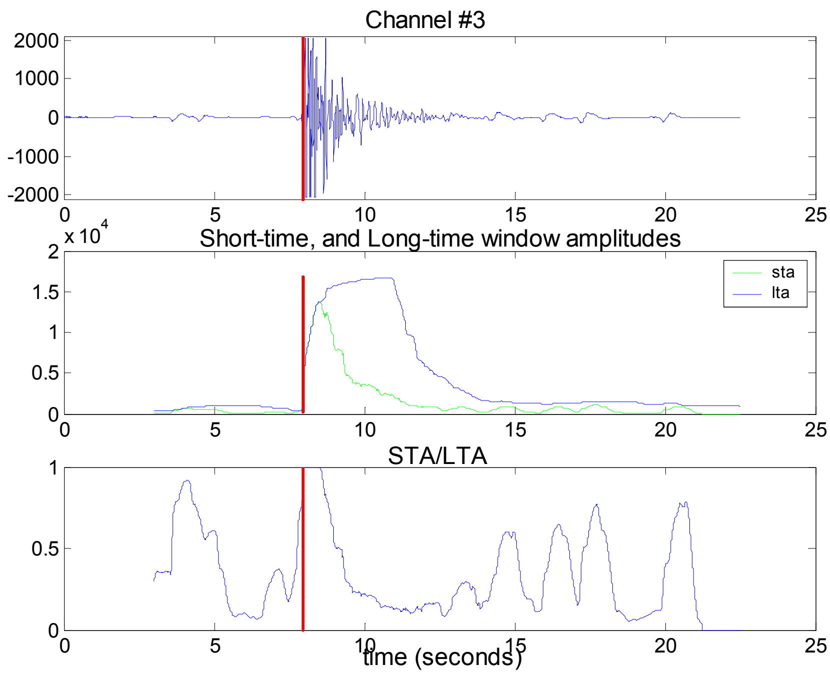

FIG. 7. (A) The microseismic event recording on Channel #3 using STA of 0.6 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

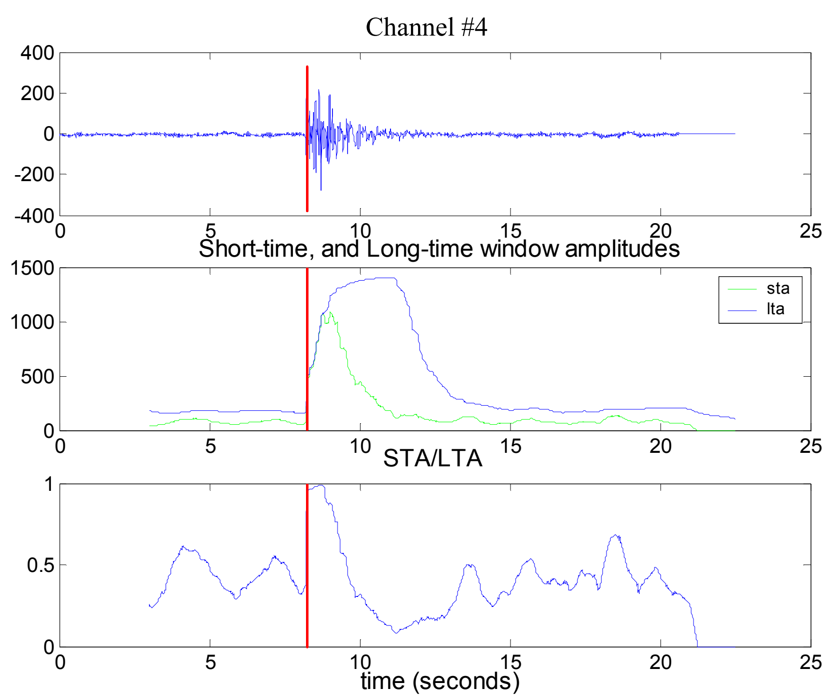

FIG. 8. (A) The microseismic event recording on Channel #4 using STA of 0.6 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

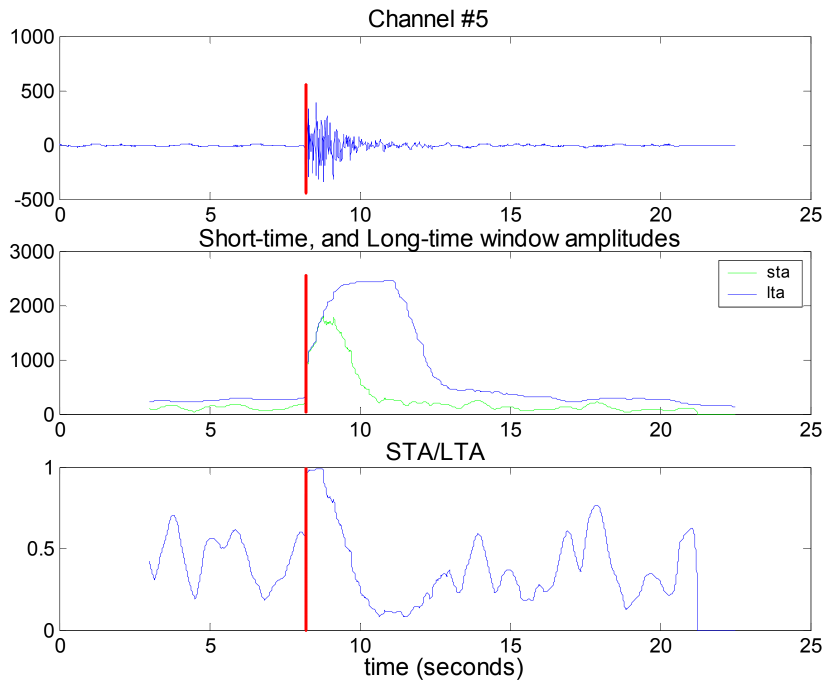

FIG. 9. (A) The microseismic event recording on Channel #5 using STA of 0.6 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

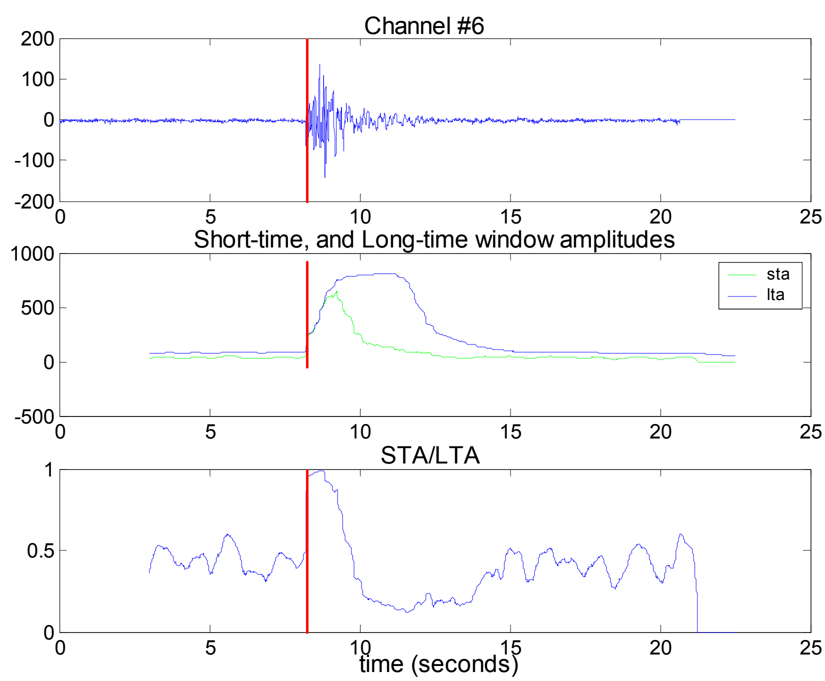

FIG. 10. (A) The microseismic event recording on Channel #6 using STA of 0.6 seconds; (B) The STA and LTA values computed; (C) The STA/LTA ratio computed. The red line indicates the time at which the event was triggered, and thus, the first P-wave arrival time.

CONCLUSIONS

Although this procedure was quite impressive at detecting the synthetic seismic event and the first P-wave arrival, it did not stand up to the test of real data. It may put too much emphasize on the background signal as a result of the L2 norm computation. Additional research may provide a means to alter this procedure to make it withstand the rigorous application of real data, as an alternative to the autoregressive technique.

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