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Automatic Event Identification From Tectonic Earthquakes with Modified Akaike Information Criterion (mAIC)

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Abstract. It is difficult to identify P- and S-waves arrival time from the recorded seismograms with low Signal – to – Noise Ratio (SNR) because the onset is not always clearly observed. However, the arrival time of P and S-waves are important for the advanced analysis, such as for seismic event localization and seismic velocity tomography. In this paper, we employ Akaike Information Criterion (AIC) with the new characteristic function (CF) so-called mAIC, that is proposed by Hendriana et al. (2018) to detect P- and S - waves onset accurately and automatically from the denoised seismic signal of tectonic earthquake events in Sunda Strait. The mAIC was proposed to overcome the window-dependence of AIC function from continuous seismogram by computing AIC in a translatable window. The results show that mAIC successfully determine the first onsite of P- and S-wave for the denoised seismogram data.

Keywords: SNR, event localization, mAIC, AIC.

1. Introduction

The earthquake data is widely used in many field and scale of seismology, not only on the tectonic and geodynamical study but also in exploration (i.e geothermal reservoir characterization). The most primary work in seismology is identification P- and S- wave arrival time of such events recorded by the station. Unfortunately, the seismogram recorded by the station usually affected by the presence of noise and make the P- and S-phase cannot be clearly identified. However, in the current, researchers have developed several methods to automatically identify first arrival of earthquake events, such as the sort-and long-time average ([1], [2]), modified energy ratio (MER) ([3],[4]), Akaike Information Criterion (AIC) ([5],[6]), short- and long-term kurtosis (S/L Kurt's) ([7]) and modified Akaike Information Criterion ([8]). P- and S-wave arrival picking accuracy affects the seismic event location determination, and the event location accuracy affects all of the subsequent seismological processing. Thus, P- and S-wave arrival picking has an important role in the sequences of seismological data processing ([9]).



Finding accurately and automatically P- and S-wave first arrival onsite becomes one of the main research, especially in analyzing the seismogram in the term of the arrival time of P- and S-wave, such as for locating hypocenter. The criterions to determine P- and S-wave first arrival onsite proposed above still have a dependency on the time windows determined of continuous seismograms. The criterion gives the inaccuracy and different value with different time windows. On the other hand, the teleseismic, regional and local earthquake also have different characteristics and need the different treatment to accurately determine the P- and S-wave arrivals.

In addition, S-wave arrival is more difficult to be picked due to the interference of P-wave and the presence of twice-reflected wave ([10]). Many researchers proposed the method for S-wave picker which separates it from P-wave arrival (see [11],[12],[13]). Although the seismic events generally can be determined from P-wave arrival time, the S-wave arrival also has an important role in locating seismic events. The present of S-wave first arrival data can provide a powerful constraint in determining hypocenter, especially when azimuthal coverage is poor. Moreover, the error in the picking of S phase arrival time can affect the focal depth estimation.

Hendriyana (2018) proposed modified Akaike information criterion method (mAIC) to pick P- and S-wave arrivals which have several advantages to be used in continuous seismogram and overcome the window dependency problem by calculating AIC in a translatable-windows. The author shows that the method effectively identifies P- and S-waves onsite. In this paper, we employ the AIC and mAIC method ([8]) to pick P- and S-wave arrival automatically from tectonic earthquake data around the Sunda Strait and treat it as the references and comparison with the results of manually picking. The results show that the method is effectively and precisely identifies the first arrivals onsite.

2. Methods

2.1 Earthquake Dataset

The sample earthquake data was downloaded from BMKG website in miniSeed format which is located around Sunda Strait. There are more than 8 receivers around this area spreading from West part of Java to South part of Sumatra Island. The downloaded data has sample rate of 20 samples per second.

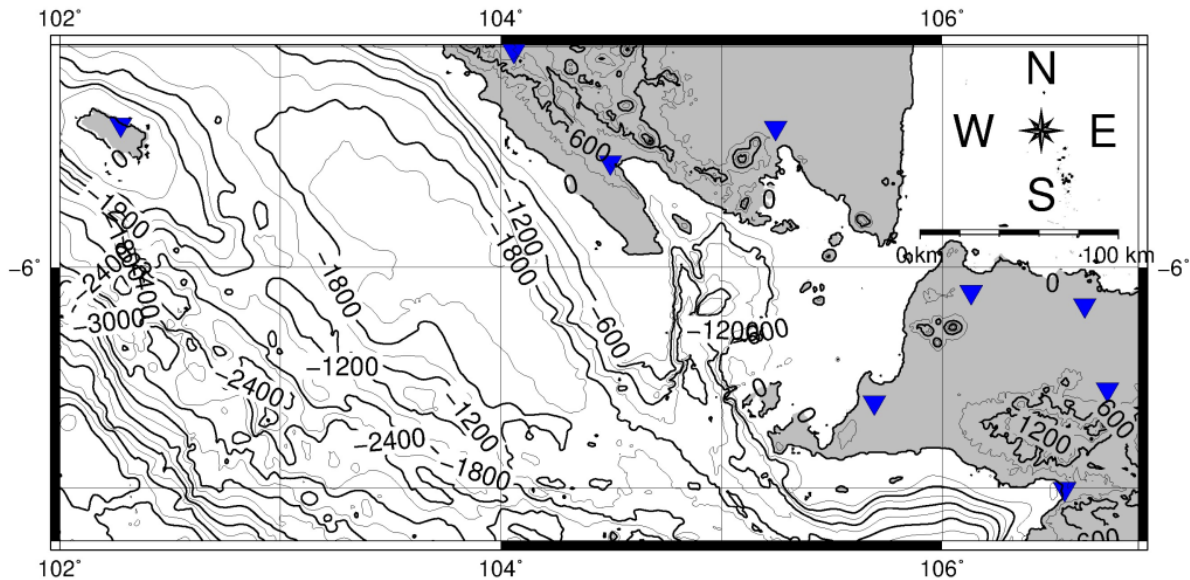


Figure 1 Contour map and receiver network around the study area (blue triangles represent the station receiver)

The preconditioning step of the seismogram data downloaded should be performed to increase SNR of recorded seismogram by removing as much as possible of the additive noise. However, the first should be determined is finding the best threshold level for an attenuation operator, AO .

$$W_d = AO(W_y) \quad (1)$$

The Eq. (1) shows that the AO is a function that maps wavelet coefficient of the noisy seismogram, W_y , onto coefficients of estimated signal interest, W_d . Donoho and Johnstone (1994) in [14] proposed an attenuation operator, called soft-thresholding function, as follow,

$$AO(W_y) = \text{sgn}(W_y)(|W_y| - \delta) \quad (2)$$

We employ the GCV (General-Cross-Validation Thresholding) (see [15]) to determine the optimum of thresholding level. In this method, the noise power was suppressed by threshold level, δ , which is applied to wavelet coefficients. GCV function is formulated as follow,

$$GCV(\delta) = \frac{1}{N} \frac{\|T_y - \tilde{T}_\delta\|^2}{\left(\frac{N_0}{N}\right)^2} \quad (3)$$

where $\tilde{T}_\delta$ are thresholded coefficients using threshold value δ and $\frac{N_0}{N}$ is the number fraction of coefficients. This method has been implemented to improve the SNR of seismogram data ([15]). To calculate the SNR of P-wave and S-wave, we employed the program code proposed by [16].

2.2 The AIC algorithm

The Akaike Information Criterion (AIC) is applied as tools to automatically detect the onsite of P-wave arrival from recorded seismogram data. Let $S = \{S_1, S_2, S_3, \dots, S_M\}$ represented the discrete seismogram data with M samples, the AIC of S is defined as ([17]),

$$AIC(i) = i \log[\text{var}(S[1, i])] + (M - i - 1) \log[\text{var}(S[i + 1, M])] \quad (4)$$

where $i = 1, \dots, M$ which mean AIC is computed from 1st the ample until N^{th} sample of a seismogram data S . $\log(a)$ means natural logarithm of a and $\text{var}(S)$ is the variance of signal amplitude.

2.3 The modified AIC algorithm

This method was proposed by [8] to avoid the chance of minimum value of AIC trapped in local minimum which leads to mislocating of onsite detection of first arrivals. This mislocating usually happened in the long seismogram. Modified AIC was proposed by alter the AIC characteristic function and designated as $mAIC$. The classical AIC characteristic function (Eq. 2) was modified as ([8]),

$$mAIC(j) = \max \left\{ AIC(i)_{j-T/2, j+T/2} \right\} - AIC(j)_{j-T/2, j+T/2} \quad (5)$$

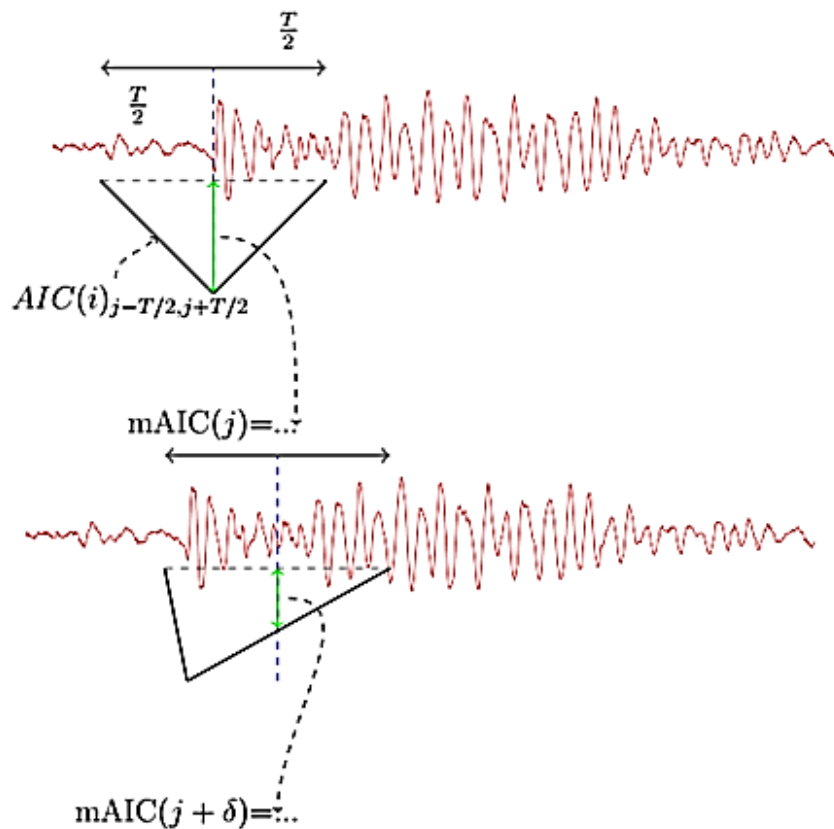


Figure 2 Computation scheme of $mAIC$ (image taken from [8])

Figure 2 shows the scheme of i^{th} AIC value, $AIC(i)_{j-T/2, j+T/2}$ computation at the point which is being evaluated at j^{th} index. The window started from $(j - T/2)^{\text{th}}$ to $(j + T/2)^{\text{th}}$. The $mAIC$ value at j^{th} index then is calculated by finding maximum value of AIC in the given window and then subtracted by AIC value at the position being evaluated.

3. Results and Discussions

The methods are implemented to recover the signal and reduce noise on recorded seismogram of an earthquake at Southern of Sumatera. Figure 3 shows that the denoised signal presents the clear onsite of P- and S-wave first arrival rather than the original observed signal. The SNR of this seismogram data has been improved by employing threshold value using GCV. The SNR value of the denoised signal

increase compared to noisy data from 4.6 to 28 for P-wave and from 4.4 to 27.7 for S-wave. This approach then is implemented to other seismogram data recorded by seismometer deployed around the study area to identify automatically first arrival of P- and S-wave. To reduce the number of data and time consuming, the high amplitude of S can be the basic for cutting signal to calculate mAIC.

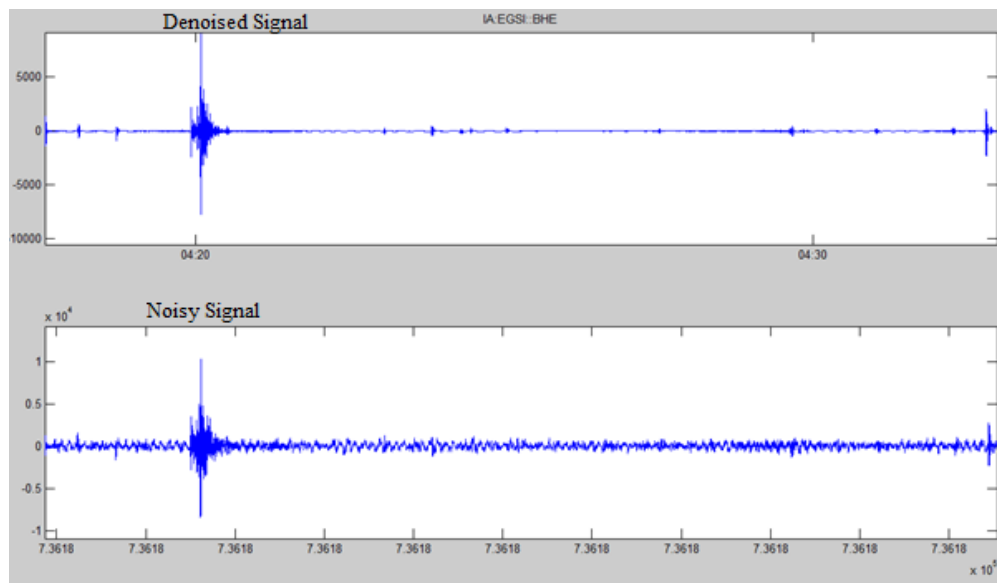


Figure 3 Comparison between noisy (bottom) and denoised signal (top) of a seismogram of 01 August 2015 earthquake recorded at EGSI station.

The denoised signal gives the P- and S-wave onsite clearer and increases the possibility to identify it precisely and accurately using the proposed method [8]. Figure 4 shows the first onsite of P- and S-wave. The blue line and red line represent the position of the first arrival of P- and S-wave wave respectively determined based on manually observation and the green line is mAIC value time series. The figure also shows that mAIC value successfully indicates the onsite P- and S-waves first arrival. The Figure 5 and Figure 6 show the result for other seismogram data.

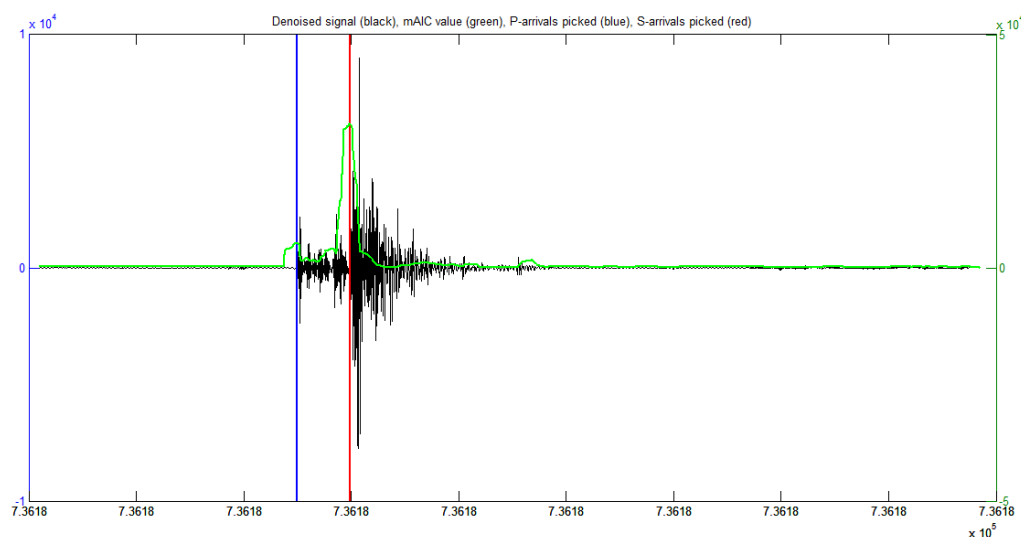


Figure 4 Picking the first arrival onsite. Denoised signal (black), mAIC (green), S-first arrival (red), P-first arrival (blue)

4. Conclusions

The mAIC proposed by Hendriyana (2018) is successfully implemented to detect P-wave first arrival onsite. It is implemented to detect the first arrival from earthquake data samples. The results are consistent regardless the width of time-window is changed. It is because the mAIC was proposed to overcome the dependences of accuracy to the length of time – window and long recorded seismogram. In this study, the time length of seismogram tested is one hour with sample rates 20 samples per second. The first arrivals onsite of P-wave is considered at the same time as mAIC in maximum value. However, in this study, we firstly reduce the noise to increase SNR (Signal to Noise ratio) to find the location of maximum absolute amplitude which is the signature of possibility seismic event by employing GCV thresholding.

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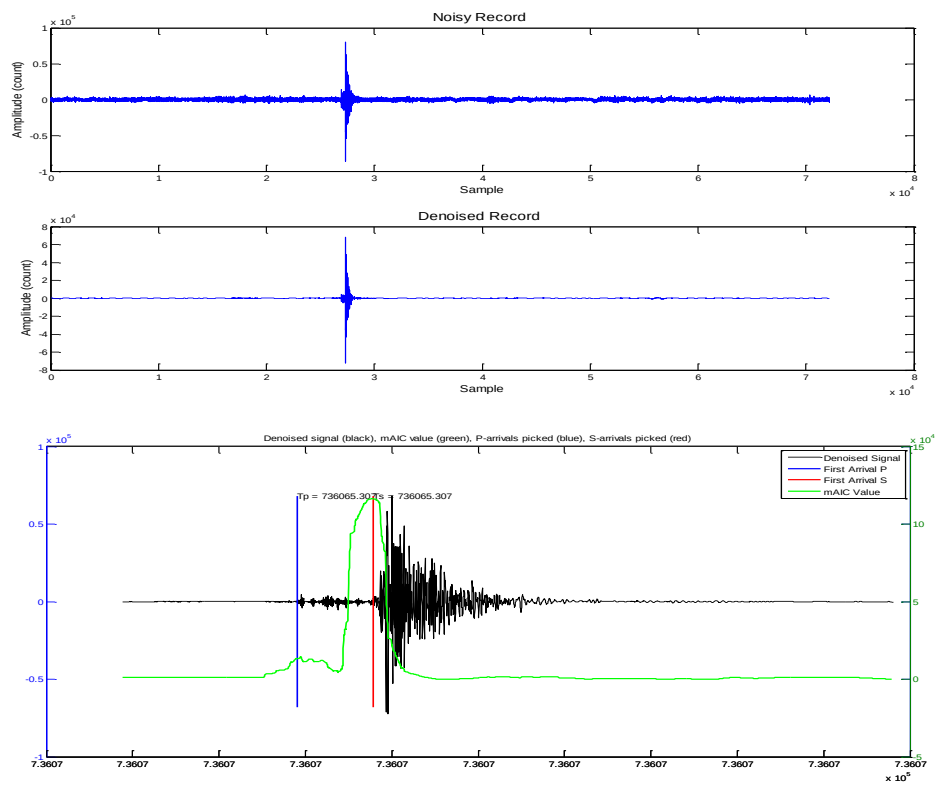


Figure 5 Frst Onsite of P-Wave (blue) and S-Wave (red) determined automatically from denoised signal of an event in 11 April 2015. The method successfully picks first arrival of P-and S-Wave automatically.

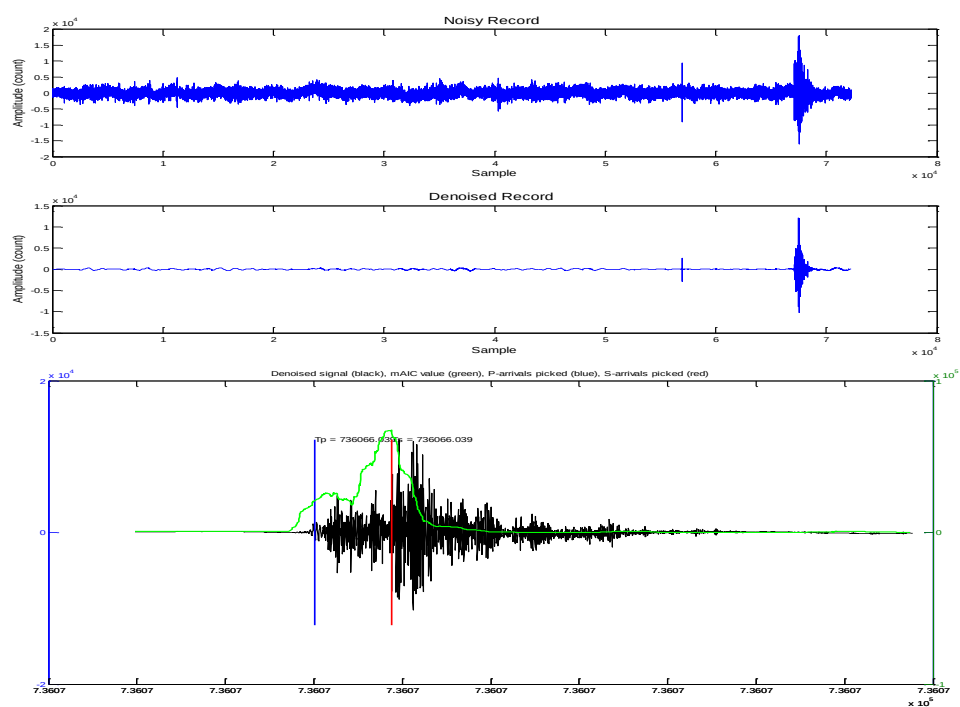


Figure 6 Frst Onsite of P-Wave (blue) and S-Wave (red) determined automatically from denoised signal of an event in 12 April 2015