Temporal Change of Spectra and Lyapunov Exponent Volcanic Tremor at Raung Volcano, Indonesia

Arin Wildani, Sukir Maryanto

Abstract*: *Spectral Analyses and estimation maximal lyapunov exponent (MLE) of volcanic tremor recorded at Raung Volcano were carried out to investigate dynamical systems regarding to their generating system. Their results of both analyses can explain the temporal change in frequency and deterministic processes of the dynamical system. Spectral analysis of volcanic tremor was estimated by the average periodogram method which includes division, Fast Fourier Transformation and averaging. MLE was estimated by graphing the relationship between Stretching Factor (S) and the number of points in the tractor (N) diagram. Content frequency of volcanic tremor Raung Volcano is range from 2.68 to 3.7 Hz. Temporally, there is no significant change, which means that there is no change in the geometry of the Raung volcanic tremor source. This is also shown by the maximal lyapunov exponent which is temporarily constant and positive. That shows that the source process of Raung volcano is chaotic

Keywords* : *Raung volcano, volcanic tremor, Maximal Lyapunov Exponent, spectral analysis

I. INTRODUCTION

Volcanic tremor is a type of seismic signal that is usually recorded around active volcanoes. Usually appear before, during and after an eruption with a duration of more than one minute or even one hour or one day [1]. Volcanic tremor is very interesting to study because the results of its analysis as a tool for forecasting eruptions and deeper understanding the physical processes that occur inside active volcanoes. Characteristics of volcanic tremor every volcano in the world are different, but several volcanic tremor analysis concepts can be applied to explain the characteristics and internal processes that occur within a volcano.

The initial study that can be done to determine the characteristics of a volcanic tremor is a spectral analysis to estimation of the frequency content. Analysis of peak frequency (spectral) is one of the ways commonly used to investigate signal properties based on frequency values [2]. this can be done by the direct segment method [3]. Tremor signals that have a long duration are divided into smaller segments and the spectrum of each segment is calculated using Fast Fourier Transform (FFT). The final spectral is the average of all previously divided spectra. This method has been used for spectral analysis of seismic signals of several volcanoes throughout the world [4-7]. Spectogram is a graph to see changes in all domains (frequency, time and amplitude). a direct comparison of the average spectrum must be made. Such spectrum comparisons from different time periods are only possible when the amount of data is relatively small and the variation observed is greater than the ambient noise level.

In addition, other research to explain the source of tremor can be done with non-linear analysis. [8] Has stated that volcanic tremor is caused by non-linear processes, the results of his research suggest that linear time-invariant systems cannot spontaneously oscillate. whereas Julian states that tremor may be caused by a stable oscillation response to low and almost zero input frequencies. Observational evidence for the existence of nonlinear processes can be found in the systematic relationship between the frequency and amplitude of tremor signals as documented in the Karimsky and Sangay volcanoes[9, 10]. On the other hand, several studies have applied nonlinear time series analysis methods to tremor recorded at volcanoes worldwide in order to detect the presence of deterministic structure [1, 2, 11-13]. Their results revealed a strange puller that described the process of source tremor in phase space and was characterized by a small number of degrees of freedom.

Raung volcano is a 3332 m high stratovolcano in the east java, Indonesia. It has caldera with 2 km-wide and 500 m-deep and one of the most active volcanoes on the island of Java. The first eruption were recorded in 1586, since 1586-1989 there were several major eruptions which caused casualties. According to the history of the eruption, the most severe eruption occurred in 1683 accompanied by large floods and lava flows which caused thousands of lives. Raung volcano has character of the eruption is explosive by producing ash that is thrown into the air and hot clouds that once covered a portion of the volcano's body. The shortest eruption period of Raung volcano between 2 eruptions is 1 year and the longest is 90 years [14].

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***** Correspondence Author
Arin Wildani*, Doctoral Student of Physics Department, Brawijaya University, Malang, Indonesia. Email: arinwildani@uim.ac.id
Sukir Maryanto, Physics Department, Brawijaya University, Malang, Indonesia. Email: sukir@ub.ac.id

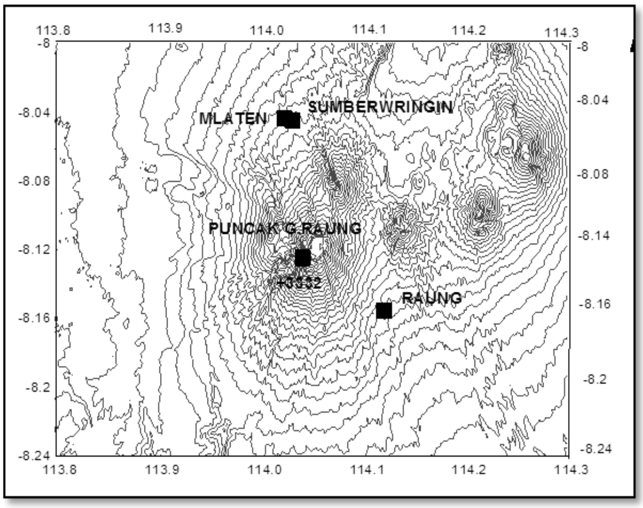


Figure 1. Location of Raung Mountain seismic station

In 2012, the Center for Volcanology and Geological Disaster Mitigation (PVMBG) stated that Mount Raung had experienced an eruption. Before the eruption was recorded volcanic tremor activity continuously with a maximum amplitude reaching 32 mm and continued until after the eruption. In this article, we analyze volcanic tremor recorded at Mt. Raung during late October- November 2012 in order to understanding the physical processes that occur inside active volcanoes. The main issues that wish to address by our analysis are 1) the possible variation of content frequency 2)The possible variations of Maximal Lypunov Exponent and 3)Which is the most plausible source mechanism of tremor volcanic tremor raung volcano.

II. METHODOLOGY

A. Raung Seismicity

The seismic and visual activity of Raung volcano is monitored by the Bandung Volcanology and Geological Disaster Mitigation Center (PVMBG) from the Raung volcano monitoring post located in Sragi Village, Singojuruh District, Banyuwangi Regency. Data used in this study are secondary data in the form of Raung mountain seismogram data from October 17 to November 16, 2012 obtained from the Center for Volcanology and Geological Disaster Mitigation (PVMBG), Bandung, West Java. The data was transmitted from the Raung mountain monitoring post in Banyuwangi, East Java. Data includes all recordings from the three Raung mountain seismic stations namely Raung, Mlaten and Sumberwringin as in Figure 1. Under normal conditions the seismic activity of Raung Mountain is dominated by shallow volcanic earthquake activity and distant tectonic earthquake as shown in figure 2. Towards the eruption in October 2012 volcanic earthquake activity decreased while tectonic earthquake activity was much increasing. Increased distant tectonic earthquake activity was followed by the emergence of volcanic tremor until on 17 October the distant tectonic earthquake was not recorded at all but volcanic tremor was recorded continuously for several days with a maximum amplitude reaching 32 millimeters as shown in figure 3. On 19 October 2012 Mt. Raung having an eruption, there was the sound of thumping and flames on the top of Mount Raung. After the eruption of volcanic tremor activity continued to be recorded until February 2013. Volcanic tremor activity decreased significantly starting from March 25, 2013, and volcanic tremor began not recorded since the beginning of April 2013.

B. Characteristic of the Volcanic Tremor

Spectral analysis was carried out to determine the frequency of the Raung volcanic tremor. Spectral analysis in this study was carried out by means of the average periodogram, this method is suitable if applied to the recording of data that is disturbed due to noise, where random noise will cancel each other out. Calculation operations using the average periodogram method include division, fast Fourier transform and averaging.

Spectrogram is used to see the dominance of the frequencies of volcanic tremor over the time of occurrence of volcanic tremor. It presents the results in two-dimensional space, with the horizontal part representing time and the vertical part representing frequency. The intensity of the amplitude at a frequency and at a time in the spectogram is expressed with a certain color value. To get the spectrogram first performed the process of volcanic tremor signals by first determining the size of the signal data frame in one unit of time and using Fast Fourier Transform (FFT). In this study spectogram analysis was performed using the help of a program from MATLAB namely "Specgram".

Frequency dominat is one of the characteristics of volcanic tremor. Figure 4 in the middle is a sample graph showing the peaks of volcanic tremor frequencies at Raung station. Based on the value of the peak peaks, the Raung volcanic tremor is spasmodic (non-harmonic) tremor, that is, there is no regularity of the peak frequency. The peak frequency value that is determined as the dominant frequency in this study is the peak frequency with the greatest value among the peak frequency frequencies as shown in Figure 4 with a dominant frequency of 3.17 Hz and 3.27 Hz

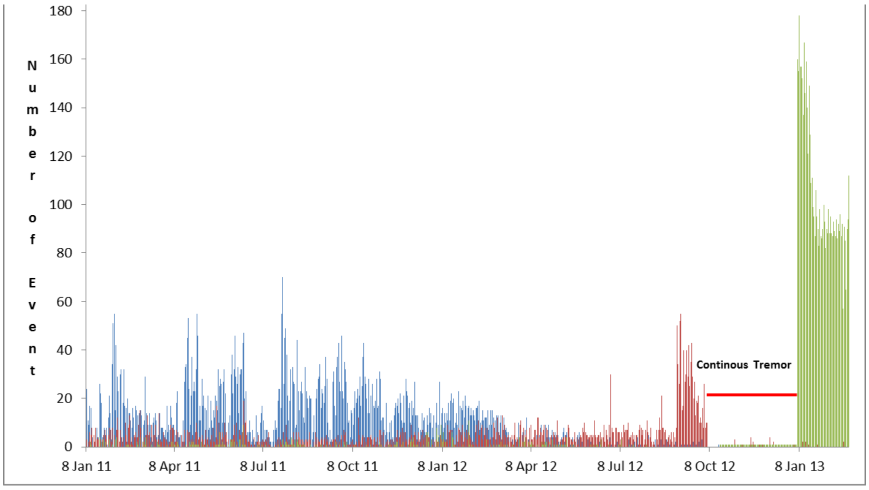


Figure 2. Seismicity Raung Volcano

Figure 5 shows the results of the spectral analysis at the three Raung mountain seismic stations. The dashed red line shows that the frequency peaks at the three seismic stations have the same pattern, which means the source of the Raung volcanic tremor at the three stations is thought to be the same source. However, Dominant frequency of the three seismic stations Raung volcano has different values. Mlaten Station and Sumberwringin Station have lower dominant frequency values than Raung Station. The dominant frequency at the two stations ranges from vulnerable 1.50 Hz - 2.3 Hz while the dominant frequency value at the Raung station is around 3.2 Hz

C. Maximal Lyapunov Exponent

Spectral analysis is good for knowing the spectrum shape of a signal or time series data from the completion of a dynamic system expressed in a differential equation, but for knowing the degree of sensitivity is not good. To find out the degree of sensitivity of the time series data, a quantitative calculation method is needed. The calculation is done by non-linear analysis of the time series data. Non-linear analysis is done by describing the phase-space diagram (aktraktor) of the time series data. The depiction of the tractor diagram is explained by the delay embedding theorem. The vector in the new space, the embedding space, is formed from data sets based on delay time.

$$y\,(k) = S(k), S(k+\tau), S(k+2\tau), \ldots, S(k+(m-1)\tau) \quad (1)$$

which τ is the delay time and m is the embedding dimension.

The exponential difference of adjacent orbits in the tractor diagram can be used as a parameter of a kaotic system or not. For example, it is assumed that two points in the x_{n1} and x_{n2} space phase diagrams and the distance between them is $|x_{n1} - x_{n2}| = \delta_0$, in time t the distance of the two points is equal to $\delta = \delta_0 e^{\lambda t}$, if the value of λ>0 the exponential equation is called Lyapunov exponent. The Lyapunov exponent value will be positive for a deterministic process while if the process is linear the Lyapunov exponent value will be zero and if the process is stochastic then the value is infinite.

Lyapunov exponent describes the size of the distribution of points in the tractor diagram. The Lyapunov exponent value is determined by graphing the relationship between the Stretching Factor (S) and the number of points in the tractor (N) diagram such as Figure 6, a straight line formed by the least-square method, the slope of the straight line is determined as the Lyapunov exponent value. In this study Mount Raung volcanic tremor data was calculated for its exponent lyapunov value, we took samples of 30 Raung volcanic tremor events recorded from October-November 2012. Figure 6 is a graphical example for estimating the lyapunov exponet value.

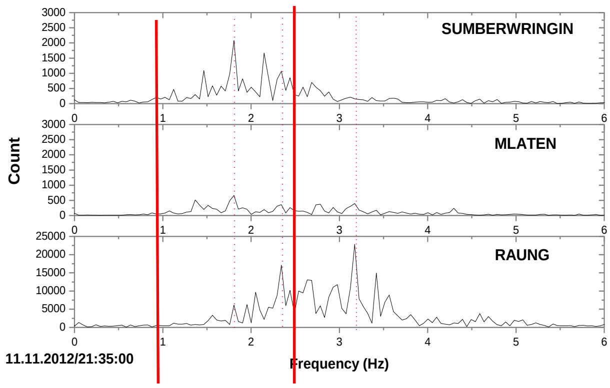
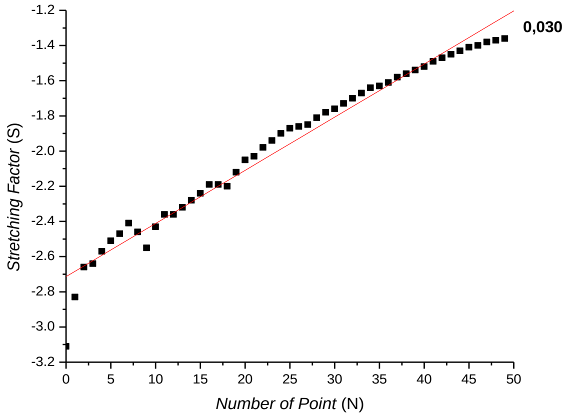


Figure 5. The peaks of the Raung volcanic tremor frequency at three seismic stations



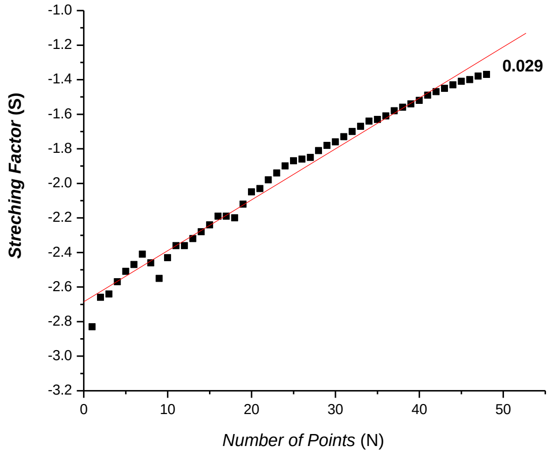


Figure 6. Example estimation maximal lyapunov exponent of volcanic tremor Raung Volcano

III. RESULTS AND DISCUSSION

In this study, temporal change content of frequency volcanic tremor Raung Volcano will discuss. Figure 7 shows the change in the value of the three peaks of the Raung volcanic volcano tremor frequency from three observation stations, namely Raung, Mlaten and Sumberwringin. From this figure, it can be seen that each observation station has almost the same frequency value, which means the source of volcanic tremor comes from the same source. And the pattern of changes in the peak values of the frequency peaks at these three stations when the dominant frequency peaks decrease, the other two peaks also look down. We suspect that the process of every Raung volcano volcanic tremor event is just that the position of the event changes, this can be caused by the flow of magma or gas approaching the surface.

Figure 8 shows the temporal change of the dominant frequency of Raung Mountain at three observation stations. Mount Raung volcanic tremor frequency values before the eruption, during the eruption and after the eruption of fluctuations that ranged in the range from 2.68 to 3.7 Hz. We suspect that the volcanic tremor before the eruption on October 19, 2012 was caused by the flow of magma / gas towards the surface and conditions continued until January so that the activities of Mount Raung until January still could be heard roaring and incandescent fires. Figure 8 also shows that the dominant frequency value from Raung station is different from the other two stations namely Mlaten and Sumber Wringin while the dominant frequency of the source and the Mlaten source is almost the same. In this connection we suspect it is caused by the propagation medium. If seen in Figure 1. The location of the Raung station is to the south of the summit and closer to the summit of Raung Mountain while the Sumberwrigin and Mlaten stations are to the north on the top of Raung Volcano and the two are close together.

IV. CONCLUSION

The conclusion of this article is dominant frequency of volcanic tremor Raung Volcano before and after eruption in 2012 has range 2.68 to 3.7 Hz. Difference in peak frequency values between Raung station and the other two stations is due to the position of the station and its propagation medium. Frequency values temporally do not experience significant changes, which means there is no change in the geomtery of the Raung mountain conduit pipe. Mximal Lyapunov Exponent of Raung Volcano has a positive value which means that volcanic tremor is caused by a deterministic process in the conduit pipe and source mechanism volcanic tremor of Raung Volcano is caused by the flow of magma in a cylindrical conduit due to non-constant pressure.

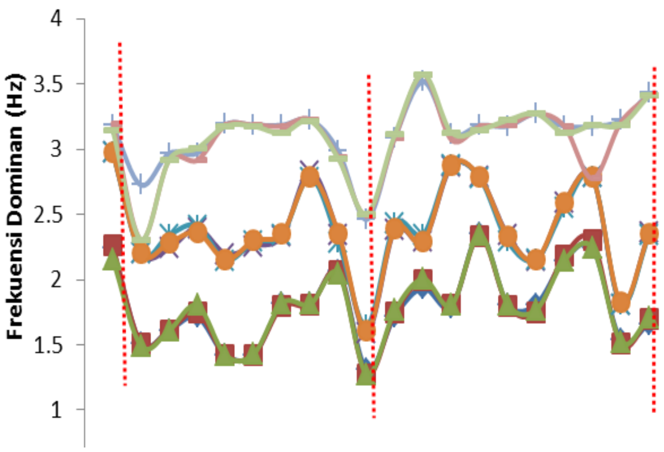


Figure 7. temporal change content of frequency volcanic tremor at Raung Volcano

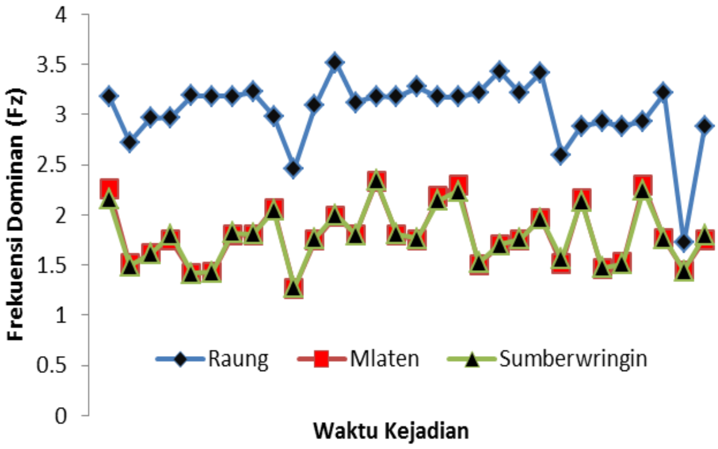


Figure 8. Temporal changes of dominant frequency at 3 stations

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AUTHORS PROFILE

Arin Wildani, is Doctoral Student in Physics Department, Brawijaya University, Malang, Indonesia. She completed M.Si and S.Si from the physics department, Brawijaya University Indonesia.

Sukir Maryanto, is a professor in the Physics Department, Brawijaya University, Malang, Indonesia. He completed S.Si from physisc department Brawijaya University,Indonesia. M.Sc from physisc department Gajahmada University, Indonesia. He was award Ph.D from Kyoto University,Japan. He published more than 100 papers in National and international Journals and conferences. His area of research is volcanology and geothermal.