Applying Wavelet Analysis to Assess the Ultra Low Frequency (ULF) Geomagnetic Anomalies prior to the M6.1 Banten Earthquake (2018)

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Abstract. The M6.1 Banten earthquake (EQ) occurred on January 23, 2018. The EQ epicenter was in Lebak Regency, Banten. The epicenter distance from the ULF geomagnetic station installed in Banten Province is about 100 km. Applying wavelet analysis on the geomagnetic time series data, we assess the ultra-low frequency (ULF) geomagnetic anomaly related to the M6.1 Banten EQ. We focused on the frequency of 0.02 Hz for the analysis of the spectral density ratio based on wavelet. We applied the Morlet wavelet as the mother wavelet in this study. The spectral density ratio analysis based on the Morlet wavelet presents the existence of the ULF geomagnetic anomalies prior to the M6.1 Banten EQ. The global geomagnetic index, Dst, did not show any peculiarity when the anomalies prior to the EQ exist. Then, we concluded that the anomaly is possibly related to the Banten EQ.

1. Introduction

The geological setting of Indonesia is very complex due to the location of Indonesia as the meeting point of some active plates. The movement of the Indo-Australian Plate, which is going toward beneath the continental plate, Eurasian plate, causes the existence of the subduction zone in the western-southern part of Indonesia. In the southern part of Java Island, there are three segments of this zona subduction, i.e., the Sunda Strait-Banten segment, West Java segment, and Central Java-East Java segment [1]. The activity of the Sunda Strait-Banten segment generates the destructive earthquakes in the surrounding Sunda Strait and Banten Province.

Banten Province locates in the westernmost of Java Island. Its capital is Serang. The total population and area of Banten Province are about 13 million people and 9,600 km², respectively [2]. One of the destructive earthquakes occurred in Banten Province was the M6.1 Banten earthquake on January 23, 2018. The earthquake was also felt in Jakarta Province, the capital of Indonesia and triggered the infrastructure fatalities in Banten Province.
Recently, the researcher reported that the ultra-low frequency (ULF) shows geomagnetic anomalies prior to the occurrence of some destructive earthquakes [e.g., 3, 4, 5, 6, 7, 8, 9, 10, 1, 12, 13]. In this study, the definition of the ultra-low frequency is for the frequency below 1 Hz since this frequency range has a deeper skin depth [14, 15]. The previous study also revealed that the study of the ULF geomagnetic anomalies prior to an earthquake could be one of the short-term earthquake forecasts [16].

Therefore, we would like to investigate the ULF geomagnetic anomalies prior to the M6.1 Banten earthquake by applying spectral density ratio based on wavelet analysis. Through this study, we would like to make a contribution to the mitigation effort from the negative effect of the catastrophic earthquake.

2. Data and Method

The epicenter location of the M6.1 earthquake is at the Lebak Regency, Banten Province, Indonesia, as presented by the red circle in Figure 1. The capital of the Lebak Regency is Rangkasbitung. The epicenter distance is about 100 km from the ULF geomagnetic station. The station recorded three geomagnetic components, i.e., the H, D, and Z components. The typical geomagnetic time series data is presented in Figure 2. We presented the data recorded on February 5, 2018. In this study, we analyzed two months of data, starting from January 1, 2018, to February 25, 2018. To minimize the artificial noise, we focused on the night time data (16:00-21:00 UT).

![Figure 1](image-url). The location of the ULF geomagnetic station and the M6.1 Banten earthquake
Figure 2. The typical geomagnetic time series data recorded in the Lebak, Banten, geomagnetic station

Then, we transformed the data from the time series to the frequency domain by applying the wavelet analysis. We employed the Morlet wavelet as the mother wavelet. We ignored the first and last three second night data due to the edge-effects of wavelet transform [9]. This effect will cause an error at the beginning and end of the wavelet transform because of the finite-length time series of data. We focused on the data range from 16:30 UT to 20:30 UT.

Then, we calculated the spectral density of each component of the geomagnetic data. The spectral density analysis concentrated only on the 0.02 Hz data. The previous study presented that the 0.02 Hz frequency range will be optimal to investigate the ULF geomagnetic anomaly prior to the earthquake [16]. Next, we analyzed the spectral density ratio to assess the possibility of the ULF geomagnetic anomaly related to the M6.1 Banten earthquake. We defined the mean±3σ as the threshold with σ is the standard deviation of the data. The ULF geomagnetic anomaly is defined if there is a spectral density ratio exceed the threshold. Lastly, we compared the spectral density ratio to the global geomagnetic activity, Dst index, to convince that the anomaly presence is associated with the earthquake, not related to the global geomagnetic storm [17].

3. Results and Discussion

Figure 3 presents the wavelet transform of the February 5, 2018, geomagnetic night data. It is the typical wavelet transform result. The figure shows that there is a higher energy zone in the higher period on the H and Z components of the geomagnetic data. The red square in the figure indicates the data range analyzed in this study to minimize the edge-effect. We did this step for all geomagnetic data.
Figure 3. The wavelet transform of the geomagnetic data. The red square indicates the data range which analyzed in this study. The scale bar denotes the energy in nT/Hz$^2$. (a) H component. (b) D component. (c) Z component

Figure 4. The spectral density ratio analysis of the Z/H, Z/D, and Z/G component from January 1, 2018, to February 25, 2018. The G indicates the total geomagnetic component. The last panel indicates the Dst index during the analyzed period. The black line indicates the day of the earthquake. The blue lines is the mean and the mean±3σ threshold.
Figure 4 presents the calculation of the spectral density ratio during the analyzed period. We calculated the ratio for the Z/D component, Z/H component, and Z/G component. The G component indicates the total geomagnetic component. The figure presents that the spectral density ratio during the analyzed period of the Z/D and Z/H components shows there is no data exceed the mean±3σ threshold. Then, we focus on the Z/G component to investigate the ULG geomagnetic anomaly related to the M6.1 earthquake.

Figure 5 shows the result of the spectral density ratio for the Z/G component. The figure indicates there is the data exceed the mean±3σ threshold on the 13th day of the analyzed period. The earthquake occurred on January 23, 2018, as indicated by the black line in figure 5. It is the 23rd day of the analyzed period. We also compare the anomaly to the Dst index. The Dst index indicates the global geomagnetic activity in the low latitude region [17]. The Dst index indicates there is a global geomagnetic storm if its index is more than ±50 nT [17]. Figure 5 presents the Dst index indicating that there is no peculiar geomagnetic activity when the ULF geomagnetic anomaly appears. The Dst index shows normal activity during the analyzed period. Then, we conclude that the ULF geomagnetic anomaly on the 13th day of the analyzed period is possibly associated with the M6.1 Banten earthquake.

The previous study presented that the ULF geomagnetic anomaly related to the M>5 earthquake has a higher possibility to appear prior to the earthquake about two weeks before the day of the earthquake [18, 19]. Our result also agrees well with these studies. Figure 5 shows that the ULF geomagnetic anomaly, which is possibly related to the M6.1 Banten earthquake, appeared about two weeks before the occurrence of the M6.1 earthquake. The result of this study also supports the previous studies related to the earthquake forecast carried out in Indonesia [6, 9, 20, 21, 22]. These studies were done in West Java, Sumatera, and Papua. They revealed that the ULF geomagnetic
anomalies related to the earthquakes that occurred in Indonesia emerged from a few days to 1 month prior to the earthquakes.

Indonesia is one of the seismically active countries in the world. Therefore, the study of the earthquake forecast would be promising research to be done in Indonesia. In the future, it could be a short-term effort to mitigate the devastating effect due to the earthquake.

4. Conclusion
We assessed the ULF geomagnetic anomalies prior to the M6.1 Banten earthquake to investigate the possibility of the anomaly existence related to the M6.1 earthquake. The M6.1 earthquake occurred on January 23, 2018. The epicenter distance from the Lebak, Banten, ULF geomagnetic station is about 100 km. We analyzed the night data of the three geomagnetic components. We applied the spectral density ratio based on wavelet analysis in this study. We employed the Morlet wavelet as the mother wavelet. The result of the spectral density ratio shows there is an anomaly about two weeks before the M6.1 Banten earthquake. We also compared the anomaly to the global geomagnetic activity, Dst index, to convince that the anomaly is not associated with the global geomagnetic anomaly. It indicates that the ULF geomagnetic anomaly possibly associated with the M6.1 Banten earthquake.

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