The ULF geomagnetic anomalous signal associated with Nias earthquake M5.3 North Sumatra Indonesia on September 6, 2018

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Abstract. A study of ultra-low-frequency (ULF) geomagnetic signals has been carried out prior to the onset of Nias earthquake M5.3 that occurred at 07:13:49 LT (Local Time) on September 6, 2018, in West Nias regency, North Sumatra, Indonesia. We analyzed three components of geomagnetic data H, D, and Z measured in Gunung Sitoli (GSI) geomagnetic station which is about 108 km from the epicenter, from January 2018 until December 2018. We used the polarization ratio method in terms of power spectrum density within 0.027-0.033 Hz frequency range to evaluate the geomagnetic data by applying Fast Fourier Transform (FFT). This work presents evidence of ULF geomagnetic anomalies exceeding the statistical threshold associated with Nias earthquake M5.3 which appeared starting from 3.5 months until 3 weeks before the earthquake. When these anomalies occurred, the value of disturbance storm time (Dst) index shows that there is no high global geomagnetic activity. Thus, it is concluded that the clear precursory anomalies detected are related to the earthquake.

1. Introduction

Indonesia has a complex active tectonically geology which is characterized by intense seismicity resulting from subduction. One of the moderate earthquakes that occurred in Indonesia in 2018 was the Nias earthquake M5.3, North Sumatra. Sumatra region is a subduction zone as a result the movement of the Indo-Australian Plate to the north under the Sunda plate with a displacement rate of around 50 mm/year [1-4], and it is colliding with the Eurasian continent to the west [1,5]. The Nias earthquake M5.3 occurred at 07:13:49 LT (Local Time) or 00:13:49 UT on September 6, 2018, in West Nias regency, North Sumatra, Indonesia. Based on the BMKG data, the epicenter of the earthquake located at 96.78°E 0.71°N and 14 km of depth, which is about 108 km distance from GSI geomagnetic station as presented in Figure 1.

Considering the great potential of earthquake events in Indonesia, it is necessary to have earthquake mitigation methods to minimize losses and casualties, one of which is by observing ULF geomagnetic anomalies. The study of ULF emissions is a reliable tool to investigate seismomagnetic effects as earthquake precursors. The previous studies presented some convincing evidences on the precursory
occurrence of ULF emissions before large earthquakes [e.g. 6-18]. The most advantage of the ULF waves is its capability to penetrate to the lithosphere over a long distance from the hypocentral region up to the Earth’s surface with a small attenuation [11, 12]. A common method to study earthquake precursors is the polarization ratio. The polarization method is based on the measurement of the ratio of the vertical magnetic field to the horizontal magnetic fields in the frequency domain. These ratios can increase in correspondence of seismogenic emissions [12]. The goal of this paper is to observe whether there are ULF electromagnetic anomalies detected from the application of the polarization ratio method associated with the Nias earthquake or not.

Figure 1. The location of the Nias earthquake M5.3. The red square in the inset is the study area. The blue star is the epicenter of the earthquake and the grey circle is the GSI geomagnetic station.

2. Data and Method
In this study, we used the data recorded in GSI geomagnetic stations (97.57°E 1.304°N) from January 2018 until December 2018 which is about 108 km from the epicenter as presented in Figure 1. The GSI geomagnetic station operated by BMKG can measure absolute values of the horizontal (H), declination (D), and vertical (Z) components with 1 Hz sampling frequency. To filter the artificial noise, we focused on data within the period time of 17:00-21:00 UT for further analysis. The Fast Fourier Transform (FFT) was performed to transform the time series data into the frequency domain data. Then, the polarization ratio \( Z/G \) (\( G \) indicates the total horizontal component) within 0.027-0.033 Hz frequency range was calculated. We have chosen the mean + 3\( \sigma \) as the threshold of an anomaly (\( \sigma \) is the standard deviation values) which were computed from the whole period of observation. To clarify that the anomaly does not caused by global geomagnetic activity and avoid false precursor, we compare the data with the disturbance storm time (Dst) index from the World Data Center for Geomagnetism Kyoto University [19]. The Dst indexes which have any daily value lower than -50 nT or greater than 50 nT indicate the present of the geomagnetic storm, thus anomalies during those periods should be ignored due to geomagnetic environmental factors [14, 18, 20-22].

3. Results and discussion
Figure 2 shows the raw geomagnetic data of GSI station during a full day recording with 1 Hz sampling frequency. The previous studies suggest that local nighttime data contain less man-made noise and less contamination of the global solar signals [e.g. 15, 18, 23, 24], therefore we only focused on four hours
of data (17:00-21:00 UT) for further analysis. The Fast Fourier Transform (FFT) with 30 minutes interval was performed to obtain the power spectrum of night data as presented in Figure 3.

![Figure 2](image1.png)

**Figure 2.** A typical of raw geomagnetic data on September 1, 2018 recorded from the GSI geomagnetic station for (a) H component, (b) D component, and (c) Z component.

![Figure 3](image2.png)

**Figure 3.** The spectrogram of the September 1, 2018 night data for (a) H component, (b) D component, and (c) Z component.
In the earliest studies on geomagnetic earthquake prediction, the ULF emission is defined to be between $0.01 - 0.1 \text{ Hz}$ \cite{8} and have been applied by most previous studies for earthquake prediction purpose \cite{11-13, 15, 23, 25, 26}. Recently, there are specific recommendations that the optimum frequencies for detecting earthquakes are around $0.02 - 0.03 \text{ Hz}$ and $0.06 \text{ Hz}$ \cite{27}, therefore we decided to focus on the frequency range of $0.03 \pm 0.003 \text{ Hz}$ in this study. The temporal variation of spectral density values from January 2018 until December 2018 for all components of the geomagnetic data based on FFT at the frequency of $0.027-0.033 \text{ Hz}$, as shown in Figure 4. To ensure that the anomalous ULF emissions were an earthquake precursors, the spectral density values were compared with the Dst index which monitors global geomagnetic activities. The Dst index indicates the global geomagnetic disturbances occurred at a low latitude and become a reference to find major events that happened during quiet days \cite{14, 15, 28}.

![Figure 4. The spectral density values of the (a) H component, (b) D component, (c) Z component, and (d) Dst index.](image)

Furthermore, Figure 5 shows the spectral density ratio between the vertical and total components ($Z/G$) compared with the Dst index. The values of $Z/G$ are computed as the representation of the daily data. It could be found that ULF geomagnetic anomalies are exceeding the statistical threshold which appeared starting from 3.5 months until 3 weeks before the earthquake. The value of the Dst index shows there is no high global geomagnetic activity when the anomalies occurred. This indicates that the clear precursor anomalies detected are not caused by global geomagnetic disturbance, but related to the Nias earthquake M5.3.

The results of this study agreed well with previous studies conducted by Ahadi \cite{14} and Yusof \cite{27}. Ahadi stated that ULF emissions depend on magnitude and distance of the hypocenter, if the magnitude of the earthquake is large but the hypocenter distance is far from the observation station, then the ULF
anomalies will be observed shorter [14]. On the other hand, Yusof stated that shallower earthquakes have a higher possibility to be predicted due to shorter distances needed that causes less attenuation, thus producing stronger anomalous signals for more effective prediction [27]. Based on the results of this study for the Nias earthquake M5.3 that occurred in 14 km of depth with the hypocenter distance around 109 km from the GSI geomagnetic station, the ULF anomalies appeared starting from 3.5 months before the earthquake. As a comparison, we take an example of the Padang earthquake M7.6 occurred on September 30, 2009, in 81 km of depth with the hypocenter distance around 139 km from the KTB (Kototabang, Sumatra) geomagnetic station, the ULF anomalies appeared starting from 26 days before the earthquake [14]. Both of these data prove that the correlation between the magnitude, epicenter distance and hypocenter distance of the earthquake subject to the appearance of the ULF geomagnetic anomalies preceding earthquake.

Figure 5. (a) The spectral density ratio (Z/G) with the horizontal blue line indicates the threshold mean+3σ. (b) Dst index with the horizontal blue lines show that the Dst index value of ±50 nT as a sign of geomagnetic storm. The vertical green line shows the day when the Nias earthquake M5.3 occurred. The grey color area is corresponding to the anomalies.

4. Conclusion
In this study, we have performed the polarization ratio analysis method associated with the 2018 Nias earthquake M5.3. The geomagnetic data from January 2018 until December 2018 recorded in GSI geomagnetic station have been analyzed to find ULF electromagnetic anomalies. As a result, the polarization ratio analysis method has successfully detected the clear anomalies which appeared starting from 3.5 months until 3 weeks before the earthquake.

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