Analysis of magnetic field anomalies before earthquakes based on ULF (Ultra Low Frequency) method using magnetic sensor data in Sumatra

Ade Fika Ramadhani¹), Syafriani*¹), Rahmat Triyono²) and Tri Ubaya²)

¹)Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Jl. Prof Hamka, Padang 25131, Indonesia
²)Meteorology Climatology and Geophysics Agency, West Sumatera, Jl. Meteorologi, Kel Silaing Bawah, Kota Padang Panjang 27118, Indonesia

*syafri@fmipa.unp.ac.id

Abstract. Sumatra has a complex tectonic system which it causes to be prone to earthquakes. Therefore, early warning before earthquake is needed with the study of earthquake precursors using Ultra Low Frequency (ULF) method. This method applied to the recording data of the Earth's magnetic field for 30 to 3 days before the earthquake event. This study also carried out the prediction of earthquake magnitude and epicenter based on the amplitude of the anomaly and the distance of the station to the earthquake location. To ensure that the anomalies that occur are not due to external interference, the data is observed based on the Dst Index. In this study was found that the percentage of success was 74% approaching the actual data.

1. Introduction

Indonesia is located between the confluence of three large plates. The movement of these plates caused many earthquakes [1], one of which is in Sumatra. The movement of these plates caused Sumatra has a complex tectonic system. The system consist of subduction zone, Sumatra fault and Mentawai fault. Because earthquakes occur suddenly, efforts are needed to predict earthquakes so that the damage that will be caused can be minimized.

One of the efforts to predict when an earthquake will occur is to use earthquake precursors based on the ULF method. Earth's magnet changes when rocks experience changes in stress before an earthquake occurs. Experimental results in the laboratory show that electromagnetic emissions have a frequency range when rocks receive stress, which means the pressure has generated a large current [2].

The physical mechanism of changes in ULF emissions related to earthquakes has been carried out by several researchers. Electrokinetic effect, where changes in pressure in rock faults cause interference with the Earth's magnetism [2]. Furthermore, the effect of induction [3] explains that earthquake source activity causes changes in the amplitude of electromagnetic waves. Then the Micro-fracturing effect [4] explains that path sources cause an increase in electromagnetic wave emissions. After that changes in large Z components compared to H components caused by lithosphere activity [5]. Finally, the occurrence of Skinny effect [6] where higher frequencies experience greater attenuation so that waves with only \( f < 10 \) Hz are present, and that frequency appears around the hypocenter of the earthquake.

The detected anomalies are influenced by earthquake parameters such as the magnitude, depth and distance of the magnetic station to hypocenter. ULF anomalies will be clearly seen if the earthquake source distance is close to the station. In this study, it will be observed that before an earthquake occurs, ULF emission anomalies can be recorded on the Earth's magnetic activity.

2. Data and Methods

The magnetic data was taken from the Sicicin Station (SCA) with latitude -0.32° and longitude 100.17°. Another station was Gunung Sitoli (GSI) with latitude 1.18° and 97.34° longitude. Meanwhile earthquake data with magnitude larger than 5 during August 2016 until April 2017 as shown in Table 1.

Table 1. The earthquake data used in this study

| No | Date          | Magnitude | Region                                      |
|----|---------------|-----------|---------------------------------------------|
| 1  | August 5, 2016 | 5.0       | Southwest of Sumatra, Indonesia             |
| 2  | August 24, 2016| 5.6       | Southern Sumatra, Indonesia                 |
| 3  | September 12, 2016 | 5.2       | Southwest of Sumatra, Indonesia             |
| 4  | September 17, 2016 | 5.0       | Southern Sumatra, Indonesia                 |
| 5  | November 7, 2016 | 5.7       | Southwest of Sumatra, Indonesia             |
| 6  | January 9, 2017   | 5.3       | Southern Sumatra, Indonesia                 |
| 7  | January 12, 2017 | 5.1       | Southern Sumatra, Indonesia                 |
| 8  | February 2, 2017      | 5.1       | Southern Sumatra, Indonesia                 |
| 9  | February 14, 2017    | 5.1       | Southwest of Sumatra, Indonesia             |
| 10 | March 7, 2017       | 5.3       | Southwest of Sumatra, Indonesia             |
| 11 | March 32, 2017      | 5.0       | Southern Sumatra, Indonesia                 |
| 12 | April 2, 2017       | 5.4       | Southern Sumatra, Indonesia                 |
| 13 | April 21, 2017      | 5.3       | Southern Sumatra, Indonesia                 |

The Ultra Low Frequency (ULF) signal is obtained by changing the spectrum from the time domain to the frequency domain using fast Fourier transform. Noise arising in the spectrum is removed using bandpass filters using equation 1 [7],

\[ F(k) = \int_{-\infty}^{\infty} f(x) e^{-2\pi ikx} dx \]  

The technique for conducting earthquake precursor studies using ULF is by polarization and signal comparison for H and Z components. Analysis of power ratio polarization using spectral analysis on the ULF spectrum. Spectrum analysis is done by the Welch method which divides the signal length (N data) into several segments overlapping 50% [8]. Each segment is carried out nFFT with the length of the window N + 1.

Calculation of the polarization of Z and H components at the nearest station and reference station (SZ / SH) and the polarization of the ratio of the main station H (H1) to the reference station (H2) (SH1 / SH2) using the equation derived by Pratess (2011). Anomalies that appear when passing this standard deviation are analyzed to predict earthquake magnitude using the equation 2 [9],

\[ M = A \times 0.1 + R \times 0.002 + 4.288 \]  

where M is the magnitude, A is the amplitude of the anomaly and R is the distance of the station to the center of shading. This distance is obtained using equations 3,

\[ R = \sqrt{(X - X_0)^2 + (Y - Y_0)^2} \]  

where X and Y are the latitude and longitude of the earthquake while X₀ and Y₀ are latitude and longitude are observer stations.
3. Results and Discussion

Earthquakes $>$ 5 SR have occurred 13 times on the island of Sumatra in the period of August 2016 to April 2017, from 13 earthquake events found inter-converging anomalies between SCN sensors and GSI sensors as many as 8 events. The earthquakes observed were at coordinates latitude 0.5° to -14° and longitude 92° to 109°. The station that records the earth’s magnetic field used as observation data is at latitude -0.32 and longitude 100.17 which is the location of the SCN sensor and at latitude 18 to 94.34 which is the GSI sensor. The data of the two sensors can be said to be earthquake precursors if the anomaly found does not coincide with a magnetic storm and if the anomaly between the two stations appears on the same date and time.

The results of the August 2016 magnetic anomaly and the Dst values during the corresponding period are shown in Figure 1.

![Figure 1](image)

**Figure 1.** The Magnetic data on August 2016. (a) SCN Station (b) GSI Station and (c) The Dst index values

Based on Figures 1a and 1b, anomalies appear at the same time at the two stations, namely on August 11, 21 and 26. The anomalies that appear are thought to be an earthquake precursor. This is also confirmed by the Dst index data in Figure 1c where during August 2016 there were several magnetic storms which caused a high Dst index value, but the storm did not affect the anomaly on August 11, 21 and 26.

This change in magnetic anomaly was followed by earthquake events as illustrated in Figures 2 and 3.
The earthquake that occurred on September 12 (Figure 2) at latitude -5.09 and longitude 101.59 with Depth 26 km and Magnitude 5.2. Based on the analysis of the anomalous data there is a match between the anomaly on August 26 and the epicenter of the September 12 earthquake where anomalies appeared 16 days before the earthquake at the same date and time. From the azimuth anomaly is calculated so that the prediction magnitude is 83% close to the actual magnitude. Anomalies on August 26 also correspond to the earthquake epicenter of September 17, 2016 shown in Figure 3. Earthquakes occur at latitude -4.68 and longitude 102.56 with depths of 56 km and Magnitude 5. Anomalies appear 21 days before earthquake and prediction magnitude 78% closer to actual magnitude.

The results of the analysis of magnetic anomalies for the February 2017 period as well as the Dst values during the corresponding period such as Figure 4.
Based on anomalous data from Figures 4a and 4b, in this period there were several earth magnetic anomalies at both stations. On the 9th, 12th, 18th and 25th of March anomalies appeared at the same time. While based on figure 4c that during March 2017 there were several magnetic storms which caused a high index value of Dst.

The period of observation of the earth’s magnet to see anomalies that corresponds to the earthquake of April 2, 2017 with Latitude -3.26, longitude 101.4 at a depth of 55 km and magnitude 5.4 as shown in the following Figure 5.

**Figure 5.** Earthquake map on April 2, 2017, with magnetic anomaly on March 9, 2017

**Figure 6.** Earthquake map on April 2, 2017, with magnetic anomaly data on March 11, 2017
Anomalies on August 11, 18 and 25 did not correspond to the earthquake that occurred as in Figure 6, Figure 7 and Figure 8 because it did not lead to the earthquake epicenter. Whereas, the anomaly on March 9 in accordance with the earthquake was observed because of the anomalies on the two convergent stations as shown in Figure 5. The anomalous amplitude is 25 at SCN stations and 5 at GSI stations. Earth's magnetic anomaly for earthquake April 2, 2017, appeared 18 days before the earthquake occurred. Calculation of magnitude obtained by the prediction success percentage of 87%.

Based on the 13 earthquakes that have been analyzed it is known that anomalies of eight earthquakes appeared and could be analyzed. This is because stress before an earthquake causes a disturbance in the magnetic field resulting in changes in the amplitude of electromagnetic waves (11). Anomaly appears on 30 to 3 days before the earthquake, while 5 other earthquakes anomalies appear but do not lead to earthquake epicenter so that the data the anomaly cannot be used as an earthquake precursor. Research on azimuth calculation is still done so that it gets perfect accuracy.

4. Conclusions

Determination of magnetic field anomalies using the ULF method to predict earthquake events is to compare the polarization of the magnetic field data of a station with an anomalous reference station that appears 30 to 3 days before the earthquake and the azimuth anomaly leads to the active zone of the earthquake. This allows the results of the anomaly of the earth's magnetic field as one of the earthquake precursors to be considered. Research using earthquake data during the period August 2016 to April 2017 where there were 13 large earthquake events. The results showed that 66% of the events found precursors. The predicted magnitude has a success percentage of 74% of the eight events that can be analyzed.

References

[1] Natawidjaja, Danny Hilmam. 2007. Gempabumi dan Tsunami di Sumatra dan Upaya Untuk Mengembangkan Lingkungan Hidup Yang Aman Dari Bencana Alam, Artikel, Geoteknologi, LIPI

[2] Panvilov, A.2014. The Result of Experiment Studies of VLF-ULF electromagnetic emission by rock samples due to mechanical action. Journal of Natural Hazard Earth Sys.Sci,14, Hlm.1383-1389

[3] Mogi, Kiyoo., 1995, Earthquake Prediction Research in Japan., J. Phys. Earth, 43, 533-561, 1995

[4] Molchanov,OA dan Hayakawa M. 1998. On The Generation of ULF seismogenic electromagnetic emission. Phy.Earth Planet.No.105,Hlm.201-210
[5] Hattori, K., 2004, ULF Geomagnetic Changes Associated with Large Earthquakes. TOA, Vol. 15, No. 3. September 2004

[6] Hayakawa M., dan Hobara Y. 2010. *Current status of seismo-electromagnetics for short-term earthquake prediction*. Geomatics. Nat Haz Risk 1, hlm. 115-155

[7] Ahadi, S., Puspito, N.T., Ibrahim, G., Saroso, S., Yumoto, K., Yoshikawa, A., Dan Muzli., 2014, Anomalous ULF Emissions and Their Possible Association With The Strong Earthquakes in Sumatra, Indonesia, During 2007-2012, *J. Math. Fund. Sci.*, Vol. 47, No. 1, Hal. 84-103

[8] Yumoto, K. 1986. Generation and Propagation Mechanisms of Low –latitude Magnetic Pulsation – A review, *Journal of Geophys.* Vol. 60, 79 - 105

[9] Syirojudin, M., Murjaya, J., Ahadi, S., K.,Yoshikawa A (2017): *improving the analyses method of ULF geomagnetic data for earthquake precursor monitoring in the Sumatera region*. Poster session, CTBT: Science and Technology Conference

[10] Freund, F., 2000, Time-Resolved Study of Charge Generation and Propagation In Igneous Rocks, *J. Geophys. Res.* B 105, Vol. 11, Hal.11001-11019

[11] Fenoglio, M.A., Johnston, M.J.S., dan Byerlee, J.D.1995. Magnetic and Electric fields associated with changes in high pore pressure in fault zone: Application to the Loma Prieta ULF emission. *J. Geophys. Res.* 87(B9), Hlm. 12951 – 12958