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THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 57 Lead Time Prediction Between Magnetic Anomaly and Earthquake Occurrence Using Lombok Eare�s Magnetic Anomalies and Seismograph Data, West Nusa Tenggara Rindi Antika Sari1, Suaidi Ahadi,2 M.Syirojudin,3 Syamsurijal Rasimeng,4 1,4 Geophysical Engineering, Faculty of Engineering, University of Lampung 2,3 Meteorological Climatological and Geophysical Agency Jakarta, Indonesia e-mail : antikasaririndi@gmail.com1), suaidi.ahadi@gmail.com2), syirojudin.bmkg@gmail.com3), syamsurijal.rasimeng@gmail.com4) Abstract. Lombok earthquake event that indicated as the major earthquake on August 5, 2018 at 21:56 WIB, with strength of 7 Mw and 10 Km depth, has a epicenter distance 30 km away to NorthEast of East Lombok. BMKG (2018) states that this earthquake occurred due to Flores Back Arc Thrusting activities, this statement concluded as a result of earthquake source mechanism movement analysis to the shifting rocks (plates) that moving up.

In an effort to mitigate earthquake disaster, BMKG try to figure out the changes in the magnetic field due to plates shifting activities that cause earthquakes by installing LEMI 018 on August 28, 2018 at Bayan field. This tool is used for measuring earth's magnetic variance data to find out the cause of the earthquake in further analysis. By using magnetic anomaly data from August to October recorded by the LEMI 018 at Bayan Station, a frequency spectrum analysis and Z/H ratio polarization was carried out to determine Onset time anomalies. As a result of data processing and analyzing, show that the lead time between magnetic anomalies and earthquake events using data from the earthquake seismograph of Lombok ,West Nusa Tenggara, has a minimum leadtime occurring for 173 hours and maximum leadtime occurring for 658 hours. Keywords : Lead Time, Magnetic Anomaly, Precursor, Seismograph. 1. INTRODUCTION Earthquake events that appear suddenly cause a lot of material losses and fatalities.

Earthquakes occur because of tectonic events that always cause the earth's surface to move, such as the collision between plates and others that will cause earthquakes. The process of stress accumulation that occurs in rocks causes the emission of electromagnetic waves, and these emissions will result in changes in the value of measuring the magnetic data of the earth. At this time a theory has been found about earthquake precursors, earthquake precursors can be done THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 58 by knowing changes in rock magnetism values in an area, with parameters from earthquake precursors including onset time, earthquake forecast zone, magnitude, and lead time. Hattori, et al (2006), illustrate the three approach models of the mechanism of the occurrence of ULF wave changes in Figure 1 by (Kamogawa, 2004).

Two models explain ULF emissions caused by electrokinetic effects and the effects of micro-fracturing and one model explains the changes in the amplitude of electromagnetic waves seen from Power Ratio (Z/H) where the H and Z components greatly influence changes in the earth's magnetic field. If a significant change in conductivity occurs in the H component while the Z component is small then it is believed to originate from the atmosphere or ionosphere, but if there is a large conductivity in the Z component but small in the H component it is believed to be a result of lithosphere activity. Figure 1. Three models of ULF emission anomalies related to earthquakes (Kamogawa, 2004). The electrokinetic effect in theory, Fenoglio, et al.

(1995) explains that this effect arises because rocks experience changes in pressure caused by deposits of silica in these rocks resulting in a disruption of the earth's magnetic flow. Induction effect according to (Kovtun, 1980; Mogi, 1985) the effect of induction is the effect that arises due to the activity at the source of the earthquake (focal zone) which causes changes in the geo-electrical conductivity and amplitude of electromagnetic waves, non- lithospheric. The effect of Micro-Fracturing Molchanov and Hayakawa (1995) explains that the emission of electromagnetic waves with the recorded Ultra Low Frequency (ULF) spectrum is assumed to experience a significant increase in the event of a fault in the rock.

Therefore only the pressure induction process can meet to explain micro-fracturing observations. This research was conducted to find out the leadtime of the earthquake, where the lead time of the earthquake is the time for estimating the occurrence of the earthquake from the time the initial anomaly appeared until the occurrence of the earthquake event. Ahadi.dkk., (2013) has conducted a 2009 earthquake earthquake precursor study related to ULF emission anomalies, namely with polarization ratios for determining the onset time and Single Station Transfer Function to determine the direction of anomalies magnetic.

Lombok is one of the regions that has a high seismic history and Lombok is also an area that has high geomagnetic value because it is located between two earthquake plants namely the subduction zone and the Flores Back Arc Thrust. So, in this study the authors used Lombok's magnetic anomaly data which was used as THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 59 an earthquake precursor. With the aim of this research is to find out the relationship between magnetic anomalies and earthquake events and determine the onset time and lead time for earthquakes 2. LITERATURE REVIEW 2.1 Research Areas The area in this study is located in the Lombok area, West Nusa Tenggara. Figure 2. Map of Research Area (Bmkg, 2018) 2.2

Lombok Tectonic Figure 3 explains that Lombok is between two earthquake generators originating from the south and north. In the south there is a subduction zone of the Indo-Australian plate that dips below the island of Lombok. Whereas from the north there is a geological structure named fault rose Flores or Flores Back Arc Thrusting. This fault rises Flores, the route extends from the Bali Sea to the east to the Flores Sea and is very close to Lombok Island (Daryono, 2011). With this, Lombok is said to be an earthquake-prone area, although with a hypocenter depth and varying magnitude. Figure 3. Subduction and Flores Zone Back Arc Thrust (Bmkg, 2018) 3. RESEARCH METHODS THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 60 The data used in this study is geomagnetic data from September 2018 to October 2018 which was recorded by the magnet LEMI-08 at bayan station, Lombok.

And also used earthquake data that has occurred with an epicenter distance of up to 500 Km from the station. The geomagnetic data to be analyzed are daily H and Z component data with an hourly time interval. Also used is the daily Dst Index data according to the time the anomaly appears as a validation to find out the cause of the anomaly arising from the earth's external or internal activities. Where the H component is believed to be more influenced by the activity of the external earth and the Z component is believed to be more influenced by the earth's internal activity (lithosphere). Geomagnetic data processing as an earthquake precursor is carried out several stages, namely, conversion, correction, Z/H Polarization Ratio, Single Station Transfer Function (SSTF), determination of anomalies as earthquake precursors and validation with earthquake events that occur 3.1 Data Conversion This conversion phase is done to change the data format to ASCII format data, this is done to facilitate reading the data 3.2

Data Correction This correction phase is carried out daily trend correction which is useful to fill in the blank data with trend data so that complete data is obtained on each component. And the diff ploting process is performed to show the difference in data with data criteria that do not exceed � 1. Furthermore, a bandpass filter process is carried out on each component, namely the H component and Z component frequency range 0.02-0.006 Hz, because the frequency range is believed to be more influenced by seismogenic activity. 3.3 Single Station Transfer Function (SSTF) This method is used to convince geomagnetic interference signals originating from the earth's internal activities (lithosphere), where according to Hattori (2004) this transfer function can solve an equation from components X,Y,and Z geomagnet. This relationship is considered a linear system that has input and output. This transfer function also has information about underground electrical conductivity or commonly called CA (Counductivity Anomaly).

With the equation as follows: Linear relationship of geomagnetic variation of components X, Y, Z ? Z (?) = A.? X (?) +B. ? Y (?) (1) To determine the magnitude of constants A and B, linear inversion is used, as follows: d = G m (2) Information : d: Data matrix (value ? Z (??)) G: Kernel matrix (values ? X (??) and ? Y (??)) m: Model matrix ((values A (??) and B (??)) = (3) Values A and B can be searched by formula m = -1 GT d (4) THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 61 = (5) The magnitude of magnetic anomalies is formulated as follows Amp (?) = And then, the magnitude of the direction of the magnet anomaly is formulated as follows ? = (Where : ?Z = Vertical Geomagnetic Component (nT) = Geomagnetic (nT) Horizontal Component (North - South) = Geomagnetic (nT) Horizontal Component (East - West) A and B = constants sought Amp = Conductivity scale (Distance between conductivity fields) = Direction of magnetic anomaly source (�) The results of SSTF processing are in the form of a quadrant graph that shows the direction of the earthquake forecast zone which will then be plotted on the map with a zero position graph according to the location of the sensor at the station. Where according to Ahadi. Et al.

(2014) the direction of this azimuth can be categorized as an earthquake precursor if it has a direction in the direction of the earthquake epicenter, with a tolerance limit of 25 � with the up and down direction of the actual azimuth. 3.4 Polarization Ratio of Z/H This method is used to determine the onset time anomaly, by analyzing standardization and daily normalization so that the daily value of component H and component Z will be obtained. Which refers to the research conducted by Prattes, et al., (2011). geomagnetic daily variation, so that it can be seen that the emission or anomalous value that arises comes from internal activities of the earth or global geomagnet. The equation used is as follows: Prattes et al.

(2011) analyzed the standardization and daily normalization with the following formula: SHDAY (?) = (6) SZDAY (?) = (7) To get statistical analysis that is better used in daily averages: S SDA (?) = (8) S SAY (?) = (9) And the daily values of H and Z components are obtained as follow: H Day = (10) Z Day = (11) For the polarization of the power ratio the following equation is used: P Day = (12) THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 62 3.5 Fast Fourier Transform This stage is used as a process to change data from the time domain to the frequency domain. The equation used is as follows: (13) Where f (k) as a function in the frequency domain, x (t) is a function in the time domain, i is an imaginary number, and t is time. 3.6

Determination of anomalies as earthquake precursor The identification of the most accurate anomaly of the earthquake is known by calculating the standard deviation value using moving average geomagnetic data, and the determination of the anomaly is seen through the daily Z and H values that have passed the standard deviation. 4. RESULTS AND DISCUSSION 4.1 Identify anomalies as earthquake precursors In determining anomalies as earthquake precursors it is necessary to identify with several parameters, including onset time, azimuth as earthquake forecast zone, amplitude as magnitude prediction, and leadtime. In this study 15 magnetic anomaly data were used as shown in Table 1 which was indicated as a precursor of recorded earthquakes from Bayan station, Lombok, West Nusa Tenggara. Tabel 1. Earth Magnet Anomaly as a Precursor Indicator No.

Earth Magnet Anomaly as a Precursor Indicator Date Time (WIB) Station Amplitudo Azimuth 1. 29-Agustus-108 13.00 Bayan, Lombok 2.247 314 2. 30-Agustus-2018 14.00 Bayan, Lombok 6.726 212 3. 02-September-2018 20.00 Bayan, Lombok 2.771 22 4. 03-September-2018 22.00 Bayan, Lombok 10.744 99 5. 04-September-2018 16.00 Bayan, Lombok 17.832 71 6. 05-September-2018 17.00 Bayan, Lombok 5.192 99 7. 14-September-2018 22.00 Bayan,Lombok 2.267 138 8. 19-September-2018 10.00 Bayan,Lombok 2.202 134 9. 22-September-2018 22.00 Bayan,Lombok 2.451 345 10. 23-September-2018 07.00 Bayan,Lombok 29.895 281 11. 01-Oktober-2018 02.00 Bayan,Lombok 3.668 105 12. 03-Oktober-2018 13.00 Bayan,Lombok 2.591 286 13. 04-Oktober-2018 17.00 Bayan,Lombok 2.532 314 14. 06-Oktober-2018 05.00 Bayan,Lombok 2.461 142 15. 08-Oktober-2018 20.00 Bayan,Lombok 3.355 333 The anomalious data was then analyzed for earthquake precursor parameters.

The first analysis carried out was spectrum analysis, signal response, diff and intensity of power spectrum to ensure that the cause of the anomaly appeared as a result of global seismogenic or geomagnetic activity. According to Ahadi, et al. (2012) the H component is believed to be more THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 63 influenced by the global or external geomagnetic activity of the earth, while the Z component is believed to be more influenced by the earth's internal activities. Figure 2a shows the signal response on H and Z components, and shows the diff ploting results and spectrograms. Seeing the data indicates that each component has a good response, does not indicate the cause of the anomaly. However, seen in Figure 2b shows that the intensity of power on component Z is greater than component H. By stating that the anomaly that appears on September 2, 2018 is a result of internal activities of the earth.

Because component Z is believed to be more influenced by internal activities of the earth, while component H is more influenced by external activities of the earth. (a) (b) Figure 2. (a) Signal Response Components H and Z. (b) Data before and after FFT and Band Pass Filter And then azimuth analysis is used as an earthquake forecast zone using the Single Station Transfer Function (SSTF) method. From the results of processing using the SSTF method, it was found that on September 2, 2018 there were identified anomalies as earthquake precursors that occurred on September 10, 2018. With azimuth value of 22,150 � and in the direction of the earthquake epicenter on September 10 2018 as in Figure 3 (a) and (b). THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 64 Figure 3. (a) Azimuth September 02 2018.

(b) Epicenter of Earthquake September 10, 2018. Figure 4 is the polarization of Z/H anomaly 02 September 2018 ratio which has been limited by standard deviation to determine the onset time anomaly and validated by the Dst index, because it refers to the research that has been done (Ibrahim, et al. 2012; Ahadi et al., 2013: 2014) Dst index is used to determine global geomagnetic activity when anomalies occur whether there are magnetic storms or not, so that it can be used to ensure that the anomalies that arise are a result of the earth's internal activities rather than global geomagnets. Data that exceeds the standard deviation is believed to be the onset time of anomalies, thus it can be seen that the onset time anomaly on 02 September 2018 is at 20.00 with an anomaly amplitude of 2,771.

Looking at the daily Dst data curve on September 2, 2018, it shows a calm global geomagnetic activity, which does not indicate a geomagnetic storm. With this, it can be ascertained that the anomalies that arise are a result of the earth's internal activities. Figure 4. Polarization ratio of the Z/H September 02 2018 4.2 Determination of earthquake lead time The lead time is the waiting time for an earthquake event, calculated from the onset time anomaly to the occurrence of an earthquake event. In determining earthquake leadtime, seismograph data from earthquake events that occur is needed. The seismograph data is then plotted with Z/H ratio polarization data, and daily Dst data. The maximum estimation of the earthquake lead time is 30 days from the anomaly appearing or before the earthquake event occurs.

Seeing the results of ploting in Figure 5, it is known that the onset time anomaly is at 20:00 with an amplitude of 2,771 and the anomaly appears when the day is quiet (quiet day) does not indicate a geomagnetic storm that occurs. Validation results with earthquake seismograph data from 10 September 2018 revealed that the lead time of the anomaly appeared THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 65 until the earthquake occurred for 175 Hours or for 8 days, with a blue dashed line marked as the September 10 2018 earthquake leadtime. Figure 5. Earthquake lead time September 10, 2018 In this study, 8 release earthquake event data were in accordance with earthquake precursors from magnetic anomaly data in Table I, which had been analyzed for earthquake precursor parameters, with an earthquake epicenter distance from the station maximum 500 Km. Earthquake events that occur have magnitudes> 4 Mw.

Table 2 is 8 magnetic anomaly data and earthquake information that have been analyzed such as anomalious data September 02 2018 and earthquake information September 10 2018. With this it can be stated that the 8 anomalies that have been identified as precursors of earthquakes are a result of internal activities of the earth (lithosphere), because it is seen from the graph of the Dst index data in Figure 6 when an anomaly appears there is no geomagnetic storm event. Determination of the lead time of 8 earthquake events in accordance with earthquake precursors and validation of the Z/H ratio polarization data with sesmograph data from each earthquake event that occurred, obtained the minimum lead time and maximum results from anomalies appearing until the earthquake event occurred for 8 days and 28 days.

With this, it can be stated that the 8 earthquake precursor data is right because it is seen from the lead time there is also no lead time that exceeds the limit that is for 30 days. (a) Onset time Seismograf DST Harian THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 66 (b) (c) Figure 6. (a) Index Dst. in August. (b) Index Dst in September. (c) Index Dst in October Table 2. Data on Anomalies as Precursors and Earthquake Data No. Date Anomalies Amplitudo Anomalies Earthquake Event Lead time (? t) Indeks Dst Magnitude (Mw) Distance (Km) 1. 29 Agustus 2018 2.247 18 September 2018 474 Hour (20 day) -20 nT 4.7 20 2. 02 September 2018 2.771 10 September 2018 175 Hour (8 day) -6 nT 4.6 15 3. 03 September 2018 10.744 11 September 2018 173 Hour (8 day) 2 nT 5.4 17 4. 05 September 2018 5.192 23 September 2018 448 Hour (18 day) -13 nT 4.4 41 5. 14 September 2018 2.267 12 Oktober 2018 658 Hour (28 day) -22 nT 4.9 485 6. 23 September 2018 29.895 11 Oktober 2018 443 Hour (18 day) -27 nT 6.4 232 7. 26 September 2018 6.757 07 Oktober 2018 261 Hour (11 day) -4 nT 5.1 46 8. 06 Oktober 2018 2.461 16 Oktober 2018 251 Hour (10 day) 3 nT 4.9 324 5. CONCLUSION Based on the research that has been done the following conclusions are obtained: THE 6TH ANNUAL SCIENTIFIC MEETING ON DISASTER RESEARCH 2019 67 1.

Changes in the Z / H magnetic anomaly at the time of the earthquake will be caused by lithospheric activity or movement of the earth's plates. 2. Each earthquake will be preceded by the appearance of magnetic anomalies, this can be used as an earthquake precursor. With leadtime between magnetic anomalies and earthquake terjaidnya is 173-658 hours. Referenches [1] Ahadi, S., Puspito, N.T., Ibrahim, G. dan Saroso, S. 2012. Determination Onset time of Earthquake Precursor by Analizing ULF-EM Emission Signal in Sumatra region, Proceeding Conference on Applied Electromagnetic Technology (AEMT), Lombok. hal. 22-26. [2] Ahadi, S., Puspito, N.T., Saroso, S., Ibrahim, G., Siswoyo. dan Suhariyadi., 2013. Prekursor Gempa Bumi Padang 2009 Berbasis Analisis Power Rasio dan Fungsi Transfer Tunggal, Jurnal Ilmia Geomatika, Badan Informasi Geospasial. Bogor. hal. 49-56. [3] Ahadi, S., Puspito, N.T.,

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