Optimum frequency identification of anomalous geomagnetic signal related to earthquake precursor in Sumatra Island

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Abstract. Many scientific studies has detected ULF (ultra-low frequency) emission before an earthquake. An earlier study of Loma Prieta 7.1 M earthquake in 1989 shows ULF anomaly ranged between 0.01-10 Hz before an earthquake. A similar study of Kushiro earthquake 6.4 Mw shows that the ULF anomaly can be detected at a frequency range of 0.022-0.1 Hz. Furthermore, a study conducted in Sumatra Island from 2007-2012 shows the ULF anomaly at 0.01-0.06 Hz. Newer study on the 2009 Padang earthquake and Mentawai 2010 earthquake shows ULF emission between 0.012-0.022 Hz. Based on the aforementioned researches, a study is conducted on frequency range of 0.01-0.09 Hz to identify the optimum ULF frequency. Study conducted in this case uses magnetic diurnal variation data from Sumatra region from 2017 to 2018, especially earthquakes recorded at Gunung Sitoli (GSI), and Sicincin (SCI) stations. Previous studies above provide an overview of ULF ranges associated with earthquakes. Based on all above, an analysis is conducted to find the precursors using data of past earthquake events by utilizing Fast Fourier Transform to transform time-domain data to frequency domain, bandpass filters to eliminate noise, power ratio of $Z/H$ to determine the time window, and Single Station Transfer Function to determine the location window. Lastly, moving average is used to assist determination of time window. Magnetic anomalies between 0.01-0.03 Hz, with amplitude exceeding monthly average, were observed before the earthquakes. Analysis in this frequency range shows occurrence of earthquake 5-6 days after geomagnetic anomalies were detected. This study shows that location window prediction is possible with 100% accuracy. Therefore, 0.01-0.03 is currently the optimum frequency for precursor analysis.

1. Introduction
At present, earthquake precursors have been better studied. An earthquake can be predicted within the range of approximately 30 days from the detected anomaly, and allows prediction of the location of the epicenter of the earthquake to the prediction of magnitude. A study of collaborative monitoring results of non-seismic earthquake precursors by BMKG and Kyushu University using the power ratio polarization method of $Z/H$ components at frequencies of 0.012 Hz and 0.022 Hz geomagnet [1].

However, in the end, the damage potential due to earthquakes remains inevitable, this event can be "predicted" to reduce the impact of damage that occur and save as many human lives as part of natural disaster mitigation.

2. Materials and Methods
2.1 Transforming magnetic diurnal variation into frequency domain

There are 5 (five) interesting Sumatra’s earthquake magnetic anomaly data in which are in the range of 3.904°N to 6.319°S and 94.087°W to 101.250°E. The earthquakes occurred on 12 July 2016, 21 November 2017, 25 May 2017, 13 June 2018 and 25 June 2018. The data is a daily magnetic variation
per second that is transformed using Fast Fourier Transform (FFT) into the frequency domain. However, only 3 (three) of the earthquakes of November 21st, 2017, June 13th, 2018, and June 25th, 2018 will be analyzed and interpreted in this study as the others two are showing too much noise disturbance.

| Table 1. Lists of detail earthquake parameters in this study. |
|---------------------------------------------------------------|
| **Mw** | **Year** | **Month** | **Day** | **HH** | **MM** | **Lon.** | **Lat.** | **Depth** | **Location** |
|--------|----------|-----------|---------|-------|-------|---------|---------|-----------|--------------|
| 5.3    | 2017     | 11        | 21      | 06    | 41    | 96.93 E | 1.37 N  | 15 Km     | 52 Km Northwest Nias, North Sumatra |
| 5.9    | 2018     | 6         | 13      | 06    | 08    | 98.61 E | 2.06 S  | 41 Km     | 105 km Southwest KEP-Mentawai, West Sumatra |
| 4.9    | 2018     | 6         | 25      | 13    | 22    | 100.08 E| 2.86 S  | 24 Km     | 107 km Southeast KEP-Mentawai, West Sumatra |

2.2 Filtering frequency spectrum
Signals resulted from FFT are sorted by creating a frequency bandwidth filter in the range of 0.01-0.03 Hz, 0.03-0.05 Hz and so on up to 0.3 Hz (with range of 0.02 Hz). To get the optimum frequency, the frequency of the ULF signal is then displayed in a graph to be compared in the cross correlation process. The signal that is the focus of study is the signal of the Z component of the magnetic field, since the H component is more sensitive than the Z component to the external field [1].

2.3 Determination of onset time
Onset time is the time which a geomagnetic anomaly is detected for the first time. This parameter is then used as the point of reference for incoming earthquakes. Using polarization ratio of \(Z/H\) it is possible to determine the onset time as introduced by Ahadi, et al. [1]. The value of \(Z/H\) ratio can also be used for predicting magnitude of upcoming earthquake.

2.4 Determining source location of the anomaly
The direction of the magnetic anomaly can be determined by using Single Station Transfer Function (SSTF) [2]. The function is essential to determine source direction of the detected anomaly from reference station, and then the result is presented in an azimuthal fashion (see an example in figure 1).

![Figure 1. Example result of SSTF from multiple stations in Sumatra (BMKG, 2018) [3].](image)

2.5 Magnitude calculation
There are three elements needed to calculate an equation that can be used to determine the magnitude of an earthquake from magnetic data. Those are value of \(Z/H\) polarization ratio (\(A\)), magnitude of earthquake (\(M\)), and hypocenter distance of past earthquake from reference station (\(D\)). The parameters then combined on a fitted model plot (shown in figure 2) to produce an equation as follows,

\[
M = 0.088 \times A + 0.002 \times D + 4.334
\]
The equation was obtained from 30 earthquakes in the Sumatra region with standard deviation of ± 0.2 and correlation coefficient of $r^2 = 0.724$.

2.6 Comparing and corroborating results with secondary data

The results of earthquake monitoring are matched with each other to see whether they support one another or not, as a control between one another. If a discrepancy between stations occurs, it must be repeated the process and evaluated.

At the initial stage, it is necessary to match the prediction data of the precursors with the earthquake event data that has occurred. Matched variables are: (1) calculation of earthquake magnitude prediction with earthquake event magnitude values (2) epicenter prediction through the SSTF method [2] with earthquake event locations, (3) time of earthquake event that occurred after the anomaly was still in a period of fewer than 30 days [1], and (4) Disturbance Storm Time index in that time span.

The next step is to compare the $Z/H$ plot at a particular frequency and related observation stations, for example 0.01-0.03 Hz at the TUN station compared to the MLB station at the same frequency and time. In other words, onset time is corrected by magnitude prediction, location prediction and Disturbance Storm Time index from another reference station.

3. Results and Discussion

3.1 Earthquake of November 21st, 2017 5.3 Mw

The earthquake on November 21st, 2017 occurred with magnitude of 5.3 Mw. The closest station to the epicenter are Gunungsitoli and Padangpanjang station. However, in this event, no magnetic anomalies are occurring and recorded at the same time (see figure 3). Therefore, it is impossible to calculate the magnitude potency and predicting earthquake foreshock zone since the onset time was not determined on higher frequency range, the value of $Z/H$ polarization ratio was too high and will give incorrect value for equation (1).
Figure 3. Z/H polarization ratio for November 21st, 2017 earthquake.

Figure 4. Z/H polarization ratio of June 13th, and June 25th, 2018 earthquake. Onset time of June 13th marked by green arrow. Onset time of June 25th marked by red arrow.
3.2 Earthquake of June 13th, 2018, 5.9 Mw

The results of determining the onset time through $Z/H$ polarization in the 0.01-0.03 spectrum show that there are indeed anomalies with that occur at the same time, the earthquake occurred 6 days after anomaly (of 7 June – 13 June) as shown in figure 4. At the Sicincin station, anomalies are also found at the same time as the Gunung Sitoli station. Further analysis shows that magnitude prediction of 5.9 Mw earthquake prediction deviates by 0.1 to 0.6. However, the location prediction is inside the boundary area of earthquake preparation zone, therefore the location prediction is successful.

Based on equation (1), the parameters of the magnitude calculations are as follows,

- Sicincin 0.01-0.03 Hz: $A = 12$ nT, $D = 251$ Km, and $M = 5.8$ Mw;
- Gunung Sitoli 0.01-0.03 Hz: $A = 2$ nT, $D = 400$ Km, and $M = 5.3$ Mw.

3.3 Earthquake of June 25th, 2018, 5.0 Mw

On 5.0 Mw earthquake, data from both stations presented 0.4 deviation in magnitude prediction. However, the location prediction is correct and the earthquake occurred 5 days after anomaly (June 20th – June 25th). Based on equation (1), the parameters of the magnitude calculation are as follows,

- Gunung Sitoli 0.01-0.03 Hz: $A = 4$ nT, $D = 450$, and $M = 5.4$;
- Sicincin 0.01-0.03 Hz: $A = 7$ nT, $D = 250$, and $M = 5.4$.

Two of the three earthquakes shows good results. The two earthquakes are on 13th and 25th June 2018. The predicted magnitude of the earthquake missed the range, even though the location prediction is correct. Whereas on the earthquake November 21st, 2017 predictions of magnitude and exact location are unable to be determined. So if at least two parameters (2/3 parameters) are correct or close, the...
prediction is considered a success. Also, the WDC index shows no significant disturbance of external magnetic field or storm, as seen in figure 7. Meanwhile, results from higher frequency ranges are showing very high $Z/H$ polarization ratio values and show significant amount of noise. So it is no longer relevant for earthquake prediction analysis. The noises from higher frequency range are expected to exist since it is part of the earth’s natural geomagnetic activities and variation amplitudes can be quantified in tenths of nT for the diurnal variation and hundreds, or exceptionally, thousands of nT in the case of strong magnetic storms [4][5]. At higher frequencies there are various other phenomena, for example geomagnetic pulsations, take place, this could explain why the 0.01-0.03 Hz frequency range is the best frequency range in this study.

Magnitude prediction and calculation in this study is still imperfect. The magnitude is not always exactly the same, because there are outliers from the magnitude data used in the fitting, this is why deviation is expected. Onset time prediction is also imperfect, sometimes there are no earthquake after detected anomaly. However prediction of foreshock location is expected to be accurate because it is directly extracted from the MAGDAS sensors using SSTF. Lastly, for future study it is necessary to have more MAGDAS stations that is closer to each other with maximum distance of 400 kilometers for the best data quality.

![Figure 7](image.png)

**Figure 7.** Disturbance Storm Time index (WDC Kyoto)[6].

### 4. Conclusion

In this study, the ULF signal most associated with earthquake precursors is in the frequency range of 0.01 - 0.03 Hz. The frequency of 0.01-0.03 Hz gives the most optimal amplitude response than the other frequencies in this study, anomalies detected on higher frequency range are more difficult to be analyzed for magnitude prediction, epicenter prediction, and onset time determining because of noise disturbance.

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### References

[1] Ahadi, S., Ibrahim G., Puspito N.T., Saroso S., (2014), Determinations Onset time of Earthquake Precursor by Analyzing ULF-EM Emission Signal in Sumatra Region, Proceeding Conference on Applied Electromagnetic Technology (AEMT), Lombok, 11 - 15 April.

[2] Hattori, K., (2004), ULF Geomagnetic Changes Associated with Large Earthquake, Journal Terrestrial, Atmospheric and Oceanic Sciences (TAO), Vol. 15, No.3, 329-360.

[3] BMKG, (2018), Precursor Review: Sumatra Region 2018, BMKG division of Potential Geophysics and Time.

[4] Syirojudin M., Masturyono, Murjaya, J., Ahadi, S., Yoshikawa, A. (2017), Improving the Analysis Method of ULF Geomagnetic Data for Earthquake Precursor Monitoring in the Sumatera Region. CTBC: Science and Technology Conference.

[5] Kivelson, M. and Russel, C.T. (1995), *Introduction to Space Physics*. Cambridge University Press, pp. 568.

[6] Merrill, R.T., McElhinny and McFadden (1998), *The Magnetic Field of the Earth*. Academic Press, pp. 549.
[7] Geomagnetic Equatorial DST Index, WDC for Geomagnetism, Kyoto DST Index service, <http://wdc.kugi.kyoto-u.ac.jp/dstdir/>.