Possible Detection of Magnetic Anomaly During Tsunami Events in Indonesian Regions Using Global Magnetogram Records

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Abstract. Ocean flow generates secondary, weak magnetic signals relative to the main field induced by the Earth spinning motion, where the secondary signals lead to magnetic anomaly. The anomaly were apparently observed as short-lived variation in secondary field components, namely the vertical $b_z$ and horizontal components $b_H$, respectively, during tsunami occurrence. In this study, maximum amplitudes associated with these components were determined using theoretical approaches and field records on global magnetogram provided by INTERMAGNET and BCMT. The roles played by a depth ratio of $h/L$ where $h$ and $L$ are the ocean depth and characteristic length, respectively, and a speed ratio of $c/c_s$ where $c$ and $c_s$ are the speed for linear long wave solution and the complex speed involving ocean diffusion, respectively, are here examined using Indonesian case studies of tsunami with respect to trans-Pacific tsunamis as reference. For cases with advection dominance, it was found that frozen-flux theory can be used to estimate $b_z$ and $b_H$, consistent with values provided by the global magnetic institutions. In short, whereas $b_z$ is a measure of water surface elevation and hence tsunami height offshore, $b_H$ is an indicator for tsunami propagation direction. Detection of magnetic anomaly prior to tsunami arrivals at coastal zones is thus possible, making it crucial for tsunami early warning.

1. Introduction
The flow of conducting fluid of seawater across the ambient geomagnetic field during tsunami passage in the open ocean generates the so-called secondary, relatively weak magnetic field. This phenomenon is referred to here as ocean dynamo [1]. In this context, tsunami-induced magnetic anomaly signal is apparently observed as magnetic perturbation with respect to the main field and possibly detected as magnetic anomaly by sensitive instrument operated on air- and land-based observatories [2, 3] and that deployed at the seafloor [4, 5]. These field records have suggested that variations in the horizontal and vertical components of the secondary field can be directly related to tsunami wave height offshore and its corresponding tsunami propagation direction, respectively. A recent study by [6] using field records provided by the International Real-time Magnetic Observatory Network (INTERMAGNET) program and Geospatial Information Authority of Japan (GIS) has explored effects of the 2011 Tohoku tsunami on the vertical component $b_z$ while other investigations may utilize ground-based magnetic data from Bureau Central de Magnetisme Terrestre (BCMT). Prior to this study, [7, 8] using numerical tsunami...
simulations applied to the same event examined the main mechanisms of tsunami signals generation, including the horizontal field $b_{H}$. Further numerical codes were used by [9, 10] to explore EM signals due to tsunami passage, focusing on the roles of water depth. A combined method of observations and simulations by [11] also used secondary fields to estimate tsunami wave height and its corresponding propagation direction. Since then, investigations into tsunami-induced signals have been crucial issues for early remote detection of the presence of a tsunami wave in the open ocean.

In this study, the generation of tsunami-induced signals in Indonesian regions is of primary interest. Adopted the methodology discussed in [12], we here use frozen-flux theory elaborated in details in [1, 9, 10] to estimate the horizontal component $b_{H}$ and compare them both to values derived from magnetogram provided by INTERMAGNET and BCMT for three recent Indonesian tsunamis, namely the 2004 Indian Ocean, the 2018 Palu-Donggala, and the 2018 Sunda Strait events. We then analyze and compare the results with respect to two trans-Pacific tsunamis, namely the 2010 Maule, Chile and the 2011 Tohoku, Japan devastating events. Detection of tsunami magnetic signals is thus possible and essential for tsunami forecasting thereby useful for the development of the Indonesian Tsunami Early Warning System (Ina-TEWS), an existing system for tsunami early warning in the country that merely relies on seismic signal monitoring. Therefore, routine monitoring of magnetic signal can be viewed as a search for an alternative method of tsunami early detection based only on seismic observations [13] following major earthquakes of any source of origin in the context of hazard mitigation study.

2. Method
Following [1], the physics of the generation of magnetic anomaly due to tsunami passage in the ocean can be examined from the magnetic induction equation as follows,

$$\partial_{t} b_{z} = -\nabla \times (F_{z} u_{H}) + \kappa \nabla^{2} b_{z}$$

Equation (1) describes how tsunami-induced signal $b_{z}$ evolves in time [1, 4, 5], where the first term on the right-hand side represents the production of the secondary field by tsunami flow $u_{H}$ of advection and the second term denotes contra-production due to ocean diffusion with constant of diffusivity $\kappa$. With respect to the time-independent main field $F_{z}$ (representing the vertical component of the field), analysis of Eq. (1) was discussed by [1] for sea surface observational points. The analysis suggested that the ratio of magnetic perturbation to the steady field $b_{z}/F_{z}$ is proportional to the ratio of sea surface elevation to the ocean depth $\eta/h$ times a speed ratio $c/c_{s}$, in which $c_{s} = c + ic_{d}$ with $c_{d}$ being the rate of diffusion [1]. Thus, as proposed by [1] and further extended by [4, 5, 9, 10] to in situ measurements at the seafloor, in the presence of diffusion, the proportionality takes the general form,

$$b_{z}/F_{z} = c/c_{s} \times \frac{\eta}{h}$$

where $c_{d}$ and $c$ are defined here as $c_{d} = 2\kappa/h$ and $c = (gh)^{1/2}$ with $g$ being gravity, respectively.

Equation (2) shows that tsunami signal is a function of water depth and describes interplay between advection with a rate of $c$ and diffusion with a rate of $c_{d}$ through the ratio $c/c_{s}$. A previous work of [9, 10] went further to quantify the maximum amplitude of a local magnetic anomaly signal $b_{z}$ by first defining the characteristic length-scale $L$ for a local occurrence as $L = (2\kappa/g^{1/2})^{1/3} = 2.53$ km and then using this value to define three different regimes based on the depth ratio $h/L$. As clearly pointed out by [9, 10] and also discussed in this study, the dynamic regimes of interest are diffusion dominance where $0 \leq h/L \leq 0.5$, intermediate where $0.5 \leq h/L \leq 2.0$, and advection takes place where $h/L \geq 2.0$.

We adopt a method developed by [1] and then explored by [4, 5, 9, 10] to derive a simple formula for estimating the maximum value possible for $b_{z}$. In particular conditions where $c/c_{s} \approx 1$ or when advection dominates over diffusion, Eq. (2) simply becomes

$$b_{z}/F_{z} = \frac{\eta}{h}$$

Equation (3) is here referred to as frozen-flux approximation and is used to the first order to estimate the vertical component $b_{z}$. In turn, [4] have used knowledge of $b_{z}$ measured at the ocean bottom to estimate the horizontal component $b_{H}$ for the 2011 Tohoku case as follows,

$$b_{H} = i b_{z}$$

Equation (4) indicates a phase difference between $b_{z}$ and $b_{H}$ signals, as discussed in [5, 12]. Notice that its application is limited in the sense that Eq. (4) is not directly derived from frozen-flux theory and
hence it may break down in some circumstances whereas Eq. (3) is applied to all cases with \( h/L \geq 2.0 \) or \( c/c_s \approx 1 \), as reported in [12].

All the data for tsunami occurrences considered in this study are examined in details. Examination includes estimates of \( b_z \) and \( b_{H1} \) by either calculation using frozen-flux theory or visual inspection on magnetogram provided by INTERMAGNET and BCMT. Direct comparison between values obtained from calculation and magnetogram may provide the essence of tsunami-induced magnetic disturbance and its dynamics for Indonesian tsunami, as well as trans-Pacific tsunamis. The data obtained include numerical values for all components of the main and secondary fields, global bathymetry, and detailed tsunami. Data for \( F_z \) are obtained from http://www.ngdc.noaa.gov/IAGA/vmod/, which is organized by International Association of Geomagnetism and Aeronomy (IAGA) in the form of International Geomagnetic Reference Field (IGRF), 12th Generation Magnetic Model, global ocean bathymetry from which the ocean depth \( h \) is obtained at http://www.ngdc.noaa.gov/mgg/global/relief/ETopo1/, which is organized by the US government through National Geophysical Data Centre (NGDC), National Oceanic and Atmospheric Administration (NOAA), and data for \( \eta \) from the 2010 Chilean and 2011 Tohoku events are all available at http://www.ngdc.noaa.gov. In addition to numerical data, graphical magnetograms are freely available at http://www.intermagnet.org (INTERMAGNET) and http://www.bcmt.fr (BCMT).

3. Results and Discussions

Two trans-oceanic tsunamis across the Pacific (the 2010 Chilean with \( M_W \) 8.8 and the 2011 Tohoku with \( M_W \) 8.9 cases) were examined as reference for \( b_z \) and \( b_{H1} \) signals detection during tsunami passage, where the maximum amplitudes provide upper bounds on both signals in each. For diffusion coming into play, theoretical prediction of \( b_z \) and \( b_{H1} \) requires some ocean parameters, such as ocean diffusivity \( \kappa = (\mu_0 \sigma)^{-1} \) where magnetic permeability \( \mu \approx \mu_0 = 4\pi \times 10^7 \) \( \text{WbA}^{-1}\text{m}^{-1} \) and conductivity \( \sigma \approx 4 \) \( \text{Sm}^{-1} \) while the complex speed \( c_s \) is calculated from \( c_s = (c^2 + c_d^2)^{1/2} \) where \( c \) and \( c_d \) are defined in previous section [see 9, 10 for details]

Table 1 provides the results for the referenced events, where values of \( b_z \) involving ocean diffusion (one column before the last one) are comparable with those estimated using frozen-flux approximation (the last column). Two stations were utilized for each event, where differences in the calculation of \( b_z \) were found to be remaining unimportant. This is supported by the data for the depth ratio \( h/L \geq 2.0 \) and the speed ratio \( c/c_s \approx 1 \) applied to all events examined, indicating cases of advection dominance. Regarding the relatively small deviation from the maximum value possible for \( b_z \), we propose that frozen-flux theory can be used to the first order to estimate \( b_z \) accurately enough when ocean diffusion is absent [12].

| Tsunami event | Magnetic station | \( h \) (m) | \( h/L \) | \( c/c_s \) | \( F_z \) (nT) | \( \eta \) (m) | \( b_z \) (nT) | \( b_z \) (nT) |
|---------------|-----------------|-------------|---------|------------|-------------|---------|-------------|-------------|
| 2010 Maule, Chili | IPM | 6,933 | 2.7 | 0.98 | 19,019.6 | 0.15 | 0.40 | 0.41 |
| | PPT | 5,085 | 2.0 | 0.94 | 18,886.0 | 0.12 | 0.42 | 0.45 |
| 2011 Tohoku, Japan | B14 | 5,830 | 2.3 | 0.96 | 37,271.6 | 2.35 | 14.45 | 15.02 |
| | KAK | 10,272 | 4.1 | 0.96 | 35,619.2 | 4.50 | 15.49 | 15.60 |

As previously addressed, estimates of \( b_z \) and \( b_{H1} \) (if possible) were performed using two approaches, namely analytic (as listed in Table 1) and graphical methods. The graphical method is here provided by magnetogram from INTERMAGNET and BCMT for examples of how tsunami passage generates secondary magnetic signals. Figure 1 provides magnetogram from INTERMAGNET, describing local perturbations due to changes in the sea surface level after a series of large tsunami waves rolled and propagated away from the Chili west coast on February 27, 2010. The magnetic disturbances were recorded at IPM station as periodic signals, particularly in the Z-component, starting at 11:55 UTC and lasting at about 12:55 UTC with its averaged amplitude \( b_z \) of 0.48 nT (during one-hour passage),
The tsunami signals recorded include the horizontal component $b_H$ printed as H in Fig. 1. Numbers on the right-side of the panel denote the corresponding main fields, with a minus sign represents vertical field lines going down to the Earth in the southern hemisphere.

**Figure 1.** Magnetogram from INTERMAGNET for the 2010 Chilean tsunami, showing the H and Z signals with F is the total field (all measured in nano tesla) observed at IPM about 3500 km away from the epicenter after approximately 5 hours-travelling across the Pacific.

The amplitude of $b_z$ shown in Fig. 1 is in good agreement with $b_z \approx 0.5$ nT for the maximum variation in the Z-component of the signals, measured by seafloor instrument reported by [5]. This is consistent with a half peak-to-peak periodic signal (for the same event) of about 1 nT reported by [2]. The $b_z$ estimated from magnetogram is also comparable with that calculated from frozen-flux theory in Eq. (3). However, the amplitude of $b_H$ is difficult to determine from magnetogram of H-component in Fig. 1. Instead, we will then estimate $b_H$ using $H = (X^2 + Y^2)^{1/2}$ where X and Y are the perpendicular components of the horizontal field, estimated from magnetogram provided by BCMT shown in Fig. 2. This gives -0.355 nT and 0.30 nT for X and Y, respectively, corresponding to the horizontal signal of $H = 0.465$ nT, suggesting that prediction of $b_H$ in Eq. (4) is remarkably satisfied. The importance of the X and Y components is that they complete tsunami vector properties and thereby we could infer the direction of tsunami propagation towards N49° W, consistent with that claimed by [5].

For the March 11, 2011 Tohoku event, a huge volume of seawater travelled from the epicenter generating a severe catastrophe that hit Japanese beaches and lands in minutes. Magnetic records from this case showed that a solitary wave induced magnetic perturbations during tsunami passage starting from 6:45 to 7:45 UTC recorded at KAK station with vertical magnetic signals recovered at a value of $b_z \approx 15.8$ nT, as depicted in Fig. 3. The value of $b_z$ obtained from magnetogram is in good agreement with $b_z \approx 15.6$ nT predicted for the same occurrence and station using frozen-flux theory (Table 1).

Further, using an ocean-bottom electromagnetometer (OBEM) deployed at the seafloor and named as B14, [4] measured variations in the vertical geomagnetic disturbance to be in the range 12–19 nT, with $b_z \approx 15.5$ nT was a mid-value, only 3% different from $b_z \approx 15.02$ nT at B14 counted from Eq. (3) using frozen-flux approximation (Table 1). In addition, we could infer that the horizontal component of the field induced by tsunami is given by $b_H \approx 12$ nT. A rather large difference in the value of $b_H$ between the observed value estimated from magnetogram in Fig. 3 below and that predicted by Eq. (4) is speculated owing to early development of a ‘tsunami wave structure’ in the near field. In this stage, $b_z$ is more predictable and reliable for use of a good indicator for tsunami wave generation and thereby the presence of a tsunami wave in the open ocean.
Figure 2. Magnetogram from BCMT for the 2010 Chilean tsunami, showing the X and Y signals (all measured in nano tesla) observed at IPM about 3500 km away from the epicenter.

Figure 3. Magnetogram from INTERMAGNET for the 2011 Tohoku tsunami, showing the H and Z signals with F is the total field (all measured in nano tesla) observed at KAK about 320 km away from the epicenter.

An interesting feature in relation to both Fig. 1 and Fig. 3 can also be examined from the calculated aspect ratios of \( h/L \) and \( c/c_s \) in Table 1. The ratio of \( c/c_s \) increases with increasing \( h/L \), meaning that frozen-flux theory implied by Eq. (3) appears to be good approximation for estimate of \( b_z \) in locations.
where the depth $h \geq 5100$ m, considering that $L = 2.53$ km after [9, 10]. Even if diffusion is included, we have $b_z \approx 14.45$ nT at B14 and $b_z \approx 15.49$ nT at KAK (Table 1), both are calculated from Eq. (2). These values remain insignificantly different from the corresponding measurements in each station for the Tohoku. This warns us that the frozen-flux application is limited with caution in the sense that it is likely to be unsuccessful when applied for events that occur in shallow waters [12].

However, the use of routine monitoring of secondary magnetic signals in the form of magnetogram for early detection of tsunami generation and propagation may help us to be aware of tsunami arrivals. Likewise, the signal detection is independent of whether it is generated by tsunami in the deep ocean. Hence, within this context it may be useful and interesting to see if magnetogram records provided by the two global institutions are alternative solutions to the existing tsunami early warning in Indonesia that relies merely on seismic surveys. We then consider three cases of Indonesian tsunamis, namely the severe 2004 Indian Ocean event, the deadly September 28, 2018 Palu-Donggala catastrophe, and the unique December 22, 2018 Sunda Strait tsunami, named after [14].

For comparison to the trans-Pacific tsunamis, we here provide the 2004 Indian Ocean tsunami with magnetogram from PHU station at 21.3°N and 105.95°E operated by BCMT. This is widely known as the 2004 Sumatra megathrust tsunami with magnitude of $M_W$ 9.1, the epicenter at 3.4°N and 95.7°E and tsunami origin time (OT) at 01:18 UTC. As illustrated in Fig. 4, the observed waveform confirms that the maximum amplitude of the vertical component was found to be $b_z \approx 2.0$ nT, recorded within time interval 1:13–1:22 UTC, consistent with time interval observed for the same event provided by INTERMAGNET (not provided in this paper). This finding is supported by previous work of [1, 12] who claimed the same value for the maximum amplitude of $b_z$ signal for this case.

![Magnetogram from BCMT for the 2004 Aceh event recorded at PHU about 2300 km away from the epicenter, showing the observed vertical component $b_z \approx 2.0$ nT.](image)

Different values of $b_z$ and $b_H$ reported from various events, either trans-Pacific tsunamis or those across the Indian Ocean, are likely caused by different geographical positions of magnetic stations (with respect to the epicenter) used in magnetic surveys, data collection and measurement techniques, types of instruments and their corresponding sensitivity [15], as well as the likely cause of differences in the recorded magnetic signals. In the 2010 Chilean case, tsunami periodic signals were observed while the 2011 Tohoku tsunami travelled like a solitary wave and in the 2004 Indian Ocean tsunami impulsive signals were recorded by both INTERMAGNET (not provided here) and BCMT (Fig. 4).
This suggests that, as addressed by [16], the relatively weak signals require sensitive magnetic sensors to examine past tsunamis and hence better predict future tsunamis.

Furthermore, possible seismic sources of tsunami generation are in question. An avoidable quest for magnetogram is on whether it remains consistent providing quick and accurate information about the presence of a tsunami wave in the ocean. As statistically found for Indonesian tsunamis during three centuries [17], records on past tsunamis indicated that most events were initiated by tectonic movement along subduction zones at plate boundaries from western to eastern Indonesian provinces. However, recent findings launched by Center for Indonesian Earthquakes in 2017 (unpublished work) have suggested that dynamics of fault planes is likely to be potential, if not the new mechanism, for the cause of major earthquakes and hence possible tsunamis. This enables us to test both accuracy and consistency of magnetogram either provided by INTERMAGNET or BCMT using recent occurrences generated by seismic activities along a Palukoro-faulting zone in the case of the September 28, 2018 Palu-Donggala and by volcanic activities towards ‘a flank collapse of Anak Krakatau in Sunda Strait’ predicted by [14] on the December 22, 2018.

The case of the September 28, 2018 Palu-Donggala was initiated by shallow foreshocks of local seismic energy release starting at 10:03 UTC and afterwards with magnitude of $M_w$ 7.5, epicentered on land at 0.18°S and 119.84°E in the northern of Palu, the capital city of Central Sulawesi province. Within minutes these shocks were followed by tsunami generation and subsequently a series of rolling tsunami waves, sweeping up all the buildings and other properties near the bay and its surroundings. Tsunami alert was issued but tragically called off before the waves coming to the nearby shorelines. Along with these two catastrophes, liquefaction that led to mudflow occurred in and around the city, making it worst as many became submerged causing more fatalities. Although the primary cause for the combined disaster remains unresolved, we believe that a strike-slip along Palu-Koro fault induced submarine landslides in Makassar Strait, and in turn generated local deadly tsunami. Figure 5 below describes magnetic anomaly recorded by instrument at GUA station in the western Pacific during limited tsunami arrival times but distinguishable from observed ‘normal fields’ in time-periods before and after the event. The vertical component achieved its peak at approximately 1.3 nT, consistent with the amplitude of $h_z \leq 2.0$ nT addressed by [1, 12] for tsunamis near the equator and comparable with magnetogram from BCMT for the 2004 Aceh case, as seen in Fig. 4.

![Magnetogram from INTERMAGNET for the 2018 Palu-Donggala event, showing the H and Z signals with F is the total field (all measured in nano tesla) observed at GUA about 3200 km away from the epicenter.](image)

**Figure 5.** Magnetogram from INTERMAGNET for the 2018 Palu-Donggala event, showing the H and Z signals with F is the total field (all measured in nano tesla) observed at GUA about 3200 km away from the epicenter.
The case of the December 22, 2018 in Sunda Strait was unique in that tsunami was generated by collapses of a partial body of Anak Krakatau following its eruption a day before in a manner similar to the one predicted and reported by [14]. Tsunami generation was arguably detected by CKI station at 14:03 UTC, a time when continuous tremors were firstly recorded by seismic sensors and about a half of an hour later the wave struck the nearby coastal regions of Banten province in the western Java and farther coastal zones of the southern Lampung, Sumatra. Dangerous alerts owing to either tectonic or volcanic activities were not issued by central authorities because of the lack of monitoring instrument for early detection of volcano-triggered tsunamis. Instead, ‘high waves’ advancing towards shorelines were initially reported as propagation of ‘high tides’ during a period of fullmoon at night on the day.

Figure 6 shows a clear anomaly recorded by equipment at CKI station in the southwest direction away from the epicenter. The vertical signal was found to be $b_z < 0.5$ nT, smaller than that observed in the Palu-Donggala depicted in Fig. 5 but remaining consistent with $b_z \leq 2.0$ nT for equatorial tsunamis after [1, 12]. The magnitude difference in the $b_z$ signal between the 2018 Palu-Donggala tsunami and the 2018 Sunda Strait event is possibly due to differences in the initial mechanical energy available for tsunami generation but discussion on the potential energy release goes beyond this work. Thus, we left this issue behind for further discussion on the importance of magnetogram in terms of early warning. However, there remains an unrevealed story of physics behind shape differences in the vertical signals between the Palu-Donggala and the Sunda Strait events. While a single soliton-wavelike was found in the former, periodic signals were observed for the Sunda Strait. We then speculate these differences for different source mechanisms responsible for each and different locations where tsunamis occurred.

![Cocos-Keeling Islands (CKI) based on 1-minute quasi-definitive data](image)

**Figure 6.** Magnetogram from INTERMAGNET for the 2018 Sunda Strait event, showing the H and Z signals with F is the total field (all measured in nano tesla) observed at CKI about 1100 km away from the epicenter.

From the trans-oceanic tsunamis across the Pacific and Indian Oceans and the last two occurrences in the eastern and western Indonisian regions, where the sources triggering events were not tectonic release along subduction zones, we could argue that for practical purposes secondary magnetic signals termed here as magnetic anomaly introduced by tsunami passage of any type of source mechanism and recorded by magnetogram are possible to detect and are becoming good indicators for the initiation of tsunami generation and hence the presence of a tsunami wave in the ocean. Considering the reliability of magnetic signals detection provided by INTERMAGNET and BCMT, this is of primary importance because we may better use a combined method of tsunami monitoring for early warning system based on both seismic and magnetic signals measured during a particular event.
Given that tsunami-magnetic signals are relatively weak in magnitude compared to the main field, this may drive us to carry out research on sensitive magnetic sensors for future work. In the framework of building a reliable tsunami early warning system, this requires an integrated approach combining theoretical analysis, field measurement and numerical simulation for a more developed method of tsunami-generated magnetic signal monitoring before the wave brings destructions on its all the way to shorelines and lands nearby. To better suit this problem, knowledge of tsunami dynamics propagating over a large distance in the ocean may also be completed with a study of tsunami amplitude variations with increasing travel time and distance as previously discussed by [18, 19], as well as prediction of tsunami arrival times that lead to accounted travel time delays for different observational stations as earlier reported by [20] from near to far field of observations. In this regard, magnetic data feasibility extracted from tsunami-generated secondary signals is of fundamental interest for remotely identifying tsunami generation and propagation hence tsunami development in the early stages.

4. Conclusion
This study has examined magnetic perturbations owing to tsunami passage within the context of ocean dynamo effects. These perturbations induce local magnetic anomaly in the ambient geomagnetic field. Relatively small variations in the secondary fields, measured as $b_z$ and $h_\text{M}$, are possibly detected by magnetic equipment operated at numerous stations distributed over the Pacific and Indian Oceans. Magnetic information in the form of magnetogram for tsunami early detection is available for free provided by INTERMAGNET and BCMT, where the vertical signal is parameterized by frozen-flux theory for advection-dominant oceans with $h/L \geq 2.0$ and $c/c_s \approx 1$. For other cases including those generated by sources other than tectonic movement at plate boundaries, the 2018 Palu-Donggala and Sunda Strait events, for example, the $b_z$ and $h_\text{M}$ signals derived from magnetogram are distinguishable from those of normal fields. Therefore, magnetogram is useful for rapid assessment of the presence of a tsunami wave in remote areas away from beaches, independent of whether a tsunami event occurs in the deep oceans or in shallower waters, or alternatively whether mechanical-seismic energy release available for such an event is of tectonic or volcanic origin or a submarine landslide. In the context of tsunami hazard mitigation study, the use of magnetogram in tsunami early warning is of significance as it may help to reduce fatalities. This method is not aimed at replacing the Ina-TEWS performance based solely on seismic signals. Instead, it provides an alternative approach for tsunami monitoring using magnetic signals in the early stages of tsunami development.

Acknowledgments
The authors would like to thank the authorities both in Postgraduate Program, The State University of Surabaya and in the University for their policy to provide research funds available for this work to complete under financial research contract No. B/51163/UN38.8/LT.02/2019 dated on July 16, 2019. The authors also sincerely thank anonymous reviewer(s) for valuable suggestions and comments on the original form of the manuscript.

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