Analysis of M 5.3 Sumbawa, Indonesia earthquake 2020 and its aftershocks based on hypocenter relocation from BMKG seismic stations

To cite this article: M Ramdhan et al 2021 IOP Conf. Ser.: Earth Environ. Sci. 873 012070

View the article online for updates and enhancements.
Analysis of M 5.3 Sumbawa, Indonesia earthquake 2020 and its aftershocks based on hypocenter relocation from BMKG seismic stations

M Ramdhan1*, Priyobudi1, A Mursityanto2, K H Palgunadi3, Daryono1

1The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), Jl. Angkasa I No.2, Kemayoran, Jakarta 10720
2The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) region III, Jl. Raya Tuban, Kuta, Badung, Bali 80361
3Physical Science and Engineering, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

E-mail: mohamad.ramdhan@bmkg.go.id

Abstract. The 2020 Sumbawa earthquake of moderate magnitude (M 5.3) produced very significant aftershocks. Based on the computation of Utsu’s method, those aftershocks would be ended after the 20th day. Those earthquakes along 20 days were relocated using double-difference method. The relocation results show the southwest-northeast orientation and getting deeper into the northwest direction. Those two directions show the strike and the dip from the fault plane of the earthquake which was consistent with the focal mechanism released by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). Those results showed the majority of earthquakes occurred at a depth of shallower than 20 km. Those earthquake depths were fit with the previous study showing the crustal thickness beneath Sumbawa Island that was about 28 km. We also found that those earthquakes occurred at splay faults propagating to decollement structure. This study is beneficial for earthquake disaster mitigation especially in updating active faults on Sumbawa Island.

1. Introduction
The tectonic system of Sumbawa Island is affected by the Indo-Australian oceanic plate subducting to the Eurasian continental plate. This interaction is caused by the formation of a back-arc thrust fault along the north of Lombok Island to the north of Flores Island (The Flores back-arc thrust) [1]. The series of large earthquakes at the north of Lombok Island in 2018 that occurred in the fault caused many casualties, injured, and infrastructure damages. Besides affected by the fault and the subduction system, earthquake activities around Sumbawa Island were also caused by some active faults, such as the earthquake that occurred on June 13th, 2020. The earthquake was considered as a moderate earthquake (M 5.3) following by a number of aftershocks. The mainshock was felt across Sumbawa, Lombok, and Bali Islands with a maximum intensity felt on Sumbawa Island at IV Modified Mercalli Intensity (MMI) and a minimum intensity felt in
Karangasem Regency, Bali Province at II MMI. The earthquake was hosted by an active fault that had not been previously clearly identified. Thus, this study has a significant contribution in delineating the active fault in the study area. Active fault identification is advantageous in mitigating one area from a disaster caused by a significant earthquake, therefore, devastating effects can be minimized. The active fault delineation had been successfully applied using hypocenter relocation results in the Palu-Koro active fault at the Palu-Donggala fault segment [2].

2. Data and Methods
We used the BMKG region III earthquake catalog for 20 days from June 13th to July 3rd, 2020 within the coordinates of 116°-120°E and 8°-10°S. We removed unrelated earthquakes with the mainshock. Figure 1 shows the study area and seismic stations used to relocate earthquakes. The time range was obtained from aftershocks decay computation based on Utsu’s method [3]. We calculated based on the method using aftershocks for 13 days as shown in figure 2 (a). Based on Utsu’s method [3], the aftershocks would be approximately insignificant after the 20th day as depicted in figure 2 (b). We applied double-difference method to relocate the mainshock and aftershocks [4,5]. Each earthquake at least has six phases (P and S phases or P phases only) and maximum distance from earthquake sources to seismic stations was considered 500 km. Those criteria had been applied successfully to detect an interface zone in the Palu-Koro active fault [6]. In this study, we utilized existing models for P-wave speed (Vp) and the ratio of P- to S-wave speed ratio (Vp/Vs) [7,8].

Figure 1. Brown reverse triangles show the seismic station position used in this study. Black rectangle indicates the study area.
3. Result and Discussion

We successfully relocated 135 hypocenters from 221 earthquakes for 20 days. The biggest aftershock magnitude was M 4.5. A number of earthquakes could not be relocated because they were not fit with the inversion criteria. We utilized the bootstrap method to compute the relative error of the hypocenter location \((X_0, Y_0, Z_0)\) \([4,9,10]\). Those results show a majority of those parameters is less than 1.5 km such as shown in figure 3. The statistic parameter of those errors is presented in table 1.

![Figure 2. Daily histogram of aftershock distribution for 13 days (a) and aftershock temporal decay based on Utsu’s method [3] (b).](image)

![Figure 3. Histograms of relative location errors of mainshock and aftershocks Sumbawa earthquakes 2020 using the bootstrap method. Confidence ellipsoids resulted from a bootstrap analysis for those errors is 95%.](image)
Tabel 1. Statistic parameters of relative error locations computed based on the bootstrap method.

| $x_0$ error (km) | $y_0$ error (km) | $z_0$ error (km) |
|------------------|------------------|------------------|
| Mean             | Min              | Max              | Mean             | Min              | Max              | Mean             | Min              | Max              | Stdev            |
| 1.09             | 0.6              | 2.07             | 0.67             | 0.23             | 1.69             | 0.98             | 0.38             | 4.98             | 0.81             |

BMKG released a source mechanism with strike orientation N224°E and dip angle 49° to northwest direction. The source mechanism was computed using moment tensor inversion [11]. Seismicity map after hypocenter relocation showing the strike orientation is consistent with the source mechanism released by BMKG as shown in figure 4 (b). Before relocation, the strike orientation of aftershock distribution is perpendicular to the strike orientation of the source mechanism as shown in figure 4 (a). This emphasizes the importance of this study in relocating hypocenter, therefore, more reliable aftershocks distribution that is consistent with tectonic stress loading orientation in this area can be useful in understanding an active fault. The results of this study were also consistent with the GPS observation study at the BIMA and LABU stations showing that the local tectonic force on Sumbawa Island was oriented towards the northwest [12]. The tectonic force had the same direction as the mainshock dip direction based on the moment tensor inversion. This showed that the M 5.3 Sumbawa earthquake was caused by the local tectonic force on the island.

The hypocenter relocation results show a significant shift in the hypocenter depth where fixed depths at 10 km could be enhanced to be more reasonable positions as shown in figures 5 (b) and 5 (d). Those fixed depths also caused misoriented dip direction as shown in figure 5 (c). The direction of dip to the northwest is more reliable after hypocenter relocation as shown in figure 5 (d). The fixed depth itself occurred because of the non-convergence during the inversion. The necessity for fast parameters in disseminating earthquake information caused unavoidable fixed depth, thus the relocation process must be applied to obtain a more precise and reasonable hypocenter location. Precise hypocenter parameters are beneficial for further tectonic studies. Meanwhile, the earthquake parameters that are disseminated by the BMKG are accurate enough for emergency response purposes. Stakeholders can use this information to perform rapid rescue and evacuation if there is a potential for a significant earthquake and tsunami disaster because the information can be received in less than 5 minutes. The results of this study show the majority of earthquake depths occurred at a depth of less than 20 km as showed figure 5 (b) and 5 (d). They were consistent with the previous study stated that the crustal thickness beneath Sumbawa Island was about 28 km [13]. The schematic model of fault structures causing the Sumbawa earthquake M 5.3 and its aftershocks are shown in figure 6. The model shows a low-angle thrust fault called a decollement structure at a depth range of 13-15 km. The fault plane became steeper before 13 km depth that indicated splay faults in which the mainshock and majority of aftershocks occurred at those structures. A number of aftershocks also propagated to the decollement structure that is located beneath those faults.
Figure 4. Seismicity map before (a) and after (b) hypocenter relocation. A-A’ and B-B’ are two vertical section lines following strike and dip directions based on the focal mechanism released by BMKG. The maximum distance of earthquakes to each line is 60 km. The yellow star shows the mainshock of the Sumbawa earthquake M 5.3. The topographic map used SRTM Non-Void Filled [14].

Figure 5. Vertical section before (a) and after (b) hypocenter relocation along strike direction. Vertical section before (c) and after (d) hypocenter relocation along dip direction. The yellow star shows the mainshock.
Figure 6. Schematic model of splay faults and decollement structure based on hypocenter relocation along dip direction. The mainshock and aftershocks of the Sumba earthquake 2020 occurred at those geology structures. The black star shows mainshock.

4. Conclusions
This study successfully delineates the orientation of strike and dip directions which is consistent with the moment tensor inversion released by BMKG and local tectonic force in the area. Those results show that the mainshock and aftershocks series occurred at splay faults and decollement structure. The Sumbawa earthquake M 5.3 was caused by tectonic force in northwest direction. The study is so worthwhile in advanced tectonic study especially in updating active faults which will be used for disaster mitigation in the area.

Acknowledgement
We are very grateful to The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) region III for providing the earthquake catalog for this research. This study also was supported by Komite Kajian Gempa bumi dan Tsunami BMKG 2020.

References
[1] Hamilton W B 1979 (US Govt. Print. Off.)
[2] Priyobudi P and Ramdhan M 2020 Jurnal Lingkungan dan Bencana Geologi 11 1–9
[3] Utsu T 1961 Geophys Mag 30 521–605
[4] Waldhauser F and Ellsworth W L 2000 Bull Seismol Soc Amer 90 1353–68
[5] Waldhauser F 2001 US Geol. Surv. Openfile report 01–113
[6] Ramdhan M and Priyobudi 2019 J. Phys.: Conf. Ser. 1341 082009
[7] Koulakov I, Bohm M, Asch G, Lühr B-G, Manzanares A, Brotopusito K S, Fauzi P, Purbawinata M A, Puspito N T, Ratdomopurbo A, Kopp H, Rabbel W and Shevkunova E 2007 J Geophys Res: Solid Earth 112
[8] Wadati K 1933 Geophys. Mag 7 101–11
[9] Billings S D 1994 Geophys J Int 118 680–92
[10] Efron B 1982 (Society for Industrial and Applied Mathematics)
[11] Minson S E and Dreger D S 2008 Geophys J Int 174 585–92
[12] Nugroho H, Harris R, Lestariya A W and Maruf B 2009 Tectonophysics 479 52–65
[13] Syuhada S, Hananto N D, Abdullah C I, Puspito N T, Anggono T and Yudistira T 2016 Acta Geophys 64 2020–49
[14] Earth Resources Observation And Science (EROS) Center 2017 Shuttle Radar Topography Mission (SRTM) Non-Void Filled