Analysis of the Mw 6.5 Ambon Earthquake (September 26, 2019) based on the aftershocks hypocenter relocation

P Supendi$^{1,2}$, A D Nugraha$^{2,3}$, S Widiyantoro$^{3,4}$, C I Abdullah$^{5}$, Daryono$^{1}$, D Karnawati$^{1}$, K H Palgunadi$^{6}$, S Rohadi$^{1}$, M T Gunawan$^{1}$, S Rosalia$^{2,3}$

1 Agency for Meteorology, Climatology and Geophysics (BMKG), Jakarta 10720, Indonesia
2 Center for Earthquake Science and Technology (CEST), Research Center for Disaster Mitigation, Institut Teknologi Bandung, Bandung 40132, Indonesia
3 Global Geophysics Research Group, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Bandung 40132, Indonesia
4 Faculty of Engineering, Maranatha Christian University, Bandung 40164, Indonesia
5 Geodynamic and Sedimentology Research Group, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung, Bandung 40132, Indonesia
6 Physical Science and Engineering, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

E-mail: pepen_geophysics@yahoo.com

Abstract. On September 26, 2019, an earthquake (Mw 6.5) occurred in the northern part of Ambon Island, Molucca, East Indonesia. The National Authority show this earthquake caused infrastructures damage and 28 fatalities. Up to October 31, 2019, the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) seismic network had recorded 479 aftershock events. We have relocated 463 out of the 479 aftershocks using the double-difference method. Our results show that some improvements in the hypocenter locations, where the focal depths of initial earthquakes fixed at 10 km have been updated to ~9.8 km depth on average. There are two aftershock clusters in a North-South direction of ~35 km length between Ambon Island and Haruku Island and in a West-East direction of ~30 km length in the Ambon Island, each with a width of ~8 km.

1. Introduction

Ambon Island, north of the Banda Arc, eastern Indonesia, was shaken by an earthquake that occurred on September 26, 2019. According to the BMKG report, this earthquake occurred at 23:46:45 UTC with a magnitude (Mw) 6.5, the epicenter is located at 3.38° S; 128.43° E with a depth of 10 km. The focal mechanism solution of the mainshock shows a strike-slip fault (Figure 1). The analysis of the BMKG shakemap indicate that this earthquake was moderate to strong level (V to VI) on the Modified Mercalli Intensity (MMI) scale in Ambon Island and its vicinity. The authority reported that there were at least 28 fatalities, 150 people were seriously injured, and 240,000 people were evacuated. About minutes after the mainshock, a sequence of aftershocks hit this area for a few weeks.

The aim of this research is to relocate the location of aftershocks to explain the relationship between the events and the existing fault in the research area. Based on historical seismicity, this area had been hit by several major events in the past, e.g., the 1674 tsunami earthquake (Mw 8.1) on the northern part of Ambon [1] and the 1950 (Mw 7.3) earthquake southern part of Ambon Island [2].
Figure 1. Map view of the research area. Inset depicts the Indonesian region. The mainshock (red star) is taken from BMKG and the focal mechanism solution extracted from the Global Centroid Moment Tensor (GCMT). Blue inverted triangles depict the BMKG seismic stations.

2. Data and Method
We used the aftershocks arrival-time data from the BMKG earthquake catalog for 36 days (26 September to 31 October 2019). During the time, there were 479 events with depths of less than 30 km for local magnitude ($M_L$) 1.5 to 5.0 with 3897 and 1482 of P- and S-phase arrival times, respectively. The BMKG hypocenter locations generated by the SeisComP3 Program (GFZ) used the IASP91 velocity model [3]. For relocating the hypocenter of the aftershocks, we used the HypoDD program [4] which utilizes the Double-Difference method [5]. The method assumes that ray paths of two or more hypocenters to the station are considered to be similar and propagate passing the same medium if the hypocenters distance pair is smaller than the hypocenters and station distance. Residuals between observed and calculated travel-time differences were minimized by HypoDD in an iterative procedure. We used the AK135 velocity model [6] for this research. To estimate the relocation uncertainty, we performed a Bootstrap method [7, 8].

3. Results and Discussion
Totally, 463 out of 479 aftershocks have been relocated (Figure 2). Our relocation result shows there are patterns in N-S and E-W headings of ~ 35 km and ~ 30 km lengths, respectively, and each with a width of ~ 8 km. Average horizontal and vertical of hypocenter uncertainty are 0.9 and 1.04 km (Figure 3). Based on the previous study [9], the fault plane of the mainshock is in the N-S direction. Our interpretation that the second trend of the aftershock in the S-W direction probably was related to triggered seismicity of the active fault by the mainshock.
Figure 2. Map view for relocated aftershocks depicted in red to green dots. The red star is the epicenter of the mainshock from BMKG. Blue inverted triangles represent the BMKG seismic stations.

Figure 3. (a) Map view of relative location uncertainties for the 463 aftershocks; (b) depth view along longitude; and (c) depth view along latitude.
We compare the relocated aftershocks with the initial locations (Figure 4). Hypocenter relocation of aftershocks indicates improvement in location, especially the initial earthquakes at fixed depth have been updated. Generally, the focal depths of relocated aftershocks in the N-S trending is less than 10 km on average. Tomography study in the area [10] also shows a significant feature at 10 km depth with a contrast velocity underlying the area between Ambon and Haruku Islands, suggesting the existence of an active fault line.

Figure 4. Distribution of the aftershocks and vertical cross-sections for (a) BMKG locations, and (b) hypoDD relocation, 463 events respectively. The red to the green dots depict the epicenter of earthquakes based on depth in km.
4. Concluding Remarks
We relocated 463 aftershocks of the Ambon earthquake from 26 September to 31 October 2019. The initial locations fixed at 10 km depth have been updated. There are two aftershock clusters in North-South and West-East directions. The N-S trend is the main fault plane located between Ambon Island and Haruku Island, whereas the S-W trend is probably related to triggered seismicity of another fault plane in Ambon Island.

Acknowledgements
We thank BMKG for the earthquake data. We made all figures using the Generic Mapping Tools [11].

References
[1]. Løvholt F, Kuhn D, Bungum H, Harbitz C B, and Glimsdal S 2012 Historical tsunamis and present tsunami hazard in eastern Indonesia and the southern Philippines J. Geophys. Res. Solid Earth 117 (B9) B09310 https://doi.org/10.1029/2012JB009425.
[2]. Latief H, Kodijat A, Ismoyo D, Bustamam B, Adyasar D, Nurbandika N, and Rahayu H 2016 Air turun naik di tiga negeri United Nations Educational, Scientific, and Cultural Organization, Office Jakarta - Indian Ocean Tsunami Information Centre (in Indonesian).
[3]. Kennett B L N and Engdahl E R 1991 Travel times for global earthquake location and phase association Geophys. J. Int. 105 429–465.
[4]. Waldhauser F 2001 HypoDD – A Program to Compute Double-Difference Hypocenter Locations United States Geological Survey.
[5]. Waldhauser F and Ellsworth W L 2000 A double-difference earthquake location algorithm: Method and application to the Northern Hayward fault California Bull. Seismol. Soc. Am. 90 1353–1368.
[6]. Kennett B L N, Engdahl E R, and Buland R 1995 Constraints on seismic velocities in the Earth from traveltimes Geophys J. Int., 122, 108–124.
[7]. Efron B 1982 The Jackknife, the Bootstrap and other Resampling Plans J. Soc. Ind. Appl. Math.
[8]. Billings S D 1994 Simulated annealing for earthquake location Geophys. J. Int. 118 680–692.
[9]. Sahara D P, Nugraha A D, Muhari A, Rusdin A A, Rosalia S, Priyono A, Zulfakriza Z, Widiyanto S, Puspito N T, Lesmana A, Kusumawati D, Ardianto, Baskara A W, Halauwet Y, Shiddiqi H A, Pradisti R, Mozef P W, Tuakia M Z, Elly E 2021 Analysis of the Source Mechanism of the Mw 6.5 Ambon, Indonesia Earthquake and Its Impact to the Surrounding Fault Network Using Local Seismic Network Data Tectonophysics 779 228709.
[10]. Nugraha A D, Supendi P, Rosalia S, Sahara D P, Muhari A, Priyono A, Zulfakriza Z, Widiyanto S, Puspito N T, Harisandi A A 2020 Local Earthquake Tomography to Investigate the Fault Geometry Causing the Mw 6.5 Ambon, Indonesia, 26 September 2019, J. Geophys. Res. Lett. (submitted).
[11]. Wessel P and Smith W H F 1998 New, Improved Version of Generic Mapping Tools Released. EOS Trans AGU 79 (47) p. 579.