Preliminary coseismic deformation associated with the July 7th 2019 M7.0 north Maluku earthquake

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Abstract. The 2019 July 7th North Maluku earthquake with M7.0 occurred in the Sangihe double subduction zone. The earthquake epicenter is located at latitude 0.54 N and longitude 126.19 E. Here, we employ continuous Global Positioning System (cGPS) observations to estimate coseismic deformation associated with the North Maluku earthquake. Using 6 days cGPS observations before the event and 6 days cGPS observations after the event we estimate coseismic deformation at 4 nearest cCGPS stations. The coseismic deformation for CTER (Ternate) cGPS stations which located about 134.80 km from epicenter is about 8.4 mm to north-west direction, while the coseismic deformation for CBIT (Bitung) cGPS station (about 151.68 km from epicenter) is 8.3 mm to the south-east direction. Coseismic deformation for another two cGPS stations (CTBL/Tobelo and CTHN/Tahuna) are about 3.0 - 3.6 mm. This value is very important to maintenance the Indonesian geodetic control network in Indonesia and earthquake studies in Indonesia.

1. Introduction

The 2019 North Maluku, Indonesia, earthquake, hereinafter terms NME, occured at 15:08:42 UTC, 07 July 2019 at a complex plate boundary in the eastern Indonesia between North Sulawesi Province in the west and North Maluku province in the east. The Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) reported the NME magnitude is Mw7.0 and the epicenter is located at 0.54°N and 126.19°E with depth at 36 km. The 2019 NME can be classified as a shallow earthquake caused by subduction plate tectonic [1]. Subduction between microplate Halmahera westward and microplate Sangihe eastward lead plate sandwiched Maluku sea until there is a double subducting plate to the bottom plate down Halmahera and Sangihe [1].

The region of 2019 NME is active arc-arc collision and a subducted plate with an inverted U-shape, having slab dipping to the west under the active volcanic ares of Sangihe and to the east under the active
volcanic arcs of Halmahera [3]. The 2014 Molluca Sea earthquake and the swarm of earthquake activity along Halmahera arc in November 2015 suggested that this region is active [2]. Figure 1 shows the tectonic setting of this study, following [3].

The use of Global Positioning System (GPS) data on earth science study have been well and widely implemented. GPS has shown capability to capture the interseismic [4],[5], coseismic [6],[7], and postseismic [8],[9] during earthquake cycle associated with plate tectonic activity. The coseismic deformation on the development of deformation model of Indonesia reference frame has been studied [10],[11],[12],[13].

One of the underlying motivations of this study is to understand coseismic deformation related to the 2019 NME with the development of deformation model of the Indonesian reference frame. The particular continuous GPS (cGPS) data used for this estimate are static measurements from stations that are part of a nationwide GPS network named the Indonesian Continuously Operating Reference Stations (Ina-CORS).

![Figure 1. Tectonic background of this study. The beach ball indicates the location of the 2019 NME. Magenta dots are aftershock until 13 July 2019 [1]. Black triangles denotes location of the cGPS stations used in this study. Inset shows the larger regional setting [18].](image)

2. GPS observations and data processing
In this study, we use cGPS data obtained from the Geospatial Information Agency of Indonesia (BIG) that are part of Ina-CORS stations. These cGPS stations are CBIT, CTHN, CTBL, and CTER. CBIT is located in Bitung city, North Sulawesi province, while CTHN is located in Tahuna city, North Sulawesi province. CTER is located in Ternate city, North Maluku province while CTBL is located in Tobelo
city, North Maluku province. The CBIT, CTHN, and CTBL stations were constructed with 3 m high concrete pillar from the ground, while CTER station was constructed on concrete benchmark on the top of roof. The cGPS distribution used in this study shows in Figure 1.

The cGPS observation data were processed using GAMIT-GLOBK [14],[15]. We included the International Global Navigation Satellite Systems (GNSS) stations of ALIC, BAKO, COCO, DARW, DGAR, GUUG, HYDE, IISC, KARR, LHAZ, MCIL, PIMO, XMIS and YARR, and tie our local network into the ITRF2014 reference frame [16]. We mapped the loosely constrained solution onto a well-constrained reference frame by minimizing the position and velocity differences of selected stations with respect to a priori values defined by the IGS14 realization of the ITRF2014 reference frame.

We analyzed daily solutions from cGPS data at each cGPS station and subtracted the velocity of six days after the 2019 NME to six days prior the mainshock, using the result as the coseismic displacements associated with this earthquake at each GPS station. Figure 2 shows the coseismic displacements at CBIT, CTER, CTHN. and CTHN.

Figure 2. Coseismic displacement of the 2019 NME. Red arrows indicate observed coseismic displacement at each cGPS stations. The beach ball indicates the location of the 2019 NME. Magenta dots are aftershock until 13 July 2019 [1]
3. Result and discussions
We found that the coseismic displacements of each GPS station directed towards earthquake rupture, with displacements at CTER towards the NW direction, displacement at CBIT towards the SE direction, while displacements at CTHN and CTBL directed towards the NE and NW (Figure 2). Our results show that CTER the nearest station from epicenter (± 134.80 km) experienced large coseismic displacements of up to 8.4 mm, CBIT (± 151.68 km) experienced displacements of 8.3, while CTBL (± 241.27 km) and CTHN (± 349.93 km) experienced displacements of 3 mm and 3.6 mm, respectively. Using empirical formula that approximate the radius of influence of earthquake [17], we calculate the coseismic displacement at each cGPS stations. The empirical formula calculate the magnitude of coseismic displacement. The residual of the coseismic displacements between observed and calculated show in the Table 1. The residual value is about 1.4 – 3.3 mm with the standard deviation is 1.1.

| Site  | Observed (mm) | Calculate (mm) | Residual (O-C) (mm) |
|-------|---------------|----------------|---------------------|
| CTER  | 8.4           | 5.1            | 3.3                 |
| CBIT  | 8.3           | 4.1            | 4.2                 |
| CTBL  | 3.0           | 1.6            | 1.4                 |
| CTHN  | 3.6           | 0.8            | 2.8                 |

The different between observed and calculate of coseismic displacement suggested that the calculation of coseismic deformation need to be improved to get better solution. The coseismic displacement of the 2019 NME is very important information to study the deformation model of Indonesia reference frame, earthquake sciences, and earthquake hazard map, respectively.

4. Conclusions
We use cGPS data to estimate a coseismic displacement of the 2019 NME. The coseismic displacement of the 2019 NME have been detected at 4 cGPS stations, although in the millimetre level. The information of coseismic displacement of the 2019 NME is very important for the development of coseismic deformation model of Indonesian reference frame, earthquake studies, and earthquake hazard map.

5. References
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