Ionosphere Anomaly Analysis before Earthquake Using GPS (Case Study: Banten Earthquake August 2\textsuperscript{nd}, 2019)

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Abstract. This research is to analyze anomalies in the ionosphere that occur when an earthquake occurs. When an earthquake occurs, three types of waves are generated, namely: acoustic waves, gravity waves, and reyleigh waves. Acoustic waves generated perpendicularly from the earth's crust during an earthquake propagate into the ionosphere, where they create electron density deviations. This phenomenon is detected as CIDs (Coseismic Ionosphere Disturbances), namely TEC (Total Electron Content) fluctuations that occur 15 minutes to 1 hour after an earthquake occurs. As a result of this deviation, the electromagnetic waves emitted by the GNSS (Global Navigation Satellite System) satellite will delay when passing through an ionosphere of approximately 300 km from the earth's surface. The earthquake data used in this study came from earthquakes in Indonesia with the potential for a tsunami, namely the Banten earthquake on August 2, 2019 (7.4Mw from BMKG) with GNSS data from the closest CORS station to the epicenter, namely the CPTN, CPTU, and CUJG stations. The processing results show that there is a TEC anomaly recorded by GPS satellite no. 29 which appears 15-20 minutes after the earthquake. Anomalies ionosphere that occurs during an earthquake are expected to be useful as an early warning system before a tsunami happened.

1. Introduction

The Indonesian archipelago located above three main tectonic plates of IndoAustralia, Pacific, and Eurasia extended from Western Sumatra to East Papua. The shift of these plates has caused tectonic activity such as deformation, volcanic eruptions and earthquakes. To monitor the development of tectonic activity, geodetic engineering studies play a very important role, namely the Global Navigation Satellite System (GNSS) technology which is can used to monitor the movement of the earth's plate and the effects that occur in the ionosphere by utilizing the GNSS satellite. GNSS technologies such as GPS Continuously Operating Reference Stations (CORS) can also be used to monitor deformations (Anjasmara et. Al., 2018; Rwabudandi I et. Al., 2019), volcanic eruptions (Nakashima et. al., 2016; Sari and Cahyadi, 2019; Cahyadi et. al., 2020) and the earthquake (Cahyadi and Heki, 2013; Cahyadi, 2014; Cahyadi and Heki, 2015; Cahyadi et. al., 2018; Cahyadi et. al., 2019). Spatial analysis for ionosphere anomalies has also been carried out using 3D tomography techniques from an altitude of 100 km to 600 km above the earth's surface (Muafiry et. Al., 2018; He and Heki, 2018). This method will be able to detect ionosphere disturbance anomalies both spatially (anomaly distribution location) and temporal (anomaly time) from 25 minutes to 1 minute before the earthquake occurs (He and Heki, 2018). TEC changes before the earthquake or what is known as Preseismic...
ionospheric anomaly have been found ~ 40 minutes before the 2011 Tohoku-ki earthquake by Heki (2011), the same TEC changes were also found before the 2005 Nias earthquake (Mw 8.6) and Bengkulu 2007 (Mw 8.5) sumatra (Cahyadi ang Heki, 2013). In addition, there is also a change in TEC after an earthquake called Coseismic Ionospheric Disturbance (CID), this change was found 15 minutes to 1 hour after the earthquake (Cahyadi and Heki, 2013; Cahyadi, 2014; Cahyadi and Heki, 2015; Cahyadi et. al., 2018; Cahyadi et. al., 2019). The ionosphere changes observed by the GNSS satellite are expected to be used as Early Warning System (EWS) before the tsunami strikes, where the tsunami waves are estimated to have a speed of about 600-700 km hours. If this tsunami wave can be detected in the high seas, there will be enough time to evacuate to a higher place.

2. Research Location
Banten is used as the research location where the Banten earthquake happened on August 2nd, 2019 with a relatively big magnitude of 7.4 MW (6.9 Mw according to BMKG) with tsunami phenomenon which happened simultaneously.

![Research location of Banten Earthquake, August 2nd 2019 with the magnitude scale of 7.4 Mw](source)

According to Meteorology, Climatology, and Geophysical Agency (BMKG). The earthquake occurred on Friday 2 August 2019 at 19:03:25 WIB with a magnitude of 6.9. The center of the earthquake (epicenter) is located at sea at coordinates 7.32 ° LS-104.75 ° East. It is located off the coast of the western end of the island of Java with a shallow depth of about 48 km. This occurs due to the collision between two plates, namely the Indo-Australian and the Sunda plate (part of the Eurasian plate). The slow but sure movement of the Indo-Australian plate at a speed of 60 mm year to the northeast against the Sunda plate, has caused the Indo-Australian plate to sink below the Sunda plate. This earthquake occurred in the lithosphere part of the Indo-Australian plate. This earthquake has a source mechanism at the center of the earthquake, which is a rotating upward fault type (Oblique Thrust Fault). Related to earthquake activity around this area, two earthquakes were recorded which resulted in a tsunami, namely an earthquake with a magnitude of 7.8 on 2 June 1994 and an M 7.7 earthquake on 17 July 2006, both of which occurred in southern Java and were the result of upward faults that occurred above the shallow plate near the Sunda-Java trench.
3. Methodology
The data used in this research are
a. GNSS Rinex observation data from the Geospatial Information Agency (BIG)
b. Satellite navigation data

Methodology used in this research can be seen in the following flow-chart:

![Flow-chart](image)

Figure 2. Data processing flow-chart.

4. Analysis and Result
4.1. SIP Plotting
Satellite-path processing using rdeph.f program which results in a position that can be plotted.
Figure 3 shows the results of plotting the GPS satellite trajectory during an earthquake, it can be seen that the satellites orbiting during the earthquake are satellites number 21, 24, 25, and 29. The results of the calculation of the TEC anomaly value show that the satellite signal that can record TEC fluctuations in the ionosphere layer is satellite number 29, this is because the orbit of satellite number 29 is the one that passes through the center of the earthquake. The blue line indicates the satellite path number 29 mapped by SIP from all observation stations when the earthquake happened. The red star indicates the epicenter of the earthquake and the black dot shows GPS CORS stations.

4.2. TEC Anomaly Plotting
TEC data was obtained by rinex observation using rd.mx.f program with the result of STEC time and value, and then plotting was done using Matlab application. The result of TEC anomaly plotting from GPS satellite can be seen as follows:
Figure 4 shows that the earthquake occurred at 12:05 UT (vertical line). The TEC anomaly data appears in all observation stations, CPTN, CPTU, and CUJG stations which are CORS BIG GPS stations. With the anomaly value of each observation station, CPTN: 0.2 TECU, CPTU: 0.2 TECU, and CUJG: 0.3 TECU, where these anomalies appear 15-20 minutes after the earthquake. The difference in the magnitude of the anomaly that occurs varies depending on the location of the GPS receiver station used. According to Cahyadi, M. N. and K. Heki (2014) the value of a small anomaly is caused by the earthquake's magnitude is not too large.

Basically, TEC measurement caused by an earthquake can be classified into two types, namely pre-earthquake and post-earthquake. One of the anomaly precursors that happened prior to the earthquake can be obtained by TEC measurement using GPS. This phenomenon is known as a pre-earthquake anomaly which happened 1-2 weeks before the earthquake, while post-earthquake happened around 3 minutes up to an hour after the earthquake. Fluctuation in post-earthquake can be used as an early warning before a tsunami happened.

5. Conclusion
Based on the research, the TEC anomaly of Banten earthquake on August 2nd, 2019 using GPS has been resulting in CID on satellite number 29 with anomaly at the CPTN station: 0.2 TECU, CPTU: 0.2 TECU, and CUJG: 0.3 TECU, where the anomaly appeared 15-20 minutes after the earthquake. TEC anomaly data can be used for future analysis as an early warning before a tsunami. Further research about TEC anomaly is expected to be carried on in the future using additional comparison data such as FORMOSAT-3/COSMIC data.
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