Analysis CID Volcanic Eruption in The Sunda Strait due to The Eruption of Anak Gunung Krakatau

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***Abstrak*—In earthquakes occur three types of waves, namely acoustic waves with vertical directions from the epicenter to the ionosphere F, gravity waves are waves generated from the tsunami, and the resulting Rayleigh waves move away from the epicenter. These waves create disturbances in the ionosphere, namely at electron density. The electron density in the ionosphere layer is called Total Electron Content (TEC). This phenomenon is detected as CID (Coseismic Ionosphere Disturbance), ie TEC fluctuations that occur ` 10 minutes after the earthquake. Earthquakes that are used as case studies are earthquakes that occur in the volcanic earthquake in the Sunda strait due to volcanic eruptions of Anak krakatau resulting in tsunamis on the Sunda Strait on December 22, 2018 (doy 356) with magnitude 5 SR at 13.55 UTC. In this study using the data of GNS (Global Navigation Satellite System) BIG CORS (Continuous Operating Reference Station) (Geospatial Information Agency uses CRKS, CPSR and CGON stations. The results of this study get that GPS number 3 detects TEC fluctuations after a volcanic earthquake. The biggest fluctuation is 0.422 TECU which is at 9 minutes after the volcanic earthquake of the child of Mount Krakatau.**

***Keywords*—Ionosphere, TEC Volcanic Earthquake.**

I. INTRODUCTION

EARTHQUAKES occur due to sudden temporary movements of the soil as a result of the release of elastic energy in seconds. Earthquakes are movements or shocks of land caused by the sudden displacement of rocks of the earth's crust. Earthquakes are produced from plate strain, volcanoes, landslides. One of the causes is the wave generated in the earthquake, namely acoustic wave is directed vertically to the height of the F layer in the ionosphere within ± 10 minutes, the wave of gravity (speed 0.3 km / s) resulting from the tsunami wave due large earthquakes, and Rayleigh waves (speeds of 4 km / s) generated from surface waves and propagate away around the earth from the epicenter (horizontal direction).

Volcanic earthquakes occur because of volcanic eruptions. The cause of this earthquake is the contact between the magma and the volcanic wall and the gas pressure in the eruption which is very strong, or the sudden displacement of the magma kitchen magma. The strength of volcanic earthquakes is actually very weak and only occurs in the area around the active volcano. Of all the earthquakes that occurred only 7% were included in the volcanic earthquake, although the damage was quite extensive as well, because it was accompanied by volcanic eruptions.

One number that occurred before the earthquake was obtained from the measurement of TEC (Total Electron Content) using GPS (Global Postioning System) data [1]. TEC fluctuations in CID (Coseismic Ionospheric Disturbance) occur 15 minutes up to 1 hour after the earthquake. Fluctuations in CID are used as EWS (Early Warning System) before the tsunami arrives. The movement of this tsunami wave is quite slow at around 600-700 km / h [2]. The TEC value is usually expressed in TECU, where 1 TECU is equal to 1016 electrons / m2. The greater the magnitude of the earthquake that occurs, the interference that will be generated in the atmosphere will also be large. This is because the amount of energy can interfere with electron density in the ionosphere up to a radius of 400 km from the epicenter [3]. This study uses data from CORS BIG stations, which CRKS, CPSR and CGON stations with doy (date of year) 356.

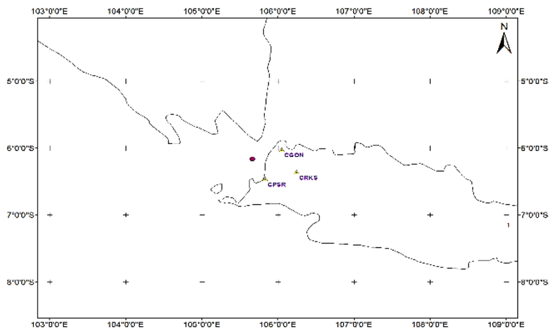

Figure. 1. Location of research in Anak Gunung Krakatau eruption and the position of Station GPS CORS BIG CPSR, CGON and CRKS.

II. METHOD

A. Location of Research

The location of this research was carried out, namely for volcanic eruption at the eruption of Mount Krakatau on 22 December 2018 with doy 356 at 13.55 UTC with epicenter earthquake 6.16 ° S 105.67° E. The observation stations used are CRKS, CPSR and CGON.

B. Data

The data used in this study include:

1) Data rinex observation (on 22nd Desember 2018 or doy 356) from BIG GPS stations using CGON, CPSR and CRKS stations.
2) Data navigation satellite
3) Program data for rdrnx.f and rdehph.f.

C. Data Processing

The stages of data processing in this research are:

1) Data Processing Rinex

The GNSS observation data in the form of rinex data obtained from the Geospatial Information Agency with CORS BIG GPS stations closest to the occurrence of volcanic earthquakes are CGON, CPSR and CRKS stations, namely at the time of the earthquake on 22 December 2018 (or doy 356) with the format "o " From BIG also obtained navigation data with doy 356 or equal to the time of occurrence of volcanic earthquakes in the format "n" for GPS. Navigation data is used to project the position of the satellite's orbit to earth using keplerian elements.

2) Data Processing GNSS

Perform RINEX data processing Observations using the rdrnx.f program to get the time and the size of the STEC value at each observation station and RINEX Navigation data processed using the rdeph.f program to get the satellite orbit position that passes on the observation day.

3) Calculation Anomaly of TEC

After the STEC value is obtained, then the calculation is done to find out the Vertical Total Electron Content (VTEC) value change relative, that is by subtracting the STEC value that has been obtained with its leveling / power six polynomials. The TEC anomaly is obtained if there is a deviation from the one period data which is greater than the median. If the data has a TEC anomaly, it is stated that there is a disturbance in the ionosphere layer, so that it is continued by plotting the results of the anomaly in the Matlab application to display the graphical visualization of the TEC changes.

4) Determination position IPP and SIP

The satellite orbit position that has been obtained from processing using the rdeph.f program in the Fortran application then processing determines the position of the Ionospheric Pierce Point (IPP) and Sub-Ionospheric Point (SIP) to determine the satellite orbit position that recorded the TEC when the earthquake occurred. This processing is done using the Matlab application, the result of which is plotting the SIP position on the surface of the earth.

5) Plotting in Matlab

This plot is to visualize the results of data processing, the first is the TEC anomaly value at each observation station so as to produce a TEC anomaly horizontally, and the second is the position of the GNSS satellite orbit that passes when an earthquake occurs and SIP on the surface of the earth. After obtaining the plotted image, then the analysis of the TEC anomaly values in the ionosphere and associated with the SIP position of the satellite that passes when the earthquake occurs.

6) Propagation of Speed

CID speed is obtained from the difference in distance between the epicenter and satellite orbit path divided by the time difference between the earthquake and the occurrence of CID. [4] CID has two different velocity components, which propagate with Rayleigh surface wave velocities (3-4 km / s) and those that propagate slowly using sound speed (0.6 / 1.0 km / s).

III. RESULTS AND DISCUSSION

A. Result of processing the Rinex GPS using Fortran

Observation data is obtained from BIG in the form of RINEX (Receiver Independent Exchange Format), then processed using the rdrnx.f program and from this program we can get the anomaly TEC, while Navigation data obtained from BIG is then processed using the rdeph.f from that program we can the the orbit of the satellite. The original processing of observation data is time (UTC) and STEC (TECU) data with a 30-second time interval on satellites recorded at each observation station. While the results of processing navigation data (broadcast ephemeris) are time (UTC) with 3-minute intervals and satellite orbit positions.

B. Satellite Track

Volcanic eruption caused by the eruption of the child of Mount Krakatau in the Sunda Strait on 22 December 2018 at 13.55 UTC with the epicenter at 6.16 ° S 105.67E ° with magnitude < 5 SR and a depth of 5 Km.

By using CORS (Continuous Operating Reference) GPS data from BIG Station CGON CRKS, and CPSR we observed disturbances in the ionosphere during the earthquake period located in West Java. This observation was carried out at the time of the occurrence of volcanic earthquakes. Observations at several CORS GPS stations were carried out to obtain the value of TEC changes caused by the volcanic earthquake of the Anak Gunung Krakatau.

In earthquakes an acoustic wave, Rayleigh, and garvitation will be generated which can cause interference in the atmosphere layer which causes fluctuations or vortations of the TEC on the surface. The greater the earthquake strength, the greater the interference that occurs in the ionsofer layer. Because the amount of energy can cause electron density disturbances up to a radius of 400 km from the epicenter.

The delay time at the ionosphere can be calculated by combining two GNSS receiver frequencies, to obtain the value of Total Electron Content (TEC). By counting the signal modulation on the carrier wave,

$$f1 = 1575.42\,MHz \quad (1)$$

$$f2 = 1227.6\,MHz \quad (2)$$

After combining the pseudorange value and the dual frequency phase carrier, the TEC can be calculated by the following formula:

$$\delta STEC = \frac{f_1^2 . f_2^2}{40.28.(f_2^2 - f_1^2)} . (\delta L_1 - \delta L_2) \quad (3)$$

Which $\delta STEC$, δL_1, δL_2 is the difference between the STEC value, phase distance L_1 dan L_2 between two consecutive epocs.

From observations at three stations GPS CORS BIG around the volcanic earthquake using GPS satellites for one day TEC anomaly was obtained. The following is a visualization of the satellite orbit that passes in the area around the earthquake that will be shown in Figure 2.

Figure 2 is the projection of GPS satellite trajectories when a volcanic earthquake occurs. It can be seen that the satellites that orbit when the earthquake occurs are satellites number 1, 3, 7, 9, 10, 11, 17, 22, 23 and 27. But the the calculation of the TEC anomaly value shows that the satellite signal that can record TEC fluctuations in the ionosphere is satellite number 3. This anomaly data appears in three observation stations, namely CGON, CPSR and CRKS stations which are BIG GPS CORS stations.

LOS (line of sight) is a propagation of GPS satellite signals from the surface of the earth to an altitude of ~ 20,000. IPP (Ionosphere Pierce Point) is an LOS junction with an ionosphere at an altitude of ~ 300 Km. at the height of the IPP it enters the layer F, which can explain the direction of the satellite's movement. Projection of IPP aboveearth is called SIP. SIP is used to do TEC calculation analysis. Figure 4 is a satellite orbit flow, the red circle indicates the epicenter of volcanic eartquake and the red dot indicates the time the earthquake occurred (IPP point). The triangle symbol is the BIG GPS CORS station, CGON, CPSR and CRKS stations. At the time of the number 3 satellite earthquake crossing the southern part of the island of Java.

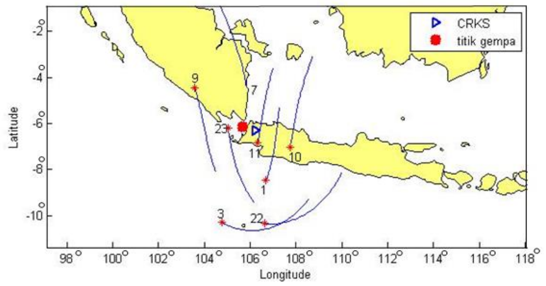

Figure 2. Satellite Orbit during the volcanic earthquake of Mount Krakatau at 13.55 to 15.39 UT.

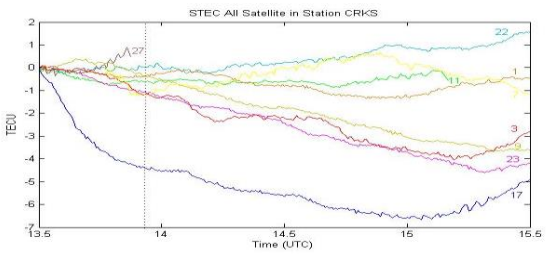

Figure 3. STEC all satellite in volcanic earthquake.

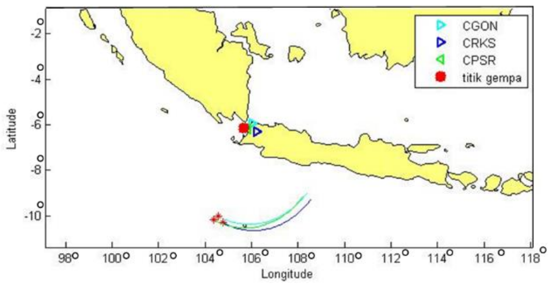

Figure 4. Plotting number orbitals number 3 on the December, 22 2018 that was mapped through SIP at all stations from 13:55 to 15:30 UT.

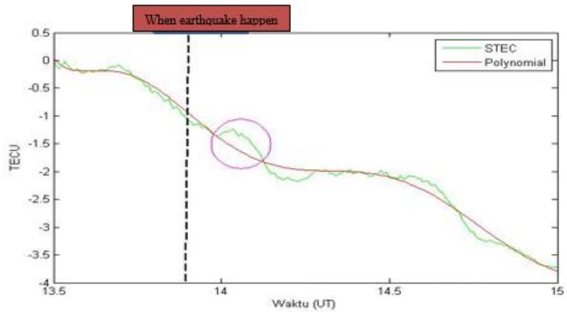

Figure 5. STEC with sixth polynomial at CGON Station.

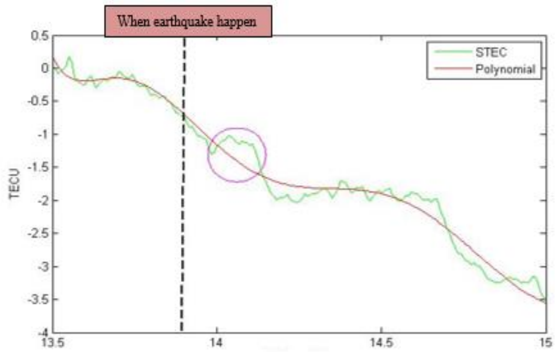

Figure 6. STEC with sixth polynomial at CPSR Station.

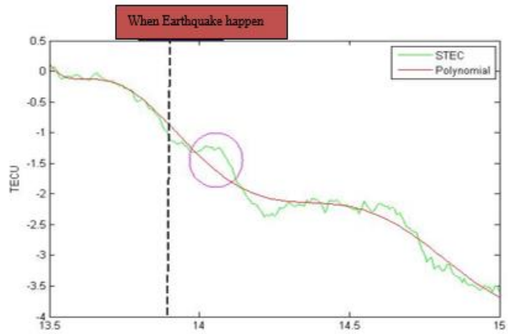

Figure 7. STEC with sixth polynomial at CRKS Station.

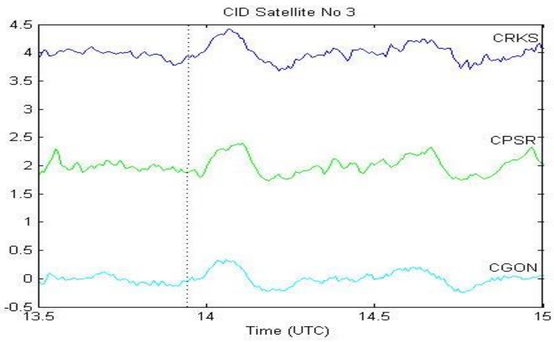

Figure 8. VTEC GPS Satellite No. 3 all stations.

C. Anomaly plotting of TEC

In this volcanic earthquake it is known that TEC fluctuations occur in satellite number 3 with the time of fluctuation occurring around 10 minutes after the occurrence of a volcanic earthquake. The following is a TEC plotting with six-level polynomial from STEC on 3 CORS BIG GPS stations. In Figure 5-7 shows the CID occurring in the volcanic earthquake at 13.55 UT in all station. With vertical dotted lines that indicate the timing of volcanic earthquakes.

The following is the STEC fluctuation image of all existing stations. The green line shows the STEC value and the red line shows the polynomial while the magenta circle shows fluctuations.

In Figure 8 VTEC ploting will be displayed from all stations. From Figure 8 you can see the GPS satellite TEC at the observation station, with the value of each observation station, namely: CGON: 0.338 TECU accured at 8 minutes after the earthquake, CPSR: 0.402 TECU at 11 minutes after the earthquake and CRKS: 0.422 TECU occurred at 89 minutes after the earthquake. The difference in the magnitude of the recorded TEC anomaly depends on the location of the CORS GPS receiver. The value that shows the biggest TEC anomaly is the receiver station which is located more closely with the earthquake location, namely the CRKS station which reaches 0.422 TECU and with anomaly occurring approximately 10 minutes after the occurrence of the volcanic earthquake.

The size of TECU is relatively small but this can be seen from the change in anomaly in Figure 8. In Figure 3 displayed STEC several satellites that crossed at 13.30 UTC - 15.30 UTC, in the picture there were

The size of TECU is relatively small but this can be seen from the change in anomaly in Figure 8. In Figure 3 displayed STEC several satellites that crossed at 13.30 UTC - 15.30 UTC, in the picture there were many satellites crossing but the one that detected anomalies was on satellite No. 3 whose satellite SIP number 3 was depicted in Figure 4. For anomalies depicted in Figure 5-7 about STEC satellite 3 at CGON, CPSR and CRKS stations, for clearer images of TEC anomalies can be seen in VTEC Figure 8, VTEC itself is the result of a reduction of STEC with polynomials.

The presence of TEC anomalies can be seen from the results of VTEC plotting of each satelt. TEC anomalies on all three stations were seen about 10 minutes after the earthquake that could be identified from the three stations where TEC fluctuated. if detected early can be used to reduce the tsunami in the Sunda Strait. The analysis of the ionosphere is caused by interference from acoustic waves due to volcanic earthquakes, which cause disturbance of the ionospheric layer consisting of free ions and electrons in the disturbed F layer, causing anomalies and causing the GPS signal to pass through the ionosphere to be disrupted. In ionospheric measurements, ionospheric delay will be eliminated so as not to interfere with the measurement results obtained but in this study it was conducted to determine the TEC fluctuations or anomalies that occur due to acoustic waves caused by earthquakes such as volcanic earthquakes from the child of Mount Krakatau.

For the results of the TEC anomaly due to volcanic earthquakes the krakatu mountain child is indeed low, namely the highest is 0.421 TEC at the CRKS station, because the electron and ion activity at night is low, thus affecting the height of the TEC value.

D. Propagation Speed

CID speed is calculated from the time difference at the point of occurrence of the earthquake with the distance from the station. In Figure 9 shows the propagation speed of three stations with satellite numbers 3.

The oblique black line shows the positive anomalous TEC relationship with the peak (red part) expressing the direction and real speed of the CID. The propagation speed is lowered using all three satellites ± 1 km / sec.

[5] demonstrated north-south asymmetry of the CID propagation, i.e. a CID hardly propagates northward because geomagnetism allows only oscillation of ionospheric electrons in the field-aligned direction in the F layer.

The presence of CID is caused by several waves in the atmosphere. The appearance of a CID due to an acoustic wave is around 10-15 minutes after the shock caused by an earthquake. With the speed of the acoustic wave from the epicenter is ~ 0.8 speed in the ionosphere f-layer region. [4]found that the CID in the earthquake had two different speed components, namely with different propagation speeds. Components that are faster (~ 4 km / s) due to waves and propagate even further than direct acoustic waves [6].

Earthquakes followed by tsunamis are usually much slower (~ 0.3 km / s) because they are caused by gravitational waves. To find out the existence of CID can be seen in Figure 8.

Figure 9 is the travel-time diagram of the CID at vulkanik earhquake Anak Gunung Krakatau in Sunda Strait at 22 Desember 2018. he CID peak (shown in red colors) detected by wavelet propagates with the apparent velocity of ~1 km/s (thin black line). The black broken vertical line indicates the occurrence of the main shock (13.55 UTC).

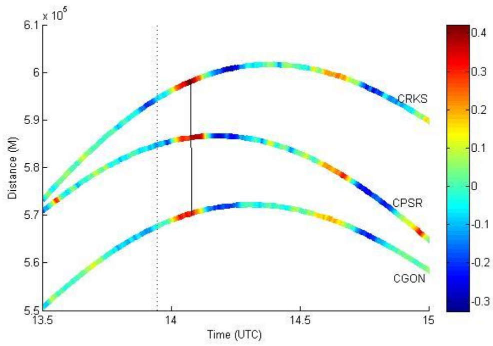

Figure. 9. Propagation Speed of satellite number 3, that explain about fluctuation of TEC by that describe by the color.

IV. CONCLUSION

Based on the processing and data analysis that has been done, the conclusions are as follows:

1) Changes that occur in the ionosphere due to the volcanic earthquake of the Mount Krakatau child on 22 December 2018 are TEC anomalies from processing GPS satellite data, where the anomaly appears about 10 minutes after a volcanic earthquake.
2) From the results of CID processing obtained by satellite number 3, there were TEC anomalies at CGON, CPSR and CRKS stations.
3) During volcanic eruption, disturbances in the ionosphere occur at different time frames. The following is the time observed after the occurrence of a volcanic earthquake on satellite number 3:

   CGON : 8 minute
   CPSR : 11 minute
   CRKS : 9 minute

At the time of the volcanic earthquake the magnitude of the disturbance in the ionosphere that occurs at each station is different, then the value of the TEC of each station in satellite number 3 is as follows:

a) CGON : 0.338 TECU
b) CPSR : 0.402 TECU
c) CRKS : 0.422 TECU

AKNOWLEDGEMENT

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