Effect of Earthquake’s Surface Wave on Ionosphere Layer

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Abstract. The lithosphere and the atmosphere/ionosphere, continue to exchange energy through various coupling mechanism. The earthquake creates energy waves, such as Direct Shock Acoustic Waves (SAWs) and Rayleigh wave induced Acoustic Waves (RAWs) and Atmospheric Gravity Waves (AGW) when the earthquakes occur at sea. If the earthquake event is large enough (Mw > 6), then SAWs, RAWs and AGWs induce the detected ionosphere plasma as an anomaly. Near the epicentrum, the Coseismic Ionospheric Disturbance (CID) diffuses at almost the same speed as the acoustic wave speed of the shock in the ionosphere. At the distant point of the epicentrum, Rayleigh waves will induce ionospheric interference. Summing up seismological information from seismo-ionospheric manifestations is a subject related to ionospheric seismology. In this study, the ionospheric response to earthquakes was analyzed using TEC data in Indonesia especially to identify surface wave using TEC data. As a case study We were used Aceh earthquake (coordinates 3.295°N; 95.982°E) on December 26, 2004. It is expected that the seismo-ionospheric manifestations show the behavior of CID.

1. Introduction

The source of ionospheric disorders can come from below and above. From below are lithosphere like earthquake, volcanic eruption and nuclear explosion. While the top of the space weather such as geomagnetic storms, CME and flares. Particularly related to earthquakes, ionospheric disorders are primarily caused by (1) shock acoustic waves (SAW), (2) Rayleigh Acoustic Wave (RAW) acoustic waves or also called Surface Seismic Waves and (3) gravity acoustic wave (Acoustic Gravity Wave, AGW) whose frequency falls between 0.1 mHz to 10 mHz. This is a collection of seismic waves present in the ionosphere. The phenomenon of the relationship between earthquakes and ionofer is called seismo-ionospheric. The study of seismo-ionospheric has been widely practiced. This is due to the fact that many advanced equipment are installed (e.g. HF Doppler Sounding, DEMETER and GNSS) en masse to monitor ionospheric plasma disturbances caused by earthquakes both on land and in space so as to facilitate study and monitoring seismo-ionospheric disorder.

Studying these seismo-ionospheric anomalies can further be used for the detection of epicenter earthquakes and tsunami early warning. In addition, it also offers the possibility of remote sensing of seismic signals [1,2] mainly for two reasons: (1) continuity of vertical displacement on the surface, the atmosphere is then forced to move at the same vertical speed as the ground surface and (2) the conservation of kinetic energy and high exponential density air density. Further, it should be noted that it is easier to detect the diffuse waves in the ionospheric plasma, rather than the neutral atmosphere due to the radio propagation properties (plasma dispersive properties).

In this paper, we study effect of earthquake’s surface wave to ionosphere using TEC data during Aceh earthquake (coordinates 3.2950N; 95.9820E) on December 26, 2004. The objective is to know
effect earthquake’s surface wave to ionosphere. Furthermore, for the long term it can be applied for earthquake epicenter detection as well as tsunami early warning.

1.1 Types of Seismic Wave
Seismology is the study of earthquakes and seismic. Seismic waves can be defined as, “the waves of energy caused by the sudden breaking of rock within the earth or an explosion” [3]. The two main types of waves are body waves and surface waves. Body waves can travel through the earth's inner layers, but surface waves can only move along the surface like ripples on water. Earthquakes radiate seismic energy as both body and surface waves.

![Image](image_url)  
**Figure 1.** Body and surface waves

1.2 State Art of Seismology
Recent observations of strong ground motion accelerations is strongly dominated by Rayleigh waves [4,5] as recorded in México earthquakes from subduction earthquakes. In many previous studies, surface waves has been used to infer the shear wave velocity structure in the upper few kilometers of the crust [6]. However, in these studies some difficulties exist in terms of identifying surface waves because they require an earthquake of magnitude about 7, which produce Rayleigh waves over a broad range of periods [7]. Large earthquakes produce important surface waves, particularly in sediment-filled areas [8]. Tanaka, Yoshizawa and Osawa [9] observed that during large earthquakes, surface waves with period around 8 sec were dominant in records of sedimentary soils of Tokyo. Then, it is clear that layering is responsible for practically all the observed effects during earthquakes. The effect of local soil conditions in modifying the earthquake motions has been established for some time.
Based on the Figure 2, the number in parentheses shows the location of each station in the map of the bottom right angle. Significant amplitudes are detected in the prolonged records in Chilpancingo (RICC) and in Teacalco (TEAC) stations, besides the recorded in México City.

2. Method
Data used as an analysis material is TEC data from satellites crossing Indonesian territory at the time of Aceh earthquake (coordinates 3.295°N; 95.982°E) of December 26, 2004; making plotting of TEC data versus time and visually analyzing the TEC data anomalies around the time of the earthquake. To refine the analysis, also used index data Dst as geomagnetic storm event parameter. The Dst Index is used to verify whether anomalies detected through pure TEC are from earthquakes or from space weather sources. And then, for more detailed analysis, an FFT analysis of TEC data from each satellite is performed. Time of surface wave to ionosphere assumed as

\[ T = \frac{\text{distance satellite to epicentrum}}{3\text{km s}^{-1}} + 8\text{ minute} \]  \hspace{1cm} (3-1)

The last, it is for conclusions.

3. Results and Discussion
From TEC data, we obtained 6 satellites at MSIA observatory and 10 satellites at NGNG observatory.
Figure 3. (a) DSTEC from MSIA observatory and (b) DSTEC from NGNG observatory on December 26, 2004

Figure 4-1, in the square visually it is not clear that there is a DSTEC pattern that is disturbed, but it is quite clear that at around 01:00 UT the pattern seems to collect all at one point and a little fluctuation DSTEC pattern. Furthermore, it is seen that the DSTEC value as if starting to experience the uptrend from that point. To ascertain whether there is any effect from the space weather, the following shows the index data Dst and the AE index.

Figure 4. (Left) Dst index on December, 2004 and (Right) AE index on December 26, 2004

The Dst Index on December 26, 2004 showed no pattern caused by aerospace weather disturbance, and from the AE index also reinforced the phenomenon. Thus, the space weather of December 26, 2004 can be said to be in quiet condition and it is certain that the space weather is not a source of DSTEC pattern trigger on December 26, 2004 at around 01.00 UT.

To see more clearly the disturbance on DSTEC, FFT analysis is performed and the results are as shown in Table 1.

Table 1. The travel time pf surface wave

| No | Name Observatory | Number of Satellite | Epicentrum | Coordinate of satellite | Travel time (Minutes) |
|----|-------------------|---------------------|------------|-------------------------|-----------------------|
|    |                   |                     |            | Eq 3-1                  | FFT                   |
| 1  | MSIA              | 1                   | 3.92° N; 95.892°E | 0.57° S; 101.14° E | 12.114                | 11.614                |
| 2  |                   | 3                   | 2.46° S; 99.99°E | 12.410                 | 13.870                |
| 3  |                   | 19                  | 4.72° S; 98.97°E | 13.319                 | 14.815                |
| 4  |                   | 20                  | 0.49° S; 95.65°E | 10.339                 | 18.940                |
| 5  |                   | 23                  | 8.92° N; 94.55°E | 11.573                 | 13.495                |
| 6  |                   | 25                  | 6.38° N; 06.35°E | 14.947                 | 19.685                |
| 7  | NGNG              | 1                   | 0.99° S; 101.3°E | 12.350                 | 15.152                |
| 8  |                   | 3                   | 2.93° S; 100.14°E | 12.670                 | 11.223                |
| 9  |                   | 11                  | 11.18° S; 90.63°E | 17.538                 | 14.881                |
4. Conclusion
Travel time of surface wave in about of 6.8 minute until to 27.2 minute after earthquake. The difference of the travel time of surface wave between the results of equation 3.1 with DSTEC data is supposed as the effect of moving away or approaching the satellite.

5. References
[1] Lognonn E P, Garcia R, Crespon F, Occhipinti G, Kherani A, Artru-Lambin 2006 *J. Seismic waves in the ionosphere. Europhys News* 37(4): 11e4
[2] Reddy C D 2016 Seismo-ionospheric anomalies and implications from recent GNSS observations in India and South-East Asia *Geode sy. and geodynamics* 17(1) pp. 11-18
[3] UpSEIS 2006 (online) What Is Seismology? ([http://www.geo.mtu.edu/UPSeis/waves.html](http://www.geo.mtu.edu/UPSeis/waves.html))
[4] Gómez-Bernal A and Saragoni R 1995 Interpretation of dynamic soil effects on México City valley using the dense accelerograph network *Proc. of the Fifth Int Conf. on Seismic Zonation*, France 1 pp. 747-754
[5] Gómez-Bernal A and Saragoni R 1996 Oscillations of the México City surface layer excited by seismic surface waves *Proc. 11th World Conf. On Earth. Eng.* 718
[6] MacBeth C D and Burton P 1985 Upper crustal shear velocity models from higher mode Rayleigh wave dispersion in Scotland *Geophysics. J. R. Astr. Soc.* 83 pp. 519-529
[7] Ewing W M, Jardetzky W S, and Press F 1957 *Elastic waves in Layered Media* (New York: McGraw Hill)
[8] Bard P Y and Bouchon M 1980 The seismic response of sediment-filled valleys. Part 2. The case of incident P and SV waves *Bull. Seism. Soc. Am.* 70 pp. 1921-1941
[9] Tanaka T, Yoshizawa S, and Osawa Y 1980 Characteristics of strong earthquake ground motion in the period range from 1 to 15 seconds *Proc. 7th World Conf. Earthquake Eng.* 2 pp. 609-616