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Abstract of Doctoral Dissertation

博士の専攻分野の名称　博士（理学）　　モハマド・ヌーア・ジャヒャディ

Degree requested　Doctor of Science　　Mokhamad Nur Cahyadi

学 位 論 文 題 名

Near-Field Coseismic Ionospheric Disturbances of Earthquakes In and Around Indonesia

（インドネシアおよびその周辺で発生した地震に伴う近傍場地震時電離圏擾乱）

ABSTRACT

Coseismic ionospheric disturbances (CIDs) appear shortly after relatively large earthquakes as a result of ionospheric irregularity associated with passing atmospheric waves excited by the earthquakes. CIDs appearing approximately 10 minutes after earthquakes are caused by acoustic waves generated by coseismic vertical movements of the crust or the sea surface, and they propagate as fast as ~1 km/second over the distance of hundreds of kilometres. In this research, it focused near field CID in and around Indonesia, especially in the 2005 Nias, 2007 Bengkulu and 2012 North Sumatra earthquake.

a. Ionospheric disturbances of the 2007 Bengkulu and the 2005 Nias earthquakes, Sumatra, observed with a regional GPS network

We studied ionospheric disturbances associated with the two large earthquakes in Sumatra, Indonesia, namely, the 2007 Bengkulu and the 2005 Nias earthquakes, by measuring the total electron contents (TEC) using a regional network of global positioning system (GPS) receivers. We first focus on CID of the Bengkulu earthquake (M_w 8.5). They appeared 11–16 min after the earthquake and propagated northward as fast as ~0.7 km/s, consistent with the sound speed at the ionospheric F layer height. Resonant oscillation of TEC with a frequency of ~5 mHz continued for at least 30 min after the earthquake. The largest aftershock (M_w 7.9) also showed clear CIDs similar to the main shock. A CID propagating with the Rayleigh wave velocity was not observed, possibly because the station distribution did not favor the radiation pattern of the surface waves. This earthquake, which occurred during a period of quiet geomagnetic activity, also showed clear preseismic TEC anomalies similar to those before the 2011 Tohoku-Oki earthquake. The positive and negative anomalies started 30–60 min before the earthquake to the north and the south of the fault region, respectively. On the other hand, we did not find any long-term TEC anomalies within 4–5 days before the earthquake. Co- and preseismic

ionospheric anomalies of the 2005 Nias earthquake (M_w 8.6) were, however, masked by strong plasma bubble signatures, and we could not even discuss the presence or absence of CIDs and preseismic TEC changes for this earthquake.

b. Coseismic ionospheric disturbance of the 2012 North Sumatra earthquakes, large intra-plate strike-slip events

We studied ionospheric responses to the 2012 April 11 Mw8.6 North Sumatra earthquake using TEC measurements with the regional GPS network. This earthquake ruptured the oceanic lithosphere off the Indian Ocean coast of North Sumatra, and is known as the largest strike-slip earthquake ever recorded. CID with rapid TEC enhancement of a few TEC units propagated northward with a speed of acoustic waves. Resonant atmospheric oscillation with a frequency ~3.7 mHz have been found as monochromatic oscillation of TEC lasting for an hour after the mainshock and the largest aftershock. We compared CID amplitudes of 21 earthquakes world-wide with moment magnitudes 6.6-9.2. They roughly obeyed a law such that CID amplitude increases by two orders of magnitude for the Mw increase of three. The 2012 North Sumatra earthquakes slightly deviated negatively from the trend possibly reflecting their strike-slip mechanisms, i.e. small vertical crustal movements for their magnitudes. We found preseismic TEC anomalies starting ~40 minutes before the mainshock and the largest aftershock similar to those found before earthquakes with Mw of 8.5 or more including the 2011 Tohoku-oki and the 2007 Bengkulu earthquakes.

CONCLUSION

Earthquake propagated seismic wave and induced ionosphere, the electron structure will change when the wave reaches F-layer ionosphere. The TEC disturbance will propagate with one of the three seismic waves eg acoustic wave, Raleigh wave or gravity wave. Our research focused to investigated two mega trust earthquake in Bengkulu 2007 and Nias 2005. In addition, there two strike slip earthquake was analyzed for affecting pre-coseismic ionospheric disturbances. Comparison between moment magnitude and amplitude of CID also was investigated in order to obtain relationship of it. The studies conducted here are summarized as follow:

a. Ionospheric disturbances of the 2007 Bengkulu and the 2005 Nias earthquakes, Sumatra, observed with a regional GPS network

This research provides the first comprehensive study of multiple aspects of CID and preseismic (both long- and short-term) ionospheric anomalies for two recent mega-thrust earthquakes in Indonesia. The studied aspects of CID include propagation speed (the observed velocity suggested its acoustic wave origin), azimuthal asymmetry of propagation, atmospheric resonance, polarity of the initial changes, and comparison of amplitudes between the mainshock and the largest aftershock.

A clear CID was found in the 2007 Bengkulu earthquake. Its apparent velocity suggested an

acoustic wave origin. The earthquake is followed by a large aftershock which occurred~12 hours later. This aftershock also showed CID signatures, and their smaller amplitudes can be explained by the difference in the earthquake magnitudes and the background TEC. These CID started with positive anomalies, similar to other reverse-fault earthquakes. The Rayleigh wave signatures were absent due possibly to the geometric alignment of the GPS network. The directivity (north-south asymmetry of propagation) of CID in the southern hemisphere was not clearly observed due to N-S asymmetry of the network. Resonant oscillations of the atmosphere with a frequency of ~5 mHz were found to follow the CID and last for half an hour.

Short-term preseismic TEC changes similar to the 2011 Tohoku-Oki earthquake were found in the 2007 Bengkulu earthquake. It was confirmed that geomagnetic activity was relatively quiet during the studied period. The behavior of TEC with the same satellite-station combination over 4 months suggests that the occurrences of similar anomalies are infrequent especially during geomagnetic quiescence. Hence it is not likely that space weather is responsible for the observed short-term preseismic TEC changes. This, together with other cases [*Heki,* 2011], suggests that the observed anomaly is relevant to the earthquake. The physical mechanism of the preseismic TEC changes remains unclear in spite of several new studies. Long-term TEC precursors were not found.

Plasma bubble occurred before and after the occurrence time of the 2005 Nias earthquake. Because their signatures were so strong, we could not even discuss the presence or absence of CID and preseismic TEC anomalies. Plasma bubbles were found on the previous and the next days, and are considered to be irrelevant to the earthquake occurrence.

Another large earthquake (M_w 8.6) and its aftershock (M_w 8.2) occurred on 12 April, 2012, within the subducting oceanic plate off the northern Sumatra [*Meng et al.*, 2012]. Considering its unique mechanism (one of the largest earthquakes with strike-slip mechanism), we have started to study its CID and preseismic TEC anomaly using the GPS data from the SUGAR network so that we can publish the results in a near future [*Cahyadi and Heki*, under review].

b. Coseismic ionospheric disturbance of the 2012 North Sumatra earthquakes, large intra-plate strike-slip events

The CIDs of the 2012 North Sumatra earthquake, the largest strike-slip earthquakes ever recorded, and its largest aftershock have been studied. Here we summarize the study as follows.

1) Acoustic wave origin CIDs were observed.
2) Monochromatic TEC oscillations of ~3.7 mHz followed the earthquake and lasted for an hour.
3) Strong northward directivity of the CID propagation was confirmed.
4) CID amplitudes of dip-slip earthquakes obeyed an empirical law such that the amplitude becomes 100 times as large for magnitude difference of three.
5) CID amplitudes of strike-slip earthquakes tend to negatively deviate from the law.
6) Preseismic TEC anomalies of ~1 TECU were found before the mainshock and the largest aftershock.