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Research Article
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A Possible Influence of Seismic Activity on Diurnal Geomagnetic Variations

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Abstract

Recent research has introduced some evidences referring to a possible connection between the variation in geomagnetic field measurements and seismic activities. Thus, the present study focuses on a certain seismic activity that occurred at the northern part of Honshu Island, Japan to find out its impact on the diurnal geomagnetic variations recorded at this region. The study of variability of daily geomagnetic variations amplitude at the northern part of Honshu Island; which is characterized by high seismic activities has introduced motivating results. Data analysis and processing indicate the presence of an unusual change in the diurnal variations amplitude in association with earthquake activity occurred on 24 March 2008 at the studied area. A remarkable anomalous behavior in the diurnal variations amplitude of the East-West horizontal geomagnetic component (D-component) was detected in the vicinity of the epicenter at the Tohno station compared with those recorded at the Kakioka geomagnetic observatory and other remote reference stations. This anomalous behavior is observed only during the day of the studied seismic event, which suggests a possible connection between the earthquake occurrence and the change of diurnal variations range. Moreover, since there were no significant external geomagnetic changes during the occurrence of earthquake as revealed from the Dst and Kp indices, the observed anomalous variability in the diurnal geomagnetic variations range of D-component can be considered as anomalous phenomenon linked with the studied seismic activity. Such anomalous phenomenon can be used for constructing earthquake warning systems.

Keywords: Diurnal geomagnetic variations; Geomagnetic anomalies; Seismic activity

Introduction

The Earth's crust is broken into several pieces that called the tectonic plates where most of earthquakes occur at the boundaries of these plates due to the tectonic plate motions and stress accumulation in the lithospheric layer. Several attempts were made to predict the upcoming earthquakes as a result of their devastating effects. The problem in earthquake prediction is that some parameters involved in this process can't be measured in a direct way such as the crustal stress [1]. Thus, researchers are trying to study and understand some anomalous geophysical phenomena occurred in connection with seismic activities.

Previous studies reveal the occurrence of geomagnetic anomalies in active seismic regions in association with earthquakes [2-5]. These anomalies can be interpreted as a result of changing magnetic rock properties and/or changing rock magnetization by increasing stress in a focal zone. These geomagnetic anomalies were considered as precursor phenomena that can give some indication about the forthcoming seismic events [5-7].

Diurnal geomagnetic variations, commonly known as daily geomagnetic variations, are fluctuations of the geomagnetic field that have a periodicity of almost a day. Such geomagnetic variations are observed at ground-based magnetometers with amplitudes of ± some tens of nT in the three geomagnetic components (H, D and Z components). The shape and amplitude of these diurnal variations strongly depend on the geographic latitude of the observing point and the Local Time. These fluctuations are mainly originated from the disturbances of the Earth's ionosphere that related to external sources such as the solar activities. In addition to the external source, the daily variations have an internal source that comes from the conductive Earth. The external field is nearly similar at two points separated by only some hundreds of km [7-10], while the internal field differs according to the change of the underground conductivities. Therefore, the difference of diurnal variations between two geomagnetic observing points should be constant by assuming that the underground conductivities are invariable. Such constancy could be destroyed by anomalous internal field (local geomagnetic anomalies) beneath one of these two observing points, which might have resulted either by lithospheric conductivity changes or some Earth currents associated with tectonic activities [11].

Monitoring and studying the variations of Earth's magnetic field recorded at stations in the vicinity of the earthquake's epicenter can be an effective tool for detecting the anomalous geomagnetic signals linked with tectonic activities [9,12-17] Thus, the technique used to detect the occurrence of any possible anomalous change of the diurnal geomagnetic variations associated with the seismic activity at Honshu Island is based on calculating, examining and the comparing the amplitude of the daily variations inside and outside the epicenteral region.

Geomagnetic Data

The geomagnetic data used in the current study are obtained from the MAGDAS and Geospatial Information authority of Japan (GSI) networks. The MAGDAS magnetometers are sensitive fluxgate type magnetometers that can measure even very minute fluctuations in the geomagnetic filed. These magnetometers have three sensors installed at three perpendicular directions to measure the geomagnetic H, D

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and Z components [18,19]. Geomagnetic data from the Tohno (TNO) station (39.37°N, 141.60°E), which belongs to MAGDAS network in Japan, is used in the present study. The geomagnetic data from the GSI stations are measured by fluxgate and proton magnetometers. The GSI raw data are one-min data for the total intensity of the geomagnetic filed, declination, horizontal and vertical components [20]. A modification of the GSI data format was made by Dr. Teiji Uozumi from International Center for Space Weather Science and Education (ICSWSE) [21], Kyushu University, Japan to make them match with the MAGDAS data format, in which (H) is representing the North-South horizontal geomagnetic component, (D) is referring to the East-West horizontal geomagnetic component and (Z) is the Vertical geomagnetic component. The data from GSI network are used from the Otaki (OTA) station (35.292°N, 140.230°E) and Yokohama (YOK) station (40.994°N, 141.240°E). In addition, geomagnetic data from Kakioka (KAK) geomagnetic observatory (36.232°N, 140.186°E), is used as a standard reference station. Figure 1 shows the location of geomagnetic stations used in the present study.

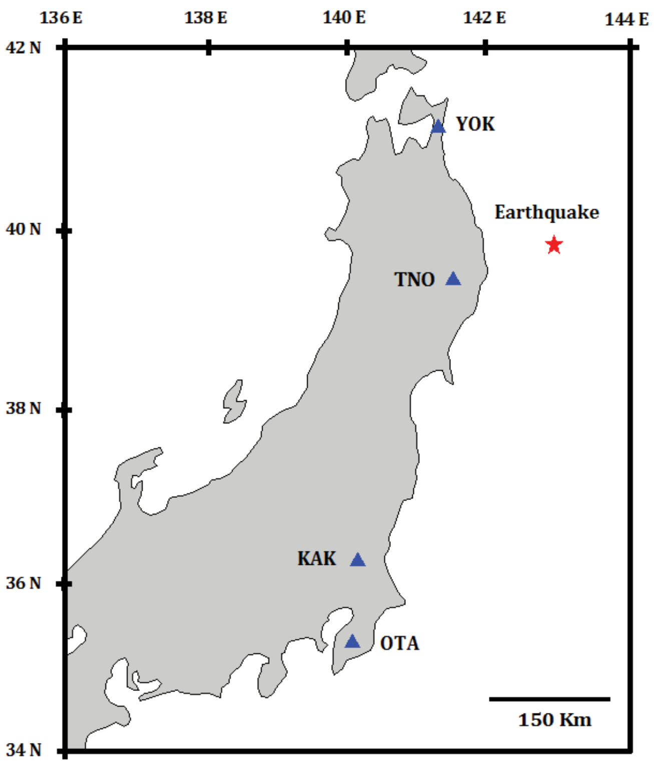

Figure 1: Locations of the geomagnetic stations (triangles) used in the present study and epicenter of the studiedseismic event (star).

Methods

Since it is difficult to detect any anomalous geomagnetic signals associated with seismic activities just by looking to the raw data, some MATLAB scripts are developed for data analysis and processing in order to obtain our goal. The variability of diurnal geomagnetic range is studied for that purpose. The range or amplitude of diurnal geomagnetic variations is calculated be taking the difference between the maximum and minimum hourly averaged values of each geomagnetic component (H, D, and Z components) in a day. The daily variations range of the three geomagnetic components recorded at the TNO station on a certain day (3 January 2008) is presented in Figure 2, where the dashed horizontal red lines represent the maximum and minimum values of hourly averaged geomagnetic data and the dashed vertical blue arrows represent the diurnal variation range for each geomagnetic component. The diurnal geomagnetic variations range of the three geomagnetic components is examined during a seismic event with magnitude (M=4.3) on 24 March 2008, 04:11:17 (local time) occurred at the northern part of Honshu Island (39.95°N & 143.18°E) at depth of 23 km. Figure 3 shows the three geomagnetic components

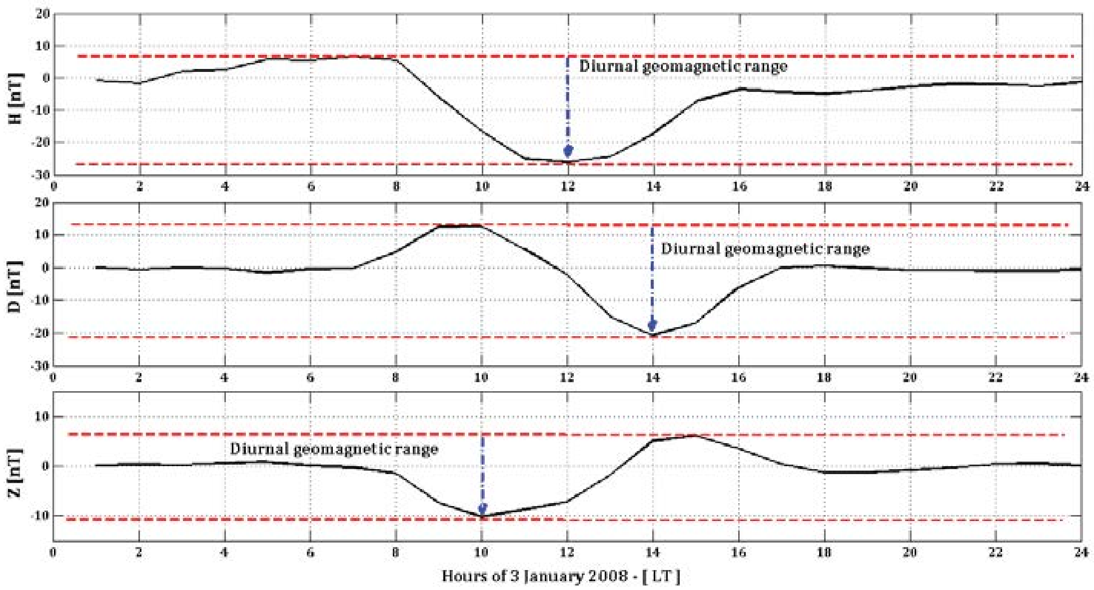

Figure 2: Hourly averaged geomagnetic dataforthe H, D and Z-components on 3 January 2008. The dashed red lines present the maximum and minimum values for each component. Diurnal geomagnetic ranges were calculated by subtracting the maximum and minimum values for each component during a day. The blue vertical arrows indicate the diurnal variation range for each component.

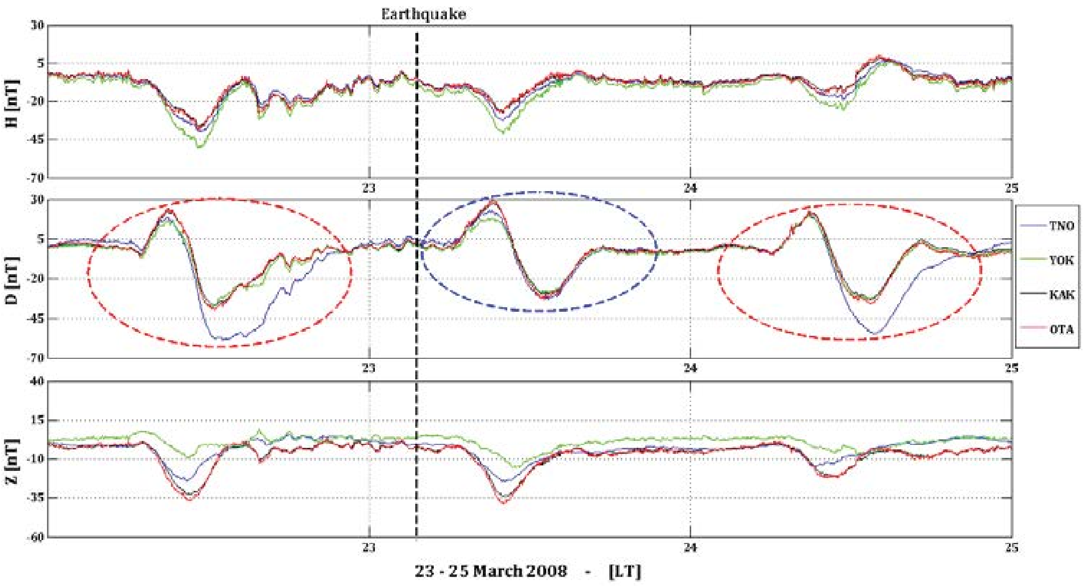

Figure 3: One-minute data for the H, D and Z-components recorded at a number of geomagnetic stations in the northern part of Honshu Island during the period 23-25 March 2008. The vertical dashed line indicates the occurrence time of the earthquake.

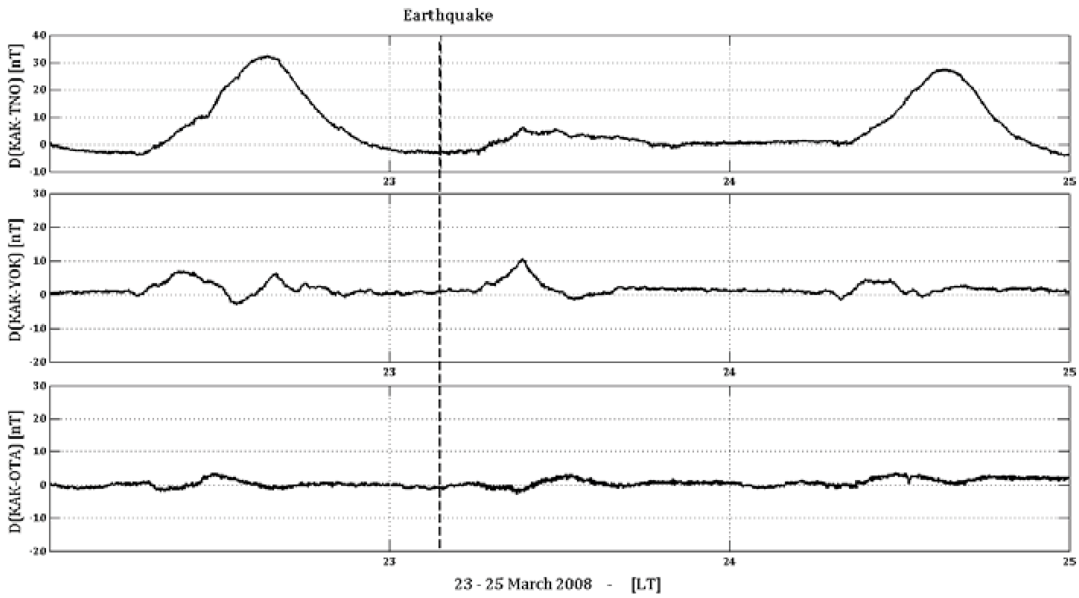

Figure 4: The differences between the D-component recorded at a number of geomagnetic stations [(KAK-TNO), (KAK-YOK) and (KAK-OTA)] in the northern part of Honshu Island during the period 23-25 March 2008. The vertical dashed line indicates the occurrence time of earthquake.

recorded at some stations located at the northern part of Honshu Island (YOK, TNO, KAK and OTA stations) during three days (23-25 March 2008). The vertical dashed line points to the occurrence time of the earthquake. The amplitudes of diurnal geomagnetic variation for the H-component are quite similar during the examined period at these stations. The Z-component at the TNO and YOK stations shows slight different behavior of the daily geomagnetic variations that may be related to different conductivity conditions under these stations. The most interesting observation is that a clear abnormal behavior in the diurnal variation range of D-component is observed during the day of earthquake compared with the day before and after the earthquake. It is observed that the variability of D-component diurnal range at all stations is approximately constant during the examined three days except for the TNO station, which shows a variable diurnal variations range in the days preceding, during and following the seismic event as presented in the middle panel of Figure 3. The differences between the D-component recorded at the KAK observatory and other stations were calculated [(KAK-TNO), (KAK-YOK) and (KAK-OTA)] and plotted in Figure 4. The difference between (KAK-YOK) and (KAK-OTA) shows minor variations with a nearly constant trend during the three days as shown in the two lower panels of Figure 4, while the difference of the D-component at the KAK and TNO stations shows significant variation during the studied three days, see the upper panel of Figure 4. For better understanding of that anomalous observation, the D-component recorded at the TNO station was compared with that measured at the KAK observatory as an ideal reference point and also with the Dst and Kp indices during 23-25 March 2008 as shown in Figure 5. Dst and Kp indices reflect the activities of the ionosphere and magnetosphere related to external sources only, and they are not linked with the internal lithospheric sources. D-component at the TNO station showed different range of daily variations during the examined three days while daily variations amplitude was almost the same at the KAK station during the same period. On the day before and after the earthquake, the diurnal variations amplitude of the D-component measured at the TNO station is much bigger compared with that of the KAK station. On the other hand, a slight difference between the D-component daily amplitude of both stations is observed during the day of earthquake.

Inhomogeneous ionospheric currents could easily affect the Earth's geomagnetic field but with regional scale; however such situation could only affect for a short time and should appear at stations that located near from each other's. While, the underground conductivity changes or Earth currents associated with seismic activities can have a localized influence on the geomagnetic measurements at active seismic regions. The amplitude of D-component at the KAK and TNO stations was examined for longer period (2 wks). The differential values are used to make the earthquake-related phenomenon much clearer. The differences of the corresponding diurnal geomagnetic range of the three geomagnetic components recorded at the TNO station and remote reference observatory (KAK-TNO) are calculated during 17-31 March 2008 and plotted in Figure 6. The difference of the diurnal range for both H- and Z-components at the TNO and KAK stations are quite similar during the studied period as shown in the upper and lower panels of Figure 6. For the D-component, the difference of the diurnal variation amplitude shows a nearly constant trend (ranges between -17 nT to -20 nT) before and after the earthquake. A remarkable decrease in the D-component diurnal range at the TNO station is observed during the day of the earthquake compared with that at the KAK station. The difference is about 2 nT during the day of the earthquake; which means that the range of the daily variations at the TNO becomes smaller than that of the KAK station.

As it can be concluded from Figures 3-6, the unusual behavior occurred only in the vicinity of the epicenter at the TNO station. Since the stations are located near from each other, they should show similar patterns of diurnal variations with nearly equal and constant range because the external geomagnetic field is approximately uniform at these stations [8]. Such observed abnormal behavior is unlikely related to the external field variations as it reveals from the Kp index and Dst data represented respectively in the two upper panels of Figure 5. So, there is a high possibility that the anomalous behavior in the daily variations range at the TNO station is related to the variation of the crustal geomagnetic field, which differs according to the change in underground conductivity beneath that geomagnetic station.

Results & Discussion

The Northern part of Japan is mainly classified as an active subduction zone. The tectonic activities linked with subduction process can be in form of faults and volcanoes. The level of seismicity in Japan is very high especially around the plate boundaries [21]. A number of studies referred to the possible connection and influence of the seismic activities on the geomagnetic measurements. However, geomagnetic anomalies linked with earthquake activities have been intensively studied; the physical mechanisms generate such anomalous geomagnetic phenomena still not fully understood. Although, there are several observational results of anomalous geomagnetic variations detected in association with large earthquake activities, it is still questionable whether earthquakes can be forecasted or not [3,22,23].

To detect any anomalous phenomena connected with the earthquake

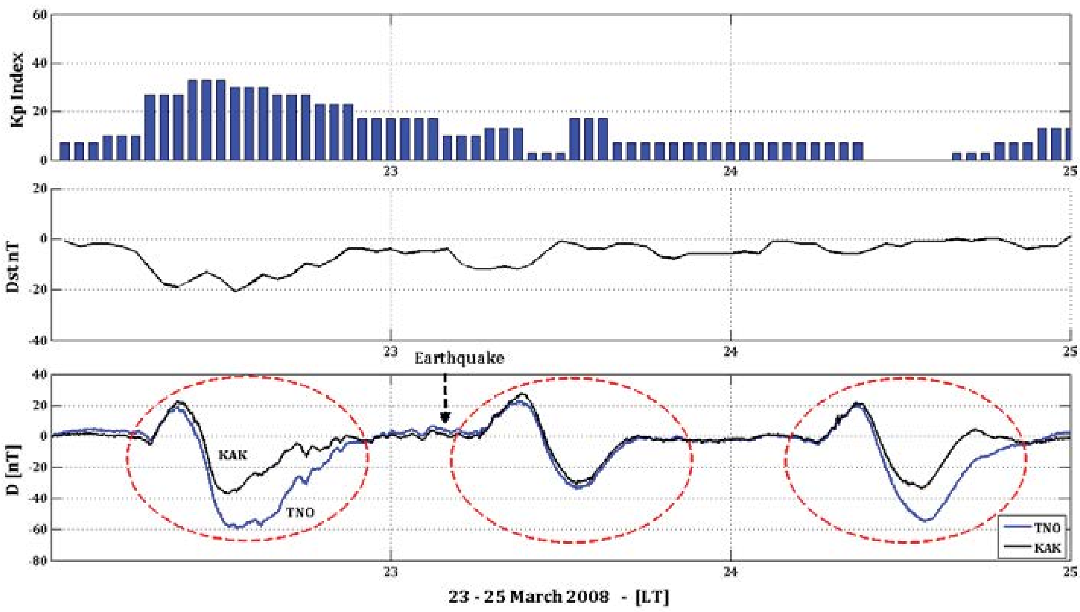

Figure 5: One-minute data for the D-component recorded at the KAK (Black) and TNO (blue) during the period 23-25 March 2008 in the lower panels. The upper two panels represent the Kp index and Dst data respectively, during the above mentioned time interval.

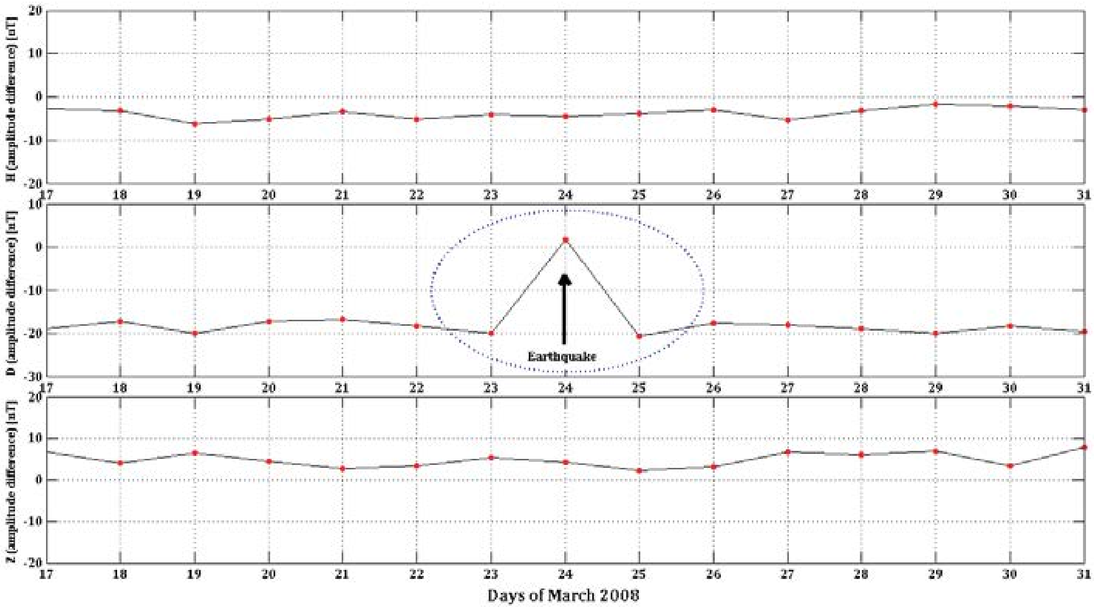

Figure 6: The difference between diurnal variation ranges (KAK-TNO) for the H, D and Z-components during 17-31 March 2008. The solid arrow indicates the occurrence time of the earthquake.

activity at northern area of the Honshu Island during 24 March 2008, the present study concentrates on studying the change of daily geomagnetic variations range by analyzing geomagnetic data from different networks prior, during and after the studied seismic event. The comparisons of diurnal geomagnetic range at the TNO with other stations and the examination of Kp and Dst indices suggest that the detected unusual phenomenon at the TNO station is not due to external magnetic perturbations, but possibly related to nearby seismic activity. Moreover, no similar observations could be found at the reference station (KAK) as demonstrated in Figures 3-6. The unusual behavior of D-component diurnal variation range at the TNO station can be considered as a distinctive anomalous phenomenon that might be related to the change in lithospheric conductivities. This suggests that the lithospheric conductivity beneath TNO is different from that beneath KAK station. Actually, the TNO station is located in a conductivity anomaly region [24,25], as well as a volcanic area. In addition, if there is a constant difference in the lithospheric conductivity between the TNO and KAK stations, a fixed difference in the diurnal geomagnetic ranges between both of them could be observed. The tectonic processes associated with the seismic activity can lead to a variation in the lithospheric conductivity at the epicenteral region and nearby areas. Telluric and Magnetotelluric currents flow in vicinity of the local high conductivities regions and create geomagnetic anomalies at the Earth's surface [26,27]. Thus, it is expected that, a temporary change in underground conductivity has occurred in the northern part of Honshu Island due to the above-mentioned seismic event. As a result, these temporary conductivity changes can be a possible cause for the observed anomalous variations. There are some other sources that can contribute to the observed phenomenon. One of these sources is the electro kinetic effect that can generate some additional geomagnetic fields when the rock fractured due to stress accumulation [5,28-30]. Another source is the influence of gases emission through the fault zones such as radon, noble gases; which can change the conductivity and modify the ionospheric electric currents intensity above the seismically active regions. Coupling between processes within the lithosphere and the ionosphere above seismically active areas is well known since several decades. Anomalous changes within the ionospheric layer had been observed in association with large seismic activities [6,31]. However, to validate these assumptions, further detailed studies are required.

Finally, the current study assumes that the observed abnormal behavior of the D-component diurnal range is most likely caused by local underground conductivity change and not by global geomagnetic disturbances. The results suggest that lithospheric conductivity can have significant influence on the amplitude of diurnal geomagnetic variations. The difference of diurnal variation range of the D-component (KAK-TNO) gives a good indication for the anomalous geomagnetic signals associated with seismic activities. So, studying the diurnal variation range can be very helpful tool for earthquake warning studies by detecting the abnormal geomagnetic variations related to earthquakes especially in regions characterizing by high underground conductivities.

Conclusion

The present study examines the relation between the diurnal geomagnetic variations and earthquake activity occurred at the northern part of Honshu Island, Japan on 24 March 2008. The results indicate a possible influence of the seismic activity on the diurnal geomagnetic variation measurements. The observed anomalous behavior is mainly a change in the amplitude of geomagnetic diurnal variation of the D-component in the vicinity of the epicenter during the day of the seismic event. The results suggest that the change of the underground conductivity associated with seismic activity has a remarkable effect on the range of the diurnal geomagnetic variations at the studied area. During the preparation period of seismic activities, lithospheric and ionospheric magnetic anomalies are generated around and above the epicenteral region of the earthquakes. Until now, it is a challenge to fully understand the physical mechanisms that stand behind the observed phenomenon, due to the complication of preparation phases of the earthquakes and also to the incomplete understanding of the underground structures at both the epicenteral region of seismic events and the observing points.

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