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The signature of the 2011 Tohoku mega earthquake on the geomagnetic field measurements in Japan

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Abstract On 11 March 2011 at 05:46:23 UTC, a mega earthquake (EQ) with magnitude (Mw) 9.0 [The 2011 Tohoku Earthquake] occurred at a depth of about 24 km near the East coast of Honshu Island, Japan as a result of a thrust faulting on or near the subduction plate boundary between the Pacific and North American plates. Geomagnetic data from MAGDAS and Geospatial Information Authority of Japan (GSI) networks have been analyzed to examine the signature of the 2011 Tohoku earthquake on the geomagnetic field measurements in Japan. Results of data analysis indicate about 5 nT increase in the total geomagnetic field intensity in the vicinity of the epicenter of 2011Tohoku EQ compared with other reference stations. Moreover, the annual range of the Z-component daily variations tends to decrease near the epicenter before the occurrence of the Tohoku EQ. Concerning the ULF emissions; the Pc 3 amplitude ratio (ZPc3/HPc3) near the epicenter at the Onagawa [ONW] station showed a good correlation with other remote reference stations before the Tohoku EQ but it started to decrease with no correlation to other stations a few weeks before the 2011 Tohoku EQ. On the other hand, the Pc 3 amplitude ratio at ONW station showed a clear anti-correlation compared with reference stations after the 2011 Tohoku EQ.

1. Introduction

The lithosphere is broken up into a number of pieces called tectonic plates and most of the earthquakes occur at the boundaries of these plates. Earthquakes can cause great damages as well as loss of many lives. Most of earthquake-related deaths are caused by the collapse of structures such as buildings and bridges during the shaking of earthquakes. Therefore, finding a way to predict earthquakes or constructing a warning system for earthquakes can be helpful for reducing the earthquake damages and mortality rate. Generally, there is no direct

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way to predict earthquakes depending on the seismicity. Thus, it is very important to look for an indirect way by finding some crustal physical parameters that can show some anomalous behavior in association with earthquakes. In this case, the variations in these physical parameters can be used as earthquake precursors. The anomalous variations in the geomagnetic field can be one of the precursors (Vere-Jones, 1995).

Several sources can cause variations in the total geomagnetic field measurable on the ground. These variations can be classified as either external or internal variations with respect to the earth's surface. The solar wind, magnetosphere and ionosphere are the main sources of the external geomagnetic variations, while the internal geomagnetic variations are linked with the tectonic processes and generally related to the induced and remanent magnetization within the lithospheric crust (Merrill et al., 1996; Mandea and Purucker, 2005). The idea of monitoring the tectonic activity using the stress-induced geomagnetic variations was proposed first by Wilson (1922). The experimental works have shown that the variation in stress field can produce changes in the rock's magnetic properties (Nagata, 1969; Revol et al., 1977; Kapička et al., 1997). Therefore, the concept of peizomagnetism has been proposed to explain the generation of anomalous geomagnetic field variation related to the tectonic processes (Stacey, 1964; Nagata, 1969, 1970; Stacey and Johnston, 1972).

Many studies have been done to examine the interrelationship between the geomagnetic field variations and the seismic activities in Japan. The results indicate a possible association between anomalous geomagnetic field variations and a number of earthquakes (Rikitake and Yokoyama, 1955; Yamazaki and Rikitake, 1970; Mogi, 1985; Hattori et al., 2002; Hattori, 2004; Nishida et al., 2007; Hayakawa et al., 2007 and Yumoto et al., 2009 among many others). Thus, precursory phenomena associated with a number of earthquakes have been reported. However, several studies have reported the interrelation between anomalous changes of the geomagnetic field and earthquakes, discussions and arguments are still arising about the signature and influence of earthquakes on the geomagnetic field measurements. Since Japan is covered by a network of well-distributed geomagnetic stations, data from MAGDAS network and the Geospatial Information Authority of Japan (GSI) have been analyzed to examine the occurrence of any anomalous geomagnetic field variation related to the 2011 Tohoku earthquake.

2. The 2011 Tohoku earthquake

Japan is located in a seismically active zone (the so-called Pacific Ring of Fire) at the Eastern edge of the Asian continental plate. Therefore, Japan is particularly prone to both earthquake and volcanic activities, sometimes to a devastating effect (as in case of the 2011 Tohoku EQ) because it is located at a point on the Earth's surface where a number of tectonic plates interact with each other. The Japanese Islands lie at the junction of four major tectonic plates; which are the Pacific plate, the Philippine Sea plate, the North American plate and the Eurasian plate as shown in Fig. 1 (Wei and Seno, 1998).

The 2011 Tohoku earthquake, also known as the Great East Japan Earthquake, struck the eastern coast of the Honshu Island, Japan with magnitude (Mw) 9.0 (after the Japan Meteorological Agency [JMA]). This earthquake was an undersea mega thrust earthquake that occurred at 05:46:23 UTC on Friday, 11 March 2011, with the hypocenter (38.322°N, 142.369°E) at a depth of approximately 24 km. It was the most powerful known earthquake to have hit Japan. The earthquake triggered extremely destructive tsunami waves of up to 38.9 meters that struck Japan (after JMA, GSI and United States Geological Survey [USGS]).

3. Geomagnetic data

The geomagnetic data used in the present study are provided by MAGDAS and GSI networks. The distribution of the geomagnetic stations is shown in Fig. 1. MAGDAS Project (PI: Prof. K. Yumoto) is recently considered the world's largest array of magnetometers, since over 60 MAGDAS real-time magnetometers are installed all over the world. The MAGDAS magnetometer is a ring core-type fluxgate magnetometer that can measure even small-amplitude geomagnetic fluctuations. It has three sensors along three orthogonal directions and measures the three components of the geomagnetic field [North–South component (H), the East–West component (D) and the Vertical component (Z)]. The sampling frequency is 16 Hz, but the instrument makes on-board calculations of the 1-s arithmetic averages of the 16-Hz data. The acquired geomagnetic data are transferred from the overseas stations to the International Center of Space Weather Science and Education (ICSWSE) at Kyushu University-formerly, Space Environment Research Center (SERC)-Japan in near real-time. Moreover, the same data are stored in a compact flash memory card in situ (Yumoto et al., 2006, 2007). Data from MAGDAS stations at Ashibetsu (ASB), Tohno (TNO), Onagawa (ONW) and Kuju (KUJ) in Japan have been used in the present study. In addition, the Legazpi (LGZ) MAGDAS station in Philippines has been used as a remote reference. The geomagnetic data from GSI stations were recorded using fluxgate and proton magnetometers. The sampling rate of the fluxgate magnetometer is one minute and the absolute observations are carried out once a year for the baseline determination. The recorded data at each station are transmitted to GSI through the public telephone line (Tanabe, 1997). The GSI stations used in the present study are Akaigawa (AKA), Yokohama (YOK), Haramachi (HAR), Shika (SIK), Otaki (OTA), Hagiwara (HAG), Yoshiwa (YOS), Totsukawa (TTK), Muroto (MUR) and Kuju (KUJ). The original data obtained from GSI stations are one minute data of the total magnetic field intensity (F), declination (D), horizontal (H) and vertical (Z) components. The GSI data format was modified by Dr. T. Uozumi at ICSWSE, the Kyushu University to match with the data format provided by MAGDAS network, in which (H) is referring to the North–South component, (D) is referring to the East–West component and (Z) is referring to the Vertical component.

4. Results of data analysis and discussion

The availability and quality of the geomagnetic data are very important factors in the study of anomalous geomagnetic variations related to seismic activities. In addition, it is commonly accepted that a network of stations are necessary for observing and extracting the precursory phenomena or anomalous geomagnetic variations associate with earthquakes. In the present