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Geomagnetic field variations observed by INTERMAGNET during 4 total solar eclipses

Jung-Hee Kim [a,b], Heon-Young Chang [a,b,*]

[a] Department of Astronomy and Atmospheric Sciences, Kyungpook National University, Daegu 41566, South Korea
[b] Research and Training Team for Future Creative Astrophysicists and Cosmologists (BK21 Plus Program), Daegu 41566, South Korea

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ABSTRACT

We investigate variations of the geomagnetic field observed by INTERMAGNET geomagnetic observatories over which the totality path passed during a total solar eclipse. As a result, we have presented results of examining the geomagnetic field data observed by 6 geomagnetic observatories during the 4 total solar eclipses (11 August 1999, 1 August 2008, 11 July 2010, and 20 March 2015). These total solar eclipses are the only total solar eclipse, since 1991 when the INTERMAGNET began to work, during which the umbra of the Moon swept an INTERMAGNET geomagnetic observatory and simultaneously variations of the geomagnetic field are recorded at the geomagnetic observatory. We have confirmed previous reports that, at least on average, during the solar eclipse characteristic increase of Y component of the geomagnetic field Y and decreases of X, Z and F are conspicuous. Interestingly, we have noted that variations of X, Y, Z and F observed during the total solar eclipse at Isla de Pascua Mataveri (Easter Island) in Chile (IPM) in the southern hemisphere show distinct decrease of Y and increases of X and Z on the contrary. We have found, however, that variations of X, Y, Z and F observed at Hornsund in Norway (HRN) at 77°N in latitude seem to be dominated by other geomagnetic occurrence since the solar activity is near maximum, and the geomagnetic field is disturbed on the day of eclipse. We further discuss a possibility of exploring an effect of the solar eclipse on the amplitude of harmonic components of the geomagnetic field using the wavelet analysis technique, which has revealed suppression in the amplitude during the middle of a solar eclipse. Finally, we conclude by discussing implications of what we have found.

1. Introduction

A solar eclipse is such an uncommon event that one has to be regarded as serendipitous for observing it at a given location on the Earth (e.g., Ahn and Lee, 2004). Particularly, total solar eclipses are almost unique in that they practically never happens under the identical circumstances involving latitudes, local time, the time of year, as well as relatively rare since these occasions are observable only within a narrow strip of a couple of hundreds km in width. Besides, it is considered as an inventive experiment in the sense that the total solar eclipse results in intricate changes in the atmosphere of the Earth which arise at all heights from the surface layer to the ionosphere (e.g., Nayak et al., 2010; Cheng et al., 2016).

For instance, Anderson (1999) has reported that the cooling due to the loss of radiative energy during the total solar eclipse begins to be noticeable when the sun is about half-covered, or the magnitude of eclipse is ~ 0.5, with air temperature reaching its minimum between 5 and 20 min after the time of maximum eclipse. As one might expect, the pattern and precise amount of the decline in air temperature are indeed different to each location, subject to various factors, such as, the time of day, local climate, even surrounding vegetation. It actually makes the atmospheric effects of a solar eclipse engaging themes of extensive research on meteorological parameters (Anderson et al., 1972; Chernogor, 2008, 2011; Akimov and Chernogor, 2010; Lyashenko and Chernogor, 2013), boundary layer physics (Antonia et al., 1979), photochemistry (Srivastava et al., 1982; Zanis et al., 2007), total columnar ozone (Chakrabarty et al., 1997; Zerefos et al., 2000), gravity wave (Chimonas and Hines, 1970; Fritts and Luo, 1993; Altadill et al., 2001, 2004; Zerefos et al., 2007; Gerasopoulos et al., 2008; Manju et al., 2014; Chen et al., 2015).

Observations of ionospheric perturbations during solar eclipses have also uncovered that the Earth's ionosphere undergoes significant changes during the solar eclipse event, though the effects are different for different ionospheric layers, including a decrease in the electron

* Corresponding author. Department of Astronomy and Atmospheric Sciences, Kyungpook National University, Daegu 41566, South Korea.
E-mail address: hyc@knu.ac.kr (H.-Y. Chang).

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concentration (Klobuchar and Whitney, 1965; Salah et al., 1986; Afraimovich et al., 1998, 2002; Tsai and Liu, 1999; Davis et al., 2001; Sridharan et al., 2002; Baran et al., 2003; Farges et al., 2003; Chandra et al., 2007; Jakowski et al., 2008; Krankowski et al., 2008; Le et al., 2008, 2009; 2010; Ding et al., 2010; Chernogor et al., 2011; Momani and Sulaiman, 2011; Singh et al., 2011; Kumar and Singh, 2012; Chernogor, 2013; Kumar et al., 2013; Lyashenko and Chernogor, 2013), an increase of the top frequency of the sporadic E layer (Datta, 1972, 1973; Chen et al., 2010; Yadav et al., 2013), generation of ionospheric acoustic-gravity waves (Farges et al., 2001; Chernogor, 2008, 2016; Grigorenko et al., 2008; Jakowski et al., 2008; Chen et al., 2011), a decrease of the critical frequencies of the ordinary mode of propagation (Cheng et al., 1992; Adeniyi et al., 2007).

Ionospheric responses to total solar eclipses can be understood by envisaging that total eclipse conditions under which solar radiation to the Earth is obscured by the Moon may be deemed the coinciding with those of the night. Then, during the total solar eclipse the photochemical activity is to decrease to night-time levels and loss rate of plasma remains unaffected (Le et al., 2009; Baran et al., 2003). It should be noted, however, that since the umbra of the Moon is fairly small compared with the size of the Earth the decay rate of the ionosphere can not be exactly same as during the night, probably due to the compensating effect of the ionization coming from the adjacent regions and the supersonic motion of the Moon's cool shadow through the atmosphere. In addition, a mathematical model based on the classical model (Chapman and Bartels, 1940; Yamazaki et al., 2011; Campbell, 1989) implies that the decrease of the ionospheric total electron content or the conductivity of the lower ionosphere in the region of the totality belt induces to modification of the current pattern in this region and subsequently geomagnetic disturbances of tens nT at ground level (Tomás et al., 2009; Ruhimat et al., 2016; Chernogor and Garmash, 2017). Although this theory is straightforward, the effect has proved very difficult to be detected in practice as the regular geomagnetic daily variations itself shows large day-to-day variability even in geomagnetically quiet conditions (e.g., Kim and Chang, 2014a, 2014b). Furthermore, disturbances of the geomagnetic field quantitatively depend on the position of both the umbra and a geomagnetic observatory, on various factors, such as geophysical conditions, latitude, longitude and local time (e.g., Malin et al., 2000; Baran et al., 2003; Adekoya et al., 2015; Adekoya and Chukwuma, 2016; Kim and Chang, 2018). Hence, to duly evaluate the ionospheric effect of a solar eclipse one needs first to check the geophysical conditions involved.

Reflecting the present situation, it is fair to say that the problem of impacts on the geomagnetic field during solar eclipses remains open. For instance, Strestík (2001) noted an increase of 10 nT in the Y component of the geomagnetic field during the 11 August 1999 total solar eclipse and a decrease in the X component of 5 nT. Özcan and Aydoğdu (2004) analyzed the 11 August 1999 total solar eclipse over Turkey and found a increase in the Y component of geomagnetic field, and no significant effect in the X component of geomagnetic field. Ladynin et al. (2011) also reported some eclipse effects in magnetic field in Novosibirsk during the 1 August 2008 solar eclipse. Curto et al. (2006) further showed that the model calculations were qualitatively consistent with ionospheric and geomagnetic data. On the other hand, Korte et al. (2001) even disclaimed any eclipse-related magnetic variation in Europe during the 11 August 1999 eclipse. A reason for this current confusing experience, despite a number of studies concerning the influence on the geomagnetic field during solar eclipses, is partly because the event itself is the outcome of a complicated dependence which can hardly be reproduced and partly because examining cryptic signal out of noisy data cannot be settled with a case study but rather demands a sort of statistical analysis by nature (e.g., Ianev et al., 1979; Iliev et al., 1996; Ateş et al., 2015).

Here, we investigate variations of the geomagnetic field observed by INTERMAGNET geomagnetic observatories over which the totality path passed during a solar eclipse (for examples of its contribution see, e.g., Afraimovich et al., 2006; Nowozynski and Slezak, 2013). That is, we concentrate our attention on geomagnetic manifestations resulting from the 4 total solar eclipses (11 August 1999, 1 August 2008, 11 July 2010, and 20 March 2015) observed by 6 geomagnetic observatories. It should be appreciated that these total solar eclipses are the only solar eclipse, since 1991 when the INTERMAGNET began to work, during which the umbra of the Moon swept one of INTERMAGNET geomagnetic observatories and simultaneously variations of the geomagnetic field are recorded at the geomagnetic observatory. Among these the umbra of the Moon during the total solar eclipse occurred at the 11th of August in 1999 proceeds over 3 geomagnetic observatories in order, for the rests one for each geomagnetic observatory. For the solar eclipse occurred on 11 August 1999, the track of the Moon's shadow began in the Atlantic Ocean, was traversing countries in Europe and Turkey, and ended in the Bay of Bengal. The totality path of the 1 August 2008 solar eclipse occurred in a narrow path through northern Canada, Greenland, central Russia, and China. Notably, the 11 July 2010 solar eclipse occurred over the southern Pacific Ocean, touching several atolls in French Polynesia, the Cook Islands, Easter Island, and Argentina's Patagonian plains. The fourth solar eclipse we have presented is that of 20 March 2015, the day of the vernal equinox. The path of its totality began off the south coast of Greenland, passed across the North Atlantic, moved over the Faroe Islands, the northernmost islands of Norway, and into the Arctic Ocean. Traces of the umbra and locations of the geomagnetic observatories are shown in Fig. 1.

The main aims of the present contribution in contrast with most of previous works are two-fold. Firstly, unlike previous studies in which efforts until now are mainly focused on a certain solar eclipse as a case study, we compare results acquired by 6 geomagnetic observatories during the 4 total solar eclipses in terms of geomagnetic and solar ecliptic parameters. In doing so, as far as we are aware we have reported for the first time geomagnetic variations measured by a geomagnetic observatory in the southern hemisphere while the totality path passed just above the geomagnetic observatory. As a result, we demonstrate that even for a given total solar eclipse a separate geomagnetic observatory may record different aspects of the geomagnetic features according to various conditions. Secondly, we demonstrate a possibility of exploring an effect of the solar eclipse on the amplitude of harmonic components of the geomagnetic field. We have attempted to obtain any signatures of influence on the temporal behavior of the variation in the geomagnetic field signal during the solar eclipse, by employing the wavelet analysis technique which is associated with the Gabor transform (Bracewell, 1965). It should be possible because the wavelet transform is able to give temporal variations of power of a mode in power spectrum of the wavelet transform, as proved its usefulness in many fields of physics and engineering, such as, acoustics, geophysics, helioseismology, image processing.

This paper is organized as follows. We begin with brief descriptions of geomagnetic data analyzed for the present paper and a procedure extracting them in Section 2. We present and discuss results of examining the geomagnetic field during the total solar eclipse in Section 3. Results of the wavelet analysis are subsequently presented and discussed in Section 4. Finally, we summarize and conclude in Section 5.

2. Geomagnetic data

We have taken geomagnetic field element data for the present analysis from the INTERMAGNET website,[1] where one can find the geographical information of 150 geomagnetic observatories around the world as well as geomagnetic field element data in close to real time. INTERMAGNET was founded to establish a global network of cooperating digital geomagnetic observatories with adopting modern standard for measuring and recording the Earth's magnetic field. The first Geomagnetic Information Node (GIN) was established in 1991, and it began to release the data since then.

[1] http://www.intermagnet.org/.