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Contrastive research of ionospheric precursor anomalies between Calbuco volcanic eruption on April 23 and Nepal earthquake on April 25, 2015

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Abstract

On April 23, 2015, the VEI4 (volcanic explosive index) Calbuco volcano abruptly erupted in Chile and the Mw7.9 Nepal earthquake occurred on April 25. In order to investigate the similarities and differences between total electron content (TEC) anomalies preceding these two types of geophysical activities, the TEC time series over preparation zones before the volcanic eruption and earthquake extracted from global ionosphere map were analyzed. We used sunspot numbers (SSN), B_z, Dst, and Kp indices to represent the solar-terrestrial environment and eliminate the effects of solar and geomagnetic activities on ionosphere by the sliding interquartile range method with the 27-day window. The results indicate that TEC-negative and -positive anomalies appeared in the 14th and 6th day before the eruption, respectively. The anomalies lasted about 4–6 h with a magnitude of 15–20 TECU. The TEC anomalies were also observed on the 14th and 6th day before the Nepal earthquake with a duration of 6–8 h, and the absolute magnitude of TEC anomalies was within 12–20 TECU. These findings indicate that the magnitude of TEC anomalies preceding volcanic eruption was larger, and the duration of TEC anomalies before the earthquake was longer, which may be associated with their particular physical mechanisms. The TEC anomalies before the Nepal earthquake in the Eastern hemisphere occurred in the afternoon local time, but those before the eruption were observed in the night local time. Peak regions of TEC anomalies did not coincide with the epicenters of geophysical activities, and the TEC anomalies also appeared in the magnetic conjugated region. Both the TEC anomalies in the preparation zone and conjugated region were distributed near the boundaries of equatorial anomaly zone and moved along the boundaries. In the moving process, sometimes the extent or magnitude of TEC anomalies in the conjugated region was larger than that in the preparation zone. Many more GPS stations and receivers should be distributed along the boundaries of equatorial anomaly zone, which will be significant in predicting volcanic eruptions and earthquakes in the low-mid-latitudes.

Keywords: Nepal earthquake; Calbuco volcanic eruption; Ionosphere; TEC anomalies; Solar-terrestrial environment; Sliding interquartile range method

1. Introduction

Ionospheric precursor anomalies before a massive earthquake were first observed by Leonard and Barnes (1965). After that, many researchers were dedicated to investigating the lithosphere–atmosphere–ionosphere phenomenon

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(Molchanov et al., 2004; Pulinets and Ouzounov, 2011; Kuo et al., 2014). A large number of results manifest that ionospheric anomalies can be caused by some geophysical activities, such as earthquakes, volcanic eruptions, and nuclear explosions (Whitcomb et al., 1973; Pulinets et al., 2004; Pulinets, 2004; Hayakawa et al., 2010). Among many earthquake events, the ionospheric anomalous variations before the Mw7.9 Wenchuan earthquake on May 12, 2008 (Klimenko et al., 2011), and the Mw9.1 Japan earthquake on March 11, 2011 (Zhao et al., 2008; Heki, 2011) were most distinct. Negative and positive anomalies were observed on the 6th (May 6) and 3rd day (May 9) over the seismogenic zone before the Mw7.9 Wenchuan earthquake, respectively. The spatial distribution of total electron content (TEC) anomalies indicates that the seismogenic zone is approximately 2850 and 1650 km apart from the epicenter in the longitudinal and latitudinal directions, respectively. The FORMOSAT3/COSMIC results also show that F_2 electron density decreased approximately 40% and the F_2 peak height descended about 50–80 km before the Wenchuan earthquake, respectively (Liu et al., 2009; Akhoondzadeh et al., 2010). In addition, the TEC was significantly increased on the 3rd day (March 8) before the Japan earthquake on March 11, 2011. Most of the TEC anomalies occurred in the afternoon local time, and positive anomalies were also observed in the corresponding geomagnetic conjugated region (Kon et al., 2011; Yao et al., 2012). Ionospheric electron density over the seismogenic zone before the earthquake was reconstructed by computerized ionospheric tomography (CIT), and the electron density in the region of 126–134°E, 18–35°N increased significantly on March 8. In order to investigate the spatial–temporal distribution characteristics of seismic-ionospheric anomalies, TEC anomalies before many earthquake events in recent decades have been analyzed (Zhu et al., 2014). The ionospheric variations before many earthquakes indicated that the rate of occurrence of ionospheric anomalies preceding an earthquake was obviously larger than at other moments, that is, the rate was proportional to the magnitude of the earthquake and inversely proportional to the days closer to the earthquake (Le et al., 2011). Besides, ionospheric anomalies associated with earthquakes usually lasted 4–6 h and occurred 1 week before main shocks. The spatial characteristic of ionospheric anomalies was related with earthquake magnitude and local time, the anomalous area did not coincide with the epicenter, and the anomalies could also be observed in the corresponding magnetic conjugated region (Pulinets et al., 2003). Hence, the temporal-spatial characteristics of seismic-ionospheric anomalies could be understood more clearly according to numerous research results. However, to the volcanic-ionospheric effect, researchers usually focused on the ionospheric anomalies after volcanic eruption or the volcanic eruption energy estimated by TEC perturbations in previous studies (Johnston, 1989; Dautermann et al., 2009a,b), and paid little attention to the temporal–spatial variations of ionospheric anomalies before the volcanic eruption.

Calbuco is a 2003-m-high volcano located in Chile (72.61°W, 41.33°S). It suddenly erupted on April 23, 2015, and the high-density volcanic ash posed a serious threat to the environment and the safety of people's lives and property (Castruccio and Clavero, 2015). A Mw7.8 earthquake occurred on April 25, 2015, whose epicenter was located in Nepal (85.33°E, 27.91°N) with the hypocentral depth of approximately 12 km. This earthquake seriously affected Nepal, China, India, and other adjacent countries to cause heavy casualties and serious economic losses (Wang and Fialko, 2015; Hayes et al., 2015). Locations of the Calbuco volcano and the Nepal earthquake are shown in Fig. 1. The times of occurrence of the Calbuco volcanic eruption and the Nepal earthquake are very close, and both are in the low-mid-latitudes and located in the Western and Eastern hemispheres, respectively, which necessitates the investigation of the comparative results of ionospheric variations before volcanic eruption and earthquake. Therefore, we analyze the ionospheric variations over preparation zones before earthquakes and eruptions, summarize similarities and differences of ionospheric anomalies preceding different types of geophysical activities, and discuss the relationship between temporal–spatial characteristics of ionospheric anomalies and the geographic position of epicenter and volcano.

2. Data and methods

2.1. GPS TEC data

The extending network of global navigation satellite system (GNSS) stations has generated a large amount of data, from which the TEC can be estimated by mapping the slant path delay of the dual-frequency L-band signals ($f_1 = 1575.42$ MHz, $f_2 = 1227.60$ MHz) observed by global distributed international GNSS service (IGS) stations (Mannucci et al., 1998). Vertical TEC (VTEC) is converted from the slant TEC (STEC) using single- or multi-layer assumption and mapping functions. The VTEC is modeled in a solar–geomagnetic reference frame with a spherical harmonics expansion up to the order of 15 (Akhoondzadeh et al., 2010). Observation data of >200 GNSS stations in the IGS network are used to compute global ionosphere map (GIM) of TEC (ftp://ftp.unibe.ch/aiub/CODE). The Center for Orbit Determination in Europe (CODE) GIMs are used to investigate the ionospheric variations preceding the Nepal earthquake and the Calbuco volcanic eruption. In that year, the CODE GIM with a 1-h time resolution covering ±180° longitude and ±87.5° latitude ranges with spatial resolutions of 5° and 2.5°, respectively (Tang et al., 2015). The error of GIM is approximately several TECU (1 TECU = 10^{16} electrons/m^2) (Le et al., 2013).