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Ionospheric characteristics prior to the greatest earthquake in recorded history

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Abstract

Although several reports on the variations of some radio observed ionospheric properties prior to the very large Chile earthquakes of 21–22 May 1960 have been published, no one up to now has reported on the variations of simultaneous E- and F-region characteristics observed at Concepción (36.8°S; 73.0°W) using a ground based ionosonde. This paper analyses values of the NmE, NmEs, h'E, NmF2, h'F, M3000F2 and fmin. Possible solar and geomagnetic activity effects are first identified and then anomalies are calculated for all characteristics using reference values (15-day running medians ± interquartile range). Occasions when anomalies are larger than an upper threshold and less than a lower threshold are discussed and compared, whenever possible, with other published studies. Further study is suggested to unambiguously associate some found possible Es-layer and M3000F2 anomalies with very strong earthquakes.

Keywords: Ionospheric characteristics; Earthquake precursors; Chile

1. Introduction

For over the last half a century many attempts have been made to identify precursors of strong earthquakes (e.g. Biagi et al. (2012) – a special issue dedicated to this subject), even lately using satellite gravity field observations (Shahrisvand et al., 2014). In the case of ionospheric precursors, some sort of reference for a given ionospheric characteristic is first derived. This must take into account all possible solar and geomagnetic variability. Only then an anomaly can be accurately calculated for hours to days before the earthquake. These anomalies are to be analysed to search for an ionospheric precursor. For a consolidated review of this type of statistical analyses see Pulinets and Boyarchuk (2004). Later references are given by Ovalle et al. (2013) who discuss total electron concentration (TEC) and maximum electron concentration (NmF2) anomalies for the Chilean 27 February 2010 earthquake. Obviously, a key point in determining anomalies is whether it is possible to screen tropospheric/stratospheric variability that reaches the ionosphere (Forbes et al., 2000; Mendillo et al., 2002; Lăstovička, 2006) from the observed ionospheric variability so as to identify likely precursor ionospheric signatures.

A large variety of studies have been put forward suggesting likely mechanisms to justify the association between observed precursor ionospheric anomalies and seismic

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activity occurring before strong earthquakes. Pulinets and Boyarchuk (2004) extensively review these proposed mechanisms. An up to date comprehensive report on how information could be conveyed from the Earth´s surface to the ionosphere through the Global Electric Circuit is given by Pulinets and Davidenko (2014).

On statistical studies, even the possibility to identify ionospheric precursors has been somewhat controversial as epitomized by Rishbeth (2007) and Pulinets (2007) a decade ago. Recently this controversy has again aroused some interest. Heki (2011) detected a clear precursory positive anomaly of TEC around focal region of the 2011 March 11 Tohoku-Oki earthquake using data from the Japanese dense network of Global Positioning System (GPS). The anomaly started ~40 min before the earthquake and reached nearly ten percent of the background TEC. He also suggested that similar anomalies were seen in the 27 February 2010 Chile earthquake, and possibly in the 2004 Sumatra-Andaman and the 1994 Hokkaido-Toho-Oki earthquakes, but not in smaller earthquakes. However, an alternative interpretation of the TEC variation in the ionosphere associated with the 11 March 2011 Tohoku-Oki earthquake is given by Kamogawa and Kakinami (2013) on the basis of the work of Kakinami et al. (2012). Their interpretation is that a tsunamigenic ionospheric hole, a wide depletion of the TEC, occurred after the co-seismic acoustic wave reached the ionosphere and gradually recovered at the normal state within several tens of minutes. The difference between the Heki (2011) and the Kakinami et al. (2012) interpretations is attributed to the different ways in which the TEC reference curves used to extract the ionospheric variations was performed. Another case comes from the analysis of ground based observations. On one side, according to Shestopalov et al. (2013), a precursor to the Chilean earthquake of 27 February 2010 consisted of a significant geomagnetic disturbance observed for about an hour at different magnetic stations of the INTERMAGNET network on February 24, three days before the event, On the other side, Romanova et al. (2015) analyzed in detail data from magnetometers, photometers, and riometers in Canada, Chile, and Antarctica (SAMBA and CARISMA networks). They find that the analysis unambiguously shows that the supposedly anomalous geomagnetic disturbance was not related to seismic activity but instead was caused by a standard isolated substorm.

For some studies on statistics and on mechanisms reported between 2013 and the time of writing a very brief review is given in the Appendix A. This is by no means to be considered as complete.

The purpose of this paper is to report on the analysis of several ionospheric characteristics both observed directly or derived from ionosonde records during two months prior to the 33 h series of very large earthquakes beginning early in the morning of 21 May (Mw = 8.1) and leading to afternoon great Chilean of 22 May 1960 (Mw = 9.5), the largest in recorded history. The analysis can be considered as a follow up to the one reported by Foppiano et al. (2008), which discussed only the critical frequency of the F-region, but using the methodology of Ovalle et al. (2013). The main purpose is again to show whether ionospheric precursors proposed on various statistical studies are consistent with the ones that could be derived for these great Chilean May 1960 earthquakes. The earthquakes are thrust events occurring at a well-defined subduction zones, where the Nazca plate subducts at a rate about 80 mm/yr underneath the South American plate. Most of the fault plane reaches the surface beneath the ocean at several km depths. Detailed reports of this series of earthquakes are given by Cifuentes (1989) and Barrientos and Ward (1990), and the many references within.

2. Data analysis

2.1. Data used

Solar and geomagnetic conditions from 21 March to 21 May 1960 are depicted in Fig. 1 in terms of the solar activity index F10.7 and the geomagnetic activity index Dst, respectively. Solar flare occurrence and characteristics for this interval are given by http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/h-alpha/tables/1960/. As it can be seen solar activity fluctuates from about 140–200, being highest 1 and 15 April and 11 May, and lowest 21 March, 8, 27 April and 17 May. The geomagnetic activity changes significantly over the same interval. A large geomagnetic storm is observed from 31 March to 10 April which seems to follow a series of flares for which Concepción is on the sunlit hemisphere: 28 March, 15:42–16:44 LT (75°W), importance 2; 29 March, 15:38–16:58, importance 2 and 30 March, 08:55–15:50, importance 1–2+. Between 24 April and 13 May successive depressions of Dst indicate a series of superposed geomagnetic storms.

Values of NmE, NmF2 and NmEs, are derived from observed E-region, F-region and Es critical frequencies over Concepción (36.8°S; 73.0°W), during 21 March–21 May 1960. Although for NmEs determination fbEs (Es blanqueting frequency) should probably be used instead of foEs, this is of no concern for the purpose at hand because finding unusual foEs is easier than fbEs. Diurnal variations of NmE, NmF2 and NmEs are given in Fig. 1 using color codes. In turn, Fig. 2 shows corresponding h'E, h'F and M3000F2 variations. Note that values are depicted at 15 min intervals. However, since for the interval 21 March–30 April only hourly values are available, values at 15 min are interpolated for the presentation's uniformity sake. Since the E-region is not observed using typical ionosondes during night-time, blank spaces are shown in Figs. 1 (NmE) and 2 (h'E) from about 17:00–06:00 LT. Also, there are several blank spaces during daytime. Some of these relate to large Sporadic-E layers below the E-region peak electron concentration, unusual absorption,