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Giant disturbance in the ionospheric F2 region prior to the M8.0 Wenchuan earthquake on 12 May 2008

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Abstract. On 12 May 2008 at 14:28 LT great earthquake (M=8.0) occurred at Wenchuan (31.00° N, 103.40° E), China. The hourly values of *fo*F2 are analyzed over ten ionospheric observatories: Haikou (20.00° N, 110.33° E), Kunming (25.00° N, 102.70° E), Guangzhou (20.00° N, 113.70° E), Chongqing (29.50° N, 106.40° E), Lhasa (29.63° N, 91.17° E), Lanzhou (36.07° N, 103.87° E), Beijing (40.00° N, 116.30° E), Urumqi (43.75° N, 87.63° E), Chuangchun (43.83° N, 125.30° E) and Manzhouli (49.60° N, 117.45° E). With a new factor, effective sunspot number R_{eff}, the results show that there were giant positive disturbances of *fo*F2 around the epicentral zone on 9 May, 3 days prior to the earthquake. Our results indicate that the observed positive ionospheric disturbances were most possibly associated with the imminent earthquake and the new analytic method has good prospects in practice.

Keywords. History of geophysics (Seismology) – Ionosphere (Ionospheric disturbances)

1 Introduction

Since the phenomenon related to ionospheric perturbation caused by the earthquake at Alaska 1964 was firstly reported (Barnes and Leonard, 1965), many researchers have devoted themselves to seismo-ionospheric research and there have been numerous observational studies of ionospheric anomalies prior to strong earthquakes (Pulinets, 1998; Silina et al., 2001; Liu et al., 2004, 2006, 2009; Rios et al., 2004; Dabas et al., 2007; Sarka et al., 2007; Chmyrev et al., 2008; Zakharenkova et al., 2008; Sharma et al., 2008; Hsiao et al., 2009; Ondon, 2009; Zhao et al., 2009). An excellent review of ionospheric precursors has been presented by Pulinets et al. (2003).

However, until recently, the existence of the ionospheric precursors of earthquake is still a controversy, because on one hand, the physical mechanism of seismo-ionospheric coupling is not well understood and on the other hand, there is some lack of appropriate ionospheric data which one could obtain more reliable evidence of the ionospheric precursors of earthquake. Hence further observations evidence is urgently needed to shed light on the problem.

In this paper, we report observations of the giant perturbations in the ionosphere F2 layer *fo*F2 prior to the Wenchuan earthquake with a new analytic method. Data obtained over ten ionosondes located at different distances from the earthquake epicenter of China are analyzed. Moreover, the method is preliminarily evaluated with two earthquakes, Tangshan and Songpan earthquakes. The possible mechanisms that could be responsible for the observed pre-earthquake ionospheric disturbances are also discussed.

2 Method for analyzing

Figure 1 illustrates the variation of *fo*F2 from 6 to 12 May 2008 over Chongqing station, from which we can find that there were evident positive perturbations of *fo*F2 on 9 May. The unusual large positive disturbances of ionosphere were also reported by other authors with data of TEC (Zhao et al., 2008; Liu et al., 2009; Zhou et al., 2009). Both solar and geomagnetic activities have important influence on variation of *fo*F2, hence we have to examine the levels of solar and geomagnetic activities firstly. The solar radio flux F107, geomagnetic indices ap and Dst were used. Figure 2 shows

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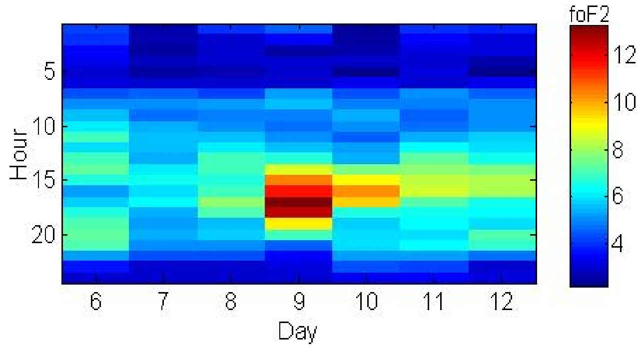

Fig. 1. Variations of *fo*F2 from 6 to 12 May over Chongqing station.

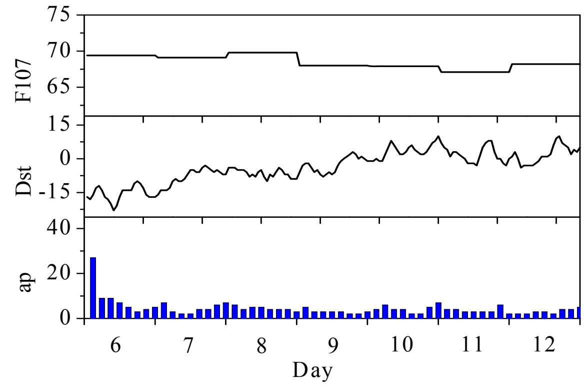

Fig. 2. Variations of F107, Dst and ap indices from 6 to 12 May 2008.

the levels of solar and geomagnetic activities from 6 to 12 May, 2008. From Fig. 2, we find that the solar activity was placid and the geomagnetic activity was very quiet, favorable to single out ionospheric perturbations due to pre-earthquake seismic activity. Different from the former methods, we will use an approach of effective sunspot number R_{eff} to analyze the disturbances of *fo*F2.

We have developed a multi-regression model with sunspot number R and geomagnetic index Ap to describe the solar cycle variation of monthly median *fo*F2 (Xu et al., 2008a, b). The monthly median values of *fo*F2 parameter are usually used to represent the "quiet" ionosphere (Cander and Mihajlovic, 1998) even if, in many cases, they do not efficiently represent the "quiet" behaviour of the ionosphere (Belehaki et al., 2000). The multi-regression model of *fo*F2 is the following

$$foF2_{h,m} = c_{0h,m} + c_{1hm}\cdot R + c_{2h,m}\cdot R^2 + c_{3h,m}\cdot \mathrm{Ap}\cdot R + c_{4h,m}\cdot \mathrm{Ap} + c_{5h,m}\cdot \mathrm{Ap}^2 \quad (1)$$

where R and Ap are twelve-month running mean values, c_0 to c_5 are coefficients at given local time h for different month m, in which c_3 represents of coaction of solar and geomagnetic activities, while c_4 and c_5 are the geomagnetic activity amplitudes. This model has a much lower error deviations from the observed, e.g., less than 1.0 MHz over Chongqing station than the linear regression which is used widely in ionospheric models (Xu et al., 2008a, c).

With the observed hourly data of *fo*F2, we can obtain the effective sunspot number R_{eff}

$$\begin{cases} R_{\mathrm{eff}} = \frac{-B+\sqrt{B^2-4AD}}{2A} & B^2-4AD>0 \\ R_{\mathrm{eff}} = \frac{-D}{B} & B^2-4AD<0 \end{cases} \quad (2)$$

where $A=c_2$, $B=c_1+c_3\mathrm{Ap}$, $D=c_0+c_4\mathrm{Ap}+c_5\mathrm{Ap}^2\text{-}foF2$. Ap is hourly value by interpolation. As shown in Eq. (2), when there is no solution of Eq. (1), we neglect the second order, i.e., we used a linear regression model of sunspot number. In addition, to examine the ionospheric disturbances, the deviation between the observed daily R and the calculated R_{eff} is determined as follows

$$\mathrm{DR} = R_{\mathrm{eff}} - R \quad (3)$$

Figure 3 demonstrates the evolution of DR map during 15:00–18:00 LT on 9 May. The positions of the ten ionosondes are marked on the map. It is shown in Fig. 3 that the various enhancement of DR started at 15:00 LT, which represented the positive disturbance of F2 region ionosphere. After 2 h evolution, the enhancement of DR was expanded and amplified with the maximum value reaching up to 135 over Chongqing station and then began to decrease. As illustrated in the Fig. 3, because of the contribution of DR over Kumming station (at 17:00 LT, the DR reached at 105 much bigger than 33 over the northern station, Lanzhou), the region predominated by the positive disturbances with rounded shape focused on the southern China, where is usually controlled by the northern equatorial anomaly in the East Asia.

The ionospheric disturbance over a limited area close to the epicenter is one of most importance characteristics reported by many authors (e.g. Pulinets et al., 2003; Rios et al., 2004), which is different from the global scale disturbance due to geomagnetic storm. The geomagnetic activity remained at considerable level (the maximum of ap reached up to 39 nT) from 2 to 6 May 2008. Hence, we check the DR amplitude on 3 May 2008. As shown in Fig. 4, the positive disturbance had an extraordinarily large scale, which implies that the method using DR successfully represents the ionospheric disturbance related to the geomagnetic storm. Over Lhasa station, more than 1200 km away from the epicentre, the DR was about 125 on 3 May, while DR remained about zero on 9 May, which is consistent with the result that there was no obvious ionospheric disturbance obtained by analysing data of *fo*F2 (Ding et al., 2010; Xu et al., 2010). The similar amplitude of DR was also found over Guangzhou station, more than 1400km away from the epicentre. Hence, the local spatial distribution of affected area can help us to exclude the other possible processes that induce the ionosphere disturbance.

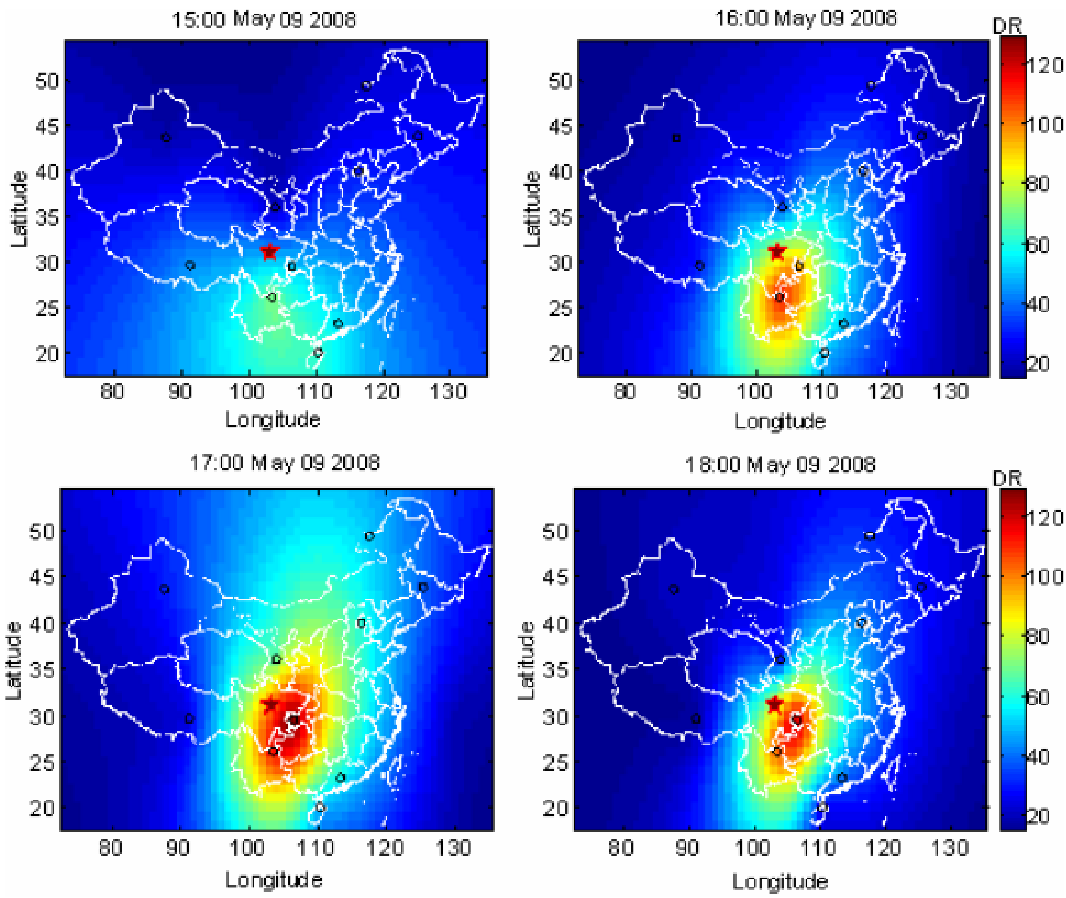

Fig. 3. Two-dimensional maps of DR on 9 May 2008 from 15:00 to 18:00 LT, respectively. The red star and black circles denote the epicenter and ionosondes, respectively.

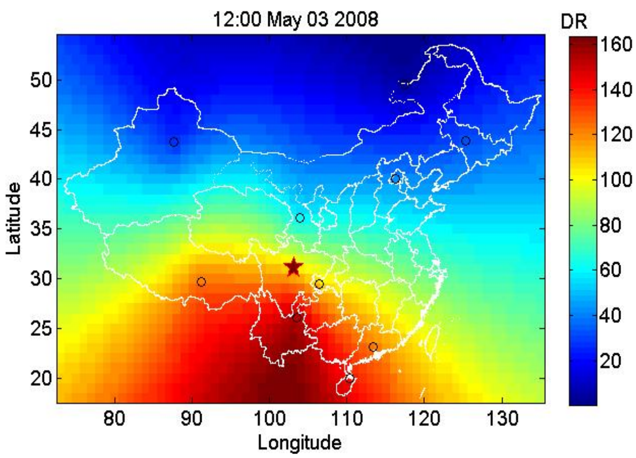

Fig. 4. Same as Fig. 3 but on 3 May 2008.

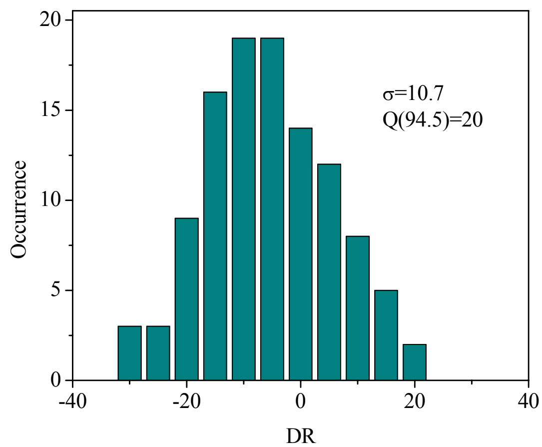

Fig. 5. The standard deviations (σ) and the distribution of DR during the interval of 10–19 May 2008 over Chongqing station.

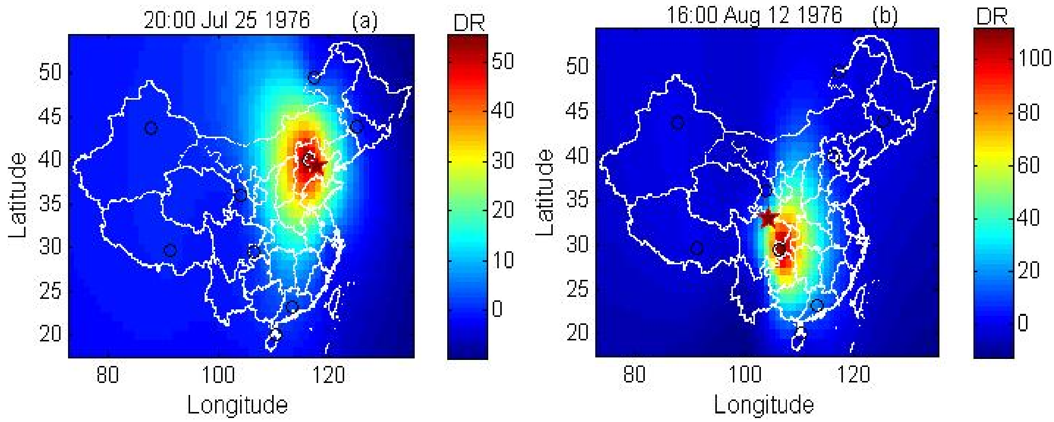

Fig. 6. Same as Fig. 3 but on 25 July (3 days prior to Tangshan earthquake occurred) and 12 August (4 days prior to Songpan earthquake occurred) of 1976.

3 Discussions and conclusions

The median values of a month (e.g., Rios et al., 2004; Singh and Singh, 2007) or a short-period data of ionosphere (e.g., Zhao et al., 2008; Hsiao et al., 2009) or similar values prior to the day the earthquake occurred are often used as references to examine the pre-earthquake ionospheric disturbance from its normal behaviour. Nevertheless this is not completely suitable because median values were introduced in the past mainly to solve radio propagation problems but they have a disputable geophysical meaning (Kouris et al., 2001). In addition, ionosphere itself has large day-to-day variability due to the solar irradiation variability, meteorological influences and solar wind energy input (Rishbeth and Mendillo, 2001). Even under geomagnetic quiet day, day-to-day variability is of great prominence. Consequently, how to select more appropriate references to examine ionospheric perturbation due to pre-earthquake seismic activity is still an open question. In this paper, we proposed a new factor, effective sunspot number R_{eff} to analyze the disturbance of *fo*F2. One of the striking advantage of this method is that the calculated R_{eff} can be compared with the observed intraday sunspot number R, which avoids the unavailability of monthly median values of *fo*F2 when the earthquake occurred or the indeterminacy of the short-period length. However, it should be pointed that DR is calculated with the model of monthly median *fo*F2 rather than the model of daily *fo*F2 which should be more compelling.

A preliminary evaluation of DR using monthly median *fo*F2 model to represent "normal" behaviour of the ionosphere over Chongqing station during the interval of 10–19 May 2008 is shown in Fig. 5. Although several aftershocks occurred during this period, there was no obvious disturbance in the ionosphere (Liu et al., 2009), which was possibly due to inadequate magnitudes of the aftershocks or changes of geologic and geophysical conditions or some reasons beyond our scope. Because *fo*F2 is often unavailable at nighttime in May 2008 due to the occurrence of Spread F, we calculate DR during 10:00–20:00 LT. One can see that the distribution of DR is approximately normal which is reasonable. There is 94.5 percent of DR less than 20 and DR has a low standard deviation of 10.7, which shows that the amplitudes of DR on these undisturbed days were much lower than that on 9 May.

Furthermore, to validate the new method of DR, it needs to analyze more earthquakes. From 1960s, there occurred more than 10 large earthquakes (M>7.0) in China, but most of the large earthquakes happened in western China. As shown in Figs. 3 and 4, there are sparse ionospheric stations in western China, hence appropriate data of *fo*F2 related to earthquakes are not abundant. Here, two impressive big earthquakes are analyzed, illustrated in Fig. 6, Tangshan (M7.8; 39.40° N, 118.00° E; 28 July 1976) and Songpan (M7.2; 32.80° N, 104.30° E; 16 August 1976) earthquakes, respectively. The results show that DR was about 60 three days prior to Tangshan earthquake occurred, and DR reached up to 125 four days prior to Songpan earthquake occurred. It should be noted that some days before the Tangshan earthquake occurred, sporadic-E significantly enhanced and a great many data of *fo*F2 were unavailable owing to the sheltering effect. Hence, DR had a moderate magnitude possibly attributed to lack of suitable data. In further work, more earthquakes will be analyzed to check this method. Simultaneously the deviation of R_{eff} from the observed daily R, i.e. DR, will be analyzed with data of several years and to develop a statistic model of DR for each month, with which abnormal disturbance related to earthquake could be assessed quantitatively. The focus of this paper is just to put forward tentatively a strategy looking for a comparable factor related to earthquake with a measurable index in stead of using reference values of ionosphere.

But what is the physical mechanism for earthquake precursors? Until recently, there is some lack of knowledge about the physical mechanism. One of the possible sources initiating the pre-earthquake ionospheric disturbances may be enhancements of the vertical quasistatic electric field in the area of earthquake preparation, which have been observed (Vershinin, 1977; Mikhailov et al., 2003). The seismo-genic-quasistatic field are generated due to the emission of radioactive particles (radon) and other charged aerosols particles into the atmosphere before the earthquake within the area of earthquake preparation zone. Kim et al. (1994) and Pulinets et al. (2000) showed that this anomalous electric field can penetrate into the lower ionosphere, which is confirmed by INTERCOSMOS-BULGAR-1300 satellite (Gousheva et al., 2008), and then can be transmitted along the geomagnetic field to the F2 region ionosphere and modify its dynamic and electron density distribution through the effect of $\boldsymbol{E} \times \boldsymbol{B}$ drift prior to the earthquake onset. However, the efficiency of electric field penetrated into the ionosphere is very low, e.g. the anomalous electric field with the amplitude of 1000 V/m near the ground of the earthquake preparation zone, the penetrated electric field in the ionosphere is only about 1 mV/m in the night conditions and even less at daytime. Such low amplitude of electric field causing such significant perturbations in *fo*F2 is doubtable. Sorokin et al. (2001, 2006) developed an electric field model with external electric current in atmosphere and it can reach up to 10 mV/m in the ionosphere, which needs to be further validated. In addition, the hypothesis on the internal gravity waves (IGW) or acoustic gravity waves (AGW) was proposed by many researchers (Hayakawa and Molchanov, 2002; Lizunov and Hayakawa, 2004; Hegai et al., 2006; Korepanov et al., 2009). However, it is difficult for the AGW to penetrate into the ionosphere (Pulinets and Boyarchuk, 2004). In particular, numerous obstacles (critical layers, reflecting layers, viscosity, thermoconductivity and other dissipation processes, etc.) keep most part of AGW from penetrating into F layer (Shalimov et al., 1998; Pulinets and Boyarchuk, 2004; Korepanov et al., 2009). At the present time, the mechanism of seismo-ionospheric coupling is still an intense topic and needs further research.

In conclusion, the anomalous ionsopheric disturbances before the great Wenchuan earthquake (M=8.0) are analyzed using effective sunspot number R_{eff} with observations over ten ground-based ionospheric stations located around the epicenter with different distances. The results show that the anomalous variation of DR were focused on a limited area, from which one can conclude that the anomalous changes in the F2 region ionosphere occurred only over the area around the earthquake epicentral zone. DR reached up to 135 over Chongqing station at 17:00 LT on 9 May, which was difficult to interpret under the quiet conditions of solar and geomagnetic activities. Moreover, the new method is preliminarily validated with tow other earthquakes, Tangshan and Songpan, respectively. Hence, these obvious positive perturbations in *fo*F2 over around the epicenter were likely due to the forthcoming great earthquake, and this new method has good potential in practice.

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