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The ionospheric perturbations prior to the Chi-Chi and Chia-Yi earthquakes

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Abstract

In this paper we analyze the greatest plasma frequency, foF2, named critical frequency, observed by the Chung-Li ionosonde (25.0°N, 121.1°E) during the period of the Chi-Chi (23.87°N, 1 20.75°E) and the Chia-Yi (23.51°E, 120.4°E) earthquakes. The previous 15-day running mean and the associated standard deviation are utilized to construct the upper or lower bound for detecting the seismo-ionospheric perturbations. It is found that the perturbation appeals in 3–4 days prior to the Chi-Chi carthquake as well as 1 3 days prior to the Chia-Yi earthquake.

1. Introduction

Earthquake precursors are difficult to recognize because of the complexity of the Earth's crust and various types of the earthquake mechanisms. and the lack of extensive geophysical and geochemical monitoring in most areas. However, there are some articles about anomalies of electromagnetic radiation. For example, some anomalous change of intensity (Gokhberg et al., 1982; Fraser-Smith et al., 1990; Fujinawa et al., 1992; Molchaniov et al., 1992), anomalous propagation of signals (Hayakawa et al., 1993), an increase of spike type noises (Oike at al., 1986), and combination of those phenomena (Yoshino et al., 1993). Recently, electromagnetic phenomena in the ionosphere associated with seismic activity have been extensively discussed (Pulinets et al., 1994; Freund, 1999; Hayakawa, 1999). Molchanov and Hayakawa (1998) observed that the VLF perturbation events appear as transient oscillations with 5–10 days period, initiated a few days before

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a large earthquake and decaying over a few days or weeks after it. Pulinets (1998) finds that before the earthquake. the distribution of the perturbed plasma at the ionospheric F2 layer around the seismic active zone produces 2 regions with enhanced and decreased concentration clearly. Liu et al. (2000) study variations of the greatest plasma frequency in the ionospheric F2-region, foF2, to search for the possible precursors of $M \geqslant 6.0$ earthquakes of 1994–1999 and find that the related precursors can be detected within 6 days before the earthquakes.

In the early morning (0147 IT) of 21 September 1999, the largest earthquake of the century in Taiwan ($Mw = 7.6$, $ML = 7.3$) struck the central island near the small town of Chi-Chi. The hypocenter was located by the Central Weather Bureau Seismological Center at 23.87°N, 120.75°E, with a depth of about 7 km (Fig. 1). There was severe destruction in many towns with over 2300 fatalities and 8700 injuries.

About a month later, at 1019 LT, 22 October 1999, another strong earthquake M 6.4 (23.51°N. 120.4°E), depth 12.1 km occurred at Chia-Yi town and destroyed some local houses (Fig. 1). In this paper, we apply a mean-based statistical technique on the foF2 variations recorded in Chung-Li, Taiwan to find seismo-ionospheric perturbations prior to the two earthquakes.

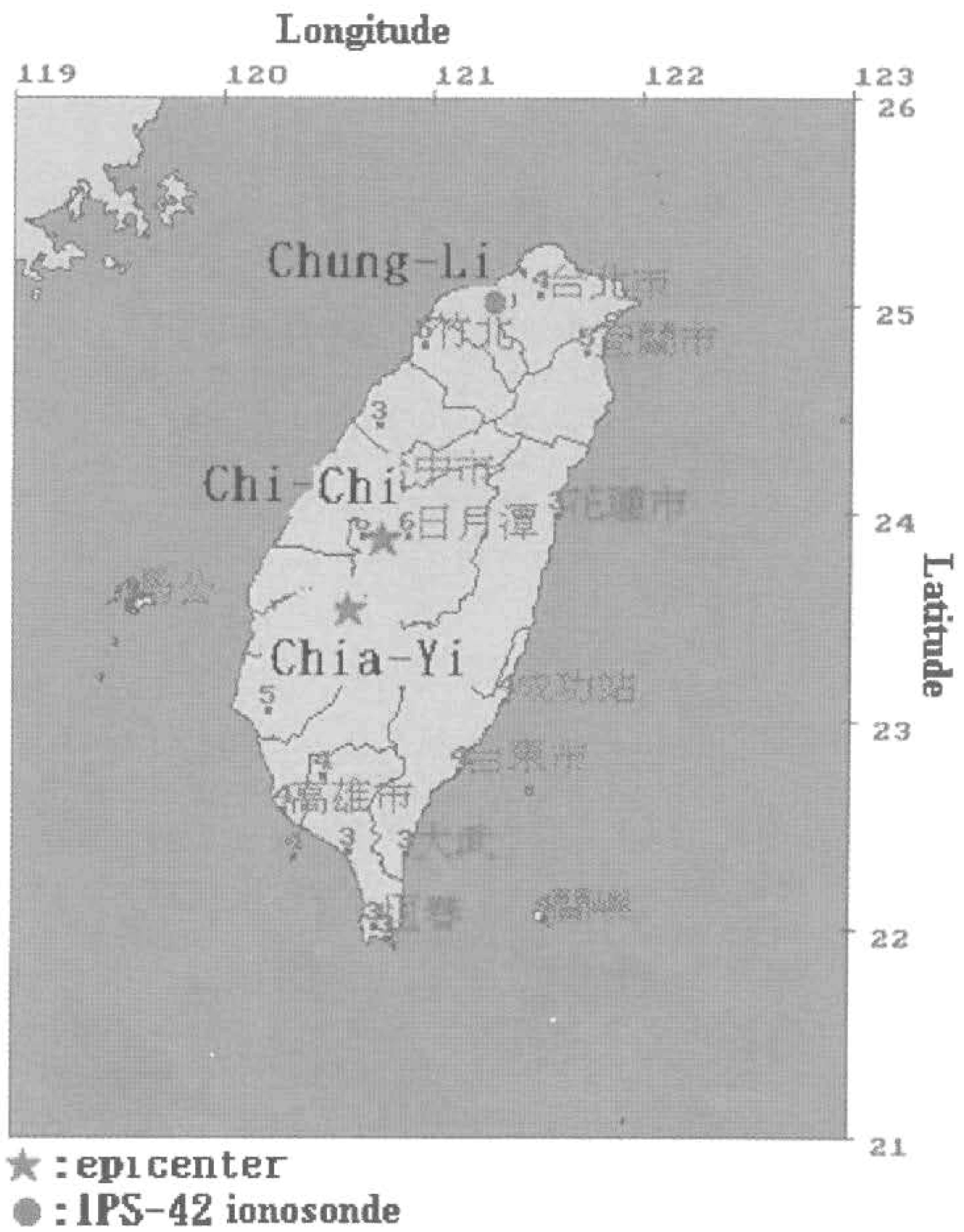

Fig. 1. The locations of the epicenters of the Chi-Chi and the Chia-Yi earthquakes, and the Chung-Li ionosonde (IPS-42).

2. Data and analysis technique

Most of our knowledge of the ionosphere comes from remote sensing by radio waves. The conventional equipment for measuring the virtual height of the ionosphere is a sweep frequency pulsed radar device called an ionosonde. The measurement of the frequency vs. the virtual height of the ionosphere obtained by an ionosonde is called an ionogram. For a vertical sounding, an ionogram displays the variation of the virtual height of reflection with frequency, where the virtual height is equivalent to the product of one-half the time-of-flight of the transmitted radio wave and the speed of light c. Usually, there are two traces, O- and X-mode appearing on an ionogram. Based on the magneto-ionic theory (for example, see Budden, 1985). The plasma frequency is equal to the vertically reflected O-mode frequency. The greatest frequency foF2 on an O-mode trace is considered to be the penetration (or largest) plasma frequency (or density) of the ionosphere (for instance, see Fig. 2e). In ionospheric terminology it is named the critical frequency.

The averaged reoccurrence of $M \geqslant 5.0$ earthquakes in Taiwan area during 1994–1997 is about 15 days (Liu et al., 2000). To consider the earthquake reoccurrence, we develop a monitoring technique which compares a suspected anomalous foF2 to an average value determined for 15 days window prior to the window containing the suspected anomaly. This window is based on an average recurrence interval of 15 days for $M > 5.0$ earthquakes from 1994 to 1997 of 15 days (Liu et al., 2000). Let $\bar{X}$ and σ be the mean value and the associated standard deviations of the observed foF2 plus its previous 15 days foF2. When the observed foF2 exceeded the upper/lower bound $\bar{X} \pm \sigma$ during a certain time period, we considered that a possible earthquake related perturbation is observed.

3. Observation

An IPS-42 Ionosonde at Chung-Li (25.0°N, 121.1°E) has been routinely operated recording ionograms every 15 min to observe the ionosphere in Taiwan area. The Chi-Chi and the Chia-Yi earthquakes are about 120 and 179 km away from the Chung-Li station (Fig. 1), respectively. Figs. 2 and 3 show the ionograms recorded at about I400LT during 16–21 September (259–264) and 17–22 October (290–295) 1999, which span the 5 days before the Chi-Chi and Chia-Yi earthquakes, respectively. It can be seen from Fig. 2 that the foF2 values on 17–18 September are about 5 MHz smaller than those of the other days. Fig. 3 displays a similar situation that the foF2 values on 19 and 21 October are about 3 MHz smaller than those of the other days. Many geomagnetic disturbances, such as magnetic storms, could significantly disturb the plasma density in the ionosphere. To isolate the seismo-ionospheric perturbations from other geomagnetic fluctuations, the geomagnetic variations are monitored. Fig. 4 displays variations of the kp and Dst index in September and October 1999. It can be seen from the upper panels of Fig. 4a and b that the kp values before 21 September and 22 October are less than about 4.0. which indicates that the geomagnetic conditions before the two earthquakes were relatively quiet. The variations of the Dst index in the lower panes of Fig. 4a and b illustrate that the sudden commencement (SSC of the two geomagnetic storms, occurred one day after the Chi-Chi and a few hours before the Chia-Yi earthquakes, on 22 September and 22 October 1999, respectively.

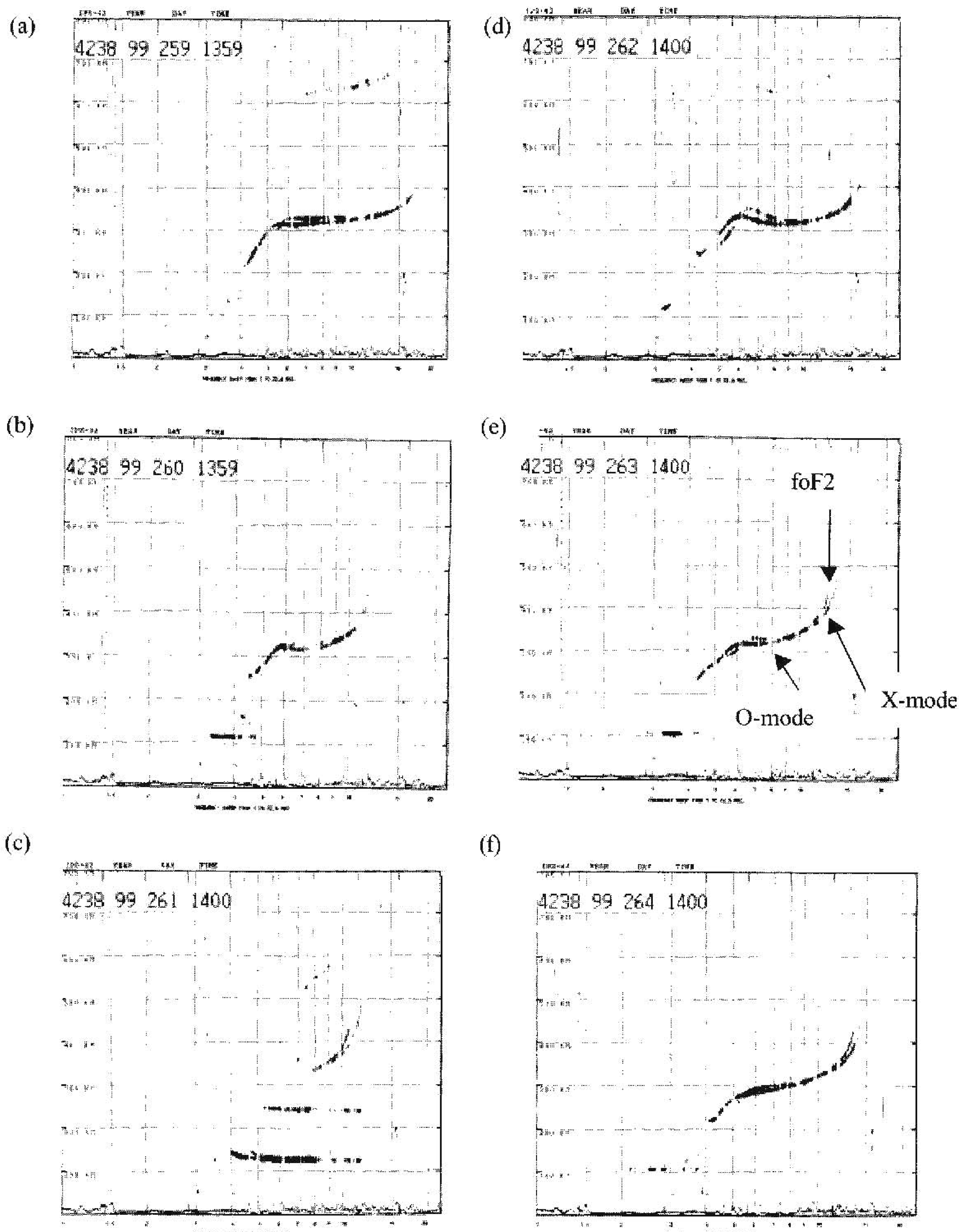

Fig. 2. The 1400LT ionograms recorded from 16 to 21 (259 264) September. The Chi-Chi earthquake occurs on 21 September (264) 1999.

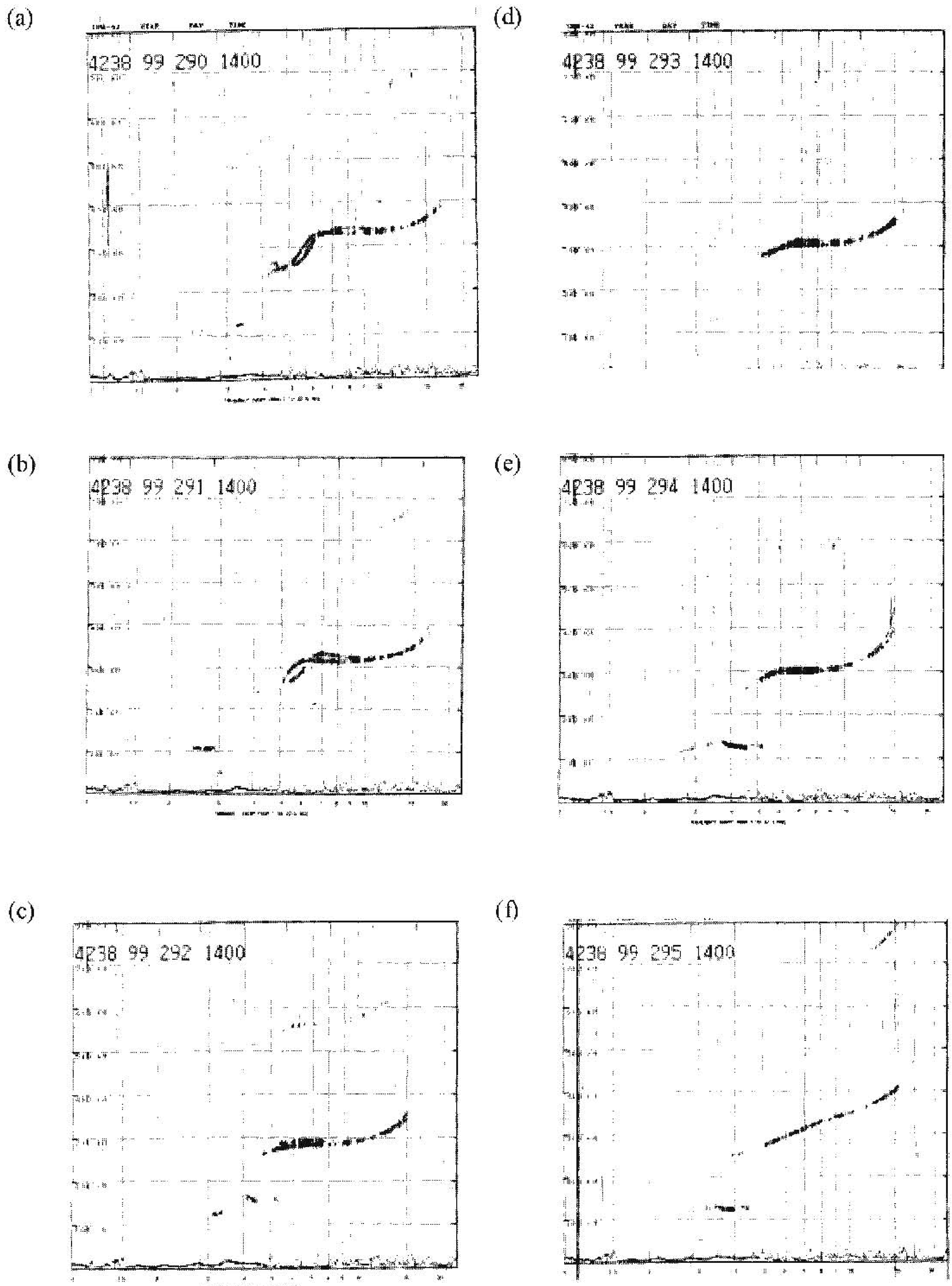

Fig. 3. The 1400LT ionograms recorded from 17 to 22 (290 295) October. The Chia-Yi earthquake occurs on 22 October (295) 1999.

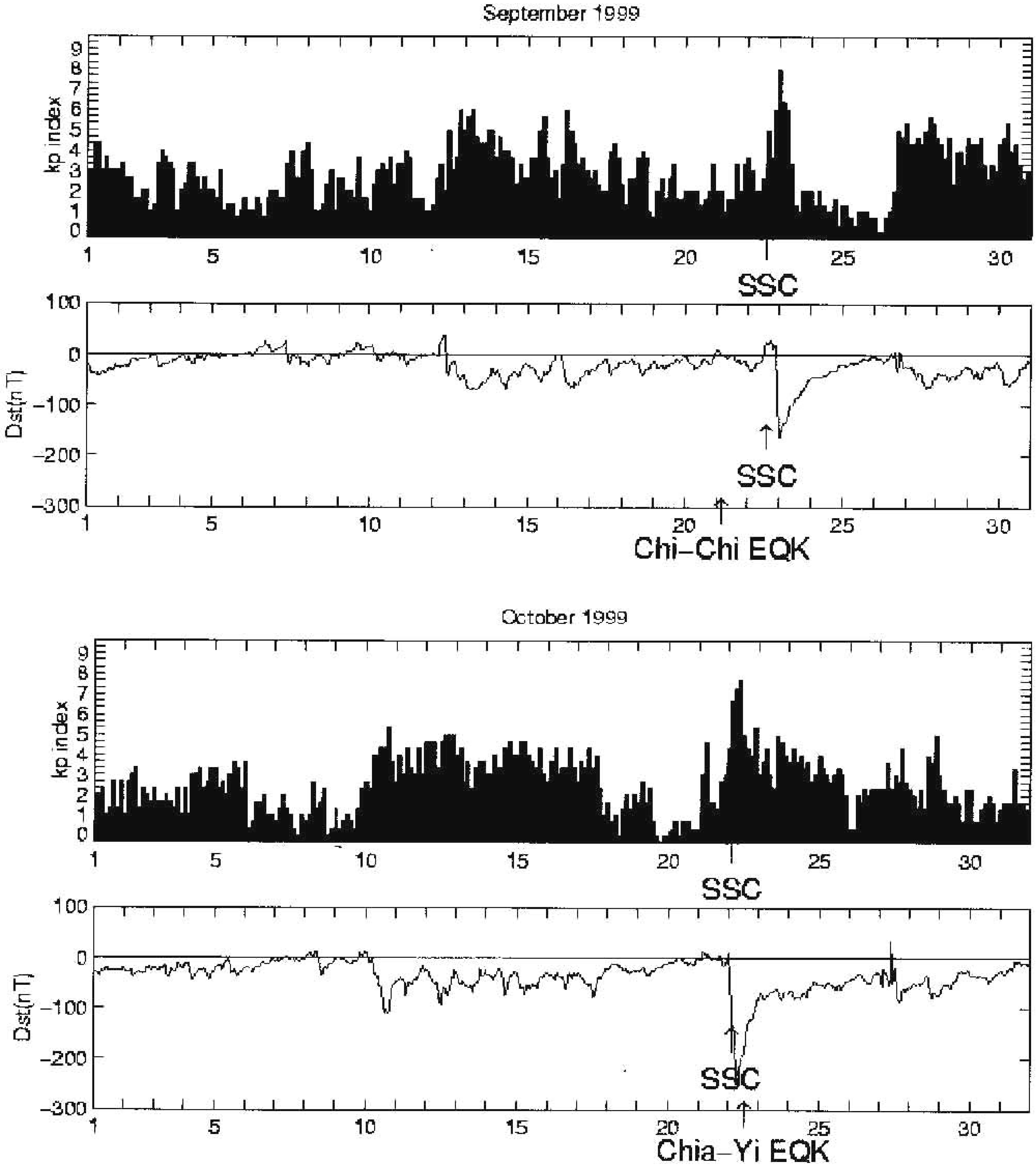

Fig. 4. The Geomagnetic Dst and kp index recorded in (a) September 1999 and (b) October 1999. SSC and EQK represent the storm sudden commencement and earthquake, respectively. Data acquired from the World Data Center WDC-C2.

To further quantitatively identify the seismo-ionosphenic perturbations, we apply the mean-based technique introduced in Section 2 on the foF2 from the recorded ionogranis in September and October 1999. Let the solid, dashed, and dotted lines represent the foF2, the previous IS—day mean and associated upper and lower bounds, respectively. Fig. 5 shows the daytime foF2 values on 17 18 September. 3–4 days prior to the occurrence of the Chi-Chi earthquake (21 September), are less than their associated lower bounds due to these perturbations. Similar features are also observed during the Chia-Yi earthquake. Fig. 6 displays perturbations appearing on 1 and 3 days prior to the Chia-Yi earthquake.

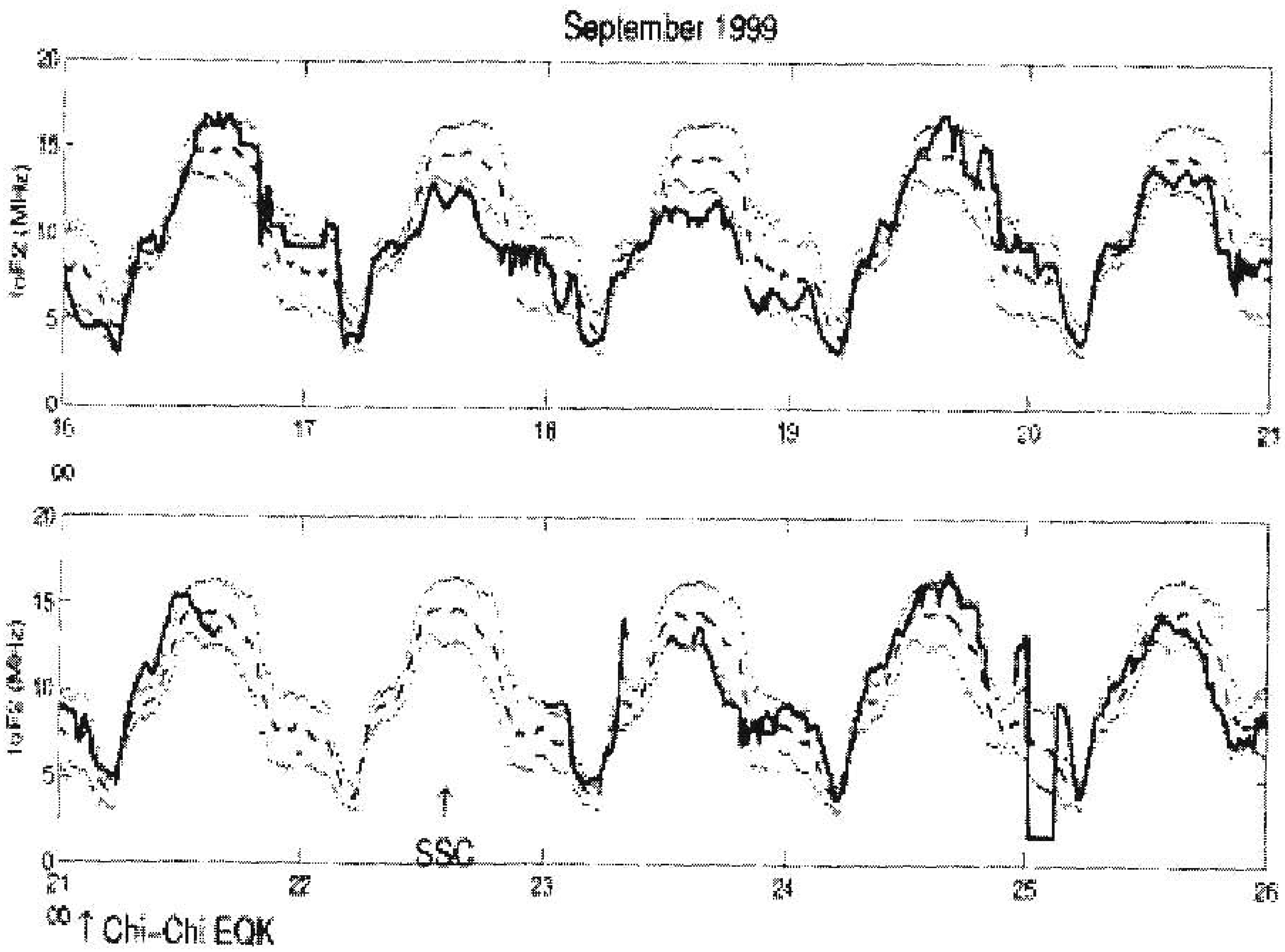

Fig. 5. The foF2 variations from 15 to 25 September 1999. The dashed, dotted, and solid lines are the 15-day running mean, associated upper and lower bounds, and foF2 observation. The upward arrows denote the occurrence of the Chi-Chi earthquake. The SSC stands the storm sudden commencement.

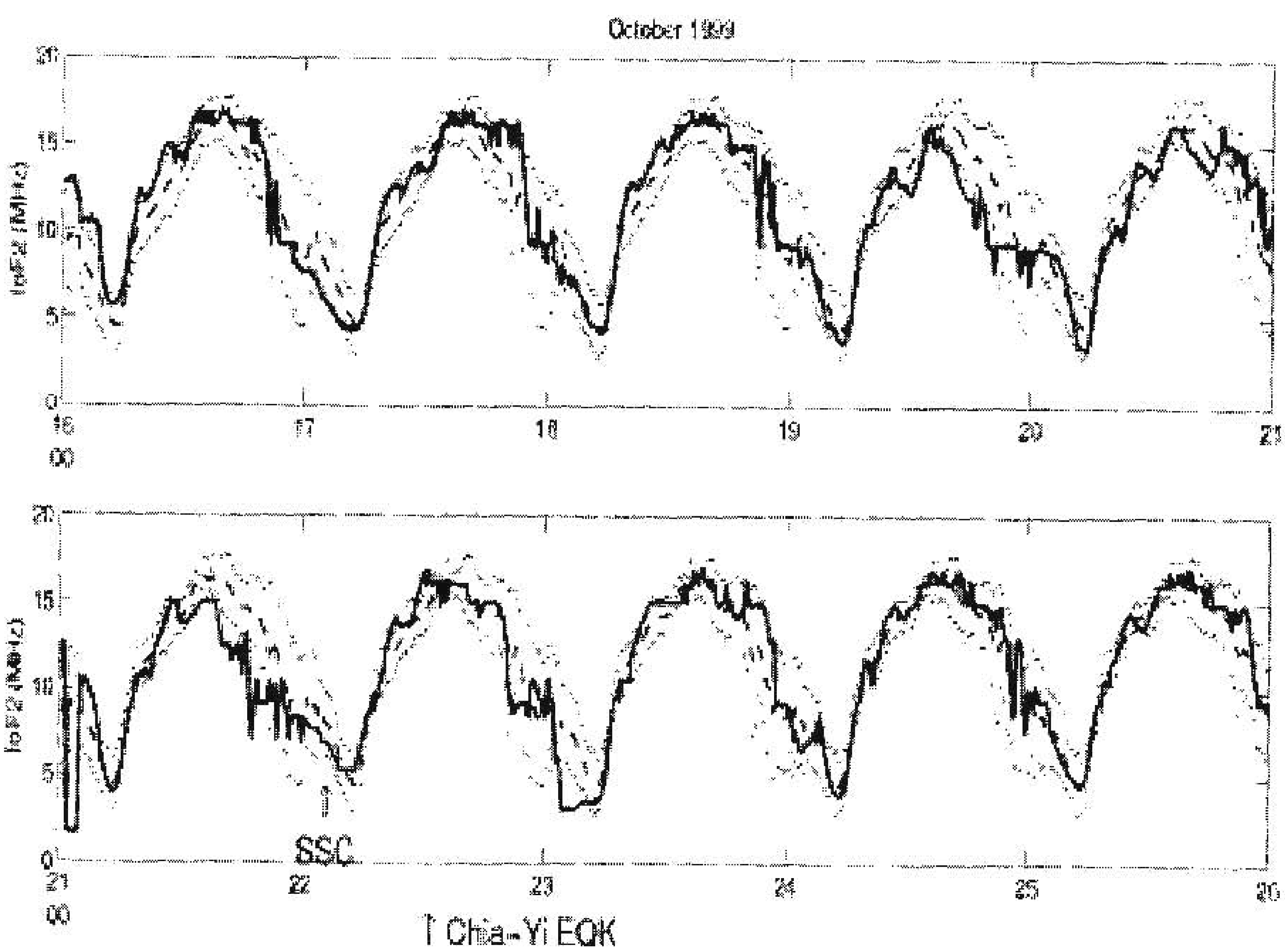

Fig. 6. The foF2 variations from 16 to 25 October 1999. The upward arrow denotes the occurrence of the Chia-Yi earthquake.

4. Discussion and conclusion

It has been found that a geomagnetic storm could trigger an ionospheric storm, which disturbs the ionospheric electron density (Davies, 1990). Figs. 5 and 6 show no significant fluctuations observed within 2–3 days (23–24 September and 23–25 October) after the 22 September and 22 October SSCs, which implies that disturbances from local seismic activities could be greater than those from geomagnetic storms.

Afonin et al. (1990) study a large database of plasma density recorded by a Russian satellite Intercosmos 24 and discover that a clear correlation between the global distribution of seismic activities and density variation appears only for daytime condition 1000–1600 LT. Chen et al. (1999) analyze the foF2 associated with $M \geqslant 5.0$ earthquakes (within a distance of 300 km to the Chung-Li ionosonde station) during 1994–1997 and find that the chance of observing the precursor between 1200 and 1800 LT within 5 days prior to the earthquakes is about 73.8%. Meanwhile, Liu et al. (2000) examine the foF2 associated with $M \geqslant 6.0$ earthquakes (within a distance of 500 km to the Chuna-Li ionosonde station) during 1994–1998 and find that precursors are all detected during 1200 and 1700 LT within 6 days before the earthquakes. Note that the initiation time of the foF2 perturbations observed within 5 days before the Chi-Chi and Chia-Yi earthquakes agrees with that found in the previous studies (Afonin et al., 1999; Chen et al., 1999; Liu et al., 2000). Therefore, by using the common statistical technique stated in this paper, the detected perturbations can be regarded the precursors for the Chi-Chi and Chia-Yi earthquakes.

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