SPATIAL DISTRIBUTION OF IONOSPHERIC GPS-TEC AND NmF2 ANOMALIES ASSOCIATED WITH THE CHI-CHI EARTHQUAKE

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ABSTRACT

Recently, scientists find an apparent reduction in GPS-TEC within 1–5 days prior to M≥6.0 earthquakes in Taiwan. However, those studies did not cross examine simultaneous data in other places to confirm seismo-ionospheric anomalies observed. In this paper, we retrieved GPS-TEC routinely published in the global ionosphere maps (GIM). Simultaneous data of ionosonde and GPS-TEC in various locations such as Taiwan and Japan are examined to check whether the anomaly observed in Taiwan during the 1999 Chi-Chi earthquake (M_W=7.6) is the local or global effect. The result shows that the anomalies in Taiwan on 3 days before the Chi-Chi earthquake are local phenomena. It means that the ionospheric disturbed area was local around Taiwan, and did not spread to Tokyo. We conclude that the disturbed area is less than about 2200 km in radius.

Keywords: *GPS-TEC, Earthquake, Seismo-ionospheric, Ionosonde*

ABSTRAK

Hasil penelitian terakhir menunjukkan bahwa terjadi penurunan nilai GPS-TEC 1-5 hari sebelum kejadian gempa dengan M≥6.0 di Taiwan. Akan tetapi hasil penelitian tersebut tidak dibandingkan dengan kejadian gempa di tempat lain pada waktu yang bersamaan untuk memastikan teramatinya anomali seismo-ionosfer. Pada makalah ini, digunakan data GPS-TEC yang secara rutin diterbitkan di *Global Ionosphere Maps* (GIM). Data ionosonde dan data GPS-TEC dari berbagai lokasi secara simultan diolah untuk memastikan apakah anomali yang teramati di Taiwan dan Jepang pada saat terjadi gempa Chi-Chi (Mw=7.6) akibat fenomena global atau lokal. Hasil yang diperoleh menunjukkan bahwa anomali yang terjadi di Taiwan 3 hari sebelum kejadian gempa Chi-Chi adalah fenomena lokal. Hal ini menunjukkan bahwa gangguan di ionosfer di atas Taiwan adalah gangguan lokal dan tidak menyebar sampai ke Tokyo. Dapat disimpulkan bahwa daerah yang mengalami gangguan adalah dalam radius kurang dari 2200 km.

Kata kunci: *GPS-TEC, Gempa, Seismo-ionosfer, Ionosonde*

1 INTRODUCTION

Many anomalous electromagnetic phenomena possibly associated with large earthquakes have been reported (e.g. Hayakawa and Fujinawa, 1994; Hayakawa, 1999; Hayakawa and Molchanov, 2002). Scientists found that the ionospheric plasma frequency decreased a few days before some large earthquakes (Pulinets et al., 1994; Pulinets, 1998; Liu et al., 2000, 2006, Saroso et al., 2008). Ionosondes have been the most popular instrument probing the ionospheric electron density for more than seven decades (Hunscucker, 1991). Currently, there are more than 200 ionosondes available worldwide. However, only a fraction of them are routinely operational. Therefore, the spatial and temporal coverage of the ionosonde observations are rather limited and difficult to use to correlate with seismic activities systematically. Meanwhile, due to the use of median and high frequencies (MF and HF), 1–20 MHz, ionosondes often suffer from the short wave fadeout and result in data gaps (Davies, 1990).

By contrast, today there are thousands of ground-based receivers of the global positioning system (GPS) deployed to monitor the Earth's surface deformation rates (see the papers listed in Calais and Amarjargal, 2000). Owing to the use of two ultra high frequency (UHF, f1=1575.42MHz and f2=1227.60 MHz) waves, the GPS studies are generally free from the short wave fadeout. Therefore, while performing Earth's surface deformation observations, the same network of GPS receivers can be also used to simultaneously and continuously monitor the ionospheric total electron content (TEC) (for example, see Sardon et al., 1994; Leick, 1995; Liu et al., 1996). Recently, scientists (e.g. Liu et al., 2001, 2004) find an apparent reduction in GPS TEC within 1–5 days prior to M≥6.0 earthquakes in Taiwan. However, those studies did not cross examine simultaneous data in other places to confirm seismo-ionospheric anomalies observed. In this paper, we retrieved GPS-TEC routinely published in the global ionosphere maps (GIM; ftp://ftp.unibe.ch/aiub/CODE/). Simultaneous data in various locations are examined to check whether the anomaly observed in Taiwan during the 1999 Chi-Chi earthquake (Mw=7.6) is the local or global effect.

2 DATA AND ANALYSIS

The Chi-Chi earthquake with M_W=7.6 occurred at 17:47 UT, 20 September 1999, in the center of Taiwan. The GPS receivers in this paper are shown in Figure 2-1. For S105 (23.0°N, 121.1°E) in Taiwan and TSKB (35.9° N, 140.1° E) in Japan, we compute GPS-TEC with GAMIT algorithm.

GAMIT is a comprehensive GPS analysis package developed at Massachusetts Institute of Technology (MIT) and Scripps Institution of Oceanography (SIO) for the estimation of three-dimensional relative positions of ground-based receivers and satellite orbits. The software is widely used by geodesy and earth science. Taiwan is located in the seismic zones around the rim of the Pacific Ocean and, therefore, earthquakes frequently occur. For instance, the recurrence interval of an M ≥ 5.0 earthquake between 1991–1999 is about 13–15 days (Liu et al., 2004). To identify abnormal signals, we compute in this paper the mean TEC ($TEC_{\_mean}$) for the previous 15 days, and the associated standard deviation (σ) at a certain time. Then we compute normalized TEC (TEC*) as is shown in the following equation,

$$TEC^{*}(t) = \frac{TEC(t) - TEC_{\_mean}(t)}{\sigma(t)} \qquad (2\text{-}1)$$

The TEC* is derived every 30 sec. but simply recorded 15 min. If the TEC* falls out of -2σ (t), we then declare the abnormal signal being detected.

We also analyze the variation of the F2-peak electron density NmF2 obtained by the ionosonde. In this paper, the data of the ionosonde located at Chung-Li (CHL; 25.0°N, 121.2°E) in Taiwan and Kokubunji (KKB; 35.7°N, 139.5°E) in Japan are used (see, Fig. 2-1). By using a similar equation as shown in equation (2-1), normalized NmF2 (NmF2*) is obtained. The sampling interval at CHL is 15 min. and at KKB, 60 min. Furthermore, we develop the algorithm which estimates GPS-TEC at arbitrary points using GIM data. The spatial resolution of GIM is 2.5 degrees in latitude, and is 5 degrees in longitude. Time resolution is 2 hours. These data are interpolated linearly and time resolution is 15 minutes, to draw GIM-TEC image. Normalized GIM-TEC (GIM-TEC*) is computed in similar manner for TEC* and NmF2*. In this paper, four GIM-TEC* values in the equatorial anomaly region are computed because Taiwan belongs to the equatorial anomaly region. These four places are corresponding to M30 (14.3°N, 30.0°E), M120 (22.1°N, 120.0°E), M210 (10.1°N, 150.0°W), and M300 (2.0°N, 60.0°W) in Fig. 2-1. The magnetic latitude of these is 12.0°N (see Table 2-1). In adding, GIM-TEC* at CHL and KKB are calculated (CHLg and KKBg). Variations of GIM-TEC* at M30, M120, M210, M300, CHLg, and KKBg, TEC* at S105 and TSKB, and NmF2* at CHL and KKB are carefully investigated.

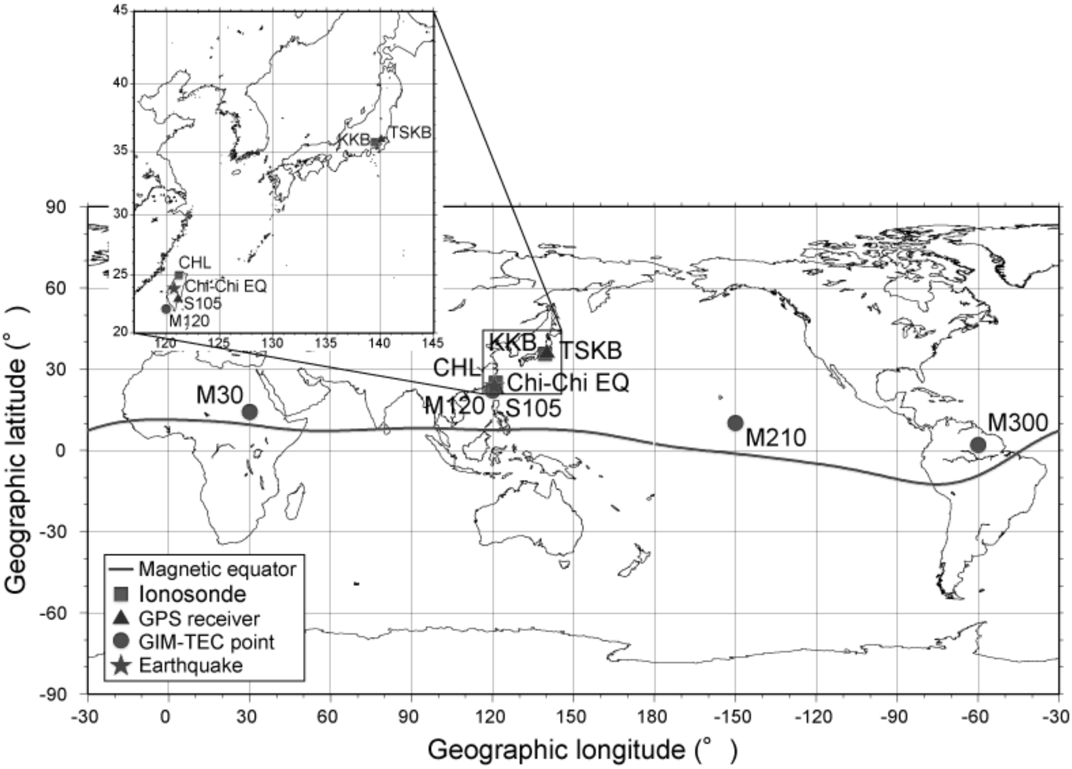

Figure 2-1: Locations of the magnetic equator, the ionosonde, the GPS receiver, the GIM-TEC point, and the Chi-Chi earthquake epicenter

Table 2-1: THE COORDINATES OF THE IONOSONDE, THE GPS RECEIVER, AND THE GIM POINT

Station	Geographic latitude	Geographic longitude	Geomagnetic latitude
Chung-Li (CHL)	25.0°N	121.2°E	15.0°N
Kokubunji (KKB)	35.7°N	139.5°E	26.8°N
S105	23.0°N	121.1°E	13.0°N
TSKB	35.9°N	140.1°E	27.0°N
M30	14.3°N	30.0°E	12.0°N
M120	22.1°N	120.0°E	12.0°N
M210	10.1°N	150.0°W	12.0°N
M300	2.0°N	60.0°W	12.0°N

3 RESULTS

Figure 2-2 shows variations of TEC, NmF2, GIM-TEC, Dst index, and Kp index from September 14 to September 26. The moment of the earthquake is indicated by the vertical broken line. On September 17 and 18, it's corresponding to the 3–4 days before the Chi-Chi earthquake, the increase of TEC in the daytime at S105 is small compared with other days. Moreover, the variation of NmF2 at CHL shows the similar variation. However, it is difficult to identify the anomalies concerned with the Chi-Chi earthquake only by the raw data. Therefore, we compute TEC*, NmF2*, and GIM-TEC* using the algorithm shown in the previous section.

Figure 2-3 indicates variations of TEC*, NmF2*, GIM-TEC*, Dst index, and Kp index in the same manner used for Fig. 2-2. The horizontal dotted lines in the figure correspond to the -2σ line of TEC*, NmF2*, and GIM-TEC*, respectively. On September 17 and 18, it's corresponding to the 3–4 days before the Chi-Chi earthquake, TEC* at S105 decreases beyond -2σ threshold. On the other hand, TEC* at TSKB decreases significantly exceed -2σ from September 15 to September 16. Although TEC* decreases exceeding -2σ slightly on September 17, but no decrease is shown on September 18. The NmF2* at CHL decreases and exceeds -2σ threshold on September 17 and 18 just same as TEC* at S105. Meanwhile, NmF2* at KKB decreases significantly from September 15 to September 16. However, NmF2* at KKB does not decrease less than -2σ on September 17 and 18.

Figure 2-4 (a) and (b) show the correlation between TEC* and NmF2* in Taiwan and Japan, respectively. There is a rather better correlation between TEC* at S105 and NmF2* at CHL, and the correlation coefficient is 0.77. Much better correlation is recognized between TEC* at TSKB and NmF2* at KKB, and the correlation coefficient is 0.82. These correlations also prove the similar variation of TEC* and NmF2* in the same area. The variations of GIM-TEC* at six points (CHLg, KKBg, M30, M120, M210, M300) are also shown in Fig. 2-3. The trend is similar with those of TEC* using GAMIT and NmF2* in Taiwan and Japan. For example, the GIM-TEC* at CHLg and KKBg decreases slightly exceed -2σ on September 17. Furthermore, GIM-TEC* at KKBg decrease exceeding -2σ from September 15 to September 16. However, GIM-TEC* at CHLg is not below -2σ threshold on September 18. Moreover, values of M30, M120, M210, and M300 on September 17 and 18 do stay within ±2σ.

Figure 2-5 (a) and (b) show the correlation of TEC* and GIM-TEC* in Taiwan and Japan from September 14 to September 26, respectively. Fig. 5 (a) shows that there is a lack of good correlation at Taiwanese data and the correlation coefficient is about 0.45. On the other hand, the correlation between TEC* and GIM-TEC* in Japan is found rather better correlation and it's the correlation coefficient is 0.72.

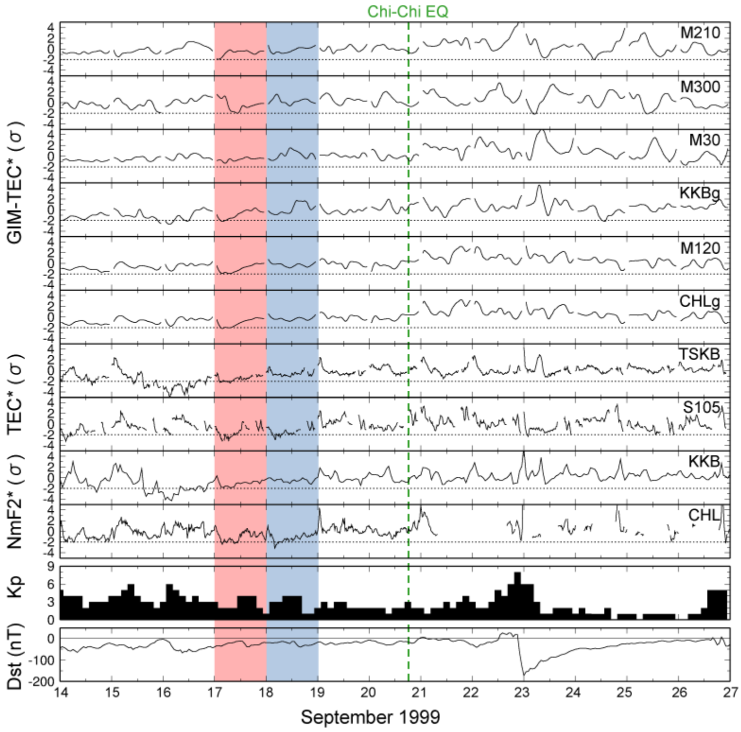

Figure 2-2:The variations of TEC, NmF2, GIM-TEC, Dst index, and Kp index from September 14 to September 26, 1999

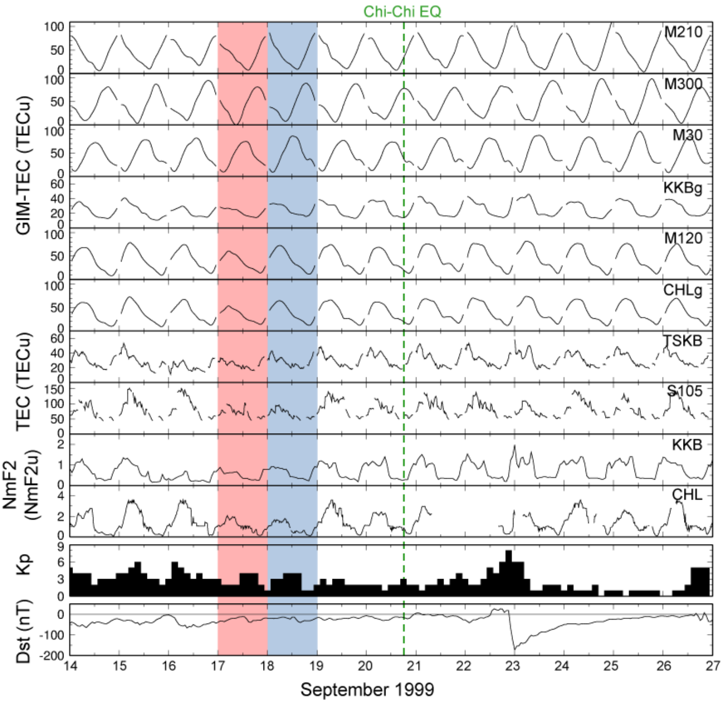

Figure 2-3:The variations of TEC, NmF2, GIM-TEC, Dst index, and Kp index from September 14 to September 26, 1999

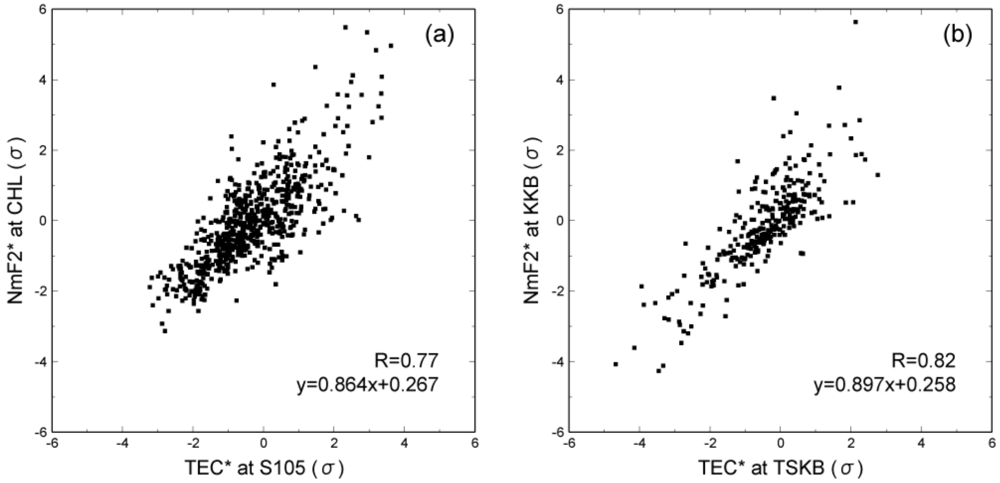

Figure 2-4:The correlation between TEC* and NmF2* in Taiwan and Japan from September 14 to September 26, respectively

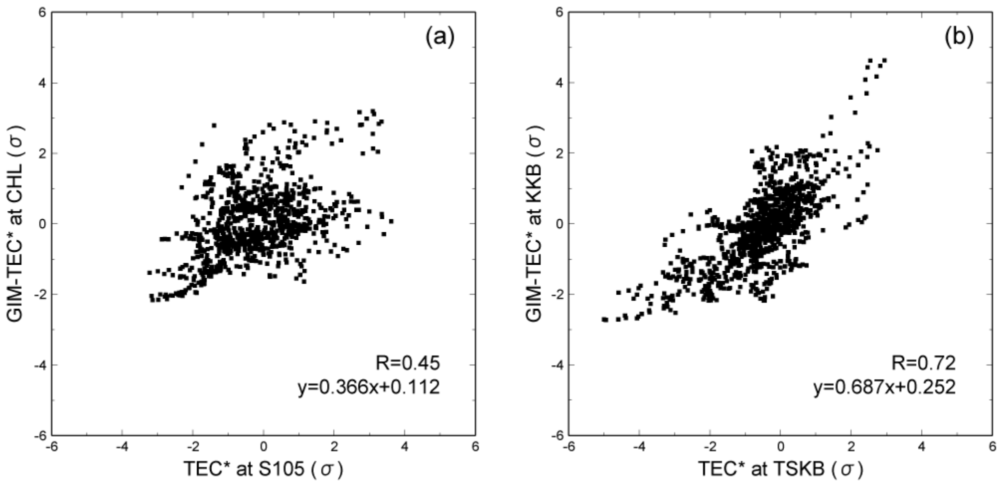

Figure 2-5:The correlation of TEC* and GIM-TEC* in Taiwan and Japan from September 14 to September 26, respectively

4 DISCUSSION AND CONCLUSION

We think that the anomalies of TEC*, NmF2* and GIM-TEC* on 5 and 6 days before the Chi-Chi earthquake observed in Japan are the influences of magnetic storm continued from 09:00 UT on September 12 to 22:00 UT on September 15 (Shiokawa et al., 2002). Furthermore, the one possibility of the cause of the anomalies is suggested for large-scale traveling ionospheric disturbance (LSTID) observed around Japan at 14:00–15:00 UT on September 15 (Shiokawa et al., 2002). We consider the possibility that the anomalies of TEC*, NmF2* and GIM-TEC* on 4 days before the Chi-Chi earthquake are the influences of two geomagnetic storm sudden commencements (SSC) occurred at 07:53 UT and 20:25 UT on September 15 (http://www.cetp.ipsl.fr/~isgi/), since the ionospheric electron density might significantly decrease from a few hours to 2 days after a SSC (Davies, 1990; Kelley, 1989). While TEC* at S105 decreases beyond -2σ threshold at 02:30 – 08:30 UT on September 17, almost at the same time, GIM-TEC* at M210 and M300 decreases to -1.9σ. It means the global ionospheric disturbance. Pulinets and Legen'ka (2003) indicated that the disturbances caused by the magnetic storms have a planetary character, although the disturbances of seismic origin are local and have much less magnitude. Therefore, the anomalies on September 17 may be the disturbance caused by the magnetic storm.

Although anomalies appeared in TEC* and NmF2* on 3 days before the Chi-Chi earthquake, it did not appear in GIM-TEC*. We think that the cause is arrangement of the GPS receivers used for computation of GIM. We referred to the list of GPS receivers used in order to compute GIM in September, 1999. However, the GPS receiver in Taiwan does not exist in it. The GPS receivers around Taiwan in the list are PIMO, GUAM, WUHN, DAEJ, and TSKB. In the area where a GPS receiver does not exist, GIM is interpolated by the spherical harmonics. It means that the ionospheric disturbance in the area is not reflected in GIM. Furthermore, anomalies did not appear in TEC* at TSKB, GIM-TEC* at KKBg, and NmF2* at KKB on September 18. Therefore, we estimate that the anomalies in Taiwan on 3 days before the Chi-Chi earthquake (September 18) are local phenomena. It means that the ionospheric disturbed area was local around Taiwan, and did not spread to Tokyo. We conclude that the disturbed area is less than about 2200 km in radius and the variations of TEC* and NmF2* in Taiwan are suggestive of existence of ionospheric disturbance prior to the 1999 Chi-Chi earthquake. The anomalies on 3 days before the Chi-Chi earthquake at least consistent with results reported by Liu et al. (2000, 2001, 2004).

There is a correlation between GPS-TEC computed by GAMIT, GPS-TEC computed by GIM and NmF2 observed by ionosonde. By using GIM, we can obtain TEC in the world easily. Therefore, our new approach which uses GIM is effective in order to detect the electromagnetic anomalies associated with large earthquakes. Although the number of the GPS receivers used in order to compute GIM before the Chi-Chi earthquake was about 100, it is about 200 in October, 2006. Therefore, becoming easy to detect more local disturbances by GIM is suggested.

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Communications Technology. The GIM data were retrieved from the Center for Orbit Determination in Europe (CODE). The Dst index and Kp index were provided by WDC for Geomagnetism, Kyoto.

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