

Changes of Geomagnetic Total Field and Occurrences of Earthquakes in Taiwan

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ABSTRACT

This paper examines variations in the geomagnetic total field recorded by eight stations in Taiwan from 1989 to 2001. A comparison of data from the international geomagnetic reference field (IGRF) and the eight stations shows that the annual change rates of the field reduce down to ± 5 nT/yr in 1997.9. Spatial and temporal analyses demonstrate that a zero isoporic zone (ZIZ) tends to lead to $M \geq 6.0$ earthquakes within 2 years in the Taiwan area.

(Key words: Geomagnetic field, Magnetometer, Earthquake, Zero isoporic zone)

1. INTRODUCTION

Electromagnetic phenomena associated with seismic activity have been extensively discussed (Hayakawa and Fujinawa 1994; Pulnests 1998; Molchanov and Hayakawa 1998; Hayakawa 1999; Freund 2000). Qi (1981) developed a model to simulate geomagnetic variations on the Earth's surface caused by underground anomalous conductivity. Zeng et al. (2001) studied a large numbers of cases in various places and found about 80% of $M \geq 6.0$ earthquakes occurred within 9 months to 2.5 years after the appearances of a zero isoporic zone (ZIZ), which is defined as the annual change rate of geomagnetic parameters to be less than or equal to ± 5 nT/yr. Although many individual cases and segmented data in China, Japan and

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Turkey have been reported, the geomagnetic fields were not continuously recorded and systematically examined.

Taiwan is located in an active part of the Circum-Pacific seismic belt. The interaction between the northwestward-moving Philippine Sea plate and the Eurasian plate depicts an intense and complicated geological structure, and results in large earthquakes in the Taiwan collision zone (Wang et al. 2002). Earthquakes in the Taiwan area are routinely documented and published by the Central Weather Bureau (CWB). In addition, a network of eight magnetometer stations equipped with continuous recording systems was established in 1989 by the Institute of Earth Sciences, Academia Sinica to monitor the geomagnetic total field of Taiwan island wide (Yen et al. 2004). Continuous records provide us a good chance to examine the relationship between annual change rates of the total geomagnetic field and occurrences of earthquakes in Taiwan from 1989 to 2001.

2. OBSERVATION AND DATA ANALYSIS

Figure 1 illustrates the locations of the eight magnetometer stations and the epicenters of $M \geq 6.0$ earthquakes (Table 1) that have occurred in the Taiwan area during 1989-2002.6. The proton precision magnetometers (GeoMetrics, Model G856) at the stations record absolute and relatively high-resolution (0.1 nT) measurements of the geomagnetic field. The Luning (LP, 25.0°N, 121.2°E) station was equipped in a seismically quiet area, while the Liyutan (LY, 24.3°N, 120.767°E) and the Tsengwen (TW, 23.3°N, 120.5°E) stations are located in western Taiwan. The other stations, Neicheng (NC, 24.7°N, 121.7°E), Hualien (HL, 24.1°N, 121.6°E), Yuli (YL, 23.4°N, 121.3°E), Taitung (TT, 22.8°N, 121.1°E) and Hengchun (HC, 21.9°N, 120.8°E) are located in eastern Taiwan. The sampling rate at the LP station is at 5-minute intervals, while the rest stations have 10-minute intervals (for detail see, Yen et al. 2004).

Let T be the total intensity of the geomagnetic field recorded at each station. The hourly value can be derived by averaging the raw data in one hour, the daily value be obtained by averaging the hourly values in one day, and then, the monthly value is calculated by averaging the daily values in one month (Chapman 1940). We therefore obtain the annual mean by averaging the monthly values in one year, T_i , where i denotes the year.

On the other hand, for each month, the method of finding out the discernible characteristic indication of geomagnetic field related to earthquakes can be found by solving for the annual change rate of \dot{T} ,

$$\dot{T}_{n,m} = \frac{\Delta T}{\Delta t} = \frac{\text{Mean}\left(\sum_{m=-6}^6 T_{n+1,m}\right) - \text{Mean}\left(\sum_{m=-6}^6 T_{n,m}\right)}{1(\text{year})}, \quad (1)$$

where n is the yearly order, and m is the monthly order. For comparison, we also calculate the

corresponding geomagnetic field and associated \dot{T} for each station by employing the international geomagnetic reference field (IGRF) model (Barton 1997).

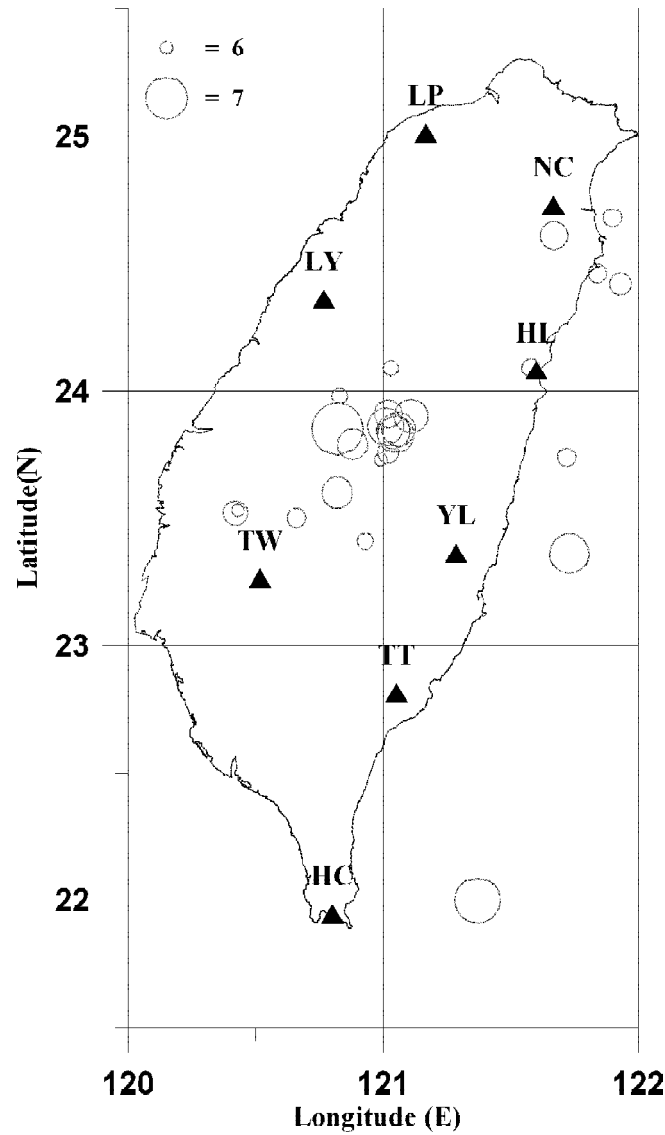


Fig. 1. The locations of the geomagnetic stations and earthquakes. The triangles denote the locations of the eight geomagnetic stations. The open circles represent the $M \geq 6.0$ earthquakes (see Table 1 for the day, depth, magnitude and locations of earthquakes).

Table 1. Occurrence day, depth, magnitude and locations for the $M \geq 6.0$ earthquakes in this study.

Year	Month	Day	Depth (Km)	Magnitude (M_L)	Longitude (E)	Latitude (N)
1994	6	5	5.3	6.2	121.84°	24.46°
1995	6	25	39.9	6.5	121.67°	24.61°
1996	9	5	14.8	7.1	121.37°	22.00°
1998	7	17	2.8	6.2	120.66°	23.50°
1999	9	20	8.0	7.3	120.82°	23.85°
1999	9	20	19.7	6.1	120.83°	23.98°
1999	9	20	3.0	6.1	121.03°	24.09°
1999	9	20	2.2	6.5	121.02°	23.91°
1999	9	20	3.5	6.6	120.88°	23.79°
1999	9	20	1.0	6.7	121.06°	23.85°
1999	9	20	1.1	6.7	121.04°	23.84°
1999	9	20	.3	6.6	120.82°	23.60°
1999	9	22	15.6	6.8	121.05°	23.83°
1999	9	22	8.9	6.3	121.02°	23.76°
1999	9	22	23.5	6.0	120.99°	23.73°
1999	9	25	9.9	6.8	121.01°	23.86°
1999	10	22	16.6	6.4	120.42°	23.52°
1999	10	22	16.7	6.0	120.43°	23.53°
1999	11	1	31.3	6.9	121.73°	23.36°
2000	6	10	16.2	6.7	121.11°	23.90°
2000	7	28	7.3	6.1	120.93°	23.41°
2000	9	10	17.7	6.2	121.58°	24.09°
2001	6	14	17.3	6.3	121.93°	24.42°
2002	2	12	30.0	6.2	121.72°	23.74°
2002	5	15	5.0	6.2	121.90°	24.68°

3. RESULTS AND INTERPRETATION

Figure 2 illustrates the annual means of the total fields, T_i , observed and derived from the IGRF models at each station from 1988 to 2001. Although there are some systematic differences, less than 100 nT, between the observation and derivation, the two total fields generally yield similarly increased tendencies before 1997. It can be seen that the overall annual change rates, $(T_{1997} - T_{1988})/(1997 - 1988)$ of the two fields lie between 24.8 and 29.7 nT/yr from 1988 to 1997. However, after 1997 the overall observed annual change rates tend to be smaller than those derived. Importantly, after 1997 and except for the YL station (9.3 nT/yr), almost all the observed annual change rates are less than 15 nT and meet the criteria of the zero isoporic (ZI) as outlined by Zeng et al. (2001).

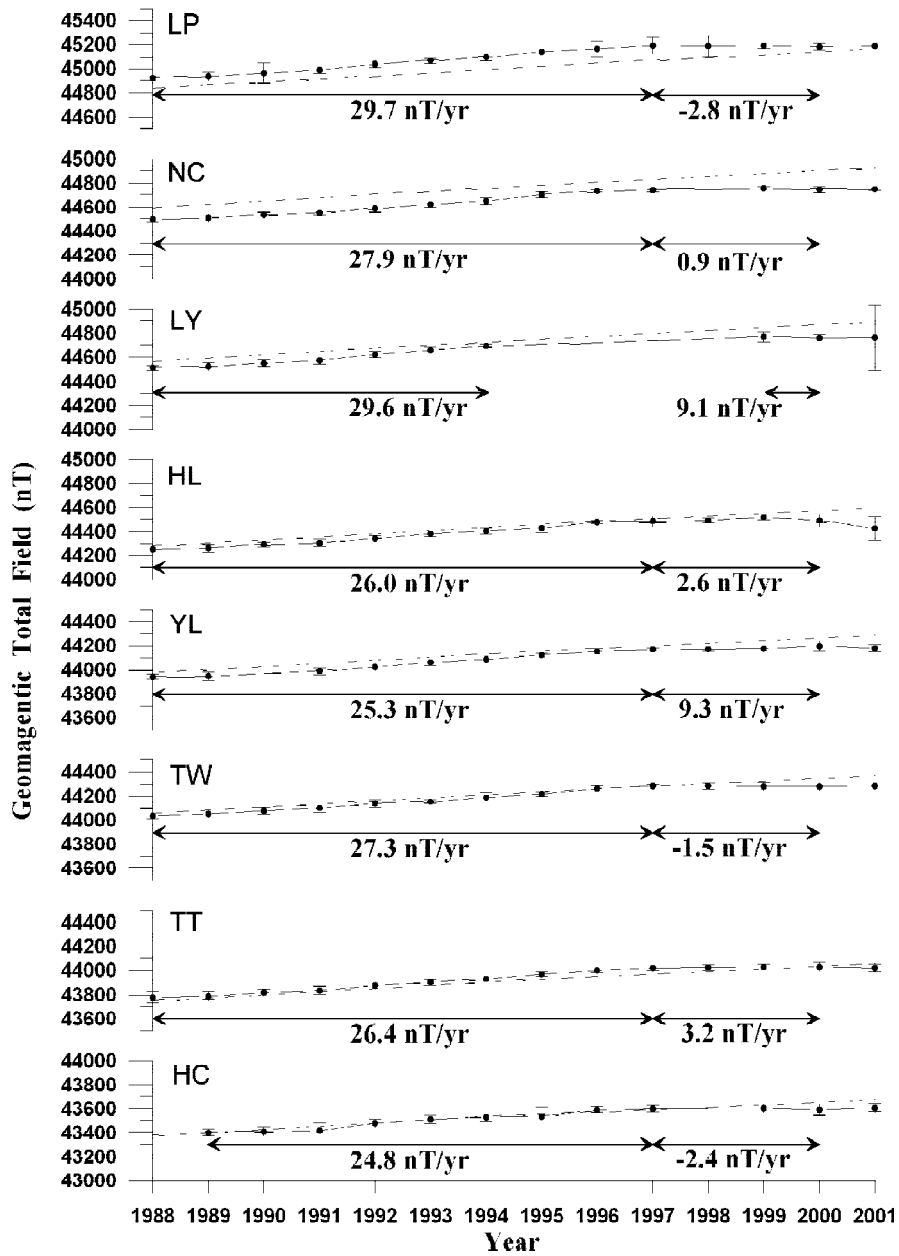


Fig. 2. Temporal variations of the geomagnetic total field during 1988 - 2001. The solid and dashed lines denote the yearly value of the observed and IGRF field, respectively. The error bars are the standard deviation of the yearly values.

Zeng et al. (2001) found that the ZIZ tends to presage $M \geq 6.0$ earthquakes by about 9 months to 2.5 years. To see if this is truly the case, Fig. 3 displays the contours of the observed annual change rates between adjacent years, $(T_{i+1} - T_i)/1$, of the eight stations and the number of $M \geq 6.0$ earthquakes that occurred in following 9 months to 2.5 years. It can be seen that the observed annual change rates are generally larger than 15 nT before 1996. However, after 1996 - 1997 the ZIZ begins to appear and the observed annual change rate around HL station is still as small as 4.6 nT/yr. After 1997, the earthquakes start to appear around the ZIZ, and are the most pronounced feature in 1999 - 2000.

The area of Taiwan is relatively small and therefore this allows us to evaluate the temporal variations of the overall, \dot{T} , and is derived by averaging the values of the eight stations. Figure 4 illustrates that the long term relationship between ZIZ in the \dot{T} and occurrences of the $M \geq 6.0$ earthquakes which clearly reveals the significant differences in the \dot{T} before and after the large earthquakes during 1989 - 2002.6. The \dot{T} varies between 15 and 45 nT during 1989 - 1996.9 but sharply decreases and reaches the ZI in 1997.9 when the earthquake number also suddenly increases and reaches its maximum value of 12 in 1999.9. A detailed study shows the ZI leads the Chi-Chi earthquake (9/21/1999, $M_L = 7.3$) and aftershocks by 2 years. By contrast, the overall IGRF \dot{T} yields constant values of 27 and 22 nT before and after 1995. After the Chi-Chi earthquake, the \dot{T} departs from the ZI (≤ 15 nT) and further goes down to -6.1 nT/yr in 2000.12, when the earthquakes also become rare.

4. DISCUSSION AND CONCLUSION

Zeng et al. (2002) found the strong earthquakes, Tangshan (7/28/1976, $M_s = 7.8$) and Haicheng (2/04/1975, $M_s = 7.3$) in China, occurred within 2.5 years after the appearance of ZIZ and the $M_s \geq 6.0$ earthquakes (1966.1 - 1969.12) in Turkey occurred within one year after the change rate in the horizontal intensity component of the geomagnetic field approached zero (Ispir et al. 1976). Eighty percent (80%) of the earthquakes in Japan from 1954 to 1966 occurred within 2.5 years after the appearance of the ZIZ in the horizontal intensity component of the geomagnetic field (Tazima et al. 1976). Results in Figs. 3 and 4 show that the geomagnetic signature of the ZIZ tends to precede the Chi-Chi earthquake and its aftershocks by about 2 years, which agrees with the previous observations.

Qi (1981) found geomagnetic variations on the Earth's surface resulting from underground anomalous conductivity. Zeng et al. (2002) suggested that before the large earthquake, the fluid expanded or compressed in the crust, which resulted in a subterranean equivalent planar current at a certain depth (10 - 20 km) in the coming epicentral region. In addition, they also developed a planar current model by taking the underground and ionospheric current systems into consideration to simulate the change of magnetic field on the Earth surface. Though the model was relatively coarse, the simulated changes of the magnetic field reveal the ZIZ phenomena before a large earthquake. Meanwhile Chen and Chen (2000) observed a low resistivity anomaly, less than 10 ohm-m, with depth ranging about 10-15 km during the Chi-Chi earthquake. They suggest the low resistivity anomaly to be related to underground fluids.

Results in this paper show that the magnetometer observations and IGRF simulations

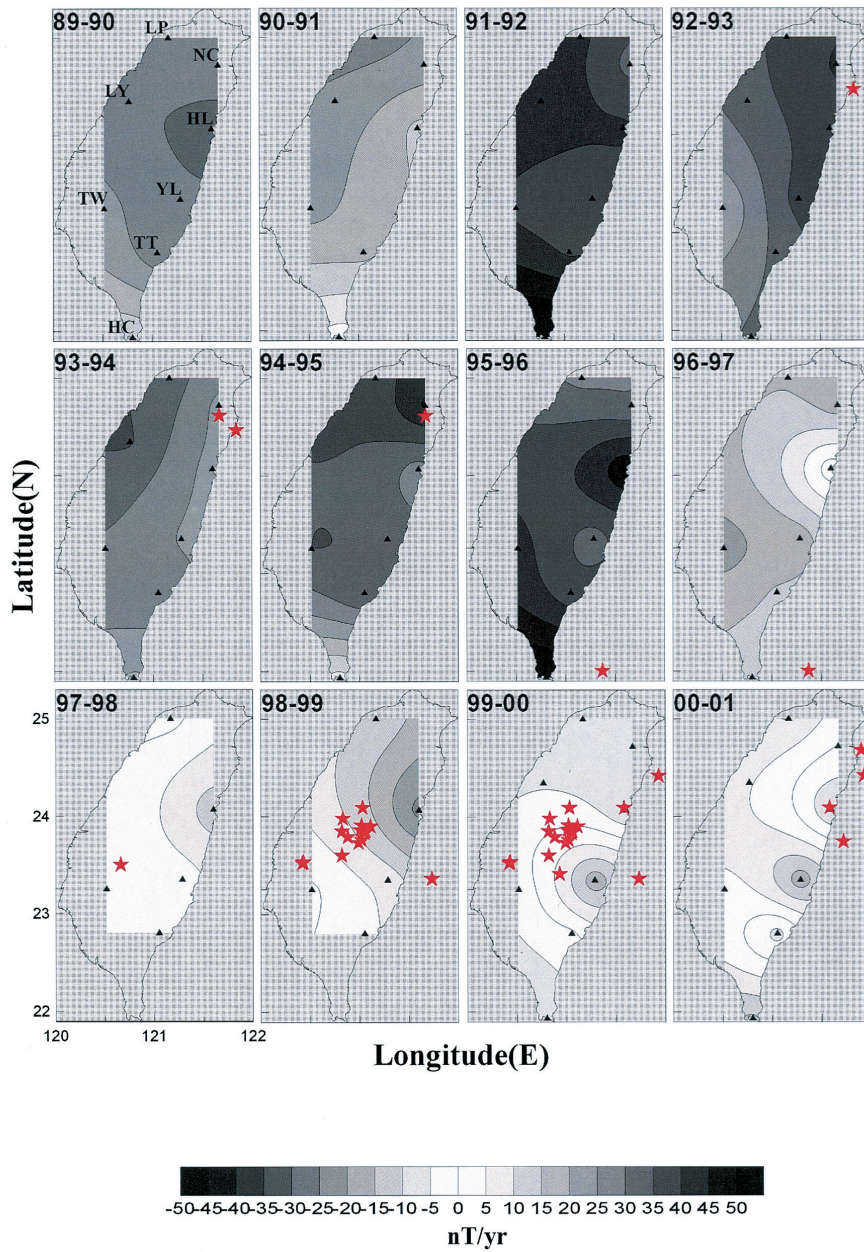


Fig. 3. The year-by-year isoporic diagrams of annual change rates in the geomagnetic total field between adjacent years from 1989 to 2001. The star symbols denote the locations of the $M \geq 6.0$ earthquakes occurring 9 - 30 months after the appearance of the ZIZ. Note that the earthquakes are plotted from 1989.9 to 2002.6.

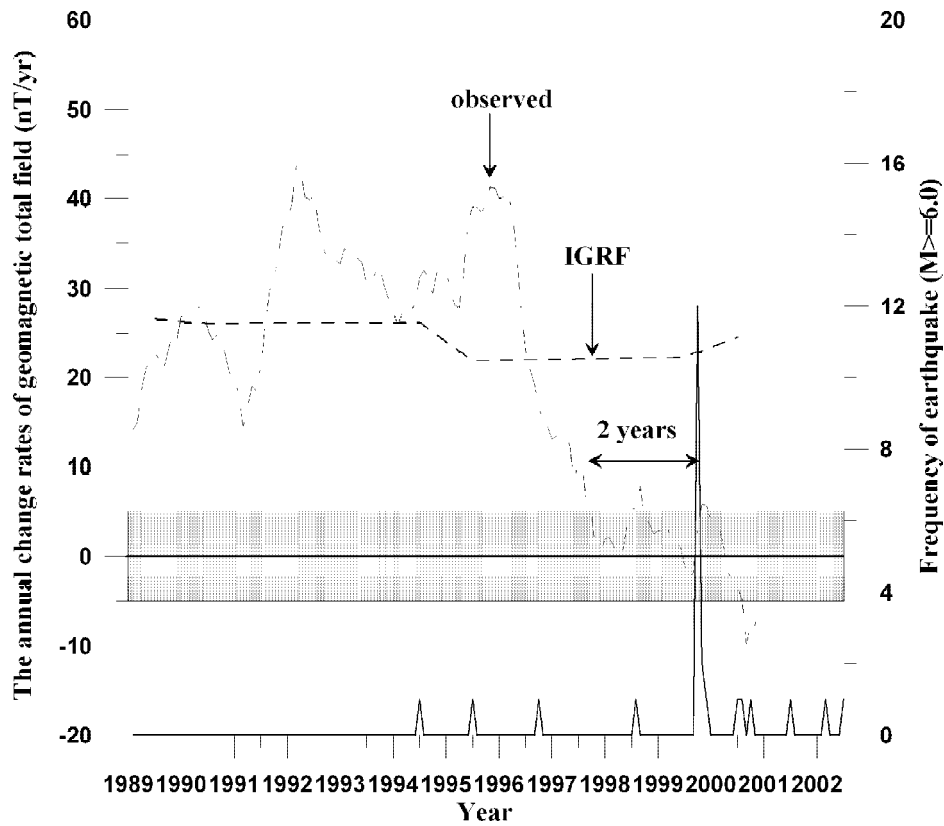


Fig. 4. The time and rate of changes of the observed and IGRF geomagnetic field as well as the number of $M \geq 6.0$ earthquakes, 1989.9-2002.6. The dot-dashed line denotes the observed rates obtaining by averaging the data of the eight stations, while the dashed line represents the IGRF results. The solid line is the monthly number of $M \geq 6.0$ earthquakes.

yield similarly increased tendencies before 1997 (Figs. 2 and 4). However, after 1997 the observed time rate of changes in the geomagnetic field become much smaller than those of the IGRF, which suggests underground structures together with their conductivity (or resistivity) and currents before large earthquakes around the magnetometers start to change and modify near-by geomagnetic fields on the Earth's surface.

Although the detailed mechanisms are not fully understood, the previous observations and simulation (Chen and Chen 2000; Zeng et al. 2002; Qi 1981) as well as current results indicate the conductivity of the crust and the current systems in both underground and the

ionosphere to be important to the ZIZ phenomena. In conclusion the long-term continuous observations of the eight magnetometers show that the spatial and temporal signatures in the zero isoporic zone (ZIZ) tend to lead $M \geq 6.0$ earthquakes within by 2 years in the Taiwan area.

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