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Geomagnetic Variations Associated with Strong Earthquakes in Yunnan Area

Xiuyi Yao[1], Zhisheng Feng[2*], Yuntian Teng[3], Yunhui Wang[1], Qiuyue Zheng[1]

[1]Yunnan Earthquake Agency, Kunming, China
[2]Jiangsu Earthquake Agency, Nanjing, China
[3]Institute of Geophysics, China Earthquake Administration, Beijing, China
Email: *fengzs2001@sohu.com

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Abstract

In order to find geomagnetic anomalies associated with $M_s \geq 6.0$ strong earthquakes in Yunnan area, geomagnetic harmonic wave amplitude ratios with *Z*, *H* and *D* components in TCH, THJ, CHX and YOS stations were analyzed. It was found that geomagnetic amplitude ratio of Yzhx experienced a trend of decrease and increase before most of strong earthquakes. Moreover, these variations in different periods were inconsistent and no similar changes appeared for Yzhy, which may relate to fault-zone conductivity variation and seismogenic structure.

Keywords

Earthquake Precursor, Geomagnetic Amplitude Ratio, Yunnan Area

1. Introduction

It has been reported that electromagnetic precursors in association with a lot of large earthquakes. Observations both serendipitous and planned have encompassed a wide variety of measurements of electric and magnetic fields [1] [2] [3] [4]. Merzer and Klemperer [5] proposed a quasi-static model, in which the conductive fault zone acts as an antenna to couple with the external geomagnetic field to generate the observed geomagnetic anomalies [6]. Precursory changes in fault-zone conductivity lead to precursory changes in observed geomagnetic field. The detection of geomagnetic perturbation prior to fault ruptures has been proposed as an effective method for monitoring crustal activities [7] [8] [9]. There have been many reports on geomagnetic changes associated with earthquakes and several methodologies are proposed such as polarization analysis [10] [11] [12] [13], principal component analysis (PCA) [14] [15] [16], Fractal analysis [17] [18] and Low-point displacement analysis [19] [20] [21]. Feng *et al.* [22] [23] [24] proposed a method named geomagnetic harmonic wave amplitude ratio analysis (we call it geomagnetic amplitude ratio analysis for short in this paper) to obtain electromagnetic emissions as a precursor to an earthquake and a lot of studies were reported [25] [26] [27] [28]. In this paper, we also use this method to analyze geomagnetic variations which may associate with strong earthquakes in Yunnan area.

Yunnan province is located in the southeast margin of Tibetan Plateau. Due to long-term extrusion between Eurasian plate and Indian Ocean plate, the geologic structure of Yunnan area is complicated and seismicity is active [29]. Some statistical results have showed that, 333 earthquakes with $M_s \geq 5.0$ happened in Yunnan area in 20th century and one earthquake with $M_s \geq 6.0$ occurred in a year on average [30]. Therefore, it is necessary to analyze the relation between magnetic anomalies and seismicity.

In this paper, we applied geomagnetic amplitude ratio analysis to historical geomagnetic data observed in Yunnan and try to find some significant precursory effect for historical earthquakes of $M_s \geq 6.0$ in Yunnan area from 1990 to 2000.

2. Geomagnetic Data and Earthquakes

There were 4 geomagnetic stations in Yunnan area from 1990 to 2000, they were Tengchong (TCH), Tonghai (THJ), Chuxiong (CHX) and Yongsheng (YOS) stations. CB-3 magnetometer was installed at every observatory and three geomagnetic components of D/H/Z were observed (H: NS component, D: EW component and Z: vertical component). Geomagnetic data from 1990 to 2000 was utilized for this analysis and earthquakes whose epicenter distance less than 300km for $M_s \geq 6.0$ and epicenter distance less than 400 km for $M_s \geq 7.0$ were selected. The distribution of stations is given in **Figure 1** and earthquakes selected are also plotted. **Table 1** lists detail information of earthquakes we used. The nearest earthquake is Yaoan M_s6.5 earthquake which happened in 15 January 2000, 70 km from CHX station. And the largest earthquake with magnitude M_s7.3 occurred in 1996, 347 km from TCH station.

Table 1. List of earthquakes $M_s \geq 6.0$ within certain epicenter distance during 1990-2000.

NO.	Date	Latitude	Longitude	Magnitude (M_s)	Depth (km)	Epicentral distance (km)			
						TCH	THJ	CHX	YOS
1	1992-04-23	22.6˚N	99.0˚E	6.9	31	310	418	372	481
2	1993-01-27	23.1˚N	101.1˚E	6.3	14	339	202	217	391
3	1995-07-12	22.0˚N	99.3˚E	7.3	9	347	424	405	534
4	1995-10-24	25.9˚N	102.2˚E	6.5	15	382	208	120	160
5	1996-02-03	27.2˚N	100.3˚E	7.0	10	300	424	273	83
6	1998-11-20	27.3˚N	100.9˚E	6.2	10	347	402	263	79
7	2000-01-15	25.5˚N	101.1˚E	6.5	30	265	228	70	126

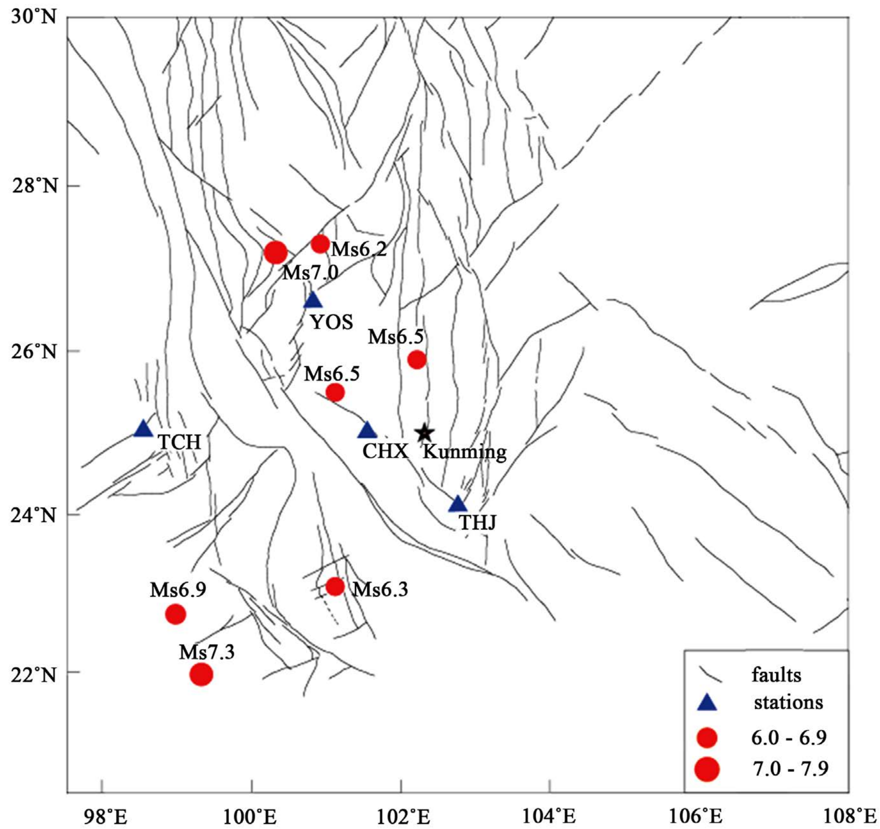

Figure 1. Distribution of geomagnetic stations and earthquakes from 1992 to 2000. Red dots indicate earthquakes selected, blue triangles represent geomagnetic stations in Yunnan area.

3. Geomagnetic Amplitude Ratio Analysis

If the structure of underground is homogeneous transversely, geomagnetic field changes with frequency as below [31]:

$$\begin{cases} \dfrac{Z(\omega)}{H_x(\omega)} = \dfrac{Z(\omega)}{H_y(\omega)} = i\dfrac{\lambda}{\theta} \\ \theta^2 = \sigma\mu\omega i + \lambda^2 \end{cases} \tag{1}$$

where the subscript x indicates NS orientation of coordinate system, y represents EW and ω is circular frequency, λ is wave number of geomagnetic field and we regard it as a constant in this paper, μ and σ represent permeability and conductivity. $Z(\omega)$, $H_x(\omega)$ and $H_y(\omega)$ indicate spectral amplitudes of Z, H and D, respectively. Each element in Equation (1) is a complex number as a function of frequency.

Geomagnetic amplitude ratios were defined as below:

$$Y_{ZH_x} = \left|\frac{Z(\omega)}{H_x(\omega)}\right|, \quad Y_{ZH_y} = \left|\frac{Z(\omega)}{H_y(\omega)}\right| \tag{2}$$

Recorded geomagnetic field consists of internal and external source field, and it is difficult to separate them. Normal geomagnetic field consists of external field and induced field for the normal horizontal-layer earth. The abnormal field only consists of the contribution of changing inhomogeneous transversely structures. When external source field is uniform and the horizontal-layer structure in the earth is electric homogeneous transversely, the vertical component will not be observed on the surface of earth. Therefore, $Z(\omega)$ which comes from normal field for uniform source is close to 0 [32]. However, the horizontal layers in the earth are electric inhomogeneous transversely and the source field is non-uniform actually. Therefore, the geomagnetic amplitude ratios of Yzhx and Yzhy could describe the changes of electric inhomogeneous transversely structures underground which are usually embodies in the changes of conductivity.

A lot of studies showed that geo-resistivity changed mostly decrease prior to earthquakes [33]. According to Equation (1), geomagnetic amplitude ratios of Yzhx and Yzhy are proportion to resistivity, so they should have similar changes. Feng and other researchers [22] [23] [24] [25] [26] found that most earthquakes occurred when geomagnetic amplitude ratios increase after decrease like resistivity expected. In this paper, we digitized every magnetogram one point per minute from 1990 to 2000 which means the sampling rate is 1 min. The waveforms of three components ($D/H/Z$) during each interval of 1200 minutes were subjected to maximum likelihood spectrum analysis. Then, we calculated geomagnetic amplitude ratios of Yzhx and Yzhy and analyzed their variations with earthquakes. In order to remove annual variation of geomagnetic field, Yzhx and Yzhy were dealt with 12-month-running.

4. Results Analysis

4.1. Variation of Geomagnetic Amplitude Ratios

According to Equation (2), geomagnetic amplitude ratios in period of 13, 20, 31, 49, 78, 113, 157 and 204 minutes of TCH, THJ, CHX and YOS stations were calculated. **Figures 2-5** show temporal variations of Yzhx and Yzhy of each

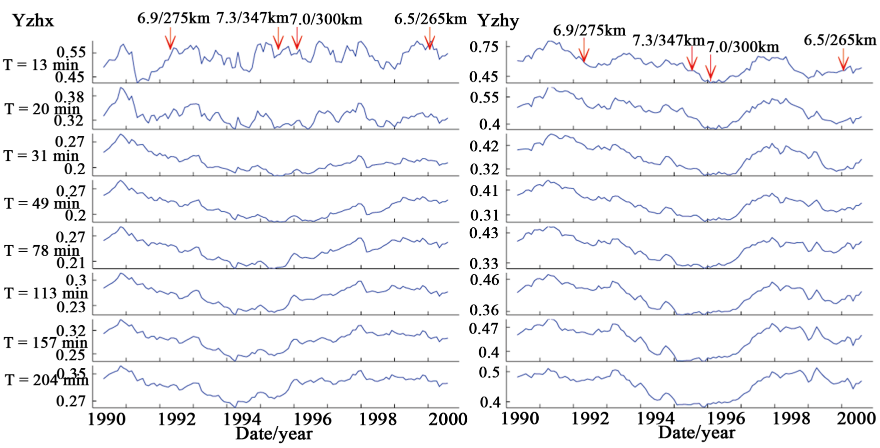

Figure 2. Temporal variations of Yzhx and Yzhy in different periods at TCH station from 1990 to 2000 and corresponding earthquakes. The vertical arrows indicate earthquakes occurrence date, magnitudes and epicentral distances also be marked, the same below.

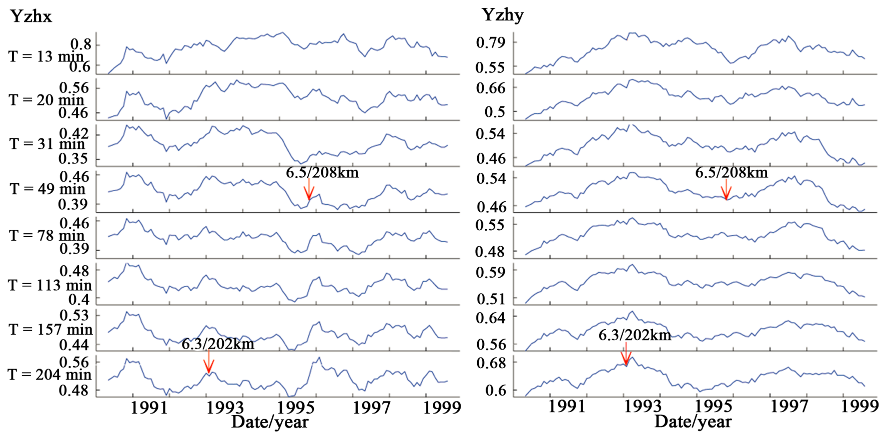

Figure 3. Temporal variations of Yzhx and Yzhy in different periods at THJ station from 1990 to 1999 and corresponding earthquakes.

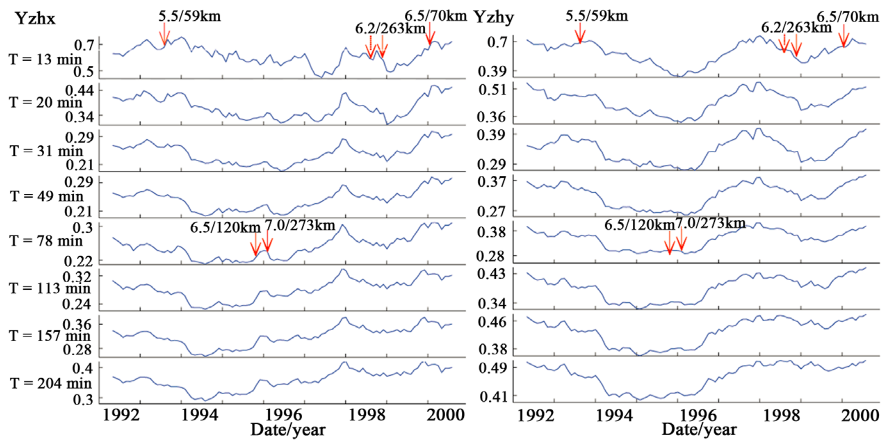

Figure 4. Temporal variations of Yzhx and Yzhy in different periods at CHX station from 1992 to 2000 and corresponding earthquakes.

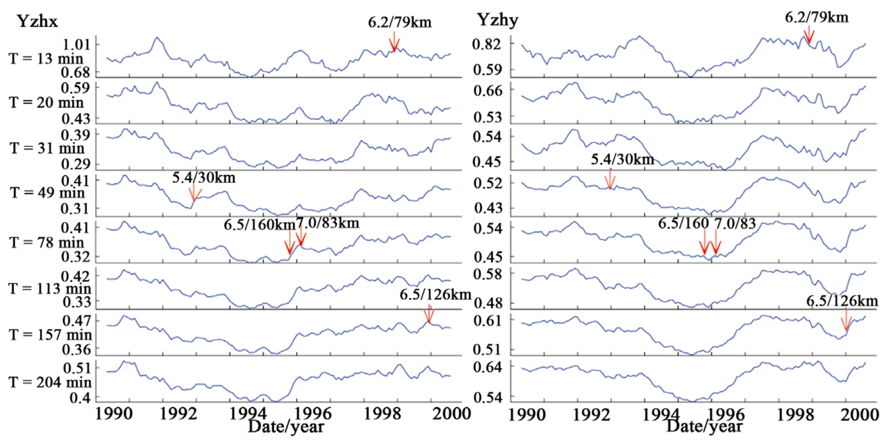

Figure 5. Temporal variations of Yzhx and Yzhy in different periods at YOS station from 1990 to 2000 and corresponding earthquakes.

station in these periods from 1990 to 2000, respectively. Furthermore, earthquakes (some earthquakes with $M_s \geq 5.0$ within very small epicentral distance) were marked with vertical arrows.

In general, the temporal variations of Yzhx and Yzhy in each period are similar especially in longer periods. That means the changes of earth conductivity in different depth were semblable especially in deeper layers. Therefore, an obvious inconsistency, which related to changes of local crust conductivity, may have relevant with earthquakes.

Temporal variations of Yzhx and Yzhy are different. First of all, Yzhy is more stable and consistent than Yzhx. Because most fault strikes in Yunnan area are north-south approximate, which means the conductivity of north-south is more changeable. And then, almost Yzhx and Yzhy in each period are small than 1.0, and reach maximum in period of 13 to 78 min then decrease with the increase of period. Lastly, geomagnetic amplitude ratios of YOS station are the largest for same period, followed by THJ, CHX and TCH. Yzhy is greater than Yzhx because the amplitudes of *H*x come from external geomagnetic field are greater than those of *H*y.

4.2. Earthquake Cases Analysis

Previous researches showed that geomagnetic amplitude ratios decrease prior to earthquakes, and most earthquakes occurred in the process of recovery [23] [24].

Figure 2 shows temporary variations of Yzhx and Yzhy at TCH station and corresponding earthquakes. It is clear that Yzhx in periods of 13 min and 20 min are inconsistent with other periods, especially those prior to strong earthquakes of M_s6.9 and M_s6.5. Refer to previous study results, we think the decrease of Yzhx last for more than 1 year may relate to earthquakes, which means the shallow crust conductivity changed before earthquakes. And earthquakes happened in the process of recovery or after that. However, these changes in Yzhy are nonexistent, which may relate to the rupture direction of fault or focal mechanism.

Figure 3 shows temporary variations of Yzhx and Yzhy at THJ station. All earthquakes happened in the process of recovery after decrease of Yzhx, but not all those decreasing situations have corresponding earthquakes. Yzhx decreased at the beginning of 1991 and return to normal at the end of 1992 and then earthquake with M_s6.3 occurred in 27 January 1993. The longer periods the decrease process is more noticeable. Similarly, later earthquake with M_s6.5 also happened during the process of Yzhx increases at the end of 1995, which decreases at the beginning of 1995. Yzhx exceeds normal value when periods are more than 78 min, while they are still below normal in other periods after increase. The process of down and up of Yzhx with inconsistency in different periods is more like precursors to earthquakes.

Figure 4 shows temporary changes of Yzhx and Yzhy at CHX station. Most earthquakes also happened in the process of increase or after that with inconsistency in different periods. Because the magnitude of M_s5.5 happened in 14 August 1993 is small, the decreasing amplitudes in Yzhx are small and only exist in periods that lower than 49 min and just last 5 months. In addition, a process of down and up of Yzhx exist in periods of 13 min and 20 min in 1997 and 1999 then earthquakes with M_s6.2 and M_s6.5 follow. Time interval between anomaly ending and M_s6.2 earthquake occurrence seems too long compared with other earthquake cases. We consult the earthquake catalogue and find that 3 foreshocks with $M_s \geq 5.0$ happened before the main shock of M_s6.2, and we mark them with dotted vertical arrows.

Figure 5 gives temporary variations of Yzhx and Yzhy at YOS station. The same as previous earthquake cases, most earthquakes occurred during the increase of geomagnetic amplitude ratios Yzhx after decrease. Moreover, the precursory variations of Yzhy to M_s6.2 earthquake happened in 20 November 1998 and M_s6.5 earthquake occurred in 15 January 2000 are more obvious than that of Yzhx.

5. Conclusions

Geomagnetic amplitude ratios in periods of 13, 20, 31, 49, 78, 113, 157 and 204 minutes of TCH, THJ, CHX and YOS stations in Yunnan area were obtained. Normally, the temporal variations of Yzhx or Yzhy in all periods are similar especially in longer periods. While, Yzhy is more stable and consistent, which means the underground conductivity of EW in Yunnan area is more stable and may relate to local geological structure of this area.

Significant decrease of Yzhx or Yzhy was found before nearby earthquakes during the whole analyzed time, and most of them happened during the process of recover to normal or after that. As other research results, we also found that the greater the anomalous amplitude, the greater the magnitude for similar epicentral distance. Take Yzhx in TCH station for example, M_s6.9 earthquake happened in 23 April 1992 and M_s6.5 earthquake occurred in 15 January 2000 with epicentral distance of 275 km and 265 km respectively. The anomalous amplitude of Yzhx before M_s6.9 earthquake reaches 28%, while that before M_s6.5 earthquake is only 19%. The specific relation between the anomalous amplitude and earthquake magnitude needs further study in the case of enough statistical samples.

6. Discussion

Moreover, Du [34] [35], Zheng [36] and Zhu [37] have found that the distribution of abnormal geo-resistivity stations and anomalous amplitudes prior to earthquakes were related to fault parameters (like strike or dip) and focal mechanism, especially the direction of principal compressive stress axis. The prominent changes occur in the component whose direction is perpendicular or nearly perpendicular to principal compressive orientation, and the abnormal geo-resistivity stations were almost along the orientation which perpendicular to the rupture direction of fault. Geo-resistivity change leads to the variation of geomagnetic amplitude ratios Yzhx and Yzhy, so the distribution of abnormal geomagnetic stations and anomalous amplitudes of Yzhx and Yzhy may also be related to fault parameters and focal mechanism. Therefore, not all geomagnetic stations can record precursory electromagnetic emissions signals usually. Fortunately, significant precursory effects were found for most of earthquakes in this paper, and it's necessary to study the detail relation between geomagnetic amplitude ratios and fault parameters or focal mechanism in further research.

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