1.2 IDENTIFYING AND LOCALIZING OF SEISMOGENIC EM ANOMALIES FROM DATA OBSERVED BY PERMANENT MT STATIONS

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ABSTRACT

The observed data from permanent magnetotelluric (MT) stations in the Southern segment of South-north Earthquake Belt of China have indicated potential seismogenic-induced electromagnetic disturbances. To simulate the seismogenic electromagnetic (SEM) anomaly, we combined the MT responses with responses from an arbitrarily oriented electric dipole underground. Synthetic results have shown that seismogenic EM radiation can produce recognizable apparent resistivity and phase anomaly in MT data for station, even far from the seismogenic zone. Long-term MT data obtained from Dali and Lijiang stations in Yunnan Province, China, were processed base on daily variation. We extracted the background (quietperiod) responses of these stations and identified two sections of data with SEM anomalies serving as precursors of two earthquake events (Yunlong & Yangbi). Selecting certain anomalous responses according to experimental criteria, we used them for inversion to determine the parameters of dipole location, including depth and orientation, and the spectrum of moment. The distribution of predicted dipoles are mostly located in or near the seismogenic area, and their azimuth generally exhibits good directivity toward the seismogenic fault, indicating the feasibility of this method in predicting the seismogenic zone. By analyzing the spatial distribution and time-varying characteristics of the inversion results of SEM anomalies in MT data, in conjunctionwith the geological and electrical structural characteristics of the predicted area and a comprehensive evaluation of seismic activity, it is expected to achieve imminent earthquake prediction.

KEY WORDS : Seismogenic EM anomaly, MT responses, dipole responses, identifying SEM, positioning SEM by inversion

INTRODUCTION

Both conventional seismic monitoring networks and permanent MT stations monitor variations of EM fields and underground electrical structures through continuous observation at fixed points. If a certain intensity of low-frequency electromagnetic radiation is generated during the process of earthquake preparation, the electromagnetic fields recorded by MT station are the superposition of the induced fields generated by natural field source variations and the electromagnetic radiation fields of earthquake preparation underground.

The MT sounding method has the characteristics of the wide frequency band and multicomponent observation. Using MT data from permanent stations to identify and extract SEM anomaly have following advantages. (1) The ratio of the mutually orthogonal electric and magnetic field is used to obtain the electric impedance of the earth and then the apparent resistivity and impedance phase. Thus the influence of earth electromagnetic field variations can be automatically eliminated. (2) Reliable regional background resistivity information at different depths can be obtained from long-term observation by the network, which is convenient for identifying and extracting SEM anomalies. (3) The impedance anomaly of a MT station not only includes the change in the resistivity of the underlying earth media caused by stress change and fracture development in the adjacent areas but also includes the electromagnetic radiation generated by pressure changes on rock body.

IDENTIFYING SEM ANOMALIES

On May 18, 2016, an M5.0 magnitude earthquake occurred in Yunlong, Yunnan, with its epicenter located at 26.10°N and 99.53°E, and focal depth ranging from 3~17 km. On March 27, 2017, an M5.1 earthquake occurred in Yangbi, with its epicenter located at 25.89°N, 99.80°E, and at depth of approximately 12 km. Figure 1 shows the epicenter and aftershock zone (light red area) of these two earthquakes, as well as the relative positions of the Dali and Lijiang MT stations near the earthquake area. The Dali Station is approximately 82.93km from the Yunlong epicenter and 47.18 km from the Yangbi epicenter. Lijiang Station is about 127.88km away from the Yunlong epicenter and 143.12km from the Yangbi epicenter.

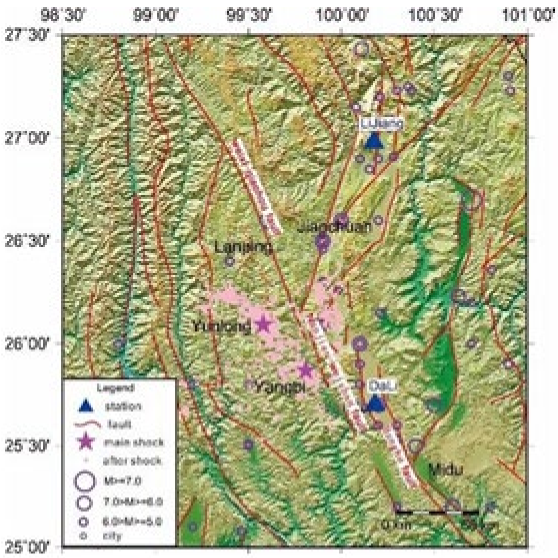

Fig. 1 The epicenters of the Yunlong and Yangbi earthquakes, and location of Dali and Lijiang station

During the quiet period, the signals observed by MT stations mainly come from the natural electromagnetic fields and induced fields in the earth near the station. The natural field source has the characteristics of a plane wave, while the earth's resistivity during the quiet period has characteristics of invariant in time. In this way, through long-term statistical averaging of station observed data, background field information with high SN ratio and high reliability can be obtained. Under the premise of excluding interference effects, responses deviated from the background field by a certain amplitude can be identified as responses containing SEM anomalies. Firstly, routine MT processing was performed on the daily observation data to obtain the apparent resistivity (ρxy, ρyx) and phase (φxy, φyx) responses of two polarization modes. Due to significant differences in apparent resistivity and phase values between different stations, or for different frequencies and polarization modes for same station, the observed apparent resistivity and phase are normalized using the background values of the corresponding frequencies of each station to unify the criteria for identifying anomalies. In this way, when the ratio is greater than 1, it indicates an enhanced response, and when it is less than 1, it indicates a weakened response. At the same time, confidence intervals (or empirical thresholds) for different components are determined based on the characteristics of electromagnetic environmental interference sources at each station. The SEM anomaly identification is then carried out according to the time-varying curve of normalized response for each frequency. Due to the varying degrees of influence of natural source fluctuations and human interferences on MT responses at different frequencies, to choose frequency with relatively stable background is recommended for identifying anomaly.

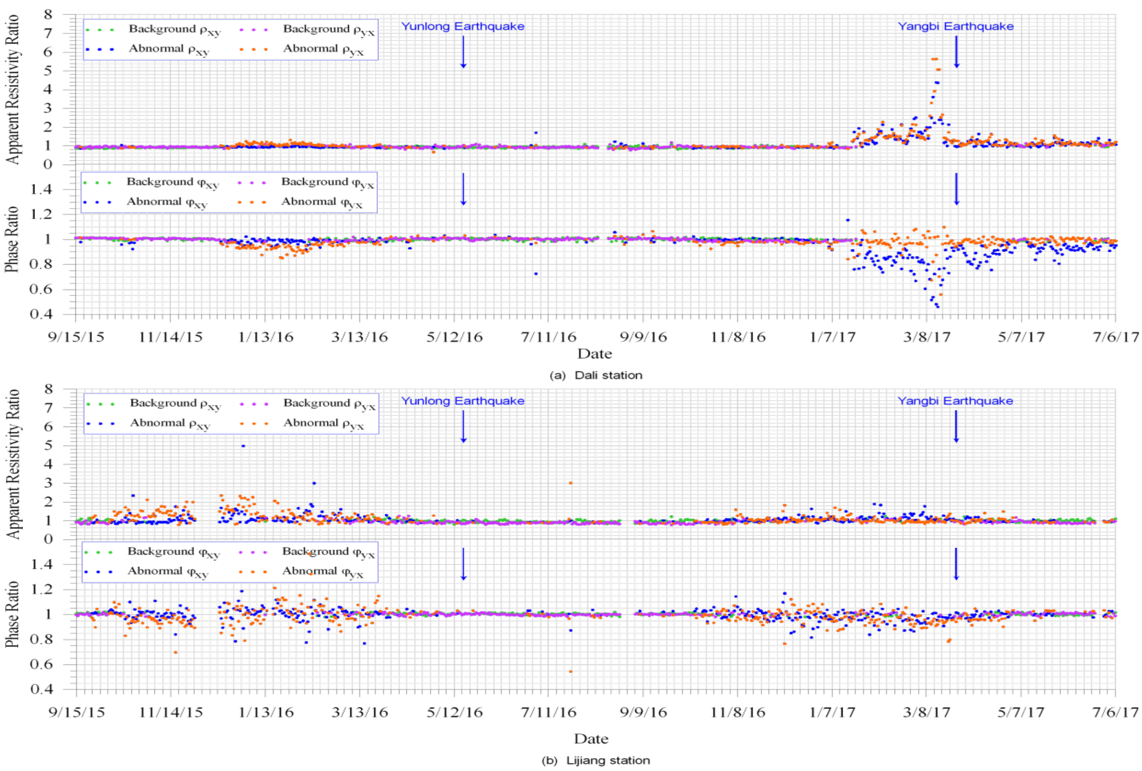

Fig. 2 Normalized apparent resistivity and phase of Dali and Lijiang Stn. for time period 9/15/2015~7/6/2017

Identifiable apparent resistivity and phase anomalies were observed at both Dali and Lijiang station before the Yunlong and Yangbi earthquake. Figure 2 shows the normalized timevarying curves of the apparent resistivity and phase at f=74Hz for both stations. The green and blue data points in the plots represent the background and abnormal response of normalized ρxy and ρxy, respectively, while the purple and orange data points represent normalized background and abnormal φyx and φyx respectively. It can be seen from Fig. 2 that the identifying process has effectively achieved the classification of observed responses. The normalized background response obtained is close to 1 and has continuity, while the abnormal response is prominent. At the same time, the abnomal rsponses for thses four parameters have good consistency. From the distribution of anomalous data points on the time-varying curve, it can be seen that the SEM anomalies begin to appear long before the earthquake, but not completely continuous. Therefore, manual analysis and judgment need to be conducted based on the time-varying characteristics of long-term observation responses for each station.

SEM POSITIONING BY INVERSION

Combination of the MT background field and the anomalous radiation field in the ground can be used to simulate the observed MT response containing SEM disturbances, the objective function for inversion can then be established. The responses of arbitrarily oriented dipoles in n-layered earth are calculated by algorithm of Hu et al. (2023). The existed inversion algorithms can be applied to obtain the physical parameters of the earth and the parameters of the radiation source in the ground. The parameters of the dipole radiation source obtained through inversion include source moment, location (x-y coordinates and burial depth), and state (azimuth and inclination) parameters. The differential ant-stigmergy inversion algorithm (Liu et al., 2015) is adopted to invert parameters of multiple dipole sources using multi-station data since this algorithm is robust to initial model.

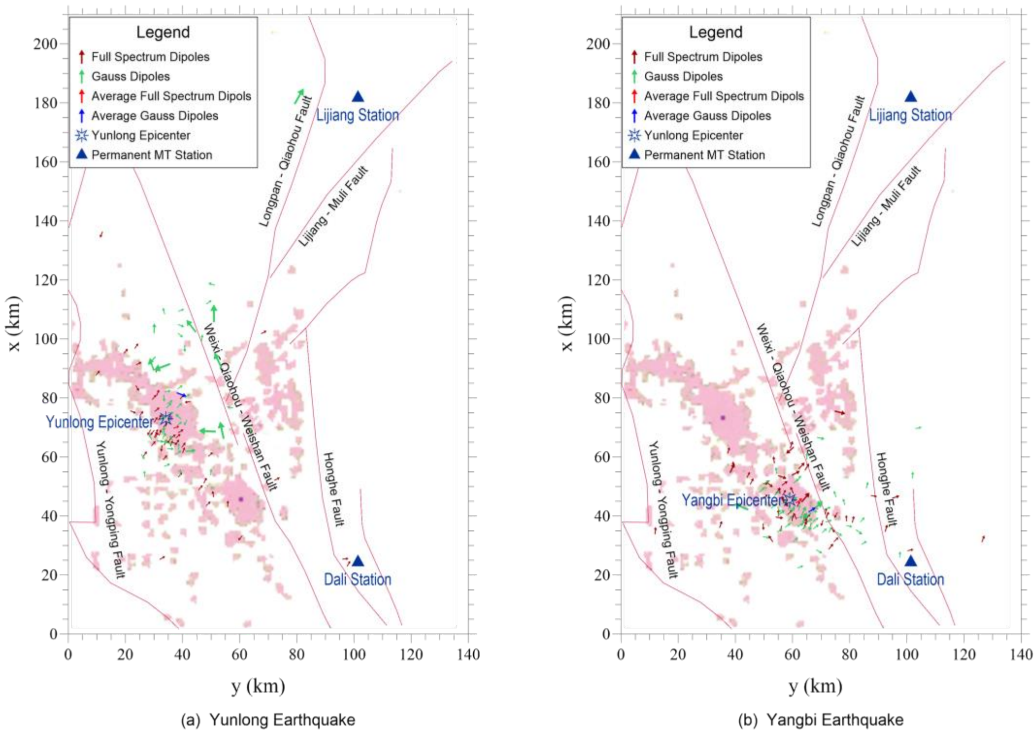

Fig.3 Location map of the underground dipoles predicted by inversion of the observed SEM anomalies of Dali and Lijiang station before the Yunlong and Yangbi earthquake

Figure 3 shows the distribution map of the underground dipole source obtained from inversion. The dark red arrow represents dipole of equal amplitude spectrum, and the green arrow represents the Gaussian dipole with high central frequency obtained from the inversion of daily anomalies. The direction of the arrow indicates the azimuth of the dipole, and its length is proportional to the dipole moment. Figure 3(a) shows the inversion results from the identified 51 abnormal daily data before the Yunlong earthquake. It can be seen that although the inversion results are scattered, the overall predicted dipoles are located in or near the seismogenic zone. The predicted equal spectrum dipoles are mainly distributed in the seismogenic area near the epicenter at average depth of 15km, with little spatial scattering. The orientation of most dipoles is approximately perpendicular to the Weixi Qiaohou - Weishan fault near the epicenter. Predicted high-frequency dipoles are at shallower depth(~7km) and more scattered in spatial distribution, with a portion distributed on both sides of the Weixi Qiaohou - Weishan fault besides the area near the epicenter; several dipoles are located near the Dali station, which may be a reflection of the observed data being interfered by the nearby noise.

Figure 3(b) shows the distribution map of inverted dipoles from the selected 55 SEM anomalies observed before Yangbi earthquakes. The spatial dispersion of the predicted dipoles is not significant, and the amplitude difference of the source moments is also small. The predicted dipoles are mainly distributed in the seismogenic area near the epicenter near the Dali station, possibly due to the fact that the Yangbi epicenter is relatively close to the Dali station and the observed anomalies have relatively large amplitude at the Dali station. In addition, there are several predicted dipoles fall near the Dali station, which may be the result of observed data being interfered by noise near the station.

CONCLUSION

The SEM anomaly causes disturbance in the apparent resistivity and phase observed at MT stations. By averaging the responses observed during the quiet period as the background and simulating responses of electric dipoles as the anomalous field, we can obtain the total observed MT field containing SEM disturbances by stacking these responses in the form of complex components of EM field. The synthesized responses can be used to invert parameters of multiple SEM radiation sources underground, and to achieve positioning of the radiation source (or seismogenic center).

It's important to note that this study is still in its preliminary stages, with limited examples. However, the research results indicate that the feasibility of applying an underground dipole source to equivalently simulate SEM radiation, followed by the inversion and positioning of underground radiation sources. Based on the comprehensive evaluation of regional geology, geoelectric structural characteristics and seismic activity, it is expected to achieve the goal of using SEM anomalies for imminent earthquake prediction.

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