

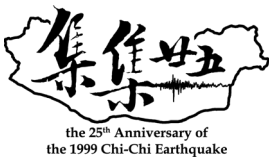
## **Inspiration from the Chi-Chi Earthquake: Challenge for Detection of Earthquake Precursor in Taiwan Revealed by Geophysical Data Analysis**

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Taiwan is located at the plate boundary of Philippine Sea Plate and Eurasian Plate with active tectonic, rapid crustal deformation and frequent earthquakes (Hall et al., 1995). There were many times disastrous earthquakes happened in Taiwan area. The most famous one is the Chi-Chi Earthquake ( $M_w=7.6$ ) that occurred on September 21, 1999. It caused loss of more than 2500 lives and collapse of more than 100,000 residential housing units. Before the earthquake occurred, there were many relevant precursors observed in geophysical data. There are several examples. The total geomagnetic intensity of the Liyutan station, about 8 kilometers from the northern end of the Chelungpu fault (considered to be related to the earthquake), fluctuated significantly for more than a month prior to the earthquake, the geomagnetic disruptions with highly anomalous amplitudes associated with the Chi-Chi earthquake (Yen et al., 2004). There are seismic quiescence and anomalous started in January 1999 and lasted about 9 months, up to the occurrence of the Chi-Chi earthquake (Wu and Chiao, 2006). The greatest plasma frequency in the ionosphere and the ionospheric total electron content (TEC) observed by the Chung-Li ionosonde ( $25.0^\circ\text{N}$ ,  $121.2^\circ\text{E}$ ) reveals three clear precursors at 1, 3, and 4 days prior to the earthquake (Liu et al., 2001). Unusual decreases of water levels were consistently observed in 78 % (= 42/54) of wells in the Choshuichi Alluvial Fan of central Taiwan about 250 days before the Chi-Chi earthquake. Variations in groundwater levels measured on anomalous wells from 1 August 1997 to 19 September 1999, which covers the 250 day unusual decreases (Chen et al., 2013). These geophysical observation data all reflect obvious precursor signals before the Chi-Chi earthquake.

Central Weather Administration (CWA) has been working hard in the direction of precursor research after the Chi-Chi earthquake. We own lots geophysical observation networks, gradually integrating the data of the Global Satellite Navigation System (GNSS), Seismic Groundwater Observation System, Geomagnetic Observation System and Telluric Electricity Geoelectric Observation System to form the Taiwan Geophysical Network for Seismology (TGNS, Figure 1) to actively conduct observation and research on earthquake precursors. The high precision GNSS survey technique provides an efficient tool to study active tectonics and geodynamics even earthquake precursors. A dense continuous GNSS site array composed of more than 500 stations in Taiwan was established by the Central Weather Administration and Other Institutes. The data GNSS stations are processed with the GAMIT/GLOBK software. By removing the common errors, the precision of GNSS data has been further improved to 2.3 mm, 1.7 mm, and 4.1 mm in the E, N, U components, respectively. Basically, these precursor phenomena that have only been observed over than data time span more than 4 years. The truth we have to face is that is almost impossible to have inter-seismic



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**International Conference in Commemoration of  
the 25<sup>th</sup> Anniversary of the 1999 Chi-Chi Earthquake:**

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September 13-14, 2024, Taipei, Taiwan

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period to observe the precursor signal when major earthquakes occurred very frequently, Especially there are more than 80% earthquake occurred in eastern Taiwan area. The previous research results tell that change of groundwater level can reflect the strain of rock mass, and observing the change of groundwater level can also be helpful for grasping the earthquake precursors. By the end of 2023, there are 6 seismic groundwater observation stations connected in real-time manner. Before a major earthquake occurs, the long-term accumulation of underground rock stress often leads to corresponding changes in the geomagnetic field. In the past, there have been several cases observed in Taiwan, such as the Hualien earthquake of 1986, the 921 Chi-Chi earthquake of 1999, the 1022 Chiayi earthquake, etc. Although most of these precursors are the results of post-event research and analysis, they are worthy of in-depth study and evaluation of the feasibility of evaluating earthquake precursors. The existing geomagnetic observation stations of CWA received a set of related equipment from the National Central University in 2006, which has been updated and maintained continuously. By the end of 2023, there are a total of 12 stations in the continuous geomagnetic observation network. From several rock fracture experiments, it has been shown that electromagnetic radiation disturbance is a common physical phenomenon in the process of fracture. The existing geoelectric observation stations of CWA received a set of related equipment from the National Central University in 2017, whose electrodes were updated and maintained continuously. By the end of 2023, there were a total of 20 stations. About the Ionospheric total Electron Content (TEC), From September 1999 to December 2002, a total of 20 earthquakes with a magnitude greater than 6.0 occurred in Taiwan, of which 16 earthquakes observed negative TEC anomalies in the 5 days before the occurrence, making the correlation reached 80%. However, the statistical result of 2023 represents about only 30% show the precursor signal in events both of anomalies before earthquakes and earthquakes after anomalies. In any case, this study comprehensively summarizes all precursor phenomena and challenges we have to face in order to achieve earthquake prediction in the future.

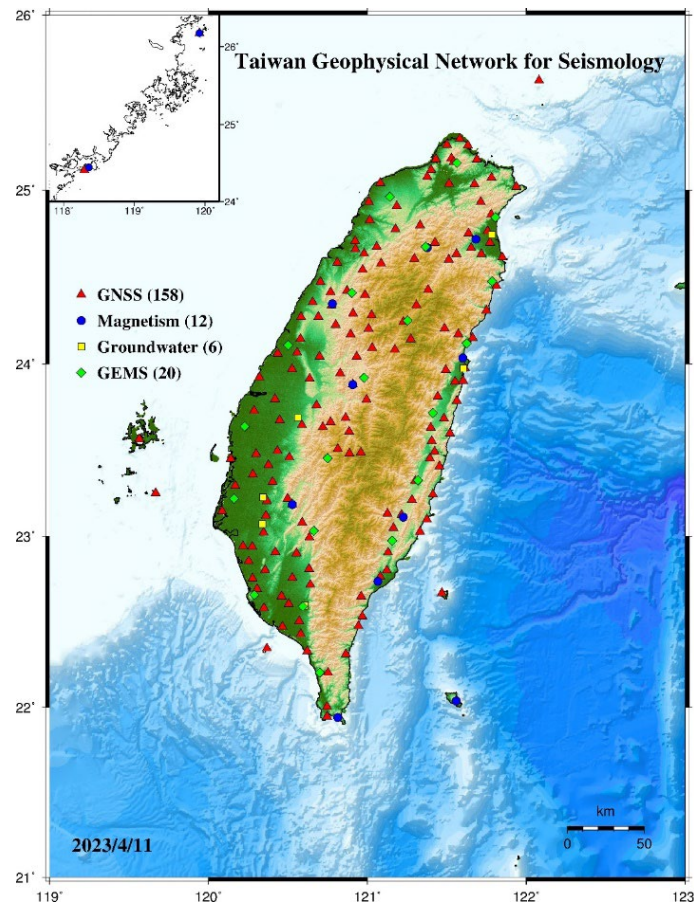


Figure 1. Taiwan Geophysical Network for Seismology (TGNS).

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