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Precursory phenomena associated with the 1999 Chi-Chi earthquake in Taiwan as identified under the iSTEP program

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Abstract

This paper presents a brief summary of several types of precursors in the lithosphere, atmosphere and ionosphere that have been positively identified in relation to the 20 September 1999 M_w 7.6 Chi-Chi earthquake and its aftershocks under the iSTEP Program.

Keywords: iSTEP; Chi-Chi earthquake; P-wave; DInSAR; Geomagnetic; Atmospheric; Ionospheric; Aftershock

1. Introduction

An M_w 7.6 earthquake struck central Taiwan with its epicenter near the small town of Chi-Chi at 01:47 LT (local time) on 21 September 1999. It caused loss of more than 2500 lives and collapse of more than 100,000 residential housing units. A program on integrated Search for Taiwan Earthquake Precursors (iSTEP) has been carried out since 1 April 2002. In this paper we summarize several types of positively identified precursory phenomena along with statistical analyses, including seismological variations, geomagnetic field changes, ground surface deformation, and ionospheric variations associated with the Chi-Chi earthquake and its aftershocks.

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2. Observations and statistical analysis

Through seismological, geomagnetic, surface deformation, and ionospheric observations, we have identified several types of possible precursory phenomena up to the time of the Chi-Chi earthquake by different methods. Fig. 1 synthesizes the results of these observations in a common time frame.

2.1. Increase of P-wave travel-time residuals

P-wave travel-time residuals determined as a by-product of earthquake location by the Taiwan Central Weather Bureau Seismic Network were used to study the variations of P-wave velocity structure in the crust near the Chi-Chi earthquake focal area (Lee and Tsai, 2004). The results obtained by using seismic data from 1991 to 2002 show that the mean P-wave travel-time residuals increased at the stations immediately west of the Chelungpu fault about six years before the Chi-Chi earthquake. Fig. 2 shows the variations of P-wave residuals at station NSY near northern part of the Chelungpu fault from 1991 to 2002. The

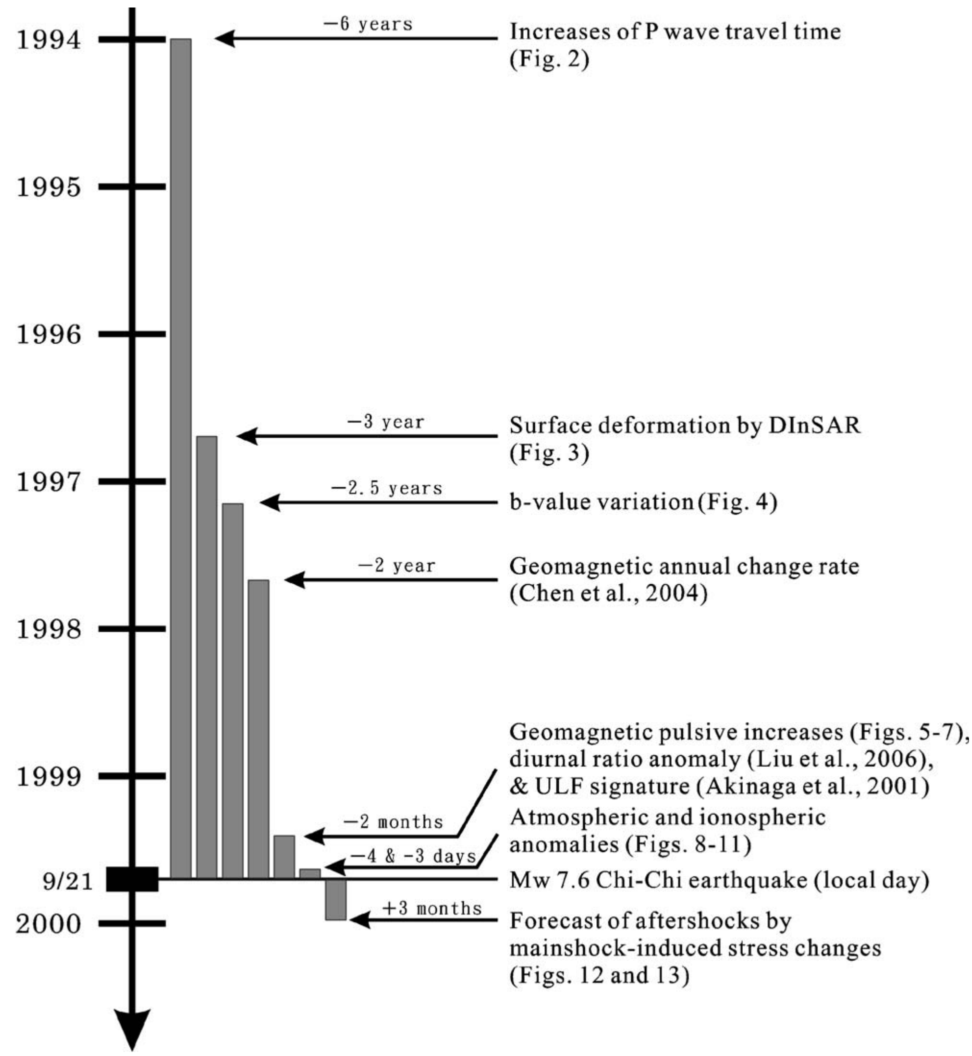

Fig. 1. Time lines of the precursors of the 1999 Chi-Chi, Taiwan earthquake, as identified under the iSTEP Program.

contour map below shows that most P waves passing through the anomalous zone east of the Chelungpu fault produced positive residuals from 1994 to the Chi-Chi earthquake. The anomalous zone is bounded by stations within 40 km east the Chelungpu fault. It implies that P-wave velocity began to decrease east of the Chelungpu fault in 1994, as a six-year precursor, possibly due to dilatancy or development of cracks in the crust (Nur, 1972).

2.2. Surface deformation before the Chi-Chi earthquake by DInSAR

Carefully chosen ERS-2 radar images were used to identify possible precursory surface deformation in the areas near the Chelungpu fault before the Chi-Chi earthquake. It was found that surface deformation began at least three years before the Chi-Chi earthquake in the areas immediately to the west of the northern segment of the Chelungpu fault where clear co-seismic surface deformation patterns were observed. Fig. 3 compares the DInSAR interferograms of the areas near the Chelungpu fault for three consecutive years before and one year after the earthquake.

2.3. Seismicity changes

In order to investigate possible precursory seismicity changes preceding the Chi-Chi earthquake, we calculated the *b*-value of the magnitude–frequency distribution (Gutenberg and Richter, 1944) in the three regions over the north, central and south parts of the Chelungpu fault (Fig. 4a). Based on complete recording of $M \geqslant 2.0$ earthquakes within 40 km in depth, temporal variations of the *b*-value from 1994/1/1 to 1999/8/31 in each of the three regions are presented in Fig. 4b. The *b* values were computed using a 100-event window sliding by 10 events. It is found that the highest *b*-value in region A appears in early 1997 and the *b*-value in region B reaches its peak in late 1997. Therefore, the *b*-value anomalies in regions A and B are a possible precursor of the Chi-Chi earthquake. Finally, although there are relatively high *b*-values in