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Review article

A review on remotely sensed land surface temperature anomaly as an earthquake precursor

Anshuman Bhardwaj[a,b], Shaktiman Singh[b,c], Lydia Sam[b,c], P.K. Joshi[d,*], Akanksha Bhardwaj[e], F. Javier Martín-Torres[a,f], Rajesh Kumar[b]

[a] Division of Space Technology, Department of Computer Science, Electrical and Space Engineering, Luleå University of Technology, Luleå, Sweden
[b] Department of Environmental Science, Sharda University, Greater Noida, India
[c] Institut für Kartographie, Technische Universität Dresden, Germany
[d] School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, 110 067, India
[e] Banaras Hindu University, Varanasi, India
[f] Instituto Andaluz de Ciencias de la Tierra (CSIC-UGR), Armilla, Granada, Spain

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ABSTRACT

The low predictability of earthquakes and the high uncertainty associated with their forecasts make earthquakes one of the worst natural calamities, capable of causing instant loss of life and property. Here, we discuss the studies reporting the observed anomalies in the satellite-derived Land Surface Temperature (LST) before an earthquake. We compile the conclusions of these studies and evaluate the use of remotely sensed LST anomalies as precursors of earthquakes. The arrival times and the amplitudes of the anomalies vary widely, thus making it difficult to consider them as universal markers to issue earthquake warnings. Based on the randomness in the observations of these precursors, we support employing a global-scale monitoring system to detect statistically robust anomalous geophysical signals prior to earthquakes before considering them as definite precursors.

1. Background

Earthquakes are one of the most sudden, most difficult to predict, and therefore most destructive natural phenomena. During the last few decades of the 20th and the first decade of 21st century (1968–2008), nearly 18,807 earthquakes of magnitudes > 4.5 have been reported by the Prompt Assessment of Global Earthquakes for Response (PAGER) system developed by the United States Geological Survey (USGS) (Marano et al., 2010). The associated casualty count has risen sharply in recent decades due to the rapidly increasing global population, with the staggering count of ~7,00,000 casualties in the first decade of the 21st century that may increase to a predicted count of 2.57 ± 0.64 million in the latter half of the 21st century (Holzer and Savage, 2013). The year 2015 alone saw several deadly earthquakes across the globe (Fig. 1), motivating a streamlining of precursory studies (Bhardwaj et al., 2017; Daneshvar and Freund, 2016).

1.1. Prediction and precursors

Earthquakes are the result of surging tectonic stress and are extremely difficult to predict (Geller et al., 1997) due to a lack of distinct statistical patterns required to model future occurrences (Console et al., 2002). However, the degree of the unpredictability of earthquakes is highly debated amongst seismologists, with several publications optimistically highlighting the usefulness and need for the continuous research on earthquake precursors to improve earthquake predictions (Wyss, 1997). The confidence in the science of short-term earthquake prediction received a boost in 1975, when a warning was issued in Haicheng, China hours before a major M7.4 earthquake, saving many lives (Cicerone et al., 2009). However, it soon received a setback due to the failure to predict the 1976 M7.8 earthquake in Tangshan that caused massive devastation (Lomnitz, 1994). Verma and Bansal (2012) have given many accounts of the successes and failures of earthquake predictions, sparking optimism and pessimism, amongst researchers, in turn. Nevertheless, the truth as of now is that the available seismological techniques have limited use for precisely forecasting the times, locations and strengths of earthquakes (Saraf et al., 2009). This indicates a need to strengthen forecasts using various proxies, called *earthquake precursors*.

Several researchers have defined the term *earthquake precursor*. Ishibashi (1988) proposed that earthquake precursors fell within two main categories: physical and tectonic. He defined a physical precursor

* Corresponding author.
E-mail addresses: pkjoshi27@hotmail.com, pkjoshi@mail.jnu.ac.in (P.K. Joshi).

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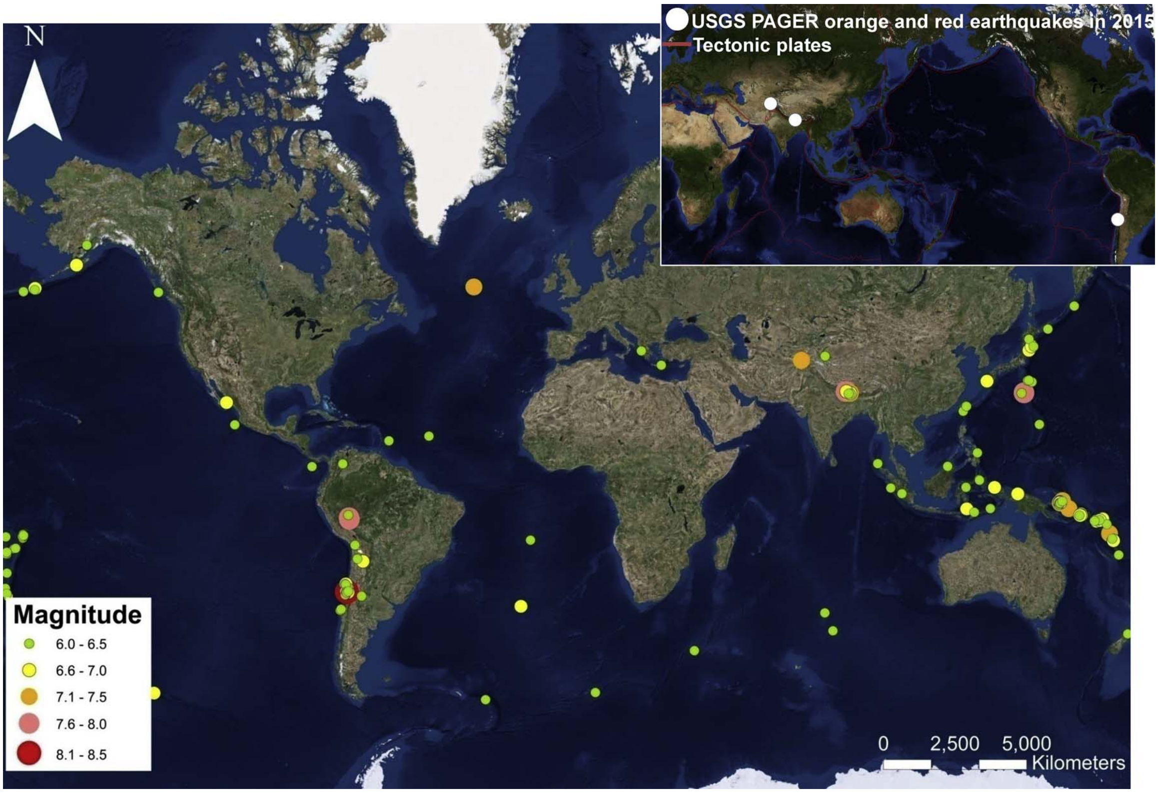

Fig. 1. This figure is generated using the United States Geological Survey (USGS) earthquake database for the period 1 January 2015 to 26 November 2015, highlighting 135 earthquakes of more than M6 (http://earthquake.usgs.gov/earthquakes/search/). The most destructive of these earthquakes are shown in the inset, falling within the criteria of USGS Prompt Assessment of Global Earthquakes for Response (PAGER) alert levels orange and red. The epicenters of these earthquakes were: (1) Nepal (28.147°N, 84.708°E), (2) Chile (31.57°S, 71.654°W), (3) Afghanistan (36.441°N, 70.717°E). More information on the PAGER levels can be found at http://earthquake.usgs.gov/research/pager/.

Table 1
Well-studied earthquake precursors.

Precursor (anomaly)	Example reference
Seismicity	Ihmle and Jordan (1994)
Electric field	Dobrovolsky et al. (1989)
Magnetic field	Balasis and Mandea (2007)
Gas/aerosol emissions	Guo and Wang (2008)
Ionospheric	Pulinets (2004)
Water level changes	Martinelli (2000)
Air temperature	Alvan et al. (2014)
Land surface temperature	Tramutoli et al. (2005)
Surface deformations	Borghi et al. (2009)
Unusual animal behaviour	Logan (1977)

to be a direct or indirect indicator of the beginning or development of an irreversible rupture-generating physical process within the preparation zone before the onset of an earthquake. However, a tectonic precursor is defined as the manifestation of a tectonic movement outside of the preparation zone of an imminent earthquake, pertaining to a sequence of particular local tectonism (Ishibashi, 1988). The International Association of Seismology and Physics of the Earth's Interior (IASPEI) defines both of these precursors together as any quantifiable change in regular environmental observations, as a preparatory mechanism before the main seismic event (Wyss, 1991). Hayakawa et al. (2000) refer to these precursors as earthquake sequences leading to the main earthquake shock and continuing for some time after it. Yao (2007) identified earthquake precursors as unusual changes in the entire physical and chemical environmental regimes at a regional scale. Cicerone et al. (2009) described precursors as a wide variety of physical phenomena preceding at least several earthquakes. A list of significantly studied precursors is given in Table 1.

The Earth observation satellites (both geostationary and sun-synchronous) provide an excellent opportunity for detailed and organized research on the proposed atmospheric and surficial precursors (Table 1) in different wavelengths and with sufficient temporal resolutions (Alvan et al., 2014; Bhardwaj et al., 2017; Freund, 2013; Piroddi and Ranieri 2012). In recent years, an increasing volume of literature has emerged on reporting the probable atmospheric, ionospheric, and surficial precursors for several large magnitude earthquakes (e.g., Bhardwaj et al., 2017; Daneshvar et al., 2014; Daneshvar and Freund, 2016; Ganguly, 2016; Petrini et al., 2012; Piroddi et al., 2014; Piroddi and Ranieri, 2012; Pisa et al., 2011) and remote sensing has played a crucial role in making such observations. The present review focuses on the detection of Land Surface Temperature (LST) anomalies using satellite observations before major earthquakes. The contemporary space-borne infrared (IR) sensors monitor the global thermal regime at varying spatial, spectral, and temporal resolutions (e.g., Terra/Aqua Moderate Resolution Imaging Spectro-radiometer (MODIS), National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer (NOAA-AVHRR) and Landsat). The repeat period for observations varies from 12 h for the sun-synchronous satellites to 30 min for geostationary satellites, thus ensuring an optimal global survey to detect changes in LST connected to an imminent earthquake (Tronin, 2006). The next section briefly describes the proposed probable physical basis behind this LST anomaly.

1.2. Proposed physical basis of LST anomalies

Enhanced thermal infrared (TIR) emissions from the earth's surface preceding an earthquake, which are often perceivable by remote sensors, can be called a *thermal anomaly* (Freund et al., 2005). Several of the studies mentioned in Fig. 2 have tried to determine the physical basis behind the thermal anomaly that causes fluctuations in the LST. These studies discuss the theoretical and experimental results, although