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Thermal IR satellite data application for earthquake research in Pakistan

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ABSTRACT

The scientific progress in space research indicates earthquake-related processes of surface temperature growth, gas/aerosol exhalation and electromagnetic disturbances in the ionosphere prior to seismic activity. Among them surface temperature growth calculated using the satellite thermal infrared images carries valuable earthquake precursory information for near/distant earthquakes. Previous studies have concluded that such information can appear few days before the occurrence of an earthquake. The objective of this study is to use MODIS thermal imagery data for precursory analysis of Kashmir (Oct 8, 2005; M_w 7.6; 26 km), Ziarat (Oct 28, 2008; M_w 6.4; 13 km) and Dalbandin (Jan 18, 2011; M_w 7.2; 69 km) earthquakes. Our results suggest that there exists an evident correlation of Land Surface Temperature (thermal; LST) anomalies with seismic activity. In particular, a rise of 3–10 °C in LST is observed 6, 4 and 14 days prior to Kashmir, Ziarat and Dalbandin earthquakes. In order to further elaborate our findings, we have presented a comparative and percentile analysis of daily and five years averaged LST for a selected time window with respect to the month of earthquake occurrence. Our comparative analyses of daily and five years averaged LST show a significant change of 6.5–7.9 °C for Kashmir, 8.0–8.1 °C for Ziarat and 2.7–5.4 °C for Dalbandin earthquakes. This significant change has high percentile values for the selected events i.e. 70–100% for Kashmir, 87–100% for Ziarat and 84–100% for Dalbandin earthquakes. We expect that such consistent results may help in devising an optimal earthquake forecasting strategy and to mitigate the effect of associated seismic hazards.

1. Introduction

The current progress in space sciences reveals different processes related with earthquakes i.e. earth's deformation, surface temperature growth, atmospheric gases, aerosol exhalation, ionospheric total electron content and electromagnetic disturbances in the ionosphere (Pulinets et al., 2006; Tronin, 2006; Pulinets and Ouzounov, 2011; Xie et al., 2013; Eleftheriou et al., 2016; Akhoondzadeh et al., 2018; Asim et al., 2017a, 2017b; Jilani et al., 2017; Barkat et al., 2017; Awais et al., 2017). These processes carry precursory information related with earthquakes and can serve as potential indicators within the context of earthquake forecasting. Most of the precursory signals contain significant information for earthquake forecasting along with their limitations, but the satellite thermal infra-red (TIR) signal has gained more attention and support from the scientific community across the world (Panda et al., 2007; Saradjian and Akhoondzadeh, 2011; Akhoondzadeh et al., 2018). This can be attributed to its ability of providing valuable precursory information prior to near/distant earthquakes (Ouzounov and Freund, 2004a, 2004b; Ouzounov et al., 2007; Tramutoli et al., 2001a, 2001b, 2005; Pulinets et al., 2006; Xie et al., 2013; Eleftheriou et al., 2016; Bhardwaj et al., 2017).

This invariability and infrequency of Land Surface Temperature (LST) are due to pre-seismic activity that alters the characteristics of soil including soil moisture, gas content and composition (Sugisaki et al., 1980; Tronin et al., 2002; Bhardwaj et al., 2017). The areas in the vicinity of earthquake epicenter experience extensive tectonic stresses prior to an earthquake event resulting in release of gases from the earth's surface to the lower atmosphere and create a localized LST anomaly. The physical mechanism behind this interesting phenomenon is systematically explained by Pulinets and Ouzounov (2011) in Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) model.

The LAIC model explains the linkage between buildup of tectonic stresses, fault activation, migration of soil gases, fluctuation of surface latent heat flux, atmospheric and ionospheric perturbations and

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occurrence of seismic event (see Fig. 10 of Pulinets and Ouzounov, 2011). Furthermore, Martinelli et al. (2015) conducted a laboratory experiment to validate the fluctuations in LST due to radon emanation in connection with the application of satellite TIR data for measurement of these perturbations (Tronin, 1996; Tronin et al., 2002; Ouzounov and Freund, 2004a, 2004b; Tronin, 2006; Pulinets, 2009; Martinelli et al., 2015). Qiang et al. (1999) reported that the release of greenhouse gases i.e. CO_2, CH_4, etc. due to tectonic stresses closer to the epicenter creates a localized greenhouse effect resulting in LST anomaly (Salman et al., 1992; Tronin et al., 2002; Ouzounov and Freund, 2004a, 2004b; Bhardwaj et al., 2017).

Several attempts have been made to correlate the pre-seismic transient features of TIR anomaly with the geodynamic activity (Tronin, 1996, 2000, 2006; Tronin et al., 2002; Tramutoli et al., 2001a, 2001b; Ouzounov and Freund, 2004a, 2004b; Ouzounov et al., 2006; Pulinets, 2009; Martinelli et al., 2015; Eleftheriou et al., 2016; Akhoondzadeh et al., 2018; Awais et al., 2017). Historically, the first application of thermal images in earthquake study was carried out in 1980's for Asia (Tronin, 1996). Later, similar research was carried out in China (Qiang and Du, 2001), Japan (Tronin et al., 2002), India (Singh and Ouzounov, 2003), Spain, Turkey, United States (Ouzounov and Freund, 2003) and Italy (Tramutoli et al., 2001a, 2001b).

The aim of this study is to analyze the temporal variation of satellite TIR imagery data within the context of earthquake forecasting for three major seismic events of Pakistan given in Table 1 (https://earthquake.usgs.gov/earthquakes/). A further aim of this study is to present a comparative and percentile analysis of daily and five years averaged LST to highlight the significance of any anomalous variations associated with seismic activity. The rationale behind the selection of these events is their large magnitude, shallow depth and damage of infrastructure. The methodology adapted in this study to analyze the pre- and post-earthquake satellite TIR imagery data is consistent with other studies (Gorny et al., 1988; Singh et al., 2002; Tramutoli et al., 2001a, 2001b, 2005; Tronin et al., 2002, 2004a, 2004b; Ouzounov et al., 2006). The significance of finding a possible significant correlation between TIR anomalies and major earthquake activity for Pakistan is more pronounced due to its seismo-tectonic settings (Fig. 1). Therefore, such studies are important within the context of avoiding possible seismic hazards associated with upcoming seismic events. The present study can also serve as a baseline for TIR data analysis related to forecasting of earthquakes in Pakistan. In what follows, we present the seismo-tectonic settings of the investigated regions.

2. Seismo-tectonic settings of the investigated regions

Tectonically, Pakistan and the surrounding areas lay on the active plates of the Indian and Eurasian, which are responsible for the high seismic activity in the region. Continental collision between these two plates has been responsible for the formation of Himalaya, Karakoram and Hindukush, which lie along the plate's boundary (Molnar and Tapponnier, 1975; Hussain et al., 2016; Eshagh and Hussain, 2016; Asim et al., 2017a; Rehman et al., 2017). Together, these tectonic features form part of north Pakistan. North Pakistan is characterized by compressional features of Main Karakoram Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and Salt Range Thrust (SRT) (Molnar and Tapponnier, 1975; Quittmeyer and Jacob, 1979; Kazmi and Jan, 1997; Wheeler et al., 2005; Ali et al., 2009; Rehman et al., 2014; Fig. 1). The well-known aspect of northern Pakistan tectonic features is their seismicity. Fig. 1 shows that number of significant earthquakes have occurred along the faults during the instrumental period of World Wide Seismographic Stations Network (WWSSN). Typical example is the Kashmir earthquake October 08, 2005. Kashmir earthquake which was responsible for the commercial, domestic and infrastructure damages experienced in Hazara-Kashmir Syntax and eastern MBT (Nakata and Kumahara, 2006; Fig. 1).

The dominant tectonic feature of West Pakistan is the Chaman fault that runs from Quetta in Pakistan to Hindukush in Afghanistan. Fig. 1 shows that the Ziarat earthquake of October, 28 2008 having magnitude of M_w 6.4 occurred near the northern part of Chaman fault. Another earthquake of M_w 7.2 occurred near the southern part of Chaman fault on January 18, 2011 (Dalbandin earthquake). In addition to the seismic activity dictated by Chaman fault system in this region, there are numerous onshore and nearshore faults in the southwestern region of Pakistan (Bilham et al., 2007; Fig. 1). The devastating 1945 Makran earthquake of M_w 8.0 produced tsunami in coastal areas of Pakistan (Geller and Kanamori, 1977; Pararas-carayannis, 2006; Rehman et al., 2014, 2015).

3. Data description and methodology

The estimation of earthquake preparation zone plays a key role for analyzing any precursory signal associated with seismic activity. This can be performed with the help of estimating the radius of earthquake preparation zone. The radius of earthquake preparation zone is estimated using Dobrovolsky relation:

$$R_D = 10^{0.43M} \tag{1}$$

Here, R_D is the radius of earthquake preparation zone in which the precursory manifestation can be monitored and M is the magnitude of the seismic event (Dobrovolsky et al., 1979). In case of TIR data, the choice of region of interest (ROI) within the earthquake preparation zone (Fig. 1 – circular zones for selected events) plays a crucial role. The amplitude of anomaly will be higher in the ROI closer to the epicenter of the event and vice versa (Tronin et al., 2002; Ouzounov and Freund, 2004a, 2004b; Ouzounov et al., 2006). Moreover, the analysis of TIR data in ROI is commonly carried out in rectangular coordinates (Latitude and Longitude) and its size can be variable. For example, Ouzounov et al. (2006) reported the TIR anomaly of Gujarat earthquake (M 7.7; 2001) and Mexico earthquake (M 7.8; 2003) with a region of interest $\approx 1^\circ \times 1^\circ$, whereas the calculated earthquake preparation zone via Eq. (1) is $\approx 18^\circ \times 18^\circ$. In current study, we have selected the region of interest ($6^\circ \times 6^\circ$; Fig. 1 – squared grids) appropriately within the earthquake preparation zone for selected events consistent with other studies (Panda et al., 2007; Tronin et al., 2004a, 2004b; Ouzounov et al., 2006). In addition to that, Pulinets et al. (2006) also claimed that it is better to choose a suitable smaller region of interest closer to the earthquake epicenter, which possesses a potential chance of registering local anomalous precursory behavior.

LST variations within the ROI are studied by using the satellite IR imagery data recorded by Moderate Resolution Imaging Spectroradiometer (MODIS) installed on Terra (Dec 18, 1999) and Aqua (May 04, 2002) satellites (Akhoondzadeh et al., 2018). The imagery record measured by MODIS at high spatial resolution gives an enhanced and significant information about the Earth's surface and atmosphere

Table 1
List of earthquakes presented in this study.

Earthquake (Case Study)	Date (DD/MM/YYYY)	Magnitude (Mw)	Latitude (°N)	Longitude (°E)	Depth (km)
Kashmir	08:10:2005	7.6	34.539	73.588	26
Ziarat, Baluchistan	28:10:2008	6.4	30.650	67.361	15
Dalbandin, Baluchistan	18:01:2011	7.2	28.732	63.920	69