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Passive microwave response associated with two main earthquakes in Tibetan Plateau, China

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Abstract

The thermal anomalies associated with earthquakes using satellite infrared data are being studied in different parts of the world for more than three decades. The thermal anomalies have emerged as one of the potential earthquake precursor. However, often cloud cover obstructs detection of the thermal anomalies. Compared to infrared, passive microwave sensors provide information about the thermal radiations under any weather conditions. In the present study, we have carried out detailed analysis of brightness temperature data derived from the Defense Meteorological Space Program (DMSP) Special Sensor Microwave/Imager (SSM/I) to determine thermal anomalies associated with the 1997 Manyi and 2001 Kokoxili earthquakes. Brightness temperature data for 13 years period from 1996 to 2008 observed from F13 satellite were considered to avoid difference in the sensor sensitivity. Based on 9 years background data that ignoring data for the years in which strong earthquake occurred, we computed Index of Microwave Radiation Anomaly (IMRA) over the Manyi-Yushu Fault (MYF) and Kun Lun Fault (KLF) zones, Tibetan Plateau. Our results indicate that the microwave brightness temperature at 19.35 GHz has higher sensitivity to the seismic anomalies in comparison to the other higher frequency channels. The IMRA with multi-region, multi-frequency, and multi-parameter variation were analyzed to validate our results. In addition, variation of different parameters (microwave brightness temperature, near surface air temperature and carbon monoxide-CO) observed for Kokoxili earthquake shows the transfer process of thermal anomalies from the focal region to the atmosphere during the preparation and occurrence of earthquake. Passive microwave satellite data combined with other surface and atmospheric parameters provide better understanding of physical mechanism of thermal anomalies associated with earthquakes.

Keywords: Passive microwave data; Earthquakes; Thermal anomalies; Carbon monoxide; 1997 Manyi earthquake; 2001 Kokoxili earthquake

1. Introduction

Earthquakes are common throughout the globe, ground and satellite observations have shown a strong coupling between land-atmosphere-ionosphere associated with earthquakes. Surface thermal anomalies prior to strong earthquakes have been observed using satellite infrared data by many researchers (Gornyi et al.,1988; Tronin et al., 2002; Saraf and Choudhury,2005; Tramutoli et al.,2005; Ouzounov et al.,2006; Tramutoli et al.,2013; Barkat et al.,2018). Such observations show a relationship between thermal anomalies and seismic activities. Further, complementary changes in surface, atmospheric, meteorological and ionospheric parameters associated with the major earthquakes were widely reported (Pulinets et al., 2006; Singh et al., 2010b,2010c; Pulinets and Ouzounov, 2011;

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Akhoondzadeh et al., 2018). However, Thermal Infrared Radiations (TIR) from earth to the satellite sensor or low thermal anomalies are difficult to detect if clouds are present (Aliano et al., 2008). Accordingly, only cloud-free pixels observed by infrared sensors can be used in analyzing and detecting thermal anomalies associated with the seismic activities (Lisi et al., 2010; Tramutoli et al., 2013, 2015a). This is one of the important drawbacks in analyzing thermal infrared data from the seismic prone areas covered with clouds. Distribution of clouds can bring cold spatial average effect that can significantly influence the computation of reference field and multi-temporal analysis to detect thermal anomalies (Aliano et al., 2008; Genzano et al. 2009). Compared with the infrared observation, microwave signals penetrate through clouds. The thermal radiations emitted from ground can be obtained during the day and night and also in any weather conditions, which will provide more continuous and effective data. Based on this physical characteristic, microwave sensors have proved to be an important tool for monitoring thermal anomalies from seismic prone and cloud covered areas (Aliano et al., 2008; Jiao et al., 2018).

Electromagnetic signals were observed in the frequency range 900 Hz-5KHz in rock fracture experiments as early as 30 years ago (Cress et al., 1987). Deng et al. (1995) observed increase in brightness temperature of rocks in the microwave frequency range with the increase of stress, and the enhancement in microwave brightness temperature prior to the rock fracture. The magnitude of brightness temperature varies in different microwave frequencies and the polarization. Emissions were detected at different microwave frequencies 300 MHz, 2 GHz and 22 GHz during loading of rocks, even after rock failures (Maki et al., 2006). Liu et al. (2016) observed enhancement of 1.5 K microwave brightness temperature with the rock stress of 100 MPa in an outdoor rock loading experiment, that provided information about the potential of microwave brightness temperature to monitor earthquake activities. Recently, a joint laboratory observation of infrared and microwave radiations was carried out, the results show precursory anomalies prior to the rock fractures (Xu et al., 2015). Maeda and Takano (2010) have detected definitive microwave signals around the epicenter using AMSR-E (Advanced Microwave Scanning Radiometer-Earth Observing System) 18 GHz brightness temperature data during Morocco M6.4 earthquake of 24 February 2004. Singh et al. (2010b) also observed anomalous brightness temperature in all polarizations and frequencies in ascending and descending modes few days prior to 2008 Wenchuan M7.9 earthquake. Chen and Jin (2010) and Liu et al. (2012) also found microwave radiation anomaly associated with M6.9 Yushu earthquake of 2010. Jie and Guangmeng (2013) observed thermal anomalies during 2010 Baja California M7.2 earthquake using the AMSR-E 89 GHz data, and found complimentary variations in the microwave radiation and the atmospheric temperature.

However, according to field observation and microwave radiative transfer model, surface microwave brightness temperature is affected strongly by soil moisture, vegetation cover and surface roughness (Mätzler, 1992; Choudhury, 1993). In the present study, an Index of Microwave Radiation Anomaly (IMRA) was proposed for the areas with relative low soil moisture and less vegetation cover. Analysis of brightness temperature data from DMSP (Defense Meteorological Satellite Program) SSM/I (Special Sensor Microwave Imager) for the period 1996–2008 were carried out over active fault zones and we observed some abnormal signals associated with earthquake activities.

2. Data and preprocessing

The SSM/I provide brightness temperature data in both vertical (V) and horizontal (H) polarizations at frequency 19.35 GHz, 37.0 GHz, 85.5 GHz and at 22.235 GHz in vertical polarization (19H represents 19.35 GHz in horizontal polarization, 19 V represents 19.35 GHz in vertical polarization, and so on), which is highly stable and have global coverage (Ferraro et al., 1996). In the present study, we have used Level-3 Equal-Area Scalable Earth-Grid (EASE-Grid) brightness temperature data (Data Set ID: NSIDC-0032) which provide global coverage of 25 km spatial resolution data.

The daily EASE-Grid brightness temperatures data were acquired using the SSM/I instrument on the DMSP-F08, F11, and F13 platforms, as well as the SSMIS instrument on the DMSP-F17 platform (Armstrong et al., 1994). The different platform has different equatorial crossing times, the observation period and the ascending equator crossing times for the platforms (Table 1). Some results have indicated that brightness temperature of SSM/I sensors on different platforms is different over same region due to instrumental offsets, sensors degradation and satellite orbital drift (Yang et al., 2011; Dai, 2015). Therefore, we have considered microwave brightness temperature data only from F13 platform. Considering satellite observation in ascending mode was affected by sunlight, we have considered only descending mode data.

The daily global land cover data are not available for polar orbiting satellites observation, some of the data along

Table 1
Coverage information of NSIDC-0032 dataset.

Platform and instrument	Temporal coverage	Ascending equator crossing times (local time)
F08 SSM/I	9 July 1987–31 December 1991	06:17
F11 SSM/I	3 December 1991–30 September 1995	18:25
F13 SSM/I	3 May 1995–31 December 2008	17:43
F17 SSMIS	14 December 2006–present	17:31

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