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Investigation of atmospheric anomalies associated with Kashmir and Awaran Earthquakes

Irfan Mahmood*, Muhammad Farooq Iqbal, Muhammad Imran Shahzad, Saddam Qaiser

Earth & Atmospheric Remote Sensing Lab, Department of Meteorology, COMSATS Institute of Information Technology, Islamabad, Pakistan

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A B S T R A C T

The earthquake precursors' anomalies at diverse elevation ranges over the seismogenic region and prior to the seismic events are perceived using Satellite Remote Sensing (SRS) techniques and reanalysis datasets. In the current research, seismic precursors are obtained by analyzing anomalies in Outgoing Longwave Radiation (OLR), Air Temperature (AT), and Relative Humidity (RH) before the two strong Mw > 7 earthquakes in Pakistan occurred on 8th October 2005 in Azad Jammu Kashmir with Mw 7.6, and 24th September 2013 in Awaran, Balochistan with Mw 7.7. Multi-parameter data were computed based on multi-year background data for anomalies computation. Results indicate significant transient variations in observed parameters before the main event. Detailed analysis suggests presence of pre-seismic activities one to three weeks prior to the main earthquake event that vanishes after the event. These anomalies are due to increase in temperature after release of gases and physical and chemical interactions on earth surface before the earthquake. The parameter variations behavior for both Kashmir and Awaran earthquake events are similar to other earthquakes in different regions of the world. This study suggests that energy release is not concentrated to a single fault but instead is released along the fault zone. The influence of earthquake events on lightning were also investigated and it was concluded that there is a significant atmospheric lightning activity after the earthquake suggesting a strong possibility for an earthquake induced thunderstorm. This study is valuable for identifying earthquake precursors especially in earthquake prone areas.

1. Introduction

Prediction of earthquakes has always been a challenging area for researchers across the globe. However, different perspectives have been utilized in order to predict earthquakes during past few decades. Various researchers have observed significant anomalies on earth surface, atmosphere and ionosphere prior to major earthquakes (Hayakawa et al., 1996a; Singh et al., 2001a, 2001b; Hayakawa and Molchanov, 2002; Dey and Sing, 2003; Di Bello et al., 2004; Pulinets and Boyarchuk, 2004; Cervone et al., 2005; Blackett et al., 2011; Heki, 2011; Carter et al., 2013; Ganguly, 2016). Long and short-lived thermal anomalies have also been revealed by satellite thermal imaging prior to major earthquakes (Tronin et al., 2002; Ouzounov and Freund, 2004; Pulinets et al., 2006a). These short lived anomalies can show positive or negative deviations of greater than 2–4 °C from 4 to 20 days before an earthquake and disappearing few days after the event (Ouzounov et al., 2007). Interestingly anomalies are not only restricted to surface level but have also been measured in the atmosphere above the clouds level (Venkatanathan and Natyaganov, 2014). These anomalies can be detected in frequency ranges between hertz and megahertz.

The earth crust underwents a variety of geophysical changes and these changes produce precursors of impending earthquake (Saraf et al., 2008; Pulinets and Ouzounov, 2011; Alvan et al., 2012, 2013). These anomalies can be explained by Lithosphere-Atmospheric-Ionospheric Coupling (LAIC) model (Pulinets and Dunajecka, 2007). Singh et al. (2006) observed a relationship between temperature rise, chlorophyll concentration, Surface Latent Heat Flux (SLHF) and ocean water upwelling during major earthquakes.

Generally, earthquake precursors are classified into three categories; surface precursors like Land Surface Temperature (LST), atmospheric precursors such as Outgoing Longwave Radiation (OLR), SLHF, Air Temperature (AT) and Ionospheric precursors like Total Electron Content (TEC) (Liu et al., 2004). Release of gases (for instance radon), slow deformation of rocks and fluctuation of water are responsible for thermal anomalies in epicentral region (Cervone et al., 2006). Theoretically, many precursory events caused by various physical and geochemical interactions are expected to happen along faults (Cicerone et al., 2009; Tronin, 2009; Freund, 2011; Adanur et al.,

* Corresponding author.
E-mail address: irfan.mahmood@comsats.edu.pk (I. Mahmood).

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2012; Alvan et al., 2013) because before an earthquake, rocks undergo major changes due to increase in stress along the faults that releases heat due to elastic behavior of crust during earthquake preparation stage (Geller, 1997). Additionally, unbalanced distribution of the electromagnetic charge is also developed due to the formation of micro-cracks. OLR is defined as the earth radiation emitted to space from top of the earth's atmosphere and depends on cloud and surface temperature (Ouzounov et al., 2007). A complex system of clouds, aerosols, atmosphere, ocean and land surface temperature variations are responsible for the reflection, absorption and emission of OLR (Ouzounov et al., 2007; Xiong et al., 2010). OLR records thermal anomalies prior to earthquake in different time scales and reflects the energy variations in the atmosphere (Kang et al., 2006; Jing et al., 2009; Xiong et al., 2010). It is controlled by temperature of earth and atmosphere, clouds and amount of water vapor in the atmosphere. Studies suggest that OLR is more intense around epicentral area one month prior to occurrence of earthquake (Liu, 2000; Kang and Liu, 2001) that can cause near surface air ionization and latent heat changes due to air humidity and AT (Venkatanathan et al., 2013). Ouzounov et al. (2007) reported anomalous OLR variations of +80 W/m^2 before the 2004 Sumatra earthquake.

Abnormal variations of AT due to pre-earthquake physical and chemical interactions on earth have been reported in different studies (Ma et al., 1982; Pulinets et al., 2006a, 2006b). Approximately 2–4 °C rise in AT along with anomalous variation of RH has been observed prior to recent earthquakes in Iran (Alvan et al., 2013). These anomalies are produced as a result of thermodynamics, degassing and ionization process which are in turn activated by accumulated stress, tectonic blocks movement and rock micro fracturing (Alvan et al., 2013). The emission of radon in epicentral areas can also produce AT and RH variations as demonstrated by LAIC model (Pulinets and Dunajecka, 2007). Increased radon activity before earthquake causes increase in ionization of air molecules increasing the thickness of air layer. Escape of gases (e.g. radon) into atmosphere causes the ionization of air molecules followed by ion induced nucleation that later causes anomalous release of latent heat and OLR leading to changes in atmospheric parameters (Air temperature, humidity, pressure) (Pulinets at al. 2015). It is also reported that α-particles ($E\alpha$ =5.4 MeV) are released due to decay of radon which can produce 3.5×10^5 electron-ion pairs on average. Considering this, the ionformation rate is ~ 6×10^8 m^{-3} s^{-1}. Therefore, increase in radon activity before earthquake and formation of hydrated ions (1 µm contains 0.4×10^{12} water molecules) causes the release of ~16 W/m^2 latent heat (Pulinets at al., 2015).

Studies have shown that SLHF anomalies and soil moisture are linked, hence there is a probability of SLHF anomalies before earthquakes. Studies by Dey and Singh (2003) and Cervone et al. (2004) have shown SLHF as a possible precursor to coastal earthquakes. Cervone et al. (2005) used wavelet analysis technique to identify SLHF maxima peaks specially associated with coastal earthquakes suggesting the presence of large scale atmospheric disturbances. Increase in SLHF prior to earthquake can be attributed to fluid movement in earth's crust and more interaction between Atmosphere-Ocean-Land (Tronin et al., 2002; Alvan et al., 2013).

Several studies have proved that prior to strong earthquakes, anomalous increase occurs in atmospheric water vapor content (Tronin et al., 2002; Dey and Singh, 2003; Cervone et al., 2004). The Electromagnetic (EM) anomalies have also been observed prior to several strong earthquakes (Fujinawa and Takahashi, 1994; Hayakawa et al., 1996b; Parrot, 2002; Pulinets and Boyarchuk, 2004). Changes in electric and magnetic field occur in epicentral region caused by surface and subsurface deformation prior to occurrence of earthquake (Madden and Mackie, 1996). During micro fracturing phase, venting of gases take place which in turn results in ionization of near ground atmosphere influencing the lower ionosphere (Toutain and Baubron, 1999; Hayakawa et al., 2001; Pilipenko et al., 2001; Omori et al., 2007; Alvan et al., 2013).

Unfortunately, there is still a huge gap of knowledge and applications related to science of earthquake precursors in developing countries (such as Pakistan, India, Nepal etc.) situated at foothills of Hindukush, Karakorum and Himalayas (HKH). HKH region is very prone to earthquake activity. These earthquakes have cost significant damages in terms of lives and economy in HKH region. Prominent examples includes 2015-Gorkha, Nepal (27.83°N, 86.07°E), 2005-Kashmir (34.47°N, 73.57°E E) and 2013-Awaran (26.95°N, 65.50° E) earthquakes.

The Kashmir Mw 7.6 earthquake of 8th October 2005 was the strongest in the region since the 1905 Kangra earthquake with a depth of 26 km. More than 80,000 people lost their lives as a result of this earthquake (Mahmood et al., 2015a, 2015b; Shafique et al., 2016). The Awaran Mw 7.7 earthquake occurred on 24th September 2013 with a depth of 15 km and approximately 800 people lost their lives due to this catastrophic earthquake (Mahmood et al., 2015a).

Reliable knowledge of earthquake precursor(s) for this region may have avoided the atrocities of these earthquakes. Therefore, this study was designed to carry out comprehensive analysis of different atmospheric parameters in order to identify the mechanism of seismic anomalies prior to major Kashmir and Awaran earthquakes using satellite remote sensing and reanalysis datasets. For comparison of data for earthquake year with historical data, mean (μ) and standard deviation (σ) are calculated using the multi-year's 2000–2004 for Kashmir and 2008–2013 for Awaran data on the same day.

2. Study area

Pakistan is one of the most earthquake prone area in Asia and has high density and complex system of active faults. It is located at intersection of three plate boundaries namely Indian, Eurasian and Arabian (Fig. 1). Indian-Eurasia plate's collision has resulted in Himalayan Frontal Arc in the north. Kashmir earthquake with Mw 7.6 occurred in north western part of the Himalayas on 8 Oct, 2005 (Fig. 1). The event occurred along the Bagh-Balakot fault with a maximum vertical displacement of 5 m followed by almost 122 aftershocks until 9th October. The area is characterized by Main Boundary Thrust (MBT) fault which is the main frontal thrust fault of Himalayan belt. A dense sequence of active faults is present in the area (Mahmood et al., 2015a, 2015b). On other hand, Awaran earthquake occurred as a result of strike slip motion along the Hoshab fault which is present on the southern strands of Chaman Fault System (Mahmood et al., 2015a). The earthquake was felt all across the region. The area is characterized by complex sequence of faults due to northward subduction of Arabian Plate beneath Eurasian Plate and also where Indian plate is sliding past Eurasian plate in northward direction. Mw 8.1, 1945 Makran earthquake was the largest event recorded in the area that generated a significant Tsunami. The event ruptured the Makran subduction mega thrust (Mahmood et al., 2015a).

3. Data and methodology

The spatiotemporal analyses were performed on OLR, AT and RH datasets from 2000 to 2005 for Kashmir earthquake, whereas, from 2008 to 2013 for Awaran earthquake. Daily OLR (W/m^2) data was acquired at the spatial resolution of 2.5° ×2.5° from Advanced Very High Resolution Radiometer (AVHRR) sensor onboard National Oceanic and Atmospheric Administration (NOAA) satellite (Liebmann and Smith, 1996). The OLR dataset is observed by NOAA polar-orbiting satellite and derived measurement of the radiative character of energy from the warmer earth surface to cooler space in the 10-12 µm infrared (IR) window.

The AT and RH data were acquired from National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis project at spatial resolution of 2.5° ×2.5°.