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Thermal radiation effects in the atmosphere initiated by pre-earthquake processes

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Abstract

The science community is still looking for pre-earthquake indicators of major seismic events in order to minimize the loss of human life. Recent advances in satellite technology have helped to increase the scientific understanding of the nature of pre-earthquake phenomena in the atmosphere and their relationship with transitional thermal anomalies. It was realized that the thermal heat fluxes over areas of earthquake preparation are a result of air ionization by Rn^{222}, its isotopes and progenies and consequent water vapor condensation on newly formed ions. Latent heat (LH) is released as a result of this process and leads to the formation of local thermal radiation anomalies (TRA) known as outgoing longwave radiation (OLR). We recorded data from the most recent major earthquakes in California (2014) Nepal (2015) that allowed us to summaries TRA's main morphological features. It was also established that the TRA is part of a more complex chain of the short - term earthquake precursors, which are explained within the framework of a Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) model.

1 Introduction

The search for pre-seismic signals has been conducted for many years [8,10,18]. Multiple observations of earthquake precursory signals have previously been reported. Recent analyses of data from multi-instrument space-borne and ground observations have provided evidence for the existence of pre-earthquake atmospheric signals [8,23]. These studies have contributed to our understanding of the physics of earthquakes and the phenomena that precede their energy release. Recent progress in earth observing space technology have also helped to advance the scientific understanding of the nature of pre-earthquake phenomena recorded in the atmosphere. Space-borne sensors on the latest NPOESS (National Polar-orbiting Operational Environmental Satellite System) and NASA EOS (Earth Observing System) provide observations that could determine the presence of lithosphere-atmosphere interaction. Studies on the relationship between satellite thermal infrared (TIR) data and earthquakes have been based on the recording of both single and multi-instruments. AVHRR imagery were used to develop simple analysis methods based on the comparisons of before and after images over the epicenter of an earthquake [3,6,32]. Newer techniques have been proposed, using sub-pixel level co-registration and geo-referenced data from both polar-orbiting and geosynchronous satellites GOES, Meteosat, AVHRR, and Landsat [1,29]. One of the main problems in detecting TIR anomalous signals is defining abnormal and normal TIR fluctuations. To address this problem, an approach was developed using a time series of TIR data over earthquake prone regions. Using pixel-level thermal radiation variance from established base lines, it was possible to identify anomalous TIR signals [2,4,15]. After the launch of the EOS satellites (1999-Terra and 2002-Aqua), a new approach for detecting pre-earthquake anomalies was developed, based on Land Surface Temperature (LST) derived from the 11-micron wavelength data [14]. Cloud overcast has been the primary obscure for the lack of TIR data. All remotes sensing methods based on TIR bands struggled from this gap in observations leading to miss in the revealing any pre-earthquake anomalies because of presence of clouds. The latest progress in the science understanding of TRA anomalies suggests that low clouds formation process naturally been enhanced over the region (land and water) of earthquake preparation as results of additional ionization in ABL (atmospheric boundary layer) triggered by the enhanced gas release (including radon) as was suggested by [22]. In order to work effectively in all type of physical conditions we start utilizing data from NOAA /NPOESS /HIRS and EOS Aqua - AIRS/AMSU sounding retrieval methodology. Such observations permit retrieving the key atmospheric/surface parameters under partially cloudy conditions. This allow to observe Outgoing Longwave Radiation (OLR) at TOA in all-sky condition.

2 Physical nature of TRA

Several processes have been considered as possible contributors to the transient short-lived ‘‘thermal anomalies’’: (a) rising fluids that would lead to the emanation of warm gases [6,26]; (b) rising well water levels and CO_2 spreading laterally and causing a ‘‘local greenhouse’’ effect [25,31]; (c) activating positive-hole pairs during rock deformation [5]; (d) frictional heat around the active fault [28] and; (e) Air ionization from radon and latent heat change due to alteration of air humidity [21,22,24]. The global studies of TRA morphologies started with the development of infrared measurements from Earth observational satellites. Due to advanced techniques of infrared data processing and inter comparison with other types of pre-earthquakes phenomena it was finally possible to develop the most plausible mechanism explaining the appearance of the thermal radiation anomalies before the seismic shock [22]. During interaction of tectonic blocks in the earthquake preparation stage the interaction and restructuring of tectonic faults takes place. Gas migrating in the Earth's crust [14] founds new ways in the restructured and activated fault system, and different gases (CO_2, CH_4, H_2, He, Rn, etc.) discharge in the near surface layer of atmosphere. Rn^{222} during decay emits α-particles with the energy E ~ 5.6 MeV. Every α-particle produces $2\cdot10^5$ electron-ion pairs ionizing the air molecules. The ions immediately enter chemical reactions forming the final composite ions This happens due to high polarization of the water molecules and their affinity for electrons. The high dipole moment of the water molecules prevents the ions from the recombination and their lifetime is at least 40 min [27]. The number of water molecules attached to the ions can be determined from the experiment; they show that the particles grow to the aerosol size nearly 1000 nm. All the water molecules which attach to the ions release latent heat due to changing their phase state from the free molecules to the bonded ones and just this heat is the major source of the TRA. Estimations show that effectiveness of the ionization process (relation of the energy release to the energy spent for the ionization) is if order of 10^8, and this figure explains the meteorological scale of the observed thermal anomalies. For example, before Sumatra December 26, 2004, and March 28, 2005 the estimated latent heat release was $3.1\cdot10^{19}$ J and $8\cdot10^{18}$ J respectively [19] when it is compared with the mechanical energy released during earthquakes themselves. Such thermal fluxes provide the OLR fluxes at the TOA level near 100 W/m^2. The TRA derived from OLR is a result of atmospheric effects described before and not of increased surface temperature [31]. In the cases under clear sky condition, water vapor is a significant factor that has strong absorption and re-emission capabilities could be registered in the long wave part of the infrared emission within the transparency window of the atmosphere 8-12 μm [32]. In the case of cloud cover, because of the general atmospheric circulation, the top of the clouds re-emitting the infrared energy as OLR at TOA. In both cases of sky conditions, the latent heat generated in the atmosphere triggered emission or re-emission (at TOA) of longwave ongoing thermal radiation in a wide range of 8-12-micron spectral window. The existence of pre-earthquake physical conditions is changing the standard OLR patterns by breaking the rapid changes into stationary over the areas of earthquake preparation.

3 TRA Methodology

One of the main parameters used to characterize the Earth's radiation environment is OLR from the Earth [9]. Observations with NPOESS and the EOS Aquia recording of atmospheric environmental parameters have revealed an increase in radiation and a transitional change in 8-12-micron band. OLR has been used in the studies of the cloud/water vapor/ radiative interaction processes, climate variability, and for climate change monitoring and was identified as one of the "Essential Climate Variables" in WMO Global Climate Observing System (GCOS). The OLR, measured at the TOA, has been associated with integration of emissions from the ground, lower atmosphere, and clouds [13]. This was used primarily to study Earth's radiative budget and for climate studies [7,12]. Daily OLR data have been used to study its variability in the zone of earthquake activity [10,15,33]. An increase in radiation and a transient change in OLR were proposed as being related to thermodynamic processes in the atmosphere over seismically active regions, and were described as thermal radiation anomalies (TRA). The characteristic of TRA was suggested by [15] as a statistical maximum change in the rate of OLR for a specific spatial location and predefined time and was constructed corresponding to the anomalous thermal field [29,30]. This radiative flux, measured at TOA, through a unit area that is associated to the specific intensity by integrating over wavenumbers (ν) and over hemispheric solid angles (θ and ϕ) is defined as:

$$OLR = \int_0^{2\pi} \int_0^{\frac{\pi}{2}} \int_0^{\infty} I_\nu^{\uparrow}(z_t; \theta, \phi) \cos\theta \, d\nu \, \sin\theta \, d\theta \, d\phi \qquad (1)$$

TRA index was constructed as a statically estimated variability in OLR for specific locations and time periods:

$$TRA_{x,y,t}\ index = \sum_{i=1}^{X}\sum_{j=1}^{Y}\sum_{t=1}^{T} \frac{\alpha_{i,j,t} * (OLR^{*}_{i,j,t} - \overline{OLR}_{i,j,t})}{\delta_{i,j,t} * \tau_{i,j,t}} \qquad (2)$$

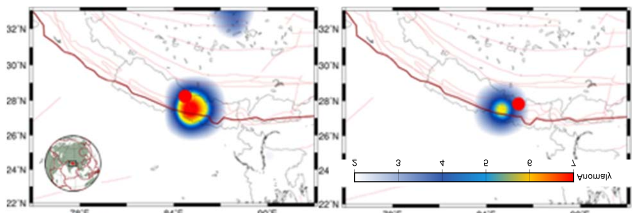
Where: x=1,X –longitude, y=1,Y, latitude, t=-1-T – time (days), 〚OLR〛 _(i,j,t)^*is the current OLR and (OLR)¯_(i,j,t) is the computed mean of the OLR field, defined for multiple years of observations over the same location and same local time, τ_(i,j,t) is the standard deviation. ETA is regional and time dependable where α_(i,j,t) – Regional weight and δ_(i,j,t) -Temporal weight are computed from the historical assessment in specific region. ETA index is regional and time dependable defined by the regional calibration coefficients α_(i,j,t) and δ_(i,j,t), predominantly connected with the regional seismo-tectonic patterns, historical earthquake events (M>6) in the area and with the coverage and quality of the thermal satellite data over the region (Ouzounov et al, 2007).

Name	Date mm/dd/yyyy)	Geographic lat/lon (°)	Time (UTC)	M	*H* (km)
Napa Valley, U.S.	08/24/2014	38.21 N/122.31 W	10:24:44	6.0	11.11
Gorkha, Nepal	04/24/2015	28.23 N/84.73 E	06:11:25	7.8	8.2
Kodari, Nepal	05/12/2015	27.80 N/86.06 E	07:05:19	7.3	15.0

Table 1. List of earthquakes (USGS) studied

4 Results

In our studies, we used OLR data from EOS Aqua/AIRS and from NCEP/NOAA's Advance Radiation Radiometer (AVHRR). A daily mean global data base, with a spatial resolution of 1° by 1°, was used to map the OLR activity and variability in the regions of three recent major earthquakes: M6.0 on August 24, 2014 in Napa Valley, CA and M7.8 and 7.3 on April 24 and May 12, 2015 in Nepal (Table 1). Daily mean OLR values were calculated from these raw data, using separate algorithms for each satellite. The transitional OLR anomalous data usually varied between 15-19 W/m^2. They are residuals derived from the daily mean OLR compared with the background field. The latter was derived from multiple years of observations, over the same location and local time, and normalized by the standard deviation [15,16]. From August 2-4 preceding the Napa Valley earthquake, a large anomalous OLR transient field at the TOA over Northern California was detected. This anomalous signal then shifted to the northeast. It was the largest OLR transition anomaly over the U.S. at the time [19]. The 2015 Nepal earthquake results revealed that, in mid-March 2015, a rapid increase of transient infrared radiation was observed in the satellite data. An anomaly can be observed near the epicenter; it reached a maximum on April 21-22, three days before the M7.8 (Figs. 1 and 2). Further analysis revealed another OLR transient anomaly on May 3-4 (8 days in advance), which was apparently associated with the M7.3 earthquake of May 12, 2015 [17]. Our results show that longwave radiation signals related to earthquake processes were observed by both NOAA/ AVHRR and Aqua/AIRS satellites as OLR hotspots, near the epicentral areas several days before the corresponding earthquakes (Figs.1 and 2). The OLR hot spots appeared quickly, stayed over the same regions for several hours, and then disappeared rapidly. The time lag for the M6.0 earthquake in California was 20 days; for the Nepal events, the time lags were 2-8 days. This enhancement of OLR could be explained as a result of water vapor condensation on ions, with a large amount of latent heat being released. The initial process involves an ionization of the near-ground layer due to an increased concentration of gasses (including radon) emitted from active tectonic faults [22]. The transient nature in radiative emission preceding large earthquakes follows a general temporal-spatial evolution pattern, which has been seen in other large earthquakes worldwide [8,30,20].



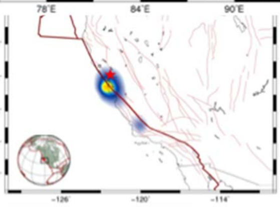


Figure 1. Satellite maps of OLR observed days before the earthquakes listed in Table 1. (Left) Nepal, April 21-22, 2015, (-2 days) (right)) Nepal, May 3-4, 2015,(-8 days); (bottom) California, August 1-3, 2014,(-21 days).

5 TRA as a part of the LAIC chain

The processes involved in the TRA generation initiate the chain of the other effects in the atmosphere reaching the altitude of the upper atmosphere and ionosphere. Large amounts of heavy ion clusters, which replace the light ions, within the area of earthquake preparation drastically change the air column conductivity and hence the parameters of the Global Electric Circuit (GEC) responsible for electromagnetic coupling between the ground and ionosphere. It creates the local anomalies of electron concentration, electron and ion temperature within the ionosphere which can be recorded by ground based and satellite techniques [22]. The cross-correlation of TRA and ionospheric anomalies is the most powerful tool for the identification of short-term earthquake precursors. Other effect which accompany the formation of TRA is the creation of conditions for the formation of linear clouds do to the transport of condensation nuclei (ion clusters of aerosol size) to the altitudes of the cloud formation.

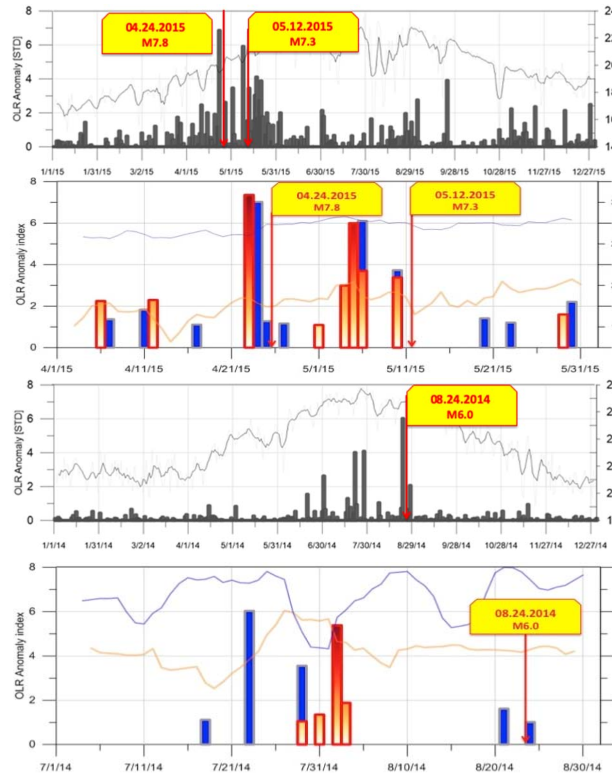


Figure 2. Time series of daily nighttime anomalous OLR for one-year NOAA/AVHRR (1 and 3, with black) and two months (2 and 4) over the epicentral regions (box 1^{o}x1^o) observed from NOAA/AVHRR (red) and AQUA/AIRS (blue) for the three earthquakes listed in Table 1

6 Conclusions

We have illustrated the possible link of transient thermal fields on the ground with pre-earthquake processes by using retrospectively/prospectively the transient variations of the OLR parameter in the atmosphere during the time of the 2014 M6 earthquake in California and 2015 M7.8 and M7.3 events in Nepal. From space-born observations of the atmospheric conditions, we have shown that there is a consistent occurrence of radiative emission (OLR) anomalies at the TOA, over the region of maximum stress associated with, and preceding, large earthquakes. Because of their relatively long duration, these anomalies do not appear to be of meteorological origins. Our analysis of atmospheric parameters for recent major earthquakes has demonstrated the presence of correlated variations of transient OLR anomalies in the atmosphere, implying their connection with pre-earthquake processes. Our results suggest the existence of a thermal radiation response in atmosphere triggered by the coupling processes between the lithosphere and atmosphere.

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