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Multi-sensor observations of atmospheric transient signals associated with large earthquakes

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[**Subject/statement of problem**] The most recent catastrophic earthquakes (2004 Sumatra, 2008 China, 2011 Japan, and 2015 Nepal) claimed thousands of lives and caused extensive economic losses. Five years after the 2011 Tohoku, Japan Great Earthquake (M9.0), the international science community is still seeking solutions for the early detection of major seismic events that would minimize the loss of life.

[**Background**]The search for pre-seismic signals has been conducted for many years (*e.g.*, Martinelli, 1998). 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 (Hayakawa, 2012; Tramutoli *et al*., 2015). These studies have contributed to our understanding of the physics of earthquakes and the phenomena that precede their energy release. Recent advances in earth observing space technology have also helped to advance the scientific understanding of the nature of pre-earthquake phenomena 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 if there is a lithosphere-atmosphere interaction.

[**Objective(s)**].We are searching for pre-seismic observations that might give warning of a major earthquake. Our investigation is based on a possible connection between satellite observations of anomalous atmospheric thermal transient signals and subsequent major earthquakes.

[**Previous work**]Studies on the relationship between satellite thermal infrared (TIR) data and earthquake have been based on both single and multi-instruments. Gorny et al. (1988), Tronin et al. (2002), and Dey et al. (2004) have used imagery recorded by AVHRR, to develop simple analysis methods based on comparisons of before and after images over the epicenter of an earthquake. 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 (Tramutoli et al., 2001, Bryant et al., 2003).

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 (Filizzola et al., 2004, Cervone et al., 2006, Ouzounov et al.,

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2007). 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 (Ouzounov and Freund, 2004). Observations with NPOESS and the EOS Aqua's Atmospheric Infrared Sounder (AIRS) of atmospheric environmental parameters have revealed an increase in radiation and a transitional change in Outgoing Longwave Radiation (OLR) in the 8-12 micron range (Ouzounov et al., 2007). OLR transitional changes recorded at the TOA (top of the atmosphere) over seismically active regions have been proposed as being related to thermodynamic processes within the earth's crust that lead to earthquakes (Ouzounov et al., 2011; Pulinets and Ouzounov, 2011).

[**Methods**]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). OLR, calculated at the TOA, was used to study the Earth's radiation budget, because it represents emissions from the Earth's surface, lower atmosphere, and clouds, and is sensitive to near surface and cloud temperatures. Daily mean OLR values were calculated from these raw data, using separate algorithms for each satellite. Observations of the NOAA AVHRR/OLR were based on the long-wave flux estimation proposed by Gruber and Krueger (1984). Observations of the NASA Aqua/AIRS OLR were based on the multispectral long-wave estimates from Mehta and Susskind (1999) and Susskind and Blaisdell (2008).

[**Results**]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 (Ouzounov et al, 2007, 2011). 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 (Ouzounov et al, 2014). 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 (Ouzounov et al., 2015).

Our results show that infrared 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 (Pulinets and Ouzounov, 2011). 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 (Hayakawa et al., 2012, Tramutoli et al., 2015 and Ouzounov et al., 2016).

[Conclusion(s)] From space-born observations of atmospheric conditions, we have shown that 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 an atmospheric response triggered by the coupling processes between the lithosphere and atmosphere.

Tabel 1. List of earthquakes (USGS) studied.

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

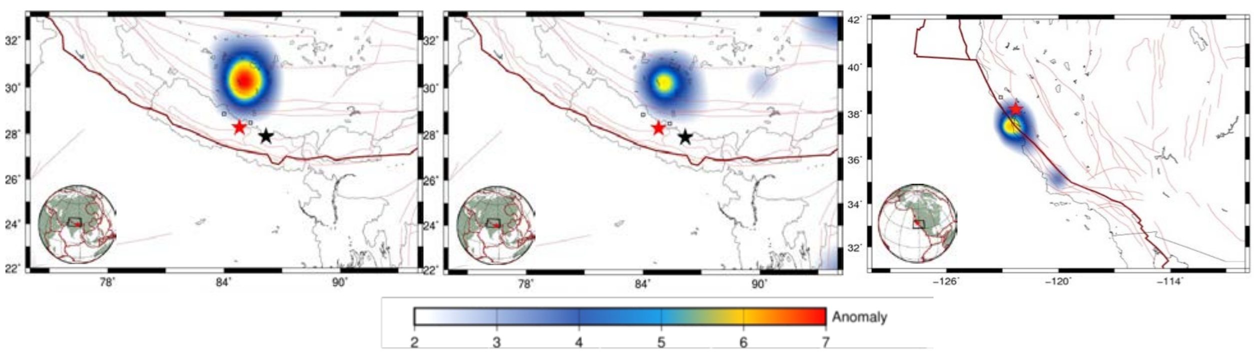
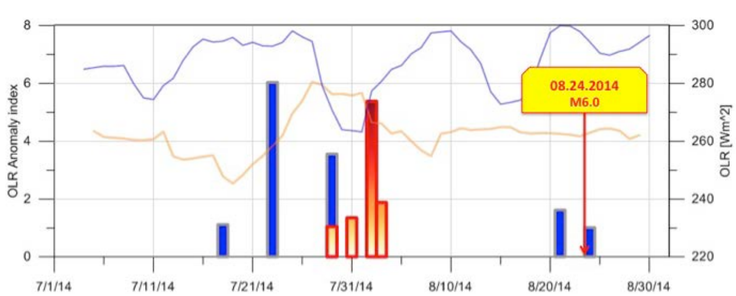


Figure 1. Pre-earthquake satellite maps of OLR observed a few days before the earthquakes listed in Table 1. (Left) Nepal, April 21-22, 2015, 00 UTC (-2 days); (Middle) Nepal, May 3-4, 2015, 00 UTC (-8 days); (Right) California, August 1-3, 2014, 00 UTC (-21 days).



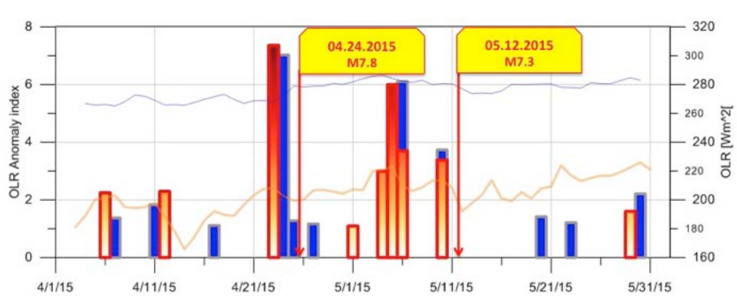


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Figure 2. Time series of daily nighttime anomalous OLR for two months over the epicentral regions (box $1^{o}x1^{o}$) observed from NOAA/AVHRR (red) and AQUA/AIRS (blue) for the three earthquakes listed in Table 1.

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