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Variability of lightning flash and thunderstorm over East/Southeast Asia on the ENSO time scales

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ABSTRACT

The variability of lightning flash and thunderstorm on the ENSO time scales over East/Southeast Asia was investigated by using 17-year (1995–2011) lightning data from the Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS), and 14-year (1998–2011) Tropical Rainfall Measuring Mission satellite (TRMM) precipitation feature data. In addition, ERA-Interim reanalysis data of the European Centre for Medium-Range Weather Forecasts (ECMWF) were used to present related environmental characteristics. It was found that the response of lightning flash to ENSO events shows remarkable seasonal and regional variations. The regions of positive (negative) lightning anomaly are mainly located at both sides of 5°–20°N (5°–15°N) in El Niño (La Niña) spring and winter, and located north of the equator in summer and autumn. There is a significantly positive correlation between lightning anomaly and the Oceanic Niño Index (ONI) over both East China and Indonesia during El Niño episodes, but no obvious correlation during La Niña episodes. The positive thunderstorm anomalies during El Niño periods are dispersed. The distribution of thunderstorm anomalies in La Niña summer and autumn is almost opposite to that in spring and winter. The correlation between thunderstorm anomaly and ONI is better over East China than that over Indonesia. In general, lightning variation follows thunderstorm intensity (number) variation over East China during El Niño (La Niña) episodes, and follows a combination of thunderstorm intensity and number variations over Indonesia on ENSO time scales. During ENSO time scales, variations of surface wind can be considered as one of the key factors to LAs. More lightning flashes present in the regions where warm moist flows intersection, and less in the regions where surface wind changes slightly or diverges. Dramatic lightning increases also occur with higher values of convective available potential energy (CAPE). In addition, higher (lower) 850 hPa relative humidity generally follows with more (less) lightning flashes, which is more obvious during El Niño episodes.

1. Introduction

The El Niño Southern Oscillation (ENSO), one of the typical interannual planetary phenomena of the tropical Pacific air–sea system, can not only affect global and regional weather and climate (Holton and Dmowska, 1989; McBride et al., 2003; Maes et al., 2006) but can also result in atmospheric circulation anomalies (Rasmusson and Carpenter, 1983; Goodman et al., 2000). Abnormal atmospheric circulations can result in a change of frequency, intensity and location of convective storms (Williams, 1992, 2005). Since lightning flashes are a good indicator of storm intensity (Baker et al., 1995), the response of lightning activity to ENSO events has received increasing interest with the increase of various lightning data (e.g. ground-based, space-based lightning observation and Schumann resonances) in recent years.

The El Niño in 1997–1998 was one of the strongest events of the 20th century which influenced many parts of the world, so the characteristics of lightning activity in different regions during this period have been an interesting topic. Using lightning data from Lightning Imaging Sensor (LIS) onboard the Tropical Rainfall Measuring Mission satellite (TRMM) and National Lightning Detection Network (NLDN), the pioneering work by Goodman et al. (2000) showed that wintertime lightning flashes, lightning days and lightning hours increased over 100%–200% over the northern Gulf of Mexico Basin during the 1997–1998 El Niño event. Hamid et al. (2001) analyzed 18 months (December 1997–May 1999) of lightning data from LIS and precipitation data from TRMM Precipitation Radar (PR), and reported an increase of lightning activity over the Indonesian islands during the El Niño event in March 1998. Based on the Optical Transient Detector (OTD) and LIS data from 1995 to 2003, Ma et al. (2005) also indicated that lightning flash significantly increased over southeastern China and the Indochina Peninsula from the spring of 1997 to the spring of 1998, especially greater than 400% in winter. Some researches (Williams et al., 2000; Boccippio et al., 2000) revealed that both lightning activity on the diurnal/annual scales and the large lightning contrast between land and ocean are dominated by the number of thunderstorms; however, more lightning flashes could also be associated with deeper clouds and larger updrafts in episodic deep convection (Williams and Renno,

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1993). Kent et al. (1995) found that more cirrus appeared at many places throughout the tropics during El Niño episodes, and the cirrus detrainment can be connected with larger vertical development. Hamid et al. (2001) found that a decrease of convection and an increase of lightning activity occurred over Indonesian islands during the El Niño event in March 1998, and suggested that more intense convection, stronger vertical development and thicker ice phase precipitation zones occur during El Niño episodes, so the intensification of convective storms is one of the main reasons for the increase of lightning activity in this region.

The characteristics of lightning variation during multiple ENSO events have been investigated. LaJoie and Laing (2008) and Laing et al. (2008) analyzed the NLDN Cloud-to-Ground (CG) lightning data in the Gulf of Mexico during 1995–2002 and showed a local lightning flash increase (decrease) during El Niño (La Niña). Kumar and Kamra (2012) also found a similar characteristic of lightning variation over South/Southeast Asia from the LIS/OTD data, and lightning variation is more sensitive to convection variation than precipitation variation on seasonal time scales. By using LIS/OTD data from 1998 to 2003, Yoshida et al. (2007) examined the lightning activity over East/Southeast Asia and the Maritime Continent presented an inverse correlationship between flash rate and Southern Oscillation Index (SOI) and a remarkable distribution contrast of the lightning over the northwest Pacific Ocean between El Niño and La Niña, and suggested that the lightning activity increase is mainly caused by convection intensification. Similar to the results of Hamid et al. (2001), Yoshida et al. (2007) also found a relationship between convection variation and baroclinicity over Indonesian islands during El Niño episodes.

Using the Schumann resonances data at Nagycenk during 1993–2005 as well as LIS/OTD lightning data, Sátori et al. (2009) showed a 10% global variability of lightning frequency from La Niña to El Niño, and further suggested that lightning increases over land and decreases over the Pacific Ocean during El Niño episodes. Besides the variation of lightning frequency, a southeastward (northwestward) move of the global lightning activity center during El Niño (La Niña) has been identified (Yang and Pasko, 2007; Sátori et al., 2009). The study of Chronis et al. (2008) showed that the global correlation map of lightning anomaly and NINO3.4 index (i.e. sea surface temperature spatial averages of the region bounded by 5°N to 5°S, from 170°W to 120°W) is similar to that of precipitation anomaly and NINO3.4 index based on the LIS/OTD lightning data and the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) data during 1998–2006, except for the middle latitudes and the western Maritime Continent.

Although convection and lightning appear to be sensitive responses to ENSO events (Hamid et al., 2001; Ma et al., 2005; Kumar and Kamra, 2012) and as unique characteristics (Chronis et al., 2008) over East/Southeast Asia on the ENSO time scales, a limited number of ENSO events were involved in the previous studies. In this paper, we investigate the responses of lightning flashes and thunderstorms to ENSO events on seasonal time scales over East/Southeast Asia (15°S–35°N, 90°–130°E) by using 16-year (1995–2011) LIS/OTD lightning data and 14-year (1998–2011) TRMM Radar Precipitation Feature (RPF) products. Furthermore, the correlations between lightning/thunderstorm and Oceanic Niño Index (ONI) are analyzed in East China (18°–32°N, 102°–125°E) and Indonesia (11°S–6°N, 95°–125°E), where significant lightning anomalies are found during ENSO cycles (Hamid et al., 2001; Ma et al., 2005). In addition, ECMWF ERA-Interim reanalysis data are used to present related environmental characteristics.

2. Data and methodology

2.1. LIS/OTD lightning data

The lightning data is from the low-resolution time monthly series (LRTMS) product with a resolution of 2.5° × 2.5°, which is one of the gridded lightning climatological data sets (Cecil et al., 2014) from the Global Hydrology Resource Center (GHRC). The lightning data of LRTMS are from OTD (1995/05–2000/03) and LIS (1997/12–2011/11), and the period in this study is from 1995/09–2011/11. Both OTD and LIS are onboard satellites in low earth orbit, and can continuously detect intra-cloud (IC) and cloud to ground (CG) lightning during both day and night. OTD is a payload on the MicroLab-1 satellite, which was launched into a 70° inclination orbit in April 1995 and retired in March 2000, and any region between 75°S and 75°N on the Earth is observed by OTD more than 400 times during each year (Christian et al., 2003). The field of view (FOV) of OTD is 1300 km × 1300 km, the observation duration for an isolated thunderstorm is approximately 4 min, and its detection efficiency is 44%–56%. LIS is a payload of TRMM, which was launched in November 1997, and its detection efficiency is 69%–88%. Since The TRMM satellite orbit inclination is 35°, LIS can detect lightning activity between 36°S and 36°N. When any storm passes through LIS's FOV (600 km × 600 km), LIS can monitor lightning flashes for approximately 90 s.

To yield LRTMS product, the flash counts from OTD and LIS are scaled by the best available estimates of detection efficiency. Because the data from OTD and LIS included spatial (7.5°) and temporal (3 month) smoothing processes, LRTMS has a complete global lightning coverage (Boccippio et al., 2000; Goodman et al., 2007), and is recommended for time series analysis in middle and lower latitudes (Cecil et al., 2014).

2.2. TRMM precipitation feature data

The 14-year (1998–2011) radar precipitation features (RPF) product of the TRMM cloud and precipitation feature database (version 7) (Nesbitt et al., 2000; Liu et al., 2008) from the University of Utah is used to identify thunderstorms. A RPF is defined by grouping pixels with TRMM PR 2A25 near surface rain greater than 0 mm/h (Liu et al., 2008). To produce RPF product, at first, the parallax correct for TRMM Microwave Imager (TMI) is carried out in order to get better location correspondences between PR and TMI observations, then the data from TMI, LIS and visible and infrared sensors (VIRS) are assigned to PR pixels by using the nearest-neighbour method.

In this paper, a RPF with flash number greater than 0 is defined as a thunderstorm, and only the precipitation features with a minimal area of 75 km^2 are utilized to remove the effect of very small precipitation features. The thunderstorm data obtained are further counted on a 2.5° × 2.5° grid. Because TRMM is a polar-orbiting satellite with an inclination of 35°, the view time of PR at a given location depends upon its latitude, and there are more view times in the mid-latitudes. The method of Wu et al. (2013) is selected to eliminate the effect of latitude on the thunderstorm number on each grid, and the formula is as follows:

$$N_{i,j} = \frac{n_{i,j}}{A_{i,j}} \cdot \text{ave}_j \tag{1}$$

where N is the corrected thunderstorm number, n is the original thunderstorm number, A is the total pixel number as given in TRMM 3A25 product, ave is the average pixel number during the corresponding period, i represents the grid sequence and j represents the time.

2.3. ERA-Interim meteorological data

As a factor that affects the convergence of moisture and the development of convection, surface wind is closely related to thunderstorm activity, especially over coastal regions (Smith et al., 2005; Steiger et al., 2002). Besides, humidity and convective available potential energy (CAPE) are also key parameters in generating thunderstorms, which can influence the dynamical structure and the potential force of convection. Meteorological parameter data used in this study consist of monthly 10-m U wind and V wind components, 850 hPa relative humidity and CAPE from the European Centre for Medium-Range