Variability of lightning flash and thunderstorm over eastern China and Indonesia on ENSO time scales

Tie Yuan, Yuelun Di

College of atmosphere, Lanzhou University, 222 Southern Tianshui Road, Lanzou, Gansu, 730000

ABSTRACT: The variability of lightning flashes and thunderstorms over eastern China and Indonesia on ENSO time scales was investigated during the period of 1998-2011 based on the flash data from OTD (Optical Transient Detector) and LIS (Lightning Imaging Sensor) and the precipitation data onboard the Tropical Rainfall Measuring Mission satellite (TRMM). It is found that a significant increase (decrease) of lightning activity appears over both of regions in spring and winter during ENSO warm (cold) episodes, which is similar to the previous studies, but an increase of lightning activity can be seen over both of regions in summer and autumn during ENSO cold episodes, and a decrease of lightning activity in summer appears over the northern part of east China during ENSO warm episodes. In spring and winter, lightning flashes generally increase with the intensification of ENSO warm episodes, which is more significant over east China than over Indonesia. During ENSO warm episodes, the decrease of thunderstorms over east China suggests that the increase of lightning flashes results from the increase of the intensity of thunderstorms, but the increase of thunderstorms over Indonesia implies that the increase of lightning flashes results from the increase of thunderstorm frequency. During ENSO cold episode, the number of thunderstorms decreases over both of regions, and the decrease of lightning flash over eastern China mainly results from the decrease of thunderstorm frequency, and the variation of lightning in Indonesia is affected by both of frequency and intensity of thunderstorms.

INTRODUCTION

The El Niño Southern Oscillation (ENSO) is well known as one of the strongest signal of inter-annual climate variation of the ocean-atmosphere system in tropical Pacific, which can influence not only global and regional weather and climate change, but also atmospheric circulation anomaly and the frequency, intensity and position of convective storms. As an accompanying production of convections, lightning activity in turn can be affected by ENSO on global and regional scales.

Though many studies have examined ENSO-related precipitation and atmospheric circulation anomalies (Curtis and Adler, 2003; Wang, 2005), there are limited studies about the ENSO effect on lightning activity. During 1997-98 ENSO warm event, more lightning flashes were observed in some regions, such as the southerneast United States (Goodman et al., 2000), southeast China and Indochina (Ma et al. 2004; Hamid et al. 2001). In addition, the studies including more ENSO events suggested the same phenomenon, which is that there are more flashes during warm ENSO phases and few flashes during cold ENSO phases (Mark and Arlene 2008; Yoshida et al., 2007; Kumar and Kamra, 2012).

The eastern China and Indonesia are two unique regions where lightning activity has significant

∗ Contact information: Tie Yuan, Lanzhou University, Lanzhou, Gansu, China, Email: tyuan@lzu.edu.cn

anomalies during ENSO episodes (Ma et al., 2004; Hamid et al., 2001), but only lightning activity in few ENSO events have been examined. In this paper, we investigate the effect of ENSO episodes on lightning flashes and thunderstorms over the eastern China (18-32°N, 102-125°E) and Indonesia (11-6°N, 95-125°E) through more ENSO events based on 16-year gridded flash data of Optical Transient Detector (OTD) and Lightning Imaging Sensor (LIS).

DATA AND METHODOLOGY

The low resolution (2.5°×2.5°) monthly time series (LRMTS) of flash rate from the Global Hydrology Resource Center (GHRC) for 16 years (1995.5-2011.11) were used to discover the variation of lightning flashes during ENSO episodes. LRMTS is one of GHRC gridded climatology products of total lightning flash rates observed by the OTD and LIS (Cecil, et al., 2012).

To examine the variation of thunderstorms during ENSO episodes, we used the data of Radar Precipitation Features (RPFs) during the period of 1998.1-2011.11 from the Tropical Rainfall Measuring Mission (TRMM) precipitation feature database of the University of Utah (Liu et al., 2008). RPFs are defined by grouping continuous TRMM Precipitation Radar (PR) near-surface rainfall > 0. Here, RPFs have at least 75 km^2, and thunderstorms are defined as the RPFs with lightning detected by LIS, otherwise non thunderstorms as the RPFs without lightning.

The Oceanic Niño Index (ONI) was used to identify ENSO warm and cold episodes, which is a 3-month running mean of SST anomalies in the Niño 3.4 region (5°N-5°S, 120°-170°W). Warm and cold episodes based on a threshold of +/- 0.5 °C for the ONI. From 1995 to 2011, there are 5 warm events and cold events (see Figure 1).

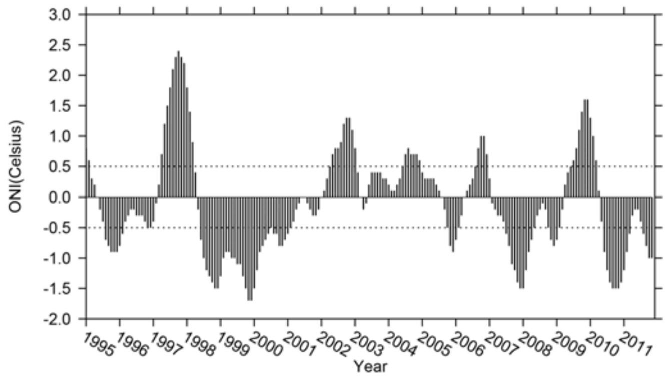

Fig. 1 The monthly Oceanic Niño Index during the period of 1995-2011

RESULT

1. The variability of lightning activity during ENSO warm and cold episodes

Figure 2 shows the spatial distributions of seasonal flash rate anomaly (departures from the seasonal average during normal episodes) during ENSO warm episodes. It can be seen that there are positive anomaly areas over eastern China and Indonesia in four seasons during ENSO warm episodes, even though the magnitudes and locations of the areas undergo some changes. There is a strongest and biggest area over eastern China in spring with the magnitude greater than 0.4 flashes km^{-2} $month^{-1}$, a smallest (weakest) anomaly area in summer (autumn), an anomaly area with the eastward movement can be seen in winter. Compares with those over eastern China, the anomaly areas over Indonesia are generally stronger and bigger. The anomaly areas over Indonesia appear shifted south in spring and winter compared with that in summer and autumn, and the anomaly areas are stronger in spring and autumn than that in summer and winter, which can reach greater than 0.4 flashes km^{-2} month^{-1}, the weakest anomaly area occurs in winter. The results here are consistent with that of Ma et al. (2004) and Yoshida et al. (2007).

The spatial distributions of seasonal flash rate anomaly during ENSO cold episodes are shown in Figure 3. It can be seen that there are apparent negative anomaly areas over eastern China and Indonesia in spring and winter, but both of negative and positive anomaly areas appear in summer and autumn. The strongest and biggest negative anomaly area occurs in eastern China in spring, where the magnitude reaches 0.6 flashes km^{-2} month^{-1}. There are two negative anomaly areas (the stronger one is located at the west, the weaker one at the east) over Indonesia in spring and winter. In addition, a bigger positive anomaly area appears in summer, both negative and positive anomaly areas appear in autumn. All the positive anomaly areas during cold episodes are weaker than that during warm episodes.

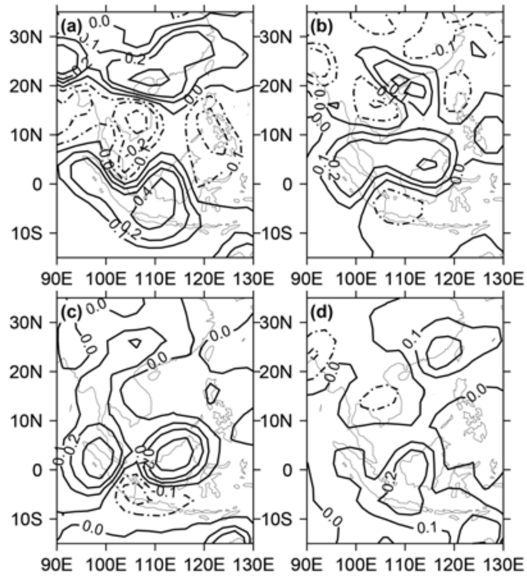

Fig. 2 The seasonal distributions of flash anomaly during ENSO warm episodes. Unit: Flashes km^{-2} month^{-1}. (a) spring. (b) summer. (c) autumn. (d) winter.

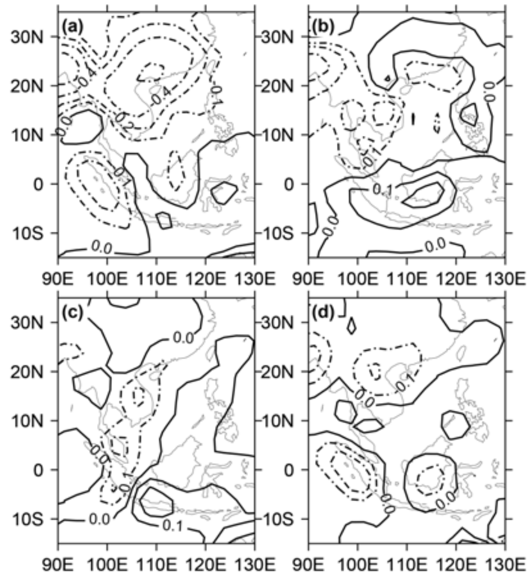

Fig. 3 Same as in Fig. 2, but during ENSO cold episodes

2. The variability of thunderstorm activity during ENSO warm and cold episodes

Figure 4 shows the spatial distributions of seasonal thunderstorm anomaly during ENSO warm episodes. It can be seen that positive anomaly areas spread over eastern China in spring, summer and autumn, with the strongest one in spring, but the centers of these areas are not same to that of lightning anomaly areas. In winter, a larger negative anomaly area occurs over eastern China, in contrast to the positive lightning anomaly area. In general, the locations of positive thunderstorm anomaly areas are consistent with that of lightning in spring in Indonesia, autumn and winter, but in summer there is a larger area with negative thunderstorm anomaly, and only a small area with positive thunderstorm anomaly, in contrast to the larger area with positive lightning anomaly.

In figure 5, the spatial distributions of seasonal thunderstorm anomaly during ENSO cold episodes are presented. It can be seen that there are similar patterns between thunderstorm and lightning anomaly in eastern China, but the locations of the anomaly centers are not same for thunderstorm and lightning, which is similar to ENSO warm episodes. Especially, a big and strong positive thunderstorm anomaly area appears over eastern China in summer, but there is a small negative lightning anomaly area here except for a positive one. In Indonesia, consistent patterns between thunderstorms and lightning anomaly can be seen in all seasons. The results suggest that the variation of lighting activity mainly results from the variation of thunderstorms in Indonesia, but the situation appear to be more complex in eastern China.

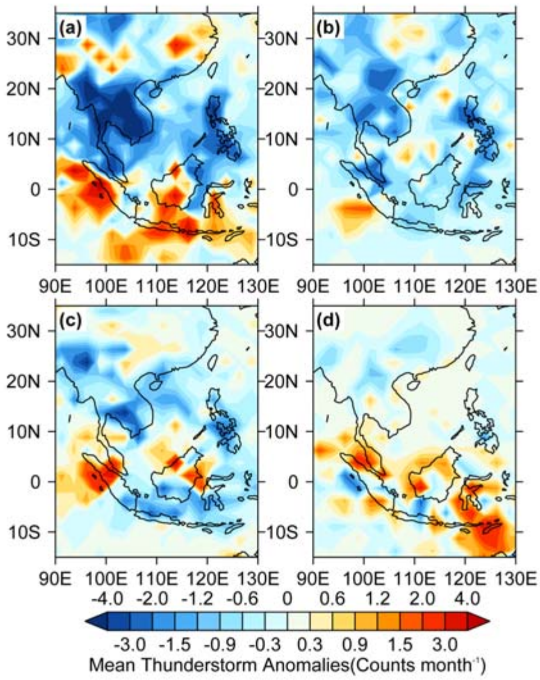

Fig. 4 Same as in Fig. 2, but for thunderstorms during ENSO warm episodes.

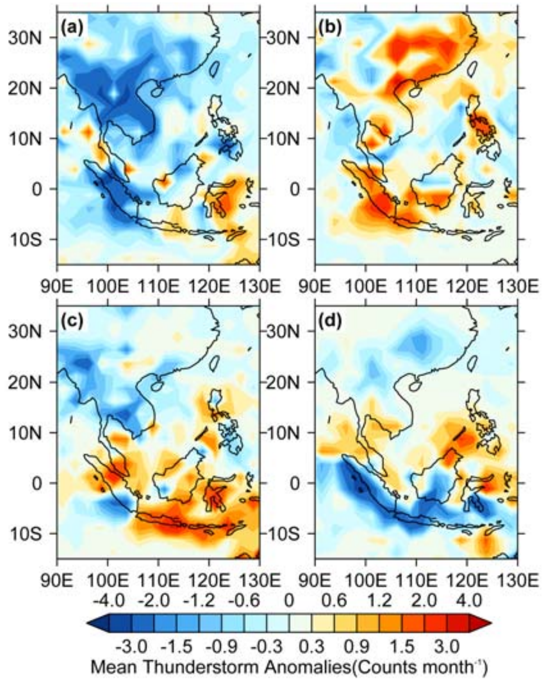

Fig. 5 Same as in Fig. 2, but for thunderstorms during ENSO cold episodes.

3. The variations of lightning and thunderstorms during individual ENSO episode

Because of the significant anomalies in spring and winter, the variations of lightning and thunderstorms over eastern China and Indonesia in spring and winter during individual ENSO episode are further investigated. Table 1 and 2 show the variations of lightning and thunderstorm to normal over eastern China and Indonesia in spring and winter during ENSO warm episodes, respectively. In general, lightning activity increases with the ONI in spring and winter during ENSO warm episodes, but in spring 2010 and winter 2004, the lightning over eastern China dramatically decreased, which may be affected by other factors. On the other hand, the thunderstorms over east China decrease with the ONI, which means that the increase of lightning over eastern China in spring and winter during ENSO warm episodes mainly results from the intensification of thunderstorm, even though few thunderstorms occur. In Indonesia, the increase of lightning generally accompanies the increase of thunderstorms, which suggests that the increase of lightning mainly result from the increase of thunderstorm frequency.

Table 1. The variation of lightning and thunderstorm to normal over eastern China (ECN) and Indonesia (IDN) during ENSO warm spring. Boldfaces indicate significant at 95%

Year	ONI(℃)	Lightning		Thunderstorm	
		ECN	IDN	ECN	IDN
1998	1.15	**32%**	**40%**	-16%	**11%**
2010	0.80	**-29%**	**5.4%**	**-38%**	**24%**

Table 2. Same as in Table 1, but for ENSO warm winter.

Year	ONI (℃)	Lightning		Thunderstorm	
		ECN	IDN	ECN	IDN
2009	1.50	28%	**18%**	-28%	8.8%
2002	1.06	31%	**17%**	-1.5%	**16%**
2006	0.85	1.1%	**14%**	-89%	**26%**
2004	0.65	-48%	**21%**	**-95%**	11%

The variations of lightning and thunderstorm to normal over eastern China and Indonesia in spring and winter during ENSO cold episodes are presented in Table 3 and Table 4. It can be seen that lightning activity significantly decreases over eastern China in spring and winter during ENSO cold episodes except for winter 2008, but there are a little more flashes during stronger ENSO cold episodes (the ONI≤0.95) and a little less flashes during weaker ENSO cold episodes (the ONI>0.95) in Indonesia, which is because that positive and negative anomaly areas simultaneously appear at this time (Figure 3). In contrast, the significant decrease of thunderstorms is found over two regions during all the ENSO cold episodes except for winter 2010 in Indonesia, more decrease appears in eastern China than that in Indonesia. The disproportionate variations between lightning and thunderstorms suggest that some thunderstorms became stronger in two regions during the periods, and the decrease of lightning in eastern China mainly comes from the decrease of thunderstorm frequency, the variation of lightning in Indonesia is affected by both of frequency and intensity of thunderstorms.

Table 3. Same as in Table 1, but for ENSO cold spring.

Year	ONI (℃)	Lightning		Thunderstorm	
		ECN	IDN	ECN	IDN
2000	-0.96	**-36%**	4.4%	**-40%**	**-18%**
1999	-0.93	**-37%**	-0.1%	**-43%**	**-18%**
2008	-0.93	-17%	**-9.1%**	-9.8%	**-12%**
2011	-0.75	**-51%**	-4.2%	**-80%**	-1.2%

Table 4. Same as in Table 1, but for ENSO cold winter.

Year	ONI (℃)	Lightning		Thunderstorm	
		ECN	IDN	ECN	IDN
1999	-1.63	-37%	-0.4%	-88%	**-27%**
2007	-1.46	-31%	2.9%	-91%	-1.2%
1998	-1.43	**-46%**	9.6%	-93%	**-19%**
2010	-1.36	**-69%**	**15%**	**-98%**	4.0%
2005	-0.80	-16%	-5.0%	-75%	-7.7%
2008	-0.73	38%	**-15%**	-44%	**-18%**
2000	-0.70	-19%	-6.4%	-66%	**-32%**

CONCLUSIONS

The variability of lightning and thunderstorms over Eastern and Indonesia on ENSO time scales was investigated based on the OTD/LIS data and TRMM precipitation feature data. The result shows that a significant increase (decrease) of lightning activity appears over two regions in spring and winter during ENSO warm (cold) episode, but an increase of lightning activity can be seen over both of regions in summer and autumn during ENSO cold episode, and a decrease of lightning activity in summer appears over the northern part of east China during ENSO warm episode. There are similar patterns between thunderstorm and lightning anomaly, but the locations of the anomaly centers of lightning are not same to that of thunderstorms. In spring and winter, lightning flashes generally increase with the intensification of ENSO warm episodes, which is more significant over east China than that over Indonesia. During ENSO warm episode, the decrease of thunderstorms over east China suggests that the increase of lightning flashes results from the intensification of thunderstorm, but the increase of thunderstorms over Indonesia implies that the increase of lightning flashes mainly results from the increase of thunderstorm frequency. During ENSO cold episode, the number of thunderstorm decreases over both of regions, and the decrease of lightning flash over eastern China mainly results from the decrease of thunderstorm frequency, and the variation of lightning in Indonesia is affected by both of frequency and intensity of thunderstorms.

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REFERENCES

Cecil D. J., D. E. Buechler, R. J. Blakeslee. 2014: Gridded lightning climatology from TRMM-LIS and OTD: Dataset description. *Atmos. Res.*, 135–136,404–414.

Curtis, S., and R. F. Adler, 2003: Evolution of El Niño-precipitation relationships from satellites and gauges. *J. Geophys. Res.*, 108, 4153, doi:10.1029/2002JD002690, D4.

Goodman, S. J., D. E. Buechler, K. Knupp, et al., 2000: The 1997–98 El Niño event and related wintertime lightning variations in the southeastern United States. *Geophys. Res. Lett.*,. 27, 541–544.

Hamid, E. Y., Z. Kawasakai, R. Mardiana, 2001: Impact of the l997-98 El Niño event on lightning activity over Indonesia. *Geophys. Res. Lett.*, 28: 147-150.

Kumar, P. R., and A. K. Kamra, 2012: Variability of lightning activity in South/Southeast Asia during 1997–98 and 2002–03 El Niño/La Niña events. *Atmos. Res.*, 118, 84-102.

Liu, C., E. J. Zipser, D. J. Cecil,et al., 2008: A cloud and precipitation feature database from nine years of TRMM observations. *J. Appl. Meteor. Climate*, 47, 2712-2728.

Ma M., S. Tao, B. Zhu, et al., 2005: The anomalous variation of the lightning activity in southern China during the 1997/98 El Niño event. *Science China Earth Sciences*, 48(9): 1537-1547.

Mark, L., and L. Arlene, 2008: The Influence of the El Niño–Southern Oscillation on Cloud-to-Ground Lightning Activity along the Gulf Coast. Part I: Lightning Climatology. *Mon. Weather Rev.*, 136:7, 2523-2542.

Wang, C., 2005: ENSO, Atlantic climate variability, and the Walker and Hadley circulations. In The Hadley Circulation: Present, Past, and Future. pp. 173 – 202, Kluwer Acad., New York.

Yoshida, S., T. Morimoto, T. Ushio, et al., 2007: ENSO and convective activities in Southeast Asia and western Pacific. *Geophys. Res. Lett.*, 34(21), L21806.