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Lightning climatology over the northwest Pacific region: An 11-year study using data from the World Wide Lightning Location Network

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ABSTRACT

Lightning data from the World Wide Lightning Location Network for the period 2005–2015 were used to investigate climatic characteristics of lightning activity over the northwest Pacific region (0°–55°N, 100°–180°E). The highest lightning densities (LDs) were observed over the coastal areas of southeast Asia and the tropical islands, which differs significantly from the distribution of the highest precipitation rates. The LD in the South China Sea (SCS) was much higher than that over the deep ocean and showed a peak that was 3 h ahead of that seen in the open sea. A sharp increase in LD on the Indo-China Peninsula and in the SCS was observed during the pre-monsoon season. The monthly variations show that the highest lightning activity occurred during July, August, and September, which is consistent with the variations in the monthly precipitation rate.

The contribution of tropical cyclones (TCs) and the impact of El Nino and La Nina events on lightning climatology over the northwest Pacific region were also examined. Two areas of maximum TC lightning were observed to the east of the Philippines and south of China, indicating that frequent lightning is produced when TCs are approaching landfall. The average LD during El Nino events increases by 10.3%, whereas during La Nina events it decreases by 4.8%. A northward shift in the positive lightning anomaly was observed in the SCS, from the southern SCS during the El Nino to the central and northern SCS during the La Nina periods.

1. Introduction

As cloud electrification is closely related to deep convection in thunderstorms, the climatology of lightning activity has been widely studied to reveal the climatic characteristics of thunderstorms and convective systems, both at regional (e.g., Kandalgaonkar et al., 2005; Kuleshov et al., 2006; Poelman, 2014) and global scales (e.g., Christian et al., 2003; Cecil et al., 2015; Albrecht et al., 2016), as well as over land (e.g., Orville and Huffines, 2001; Qie et al., 2003; Yang et al., 2015) and ocean (e.g., Hidayat and Ishii, 1998; Altaratz et al., 2003; Bovalo et al., 2012). This study focuses on lightning climatology over the northwest Pacific region, but the study domain extends beyond the ocean to cover the area of 0°–55°N and 100°–180°E. Therefore, the distribution of lightning over the entire life cycle of tropical cyclones (TCs) generated over the northwest Pacific Ocean, as well as the contrast in lightning activity between the ocean and the land, can be investigated. This region covers East/Southeast Asia, the South China Sea (SCS), the deep ocean of the northwest Pacific, and tropical islands of the Maritime Continent (MC).

The northwest Pacific region is affected by a variety of climatic systems and shows unique weather patterns. Due to the Asian monsoon, this region is a significant monsoon-affected area in the world. Convection over this region during the monsoon season is a significant contributor of precipitation and heat in the Northern Hemisphere (Johnson and Ciesielski, 2002). The northwest Pacific region is also the most active TC basin globally, and experiences the largest number of intense tropical storms. Moreover, the northwest Pacific region is an El Nino Southern Oscillation (ENSO)-sensitive area, which is indicated by the great contrast in convection between the El Nino and La Nina events (Curtis and Adler, 2003). Investigation of lightning climatology over the northwest Pacific region could help to improve our understanding of the occurrence and variability of intense convections and thunderstorms in this region.

Decade years of observations by the Tropical Rainfall Measuring Mission (TRMM) satellite have allowed climatological studies of global lightning activity. Global lightning maps (e.g., Christian et al., 2003; Cecil et al., 2015) based on data from the Lightning Imaging Sensor (LIS) and Optical Transient Detector (OTD) describe that the northwest Pacific region is an area of high lightning occurrence, with Malaysia and Indonesia being the global lightning hotspots (Albrecht et al.,

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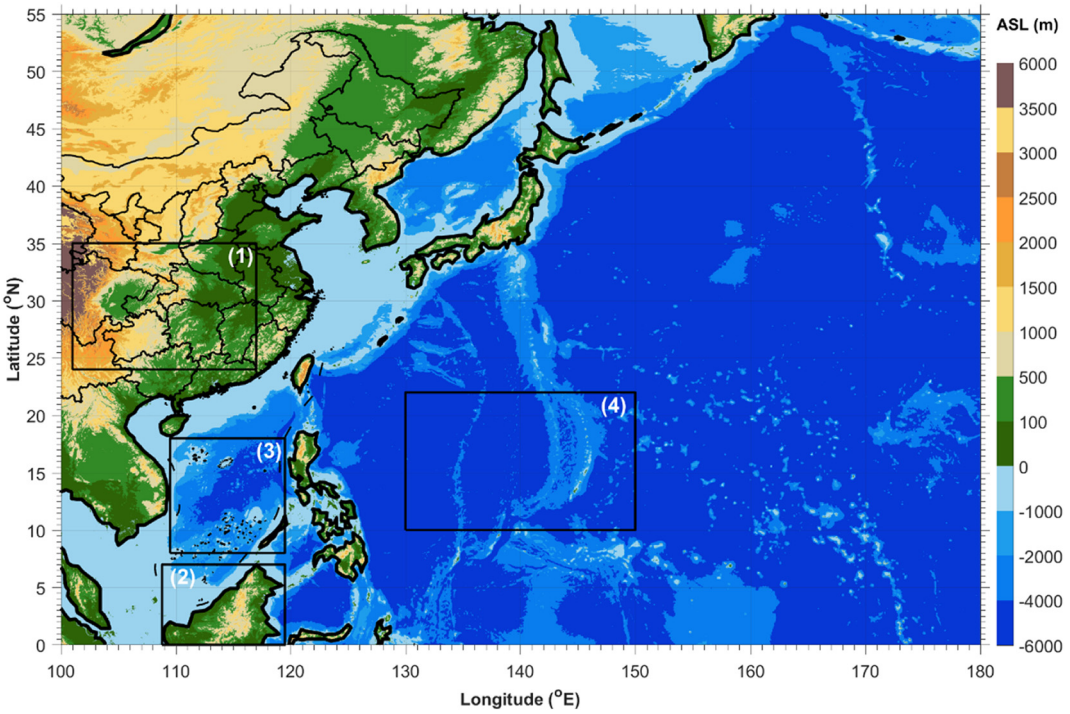

Fig. 1. Plan view of the northwest Pacific region analyzed in this study overlaid terrain elevation (m). Designated (1) inland, (2) tropical islands, (3) the South China Sea, and (4) the open sea with boxes are sampled for diurnal variation.

2016). Other studies have used ground-based lightning detection networks to investigate regional lightning activity across the northwest Pacific region. These studies reported high flash rates on tropical islands including Malaysia (Venugopal et al., 2016) and Indonesia (Hidayat and Ishii, 1998), an unusually high frequency of lightning strokes during winter season in Japan (Iwasaki, 2014; Tsurushima et al., 2017), and a high flash density during the monsoon season in Southeast China (Yang et al., 2015; Zheng et al., 2016). Since the northwest Pacific region is an area with large lightning occurrence, more detailed analysis of climatological lightning activity, in terms of the spatial, seasonal, and diurnal distributions, is required.

Frequent lightning has been observed in TCs (or typhoons) in the northwest Pacific Ocean over the last two decades. Lightning was originally considered to be sparse in tropical storms, because there is little supercooled water above the melting level and a lack of ice particles in tropical clouds (Willoughby et al., 1982; Black and Hallett, 1986). With the development of lightning detection systems in Asia, as well as the global network, more and more studies have highlighted that lightning in TCs in the northwest Pacific is a common event. Pan et al. (2010) first described intense lightning activity in super typhoons over the northwest Pacific. Hereafter high lightning densities (LDs) were also observed in weaker intensity storms as tropical depressions and tropical storms (Zhang et al., 2015). Lightning flash rate was found to be related to TC intensity (Pan et al., 2014). Lightning outbreaks in the eyewall/inner core were found to be an indicator of TC intensification (Zhang et al., 2012). Case studies (Zhang et al., 2013; Wang et al., 2016) of Typhoon Molave (2009) and Super Typhoon Haiyan (2013) also highlighted the relationship between lightning and TC intensity changes, and described in detail the lightning characteristics associated with the evolution of TC convection. These previous studies focused mainly on the lightning distribution in typhoons and its relationship with TC intensity. The contribution of TCs to the climatological lightning over this region has not been studied yet.

El Nino and La Nina events are anomalous climate phenomena within the global ocean-atmosphere system. This is supported by the evidence that sea surface temperatures (SST) over the central and eastern Pacific Ocean are higher or colder than normal. Accompanied by the eastward migration of the warm pool, El Nino causes a shift in convective activity from the western to the central and eastern Pacific (Curtis and Adler, 2003). La Nina event generally appears after El Nino, with a cooling of the SST in the same areas. The major impacts of El Nino/La Nina over the northwest Pacific region are variations in the magnitude of convective storms (Curtis and Adler, 2003; Kumar and Kamra, 2012), suppressed convective rainfalls (Hamid et al., 2001), changes in precipitation patterns (Yoshida et al., 2007), and enhancement of storm intensity (Hamid et al., 2001; Williams, 2005). Since lightning is closely linked to storm intensity and deep convection, connections between lightning activity and El Nino/La Nina events have been found over this region. The number of lightning flashes was found to be increased during the El Nino periods in southern China (Ma et al., 2005), South/Southeast Asia (Kumar and Kamra, 2012), and the Western Pacific and the MC (Hamid et al., 2001). In contrast, during the La Nina periods, lightning activity was reported to be decreased over the same areas (Yoshida et al., 2007; Kumar and Kamra, 2012). Lightning and convection have shown a southeastward shift during the El Nino events in South/Southeast Asia (Kumar and Kamra, 2012). In addition, the spatial distribution of positive anomalies is found to be varied with the seasons (Ma et al., 2005).

The objective of this paper is to study the climatology of lightning activity over the northwest Pacific region (0°–55°N, 100°–180°E). Using 11-year of World Wide Lightning Location Network (WWLLN) data covering the period 2005–2015, we will seek to understand: (a) the spatial distribution and the seasonal and diurnal variations of lightning activity over this region, (b) the contribution of TCs to the climatological lightning, and (c) the impact of El Nino and La Nina events on lightning activity over this region. The remainder of the paper is organized as follows. Section 2 introduces the data and methodology used in this study. Section 3 provides the results and discussion. The conclusions are given in Section 4.