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CLOUD-TO-GROUND LIGHTNING OVER THE INDIAN SUBCONTINENT

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1. Introduction

The geolocation of lightning discharges is important in a wide variety of applications. These include lightning warning and safety applications, thunderstorm nowcasting and forecasting, locating lightning-caused damage to resources and infrastructure, risk assessment, geophysical research, insurance, and a variety of other real-time and forensic applications. The most common way to geolocate lightning is by using a lightning locating system (LLS), which may be a ground-based or satellite-based electromagnetic (including optical) sensor or a network of sensors (e.g. Nag et al. 2015). Ground-based long-range lightning locating systems such as the Global Lightning Dataset GLD360 (Said et al. 2013) typically have numerous sensors located across the world and continuously report lightning activity in all parts of the world in quasi-realtime.

The Indian Subcontinent is among the most lightning-rich areas on earth. Recent studies (e.g. Holle 2016a,b) have shown that a substantial number of people are killed or injured by lightning in this region, especially during agricultural activities. Current totals of annual fatalities include the following:

- Bangladesh: Multiple-fatality incidents occur nearly every year, such as 64 over a two-day period in 2016 (Holle and Islam 2017). The annual number of fatalities is 251 per year in the last six years (Dewan et al. 2017).
- India: Annual fatality totals in recent publications range from 2234 (Selvi and Rajapandian 2016), to 1755 (Illiyas et al. 2014), to 159 (Singh and Singh 2015). The wide range indicates the difficulty in identifying death tolls. In addition injuries occur several times as frequently as deaths, but are generally underreported.
- Sri Lanka: 49 deaths per year (Gomes et al. 2006).

National-scale statistics for lightning fatalities and lightning-caused infrastructure damages are not readily available for this region, to the best of our knowledge, and are needed in order to better understand the impact of lightning to people and infrastructure in the Indian Subcontinent (Holle 2016). Additionally, the location, frequency, time of year, and time of day of lightning need to be identified.

This paper provides the first depiction of cloud-to-ground lightning over the Indian Subcontinent using data from GLD360. Additionally, we present some initial results on diurnal and seasonal variations in lightning activity in this region. Such information is valuable to aid understanding of where to focus safety education to reduce lightning fatalities and injuries, the impacts of lightning on power utilities and other infrastructure, and the meteorological conditions associated with cloud-to-ground lightning in this region.

2. Data

We analyzed cloud-to-ground lightning strokes reported by the GLD360 occurring in and around the Indian Subcontinent region (see Figure 1 for a depiction of the region of interest in this study) from 2012-2016. GLD360 predominantly reports cloud-to-ground strokes along with some cloud pulses, but does not identify each type. The vast majority of cloud pulses have estimated peak currents less than 10 - 15 kA. In order to remove cloud pulses from our dataset we excluded GLD360-reported lightning events with estimated peak currents between -10 kA and +15 kA.

The cloud-to-ground flash and cloud-to-ground stroke detection efficiencies of the GLD360 in this region during the 2012-2016 period are expected to be around 45-60% and 30-40%, respectively. No corrections for less than perfect detection efficiency were applied to the estimates of stroke densities presented in this preliminary study. The location accuracy for GLD360 is expected to be 5 to 8 km (Said et al. 2013; Said and Murphy 2016).

3. Study domain

Major cities and topographic features in the Indian Subcontinent and surrounding regions are shown in Fig. 1. The Himalayas are prominent as the east-west-oriented barrier to the north. Somewhat lower mountain ranges oriented from north to south are apparent both to the northwest, as well as in the northeast portions of India and Bangladesh. These ranges on the east and west sides of the broad lower-altitude plains make this a specific region that can be addressed separately from the Tibetan Plateau to the north.

4. Annual cloud-to-ground stroke density

The stroke density map for the full five-year dataset is shown in Fig. 2. On average, 64,566,091 strokes per year were reported by GLD360. There is a very sharp cut-off from larger densities in the south to small values to the north of the Himalayas.

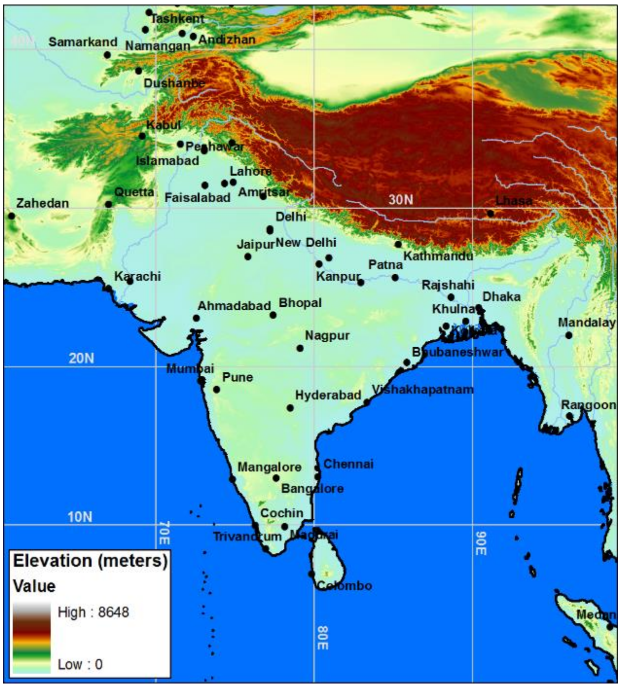

FIGURE 1. Major cities and elevations in the study domain (Indian Subcontinent and surrounding regions).

Four regions are indicated by rectangles in Fig. 2. Lightning is less frequent over the broad northwest plains (A). The largest stroke densities are in the northeast subcontinent (B), the southwest coast of India (C), Sri Lanka (D), and the northwest base of the Himalayas. There is also extensive lightning over the northern Indian Ocean.

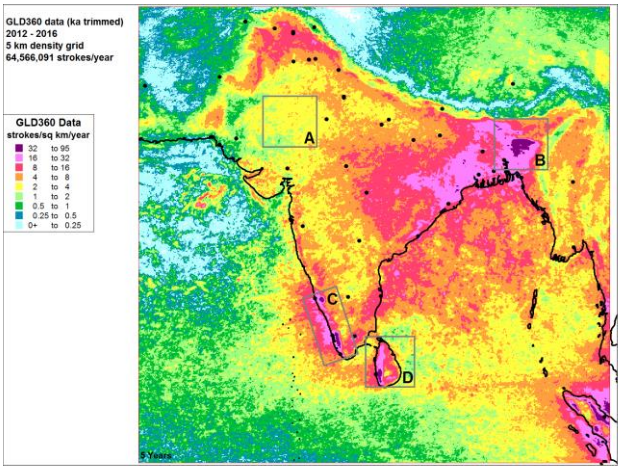

FIGURE 2. Average annual stroke density (strokes km^{-2} yr^{-1}) from 2012-2016.

5. Diurnal variations

In regions A, C, and D of Fig. 2, most lightning occurs between late morning and late afternoon (Fig. 3). However in the northeast subcontinent (region B), lightning is widely spread across all hours of day and night, compared with stronger afternoon peaks at the other three locations. This all-day maximum is also indicated by lightning fatalities in Bangladesh (Dewan et al. 2017). The season when this reduced diurnal variation occurs will be examined in detail in a later study, although the results shown below suggest that most of the lightning in region B occurs between March and September.

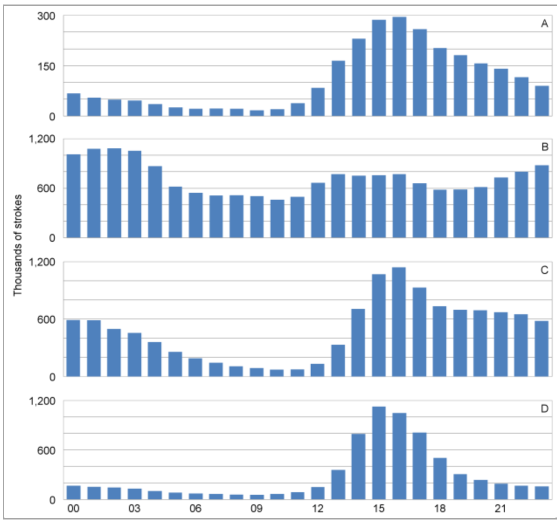

FIGURE 3. Diurnal variation of annual strokes in the four regions A through D from 2012-2016.

6. Seasonal variation

Commonly accepted definitions have been used to divide the year into months comprising pre-monsoon, monsoon, post-monsoon, and winter seasons. We use Dimri et al. (2013)'s definition of "winter" as the December-January period.

Significant lightning occurs in the south and northeast during the pre-monsoon months. The largest coverage of cloud-to-ground lightning is during the monsoon season, but with a relative minimum in southern India and Sri Lanka relative to the pre- and post-monsoon months. Post-monsoon months have a general lessening of lightning strokes, and winter has the least lightning although westerly disturbances may bring widespread rain (Selvi and Rajapandian 2016).

7. Seasonal migration

The progression of the pre-monsoon lightning activity is shown by ten-day periods from early April to late May in Fig. 5. The lightning density tends to increase over Sri Lanka and the southern and eastern parts of India, but is present through the period in the northeast. The largest number of lightning fatalities in Bangladesh occurs during the pre-monsoon period (Dewan et al. 2017).

The progression of lightning strokes during the retreating monsoon is shown in ten-day periods from early September to late October in Fig. 6. The retreat is sporadic but lightning continues along the oceanic coastlines, especially toward the southern portion of the region, into October.

We should, of course, caution that a five-year sample, when broken down into specific 10-day periods, is not quite sufficient to allow a complete generalization of the climatology. In both Figs. 5 and 6, specific storms appear to have an outsized impact on the lightning densities in some areas, particularly in the Bay of Bengal. A longer history is almost certainly warranted before drawing too many general conclusions about the seasonal migration, but Figs. 5 and 6 at least give a good general idea.

8. Summary and conclusions

A summary of cloud-to-ground lightning strokes was presented for the Indian Subcontinent from 2012 through 2016. GLD360 reported 64,566,091 per year, on average, in this region. No corrections for less than perfect detection efficiency of the LLS were made in this preliminary study. Strong regional variations indicated that strokes were most frequent near the Himalayas and oceanic coastlines. The time of day of lightning peaked in the afternoon for several areas, but the northeast subcontinent had minimal variations through the day and night. Most strokes occurred during the monsoon (June-September), with nearly as much lightning during the pre-monsoon (March-May) season. Much less lightning occurred in the post-monsoon (October-November) and winter (December-February) seasons.

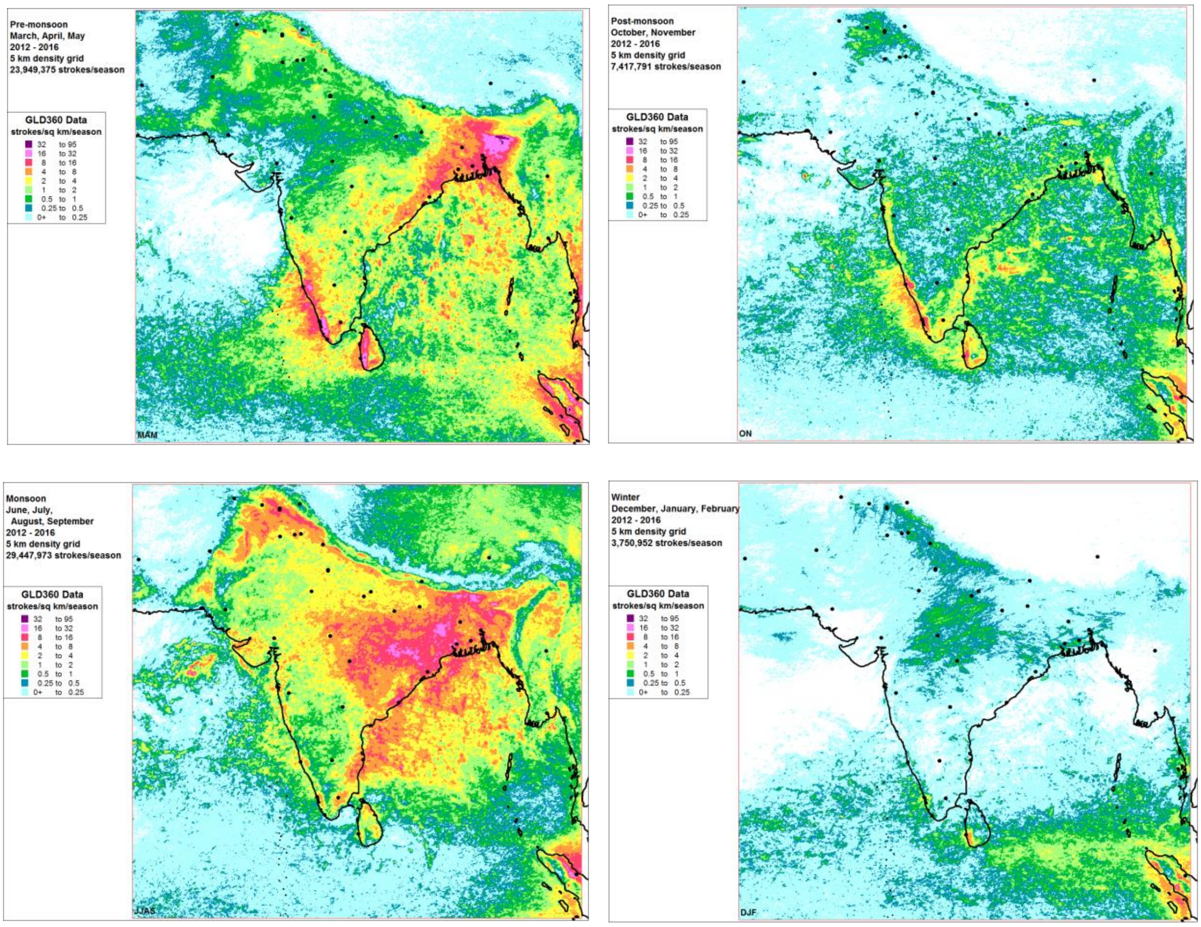

FIGURE 4. Stroke density by season. Upper left: Pre-monsoon months of March, April, and May. Lower left: Monsoon months of June through September. Upper right: Post-monsoon months of October and November. Lower right: Winter months of December through February.

Acknowledgment

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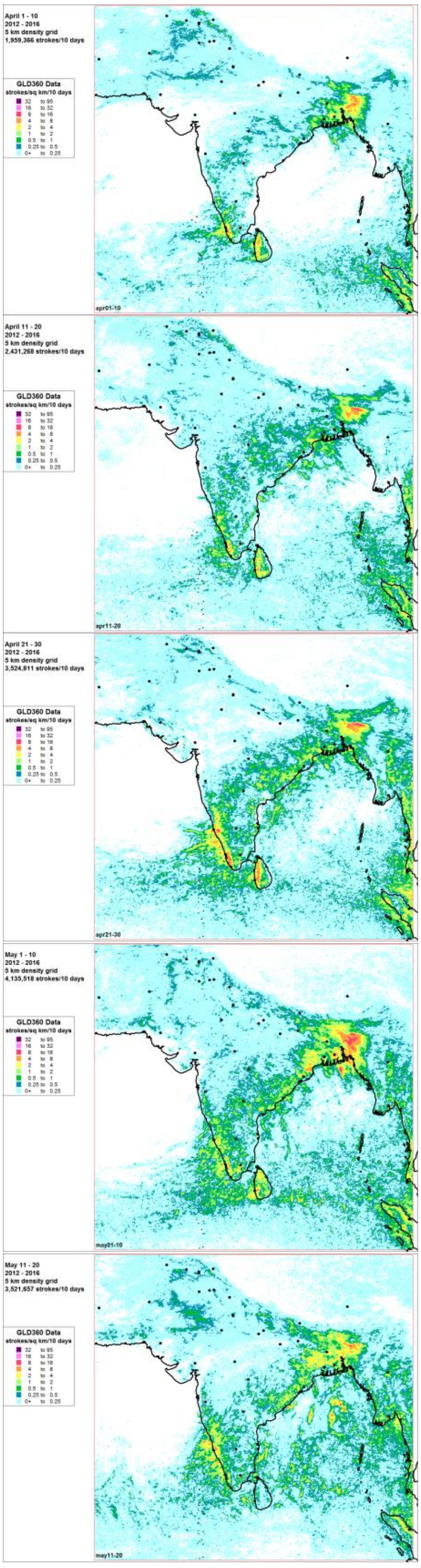

FIGURE 5. Stroke density in ten-day periods during the advance of the monsoon.

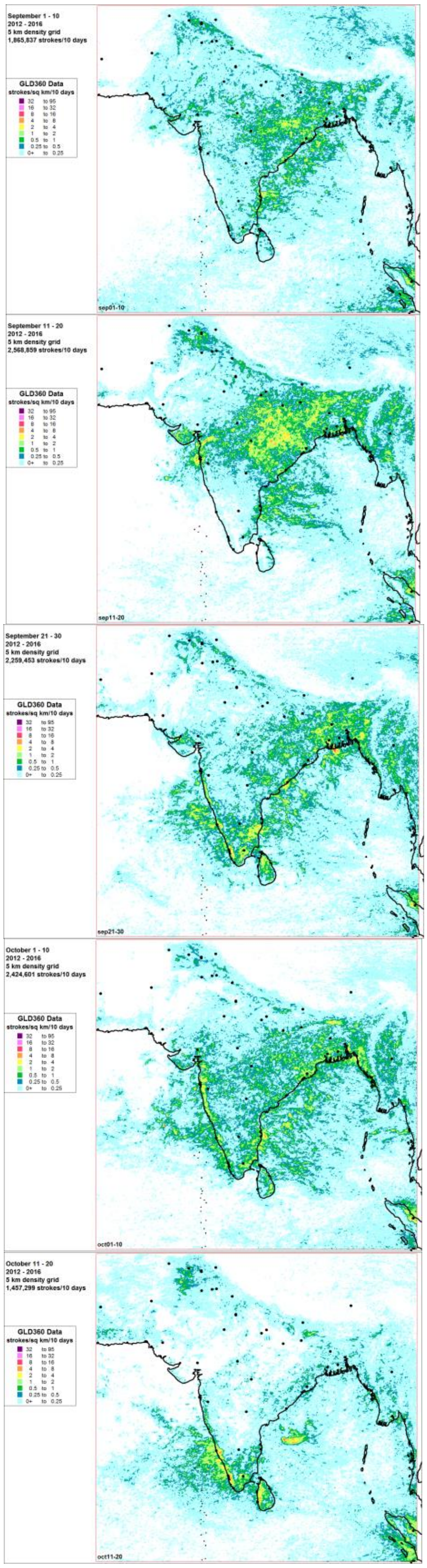

FIGURE 6. Stroke density in ten-day periods during the retreating monsoon.

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