Diurnal cycle of lightning activity over continental regions

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ABSTRACT: Satellite and ground network observations of lightning flash distribution data are used to examine the diurnal cycle of lightning activity over the tropical and subtropical regions of South America. A harmonic analysis was used to study the spatial variations in the peak and strength of diurnal lightning activity across this area. The results show that in the north and center regions of South America the time of maxima lightning activity was concentrated in the late afternoon to evening hours (between 5:00 p.m. and 7:00 p.m. local time), which may be associated with the peaking of the local convective activity associated with heating of the surface caused by daytime insolation. In the subtropical South America, particularly the area limited by [-25°; -40°] of latitude and [-70°; -50°] of longitude, the time of maximum lightning activity was shifted to nocturnal hours, extending from close to midnight to early morning hours. This behavior can be associated to the peak in MCSs in the morning hours in the region. A close connection between peak time of lightning activity and peak time of precipitation events have been observed by comparing the current results with other published studies.

INTRODUCTION

The diurnal patterns of meteorological phenomena including studies on precipitation, hail, wind and lightning provide significant information about convective activity in the region under study. The diurnal variability in thunderstorms has been related directly to the forcing mechanism of thunderstorm creation and to the associated rainfall patterns [Sterling, 1985]. As a result of boundary layer destabilization caused by daytime insolation over land, the time of maximum frequency of precipitation is noted in the afternoon hours [Dai, 2001; Nesbitt and Zipser, 2003; among others]. However, there are numerous synoptic and mesoscale meteorological phenomena, such as Mesoscale Convective Systems for instance, which if they have a certain frequency may alter or change the maximum frequency time of the typical diurnal cycles in a given region.

Although, there are a significant number of studies examining the diurnal patterns of weather processes mainly precipitation and thunderstorm activity over wider areas across South America, there is relatively limited number of studies examining the diurnal patterns of lightning activity over this continent, possibly because of the scarcity of lightning data, particularly before the end of the 20th century. Since, the availability of satellite based high-temporal resolution lightning data, such as the Tropical Rainfall Measuring Mission (TRMM) dataset, it is now possible to examine diurnal patterns of lightning activity in

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less explored regions.

Blakeslee et al. [2012], using lightning data derived from the Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS), studied the annual diurnal lightning cycle for the entire world and for continental and oceanic regions and its seasonal variations. Over continental scale, a strong diurnal cycle was found with a peak in lightning activity between 15:00 and 17:00 Local Time (LT). Also, the authors studied the geographical distribution of the diurnal lightning peak activity and found that, at some specific locations, Central United State, Argentina and West Africa, the diurnal peak shifts toward late local evening or early local morning.

While there are a several studies examining diurnal processes at the regional scale in South America, there is a shortage of literature examining the diurnal variation of lightning activity in this continent. In order to fill this gap, in the present study we analyze the diurnal patterns of lightning activity in tropical and subtropical South America with the availability of high temporal resolution data from TRMM data from 1998 to 2012 and World Wide Lightning Location Network from 2008 to 2012.

DATA AND METHODOLOGHY

The lightning data used in this study came from two independent lightning detection systems LIS-OTD and WWLLN. The LIS-OTD data used to analyze the diurnal patterns of lightning activity are the Low Resolution Diurnal Climatology (LRDC) based on the lightning data detected by LIS and OTD during the period between 1995 and 2012. The LRDC represents the mean diurnal cycle, in local solar time, and it has unit of flash km^{-2} h^{-1} [Cecil et al., 2012]. The WWLLN (http://wwlln.net) is a real-time, world-wide, ground network that detects preferentially strong lightning strokes. The WWLLN has detection efficiency < 10% [Rudlosky and Shea, 2013] and a location accuracy of ~5 km [Abreu et al., 2010].

Since LIS/OTD only detect lightning which occurs within the field of view of the satellite, and this is continuously moving across the surface of the Earth, a given region is only covered for a brief period of time and this coverage need not necessarily occur every day. Suitably averaged and gridded the LIS/OTD data provide a very accurate and complete characterization of lightning activity in the covered area. Therefore, it is important to contrast the results obtained from both networks to validate the WWLLN in order to be able to use it in areas that are outside the scope of LIS/OTD or to use for particular events not detected by LIS.

In order to characterize and quantify the local diurnal cycle on lightning activity, a harmonic analysis was performed in each grid cell. The diurnal cycle was fitted using a sinusoidal function with a 24 hours period as follow,

$$FR_{DC}(t) = a + b\sin\left(\frac{2\pi}{24}t + c\right) \qquad (1)$$

where FR_{DC} is the mean diurnal flash rate (flashes km^{-2} h^{-1}), a is the mean value of the lightning activity during the 24 hours period (flashes km^{-2} h^{-1}), b is the amplitude of the lightning activity oscillation on the period considered (flashes km^{-2} h^{-1}) and c the phase of the diurnal cycle (radians) which is an indicator of the time when the maximum lightning activity occurs. To obtain information on the shape of the diurnal distribution, the ratio between the amplitude and the mean value (NA=b/a) was calculated for each grid cell and the following criteria were used,

NA < 0.5 indicates a lack of a well-defined peak on lightning activity or a double maximum,

0.5 < NA< 1.0 indicates a diurnal trend with a clear peak, and

1< NA indicate a well developed diurnal cycle with a clear peak in the diurnal lightning activity.

These criteria are consistent with those proposed by Easterly and Robinson [1985].

RESULTS AND DISCUSSIONS

Figure 1 shows a map of South America along with the local time of maximum lightning activity during the 24 h daily cycle (vector plot) and the NA values (color plot) for data from LIS-OTD and WWLLN.

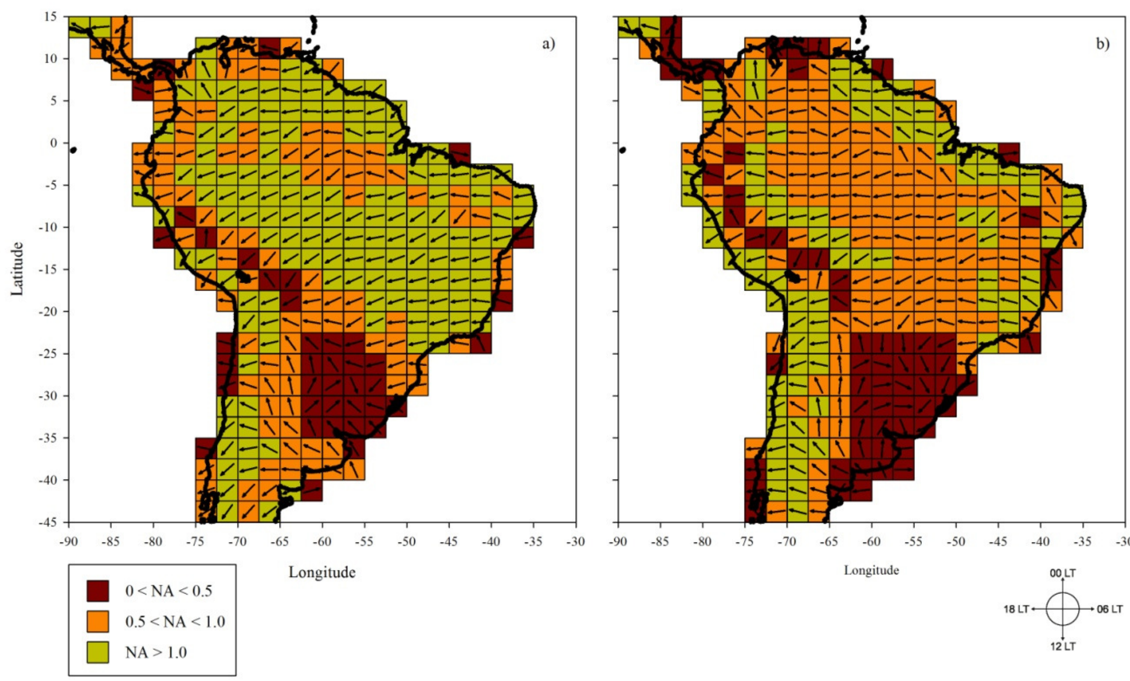

Figure 1. Local time of maximum lightning activity during the 24 h daily cycle (vector plot) and NA values (color plot) for data from a) LIS-OTD and b) WWLLN.

The results of both data set are in good agreement and show that in the north and center regions of South America, a well developed diurnal cycle is observed with a peak on lightning activity mainly concentrated in the late afternoon to evening hours (between 17:00 and 19:00 LT). This can be related with the peaking of the local convective activity associated with heating of the surface in the interiors of the landmasses. Interestingly, in the area limited by [-25°; -40°] of latitude and [-70°; -50°] of longitude, which includes Paraguay, northeastern Argentina, south Brazil and Uruguay, including La Plata basin, the time of maximum lightning activity is more variable and it is mainly shifted to nocturnal hours, extending from close to midnight to early morning hours.

Liu et al. [2010] studied the geographical distribution of rainfall from thunderstorms, electrified shower clouds, and non-electrified shower clouds over the globe. They found that non-electrified rainfall dominates the total rainfall over oceans and over the Amazon in South America; while thunderstorms contribute a large amount of rainfall over land, including some heavy rainfall regions over northern Argentina. Particularly, they showed that nearly all rainfall over northern Argentina and La Plata basin is from thunderstorms. This suggests that the diurnal cycle of precipitation should be closely related to the diurnal cycle of lightning activity in this region.

Romatschke and Houze [2013] reported that in the regions located in the continental tropics of South America, the precipitation comes mainly from convective systems with large stratiform components which peak in the afternoon as a result of solar heating. Likely, these are the systems that produce the diurnal cycle of the lightning activity reported in the current work in these regions. While, at the southern foothills of the Central Andes (-25°; -40° of latitude), most of the precipitation comes from systems of small horizontal dimension but featuring deep convective cells, which first appears over the slopes of the Andes in the afternoon; in good agreement with the maximum time on lightning activity on this region. It has been shown [Matsudo and Salio, 2011; Rasmussen and Houze, 2011; among others] that these systems move eastward over the La Plata basin region, in association with a midlatitude disturbance, where they grow into large systems. These systems are likely to cause the time of maximum lightning activity occurring during nocturnal hours in the region.

Romatschke and Houze [2013] also found that a significant portion of precipitation in the La Plata basin is contributed by large MCCs. They suggested that MCSs tend to develop initially from convective cells triggered in the afternoon in the region of southern foothills of the Central Andes. The nocturnal/early-morning maximum is aided by the input of moisture by the diurnally modulated South American low-level jet [Marengo et al. 2004; Romatschke and Houze 2010; Rasmussen and Houze 2011]. Consistently with this type of storm movement and evolution, the time sequence of lightning activity shown in the region around La Plata basin is in agreement with the current results.

Northern Argentina is region with large and frequent MCSs, which presents favorable conditions for severe thunderstorm development; a low-level jet bringing moist air from Amazonia, high terrain (Andes Mountains) lifting the low-level air and releasing convective instability and a strong low-level wind shear [Brooks et al., 2003; Zipser et al., 2006]. These conditions seem to be the responsible factors for the peak of lightning activity does not occur in the late afternoon but it is shifted to nocturnal hours over these areas.

CONCLUSIONS

In this study the diurnal variation of lightning activity in South America was examined using data from two independent lightning detection systems LIS-OTD and WWLLN. Harmonic analysis was used to detect the spatial variations in the peak and strength of diurnal lightning activity across the studied area. A close connection between peak time of lightning activity and peak time of precipitation events have been observed by comparing the current results with other published studies.

Generally, in the north and center regions of South America the time of maxima lightning activity was concentrated in the late afternoon to evening hours (between 5:00 p.m. and 7:00 p.m. LT), which may be associated with the peaking of the local convective activity associated with heating of the surface caused by daytime insolation. While, in the subtropical South America, particularly the area limited by [-25°; -40°] of latitude and [-70°; -50°] of longitude, including La Plata basin, the time of maximum lightning activity was shifted to nocturnal hours, extending from close to midnight to early morning hours. This behavior can be associated to the peak in MCSs in the morning hours in the region. A significant portion of precipitation in the area is contributed mainly by large MCCs, which tend to develop initially from convective cells triggered in the afternoon in the region of southern foothills of the Central Andes.

The strength of the diurnal cycle was stronger in the areas of the north, center and east of South America, including Amazon basin; stressing the relevance of the local-level convective processes in these regions. The cycle was weaker in general in the subtropical South America (northeastern of Argentina, southern Brazil and Uruguay), where the MCSs predominate.

The results of this study provide valuable information about convective processes in tropical South America. Given the relative abundance of published literature on the diurnal timing of precipitation events, the current results further extend our understanding of atmospheric processes in this region.

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