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Key Points:

- The diurnal variations of lightning activity was assessed over South America
- Lightning activity was concentrated in local afternoon in tropical South America
- Nocturnal lightning activity was observed over subtropical South America

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Diurnal patterns in lightning activity over South America

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Abstract Satellite 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 is used to study the spatial variations in the peak and strength of diurnal lightning activity across this area. Results show that in the northern and central regions of South America, the times of maxima in lightning activity was concentrated from late afternoon to evening hours (between 14:00 and 18:00 local time), which may be associated with the peaking of the local convective activity connected with heating of the surface caused by daytime insolation. In subtropical South America, particularly in the area limited by 25°S, 35°S of latitude and 70°W, 50°W 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 mesoscale convective systems in the region which occurs in the morning hours. The annual flash densities in the tropical and subtropical parts of the continent were found to have comparable magnitudes. However, the contribution of the continental tropics to the global electric circuit dominates over the continental subtropics contribution throughout all seasons, since the surface covered by the tropical region is more than twice the area covered by the subtropical region.

1. Introduction

Numerous studies show that convective cloud systems produce most of the precipitation and severe weather in the tropical and subtropical parts of the continent of South America [*Pereira and Rutledge*, 2006; *Zamboni et al.*, 2010; *Rasmussen and Houze*, 2011; *Durkee et al.*, 2009; *Romatschke and Houze*, 2013, among others]. In particular, *Zipser et al.* [2006] and *Romatschke and Houze* [2010] found a maximum of extremely deep convective cores in northern Argentina. The conditions leading to the development of mesoscale convective systems (MCSs) and mesoscale convective complexes (MCCs) in different regions of South America have been studied by *Salio et al.* [2007] and *Romatschke and Houze* [2010], among others.

It is known that 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 directly related to the forcing mechanism of thunderstorm generation and to the associated rainfall patterns [*Sterling and Robinson*, 1985]. As a result of boundary layer destabilization caused by daytime insolation over land, the time of maximum frequency of precipitation is found in afternoon hours [*Dai*, 2001; *Nesbitt and Zipser*, 2003, among others]. However, there are numerous synoptic and mesoscale meteorological phenomena, such as MCSs for instance, which, if occurring often or frequently, may alter the maximum frequency time of the typical diurnal cycles in a given region.

In particular, the diurnal cycle of precipitation has been investigated in different regions of South America. For instance, *De Angelis et al.* [2004] analyzed the climatology of rainfall characteristics over tropical and subtropical regions in order to evaluate the nature of the diurnal rainfall variations, *Angelis et al.* [2004] studied the diurnal cycle of rainfall over the Amazon, and *Rickenbach* [2004] examined the diurnal variation of clouds and rainfall in southwestern Amazonia. The results of these studies point out the existence of a secondary nocturnal maximum in addition to the primary afternoon one, suggesting that daytime insolation is not the only acting force over the region. *Romatschke and Houze* [2013] also studied the diurnal and regional variability of precipitating cloud systems in different regions of South America. They found that the precipitation in the continental tropics is generally produced by convective systems of large stratiform compositions. At the northeastern foothills of the central Andes, nocturnal convective systems of medium to large horizontal scale occur where a moist low-level flow is lifted over the foothills. On the other hand, the regions over the continental subtropics tend to be of an intensely convective nature, especially at the eastern foothills of the Andes. As the disturbance moves east over the La Plata basin, nocturnal convective systems of larger horizontal scale with wide stratiform regions occur in a zone of general convergence. In contrast, over the Amazon basin, daytime systems are smaller than nocturnal systems. Radar echoes of precipitation ($>$40 dB) over the Brazilian Highlands (covering most of the eastern, southern, and central portions of Brazil) are generally smaller in horizontal scale, more convective, and mostly occur during the afternoon over elevated terrains.

There are many field observations [*Lhermitte and Williams*, 1985; *Carey and Rutledge*, 1996; *Petersen et al.*, 1999; *Deierling et al.*, 2008], which clearly show that lightning production in thunderstorms is associated to the presence of ice particles and strong updrafts in the mixed-phase region of the clouds, located between the 0°C and −40°C isotherms; although *Ávila et al.* [2011] showed that important charge separation can occur even in glaciated regions above the −40°C isotherm, which means that the regions of the clouds, where the charge separation mechanisms are active, are larger than previously thought. These results suggest a strong link between lightning production and clouds' microphysical and dynamical characteristics. 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 a 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 twentieth century. With the availability of satellite-based high-temporal-resolution lightning data, such as the Tropical Rainfall Measuring Mission (TRMM) data set, it is now possible to examine diurnal patterns of lightning activity in less explored regions. Given the strong diurnal signal in rainfall patterns in different parts of South America, in this study we will focus on lightning activity across this continent.

A few regional-level studies examining lightning patterns were conducted in South America. For instance, *Williams et al.* [2002] and *Altaratz et al.* [2010] showed that lightning activity in the Amazon region is affected by smoke; *Naccarato et al.* [2003] analyzed the aerosol effects on the density and polarity of cloud-to-ground lightning over urban areas of southeastern Brazil. *Collier et al.* [2013] used the Lightning Imaging Sensor (LIS) data to derive regional lightning climatologies for several countries in South America. These climatologies were used to assess the degree of interannual variability of lightning. The "Catatumbo lightning" in Venezuela was reported as the region with the highest annual flash density (flashes $\mathrm{km}^{-2}\,\mathrm{yr}^{-1}$) of the globe with almost 250 flashes $\mathrm{km}^{-2}\,\mathrm{yr}^{-1}$ [*Albrecht et al.*, 2011]; the high lightning activity centers in the region were recognized and analyzed in terms of time scales ranging from hours to years by *Bürgesser et al.* [2012] using the World Wide Lightning Location Network data.

Rasmussen et al. [2014] studied the seasonal, diurnal, and extreme storm-related lightning in subtropical South America using TRRM satellite data. They found maximum lightning activity over northeastern Argentina and Paraguay during spring and fall, while during summer, lightning activity is concentrated over the foothills of the Andes. The maximum lightning activity during the transition seasons is related with deep convective storms with large horizontal areas, and the lightning maximum over the foothills of the Andes is associated to deep convective storms with small to large horizontal areas. The diurnal analysis shows a nocturnal maximum of lightning activity over the foothills of the Andes.

It is generally accepted that lightning is one of the main current sources for the global electric circuit (GEC) [*Bering et al.*, 1998; *Williams*, 2009; *Liu et al.*, 2010]. In fact, the diurnal patterns of the lightning activity are of primary significance to elucidate the variation of fair weather electric field with universal time (Carnegie curve). *Blakeslee et al.* [2014], using lightning data derived from the Optical Transient Detector and the Lightning Imaging Sensor (LIS), studied the annual and seasonal variations of the diurnal lightning cycle for the entire world and for continental and oceanic regions and examined their implications for the GEC. Overall, the authors showed that over continental scale, a strong diurnal cycle was predominant 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 States, Argentina, and West Africa, the diurnal peak shifts toward late local evening or early local morning. Particularly, they found that the contribution of South America to the GEC is mainly during spring and summer seasons in the Southern Hemisphere (SH).

While there are a number of studies examining diurnal processes at the regional scale in South America, there is a shortage of literature examining the geographical distribution of the diurnal variation of lightning activity

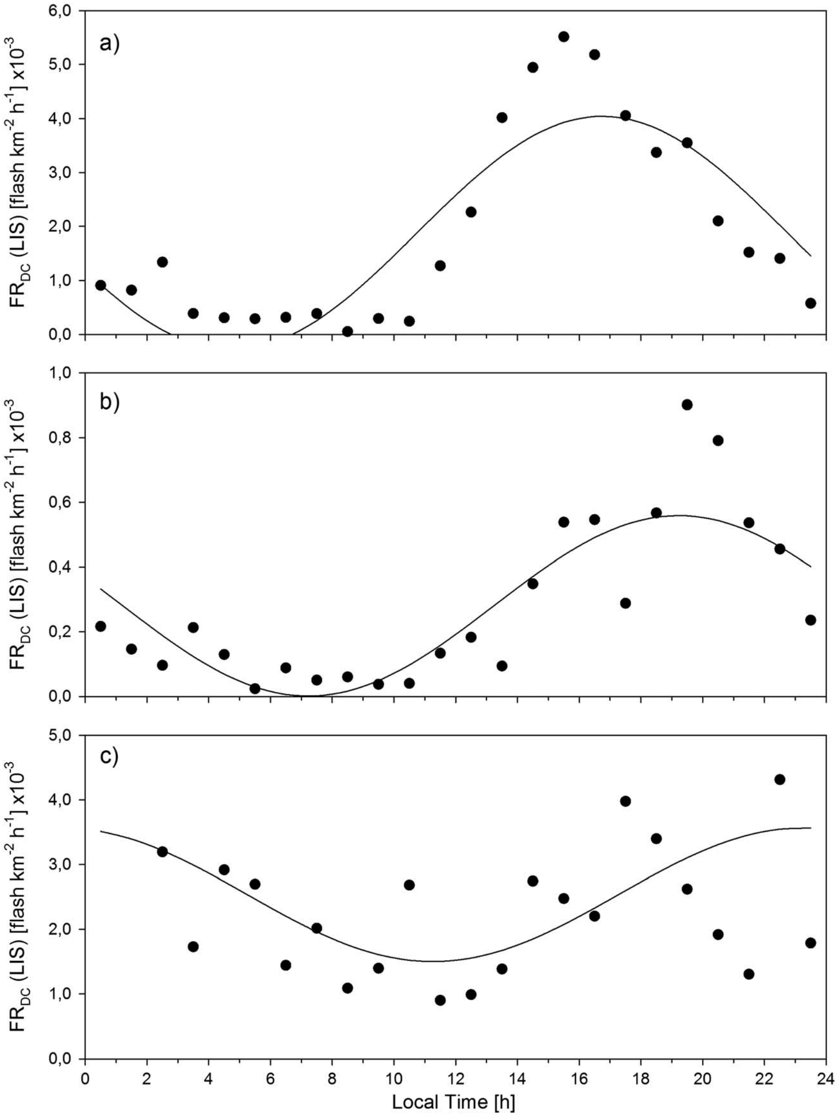

Figure 1. Diurnal cycles of lightning activity derived from LIS data (black circles) and the sinusoidal fit (solid line) for a spatial resolution of 2.5° with grid cell center at (a) 61.25°W of longitude and 8.75°S of latitude, (b) 63.75°W of longitude and 23.75°S of latitude, and (c) 56.25°W of longitude and 31.25°S of latitude.

in this continent. In order to fill this gap, in the present study, we analyze the seasonal 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 2013. We discuss the possible causes for the different patterns of lightning activity observed in terms of local meteorology and compare these results with those from similar studies done in other regions of the world. We also compare the seasonal diurnal flash rates for the tropical and subtropical parts of the continent, and the implications for the global electric circuit are examined.

2. Methodology and Data

This study uses data from the Lightning Imaging Sensor (LIS), which is a space-based instrument on board the TRMM satellite (http://thunder.msfc.nasa.gov), specifically designed to continuously detect the total lightning activity, both intracloud and cloud to ground (CG) [*Christian et al.*, 1999], of any given storm that passes through the field of view (600 × 600 km^2) of its sensor. The observation time of a given storm is 80 s. Since the TRMM satellite orbit has an inclination of 35°, the LIS instrument can only detect lightning activity between

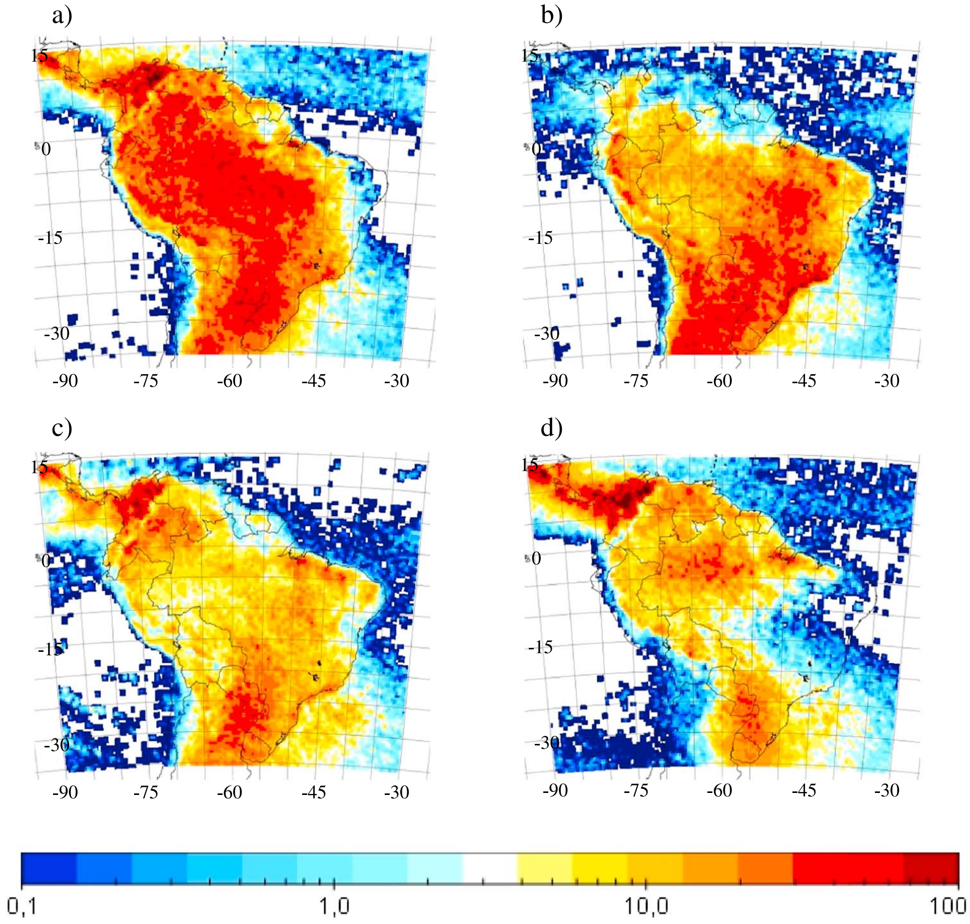

Figure 2. Seasonal distribution of mean annual flash density derived from LIS between January 1998 and December 2013 with a spatial resolution of 0.5° × 0.5° for the period of (a) September-October-November, (b) December-January-February, (c) March-April-May, and (d) June-July-August. The color scale represents the annual flash density in flashes $\mathrm{km}^{-2}\,\mathrm{yr}^{-1}$.

35°N latitude and 35°S latitude. *Buechler et al.* [2014] studied the LIS instrument stability between 1998 and 2010 and found no apparent degradations of the instrument and no discernible trend over time.

The TRMM is continuously moving across the surface of the Earth; hence, a given region is only covered by LIS for a brief period of time, and this does not necessarily occur every day. Therefore, to have an accurate and complete characterization of lightning activity in the covered area, a suitably averaged and gridded data set is necessary.

In order to obtain these suitable data, the lightning data detected by LIS during the period between 1998 and 2013 were used to compute the seasonal annual flash density of the diurnal cycle as proposed by *Cecil et al.* [2012]. The detected flashes and the total viewtime were accumulated on 1 h (local solar time) × 2.5° × 2.5° bins from each orbit. The flash count is scaled with the appropriate detection efficiency, and the viewtime is the observation durations multiplied by the size of the grid box. The combined flash rate is computed as the ratio between the sum of LIS-scaled flashes and the sum of LIS viewtimes. The combined flash rate represents the mean diurnal cycle, in local solar time, and it has unit of flash $\mathrm{km}^{-2}\,\mathrm{h}^{-1}$.

In order to do a quantitative analysis of the peak amplitude and phase of the local diurnal cycles, the data were fitted using a harmonic analysis in each grid cell. The diurnal cycle was fitted using a sinusoidal function with a 24 h period as follows:

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

where FR_{DC} is the mean diurnal flash rate (flashes $\mathrm{km}^{-2}\,\mathrm{h}^{-1}$), a is the mean value of the lightning activity duringthe 24 h 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 is the phase of the diurnal cycle (radians) which is an indicator of the time when the maximum lightning activity occurs. Here for simplicity, it is assumed that the one harmonic model reproduces fairly well the properties of amplitude and phase of the data, which are the relevant ones for the present work. However, in order to evaluate the deviation from the sinusoidal behavior, a more general approach needs to be considered. To obtain information on the shape of the diurnal distribution, the ratio between the amplitude and the mean value ($\mathrm{NA} = b/a$) was calculated for each grid cell, and the following criteria were used, in agreement with those proposed by *Easterling and Robinson* [1985]:

$\mathrm{NA} < 0.5$ is considered as a lack of a well-defined peak on lightning activity or a double maximum,
$0.5 \leq \mathrm{NA} \leq 1.0$ is considered as a diurnal cycle with a clear peak, and
$1 < \mathrm{NA}$ is considered as a well-developed diurnal cycle with a prominent peak in the diurnal lightning activity.

The accuracy of the fit in each grid cell was evaluated by calculating the R^2 parameter. R^2 parameter is the square of the correlation between the response values and the predicted response values. R^2 can take on any value between 0 and 1, with a value closer to 1 indicating that a greater proportion of variance is accounted for by the model.

As an illustration of the data analysis, Figure 1 displays the details of diurnal cycles representing three different regions and the sinusoidal function fitted for LIS data (solid line). The boxes represent areas with different lightning characteristics. The black circles indicate the number of flashes km^2 h obtained from LIS using a spatial resolution of 2.5°. Figure 1a shows a marked diurnal cycle of lightning activity in the grid cell center at 61.25°W of longitude and 8.75°S of latitude sited in the Amazon basin within the tropical region of South America, with a flash peak between 15:00 and 17:00 LT and a NA parameter of 1.32. Figure 1b displays the diurnal variation of lightning activity in the grid cell center at 63.75°W of longitude and 23.75°S of latitude located over the slopes of the Andes within the subtropical region of South America. The analysis over this grid shows a flash peak around 21:00 LT and a NA parameter of 0.86. Figure 1c displays the diurnal cycle in the grid cell center at 56.25°W of longitude and 31.25°S of latitude located at the La Plata basin in the subtropical region, with the maximum lightning activity at midnight and a NA parameter of 0.21.

The harmonic analysis performed shows a good correlation between the response values and the predicted response values in the first two grid cells (Figures 1a and 1b). Both grid cells present an R^2 parameter of 0.75. For the grid cell over the La Plata basin (Figure1c), the R^2 parameter is 0.31, which means that the model is not capable to explain the variance showed by the lightning data.

In general, the results show that the harmonic analysis performed is reasonably accurate ($R^2 > 0.5$) to represent the diurnal cycle of lightning activity when the NA parameter shows values higher than 0.5. For lower values of NA, the model is not able to explain the lightning data variation observed.

3. Results and Discussions

South America (SA) is considered as one of the major tropical continental zones of active convection and lightning activity [*Christian et al.*, 1999, 2003; *Boccippio et al.*, 2000; *Zipser et al.*, 2006]. Figure 2 displays the seasonal lightning distribution maps over SA. This figure shows the seasonal distribution of mean annual flash density (AFD) (flashes km^{-2} yr^{-1}) derived from LIS between January 1998 and December 2013 with a spatial resolution of 0.5° × 0.5°. The maximum seasonal AFD occurs in the September-October-November (SON) period; a lightning activity higher than 40 flashes km^{-2} yr^{-1} covers practically the whole area observed in SA (Figure 2a). The December-January-February (DJF) period also displays a significant lightning activity, similar to the SON period, mainly on the southern part of the examined region; meanwhile, the AFD is lower over the northern and central parts of the continent, corresponding to the winter season over the Northern Hemisphere (NH) (Figure 2b). The AFD in SA diminishes in March-April-May (MAM) period during the autumn season of the SH (Figure 2c), and finally, the lightning activity is substantially enhanced over the NH of SA during the June-July-August (JJA) period, corresponding to the summer season in this region (Figure 2d). It is interesting to note in Figure 2 a region located in the northeastern part of Argentina, southern Brazil, Paraguay, and Uruguay (including the La Plata basin), which presents a large, steady AFD (>20 flashes km^{-2} yr^{-1}) throughout all seasons of the year. This area was related with a wide convective core associated with a high lightning activity during spring and fall seasons [*Rasmussen et al.*, 2014].

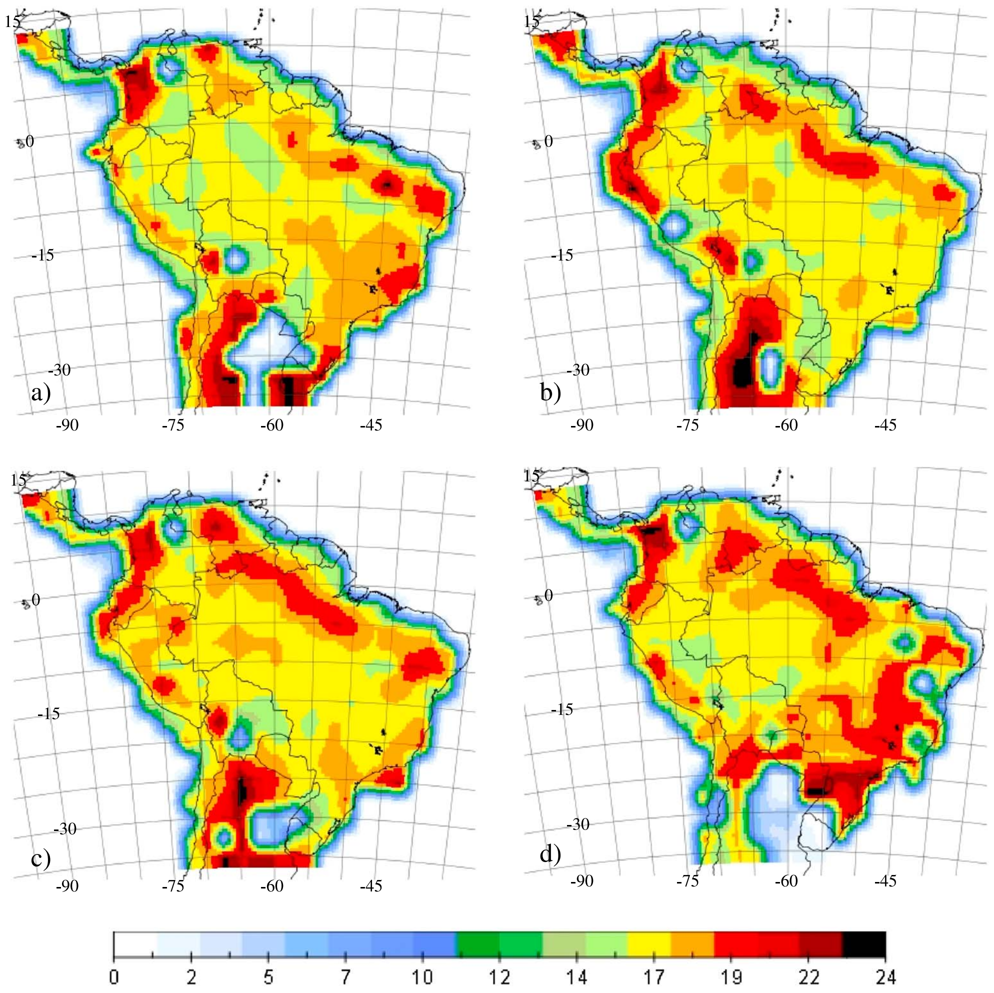

Figure 3. South America maps with the local time of maximum lightning activity during the 24 h daily cycle for the period of (a) September-October-November, (b) December-January-February, (c) March-April-May, and (d) June-July-August.

Figure 3 shows the maps of South America along with the local time of maximum lightning activity during the 24 h daily cycle during SON (Figure 3a), DJF (Figure 3b), MAM (Figure 3c), and JJA (Figure 3d). The results show that in the northern and central regions of South America, the time of maximum lightning activity (across all seasons) was mainly concentrated between 14:00 and 18:00 LT, which can be associated with the peaking of the local convective activity linked to the heating of the surface in the interior of the landmasses. These results are in agreement with those reported by *Pinto et al.* [2003], who found similar local time distribution of the negative cloud-to-ground lightning flash in the tropical part of South America. Interestingly, in the subtropical part of the studied region, the area limited by 25°S, 35°S of latitude and 50°W, 70°W of longitude, which includes Paraguay, northern Argentina, southern Brazil, and Uruguay, including the La Plata basin, the time of maximum lightning activity is more variable and is mainly shifted to nocturnal hours, extending from close to midnight to early morning hours throughout the seasons of the year. In agreement with these results, *Rasmussen et al.* [2014] found nocturnal maximum of lightning activity over the foothills and Sierras de Córdoba (30°S and 35°S of latitude and around 65°W of longitude) for all seasons considered (except in JJA).

Liu et al. [2010] studied the geographical distribution of rainfall from thunderstorms, electrified shower clouds, and nonelectrified shower clouds over the globe. They found that nonelectrified rainfall dominates the total rainfall over oceans and over the Amazon basin in South America, while thunderstorms contribute a large amount of rainfall over land, including some heavy rainfall regions over northern Argentina.

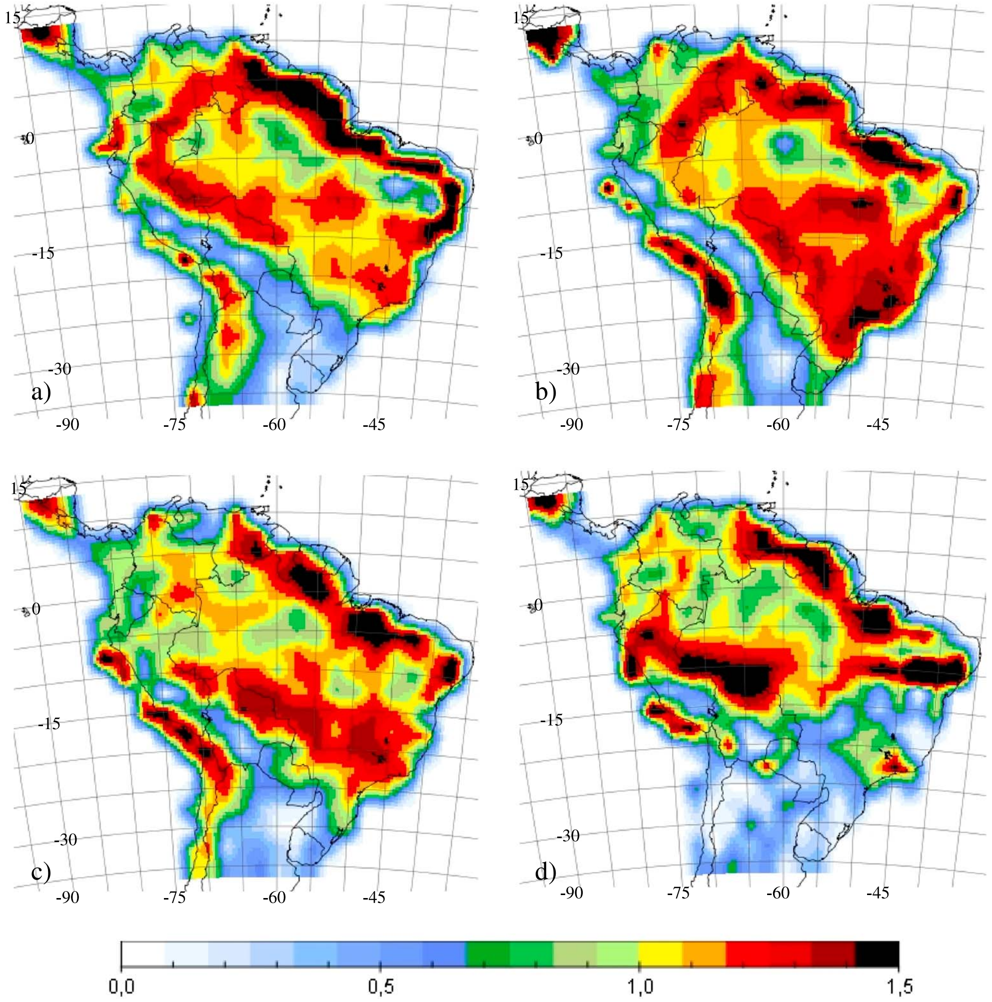

Figure 4. South America maps with the values of the NA parameter for the period of (a) September-October-November, (b) December-January-February, (c) March-April-May, and (d) June-July-August. The color scale represents the NA values.

Particularly, they showed that nearly all rainfall over northern Argentina and the 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. On the other hand, at the southern foothills of the central Andes (25°S, 35°S of latitude), most of the precipitation comes from systems of small horizontal dimension but featuring deep convective cells. These cells first appear over the slopes of the Andes during the afternoon, coinciding with the time of maximum in lightning activity in this region. It has been shown [*Matsudo and Salio*, 2011; *Rasmussen and Houze*, 2011; *Rasmussen et al.*, 2014, among others] that these systems move eastward toward the La Plata basin region, in association with a midlatitude disturbance, where they grow into large systems. These systems are expected to cause the time of maximum lightning activity to occur 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 MCSs. They suggested that MCSs tend to develop initially from convective cells triggered during the afternoon in the region of the southern foothills of the central Andes. The nocturnal/early morning maximum is supported by the input of moisture from the diurnally modulated South American low-level jet

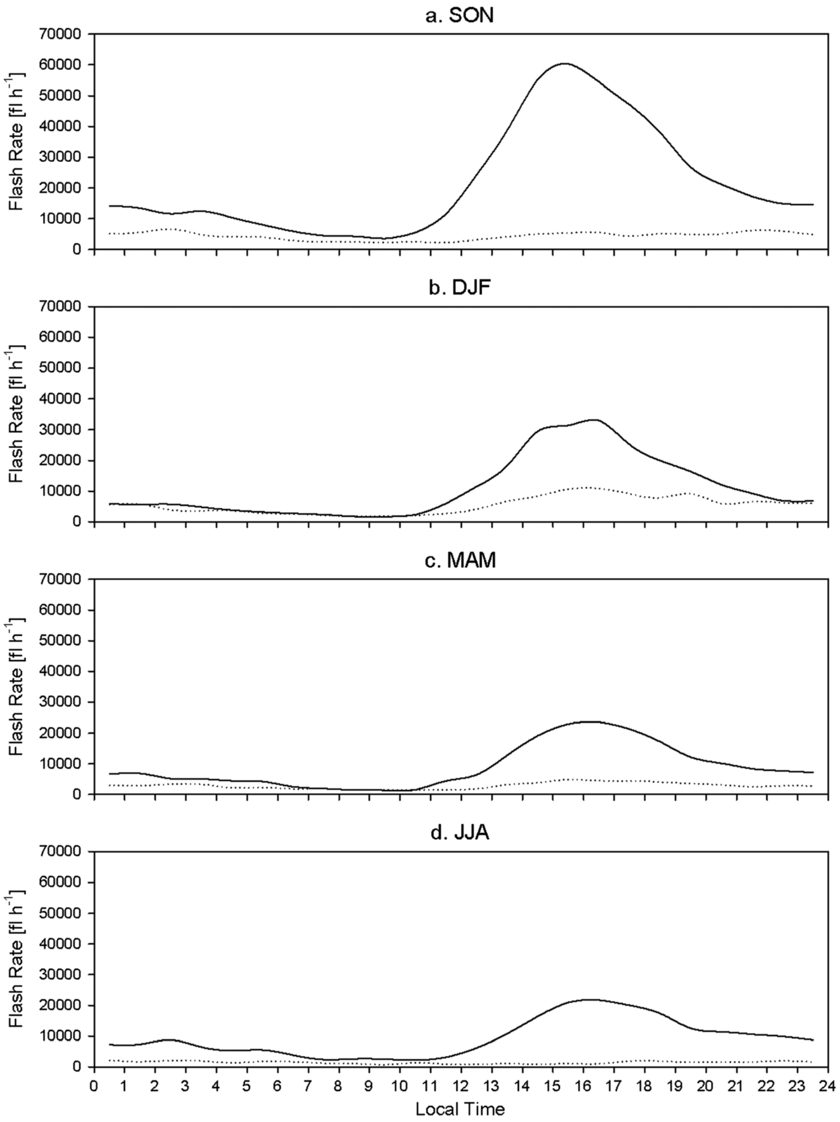

Figure 5. The 24 h daily cycle of the seasonal flash rate for the tropical region (solid line) and for the subtropical region (broken line).

[*Romatschke and Houze*, 2010; *Rasmussen and Houze*, 2011]. Consistent with this type of storm movement and evolution, the time sequence of lightning activity shown in the region around the La Plata basin is in agreement with the current results.

The strength of the diurnal cycle is represented by the parameter NA and is mapped in Figure 4 during SON (Figure 4a), DJF (Figure 4b), MAM (Figure 4c), and JJA (Figure 4d). During the periods of abundant lightning activity (SON and DJF), the areas of the north, center, and east of South America, including the Amazon basin, display a marked diurnal cycle of lightning activity with NA values around or higher than 1 and flash peaks between 14:00 and 18:00 LT. These results, together with those displayed in Figures 3a and 3b, support the importance of the local-level convective processes in these regions. The areas over the eastern foot of the Andes in Bolivia, Peru, and western Argentina present NA values between 0.5 and 1 indicating the presence of a fairly well-defined peaks of lightning activity mainly between 18:00 and 21:00 LT (see Figure 1b). Northeastern Argentina, southern Brazil, and Uruguay show NA values lower than 0.5, associated with low values of R^2 ($R^2 < 0.5$), indicating a lack of a well-defined peak on lightning activity. Therefore, the time of maximum activity is not well defined by the model, and lightning can occur during any time of the day.

Regarding the trend of the diurnal cycle of lightning activity in other parts of the world, several studies have examined the summertime diurnal distributions of lightning, thunder, and precipitation over the USA and found that the Central USA presents another region where the peak of lightning activity does not occur in the late afternoon to evening hours (between 15:00 and 19:00 LT), but it is shifted to nocturnal hours. *Zajac and Rutledge* [2001] examined the cloud-to-ground (CG) lightning activity using the National Lightning Detection Network (NLDN) data from 1995 to 1999. They found a diurnal trend with a clear maximum over southeastern, eastern, and western USA with maxima between 15:00 and 18:00 LT, while over Central USA, this analysis shows a lack of a well-defined diurnal cycle with the maximum frequency of lightning occurring at nighttime. *Holle* [2012] also used CG lightning data from NLDN and showed that Central USA presents CG lightning almost all day long with a strong maximum between midnight and 02:00 LT. *Lyons et al.* [1998] studied the CG flash with peak current $>$75 kA detected by the NLDN during summer months; their analysis shows that 67% of the large peak current CG flashes with positive polarity (LPC + CG) are observed over Central USA; the diurnal cycle of LPC + CG shows a peak at 02:00 LT. *Carey and Buffalo* [2007] found a high frequency of positive storms over Central United States with 30–90% of all warm season severe storm being positive storms; positive storms are defined as those with more than 25% of positive ground flashes. *Villarini and Smith* [2013] found extreme lightning activity over Central U.S. and west of the Appalachian Mountains during summertime, with an enhanced positive flash density over the upper Mississippi River basin. Positive cloud-to-ground lightning flashes are produced by the stratiform region of MCSs and supercell storms. Since the peak current magnitude of +CG increases with the development of this region and reaches its maxima when the stratiform region is most intense [*Petersen and Rutledge*, 1992], the +CG over Central USA seems to be associated with this type of systems.

It follows that Central USA and northern Argentina are regions with large and frequent MCSs. Both regions present favorable conditions for severe thunderstorm development; they are the following: low-level jets bringing moist air (from Gulf of Mexico and Amazonia, respectively), high terrain (Rocky and Andes Mountains, respectively) 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 MCSs are expected to be the ones responsible for the peak in lightning activity not to occur in the late afternoon but to be shifted to nocturnal hours over these regions.

Considering that the tropical region (TR) of SA displays strong diurnal variation, with a lightning peak in afternoon hours, while the subtropical region (SR) displays a not-well-defined diurnal pattern, it seems relevant to separately examine the flash rate contribution made by both the tropical and subtropical parts of the continent of SA to the GEC and Carnegie curve, as mentioned in the Introduction section. Figure 5 displays the 24 h daily cycle of the flash rate coming from these two regions during SON (Figure 5a), DJF (Figure 5b), MAM (Figure 5c), and JJA (Figure 5d). The TR displays a strong diurnal variation with lightning activity peaking between 14:00 and 18:00 LT, and the flash rate amplitudes are different for different seasons; the maximum diurnal flash rate occurs in SON period, and then the lightning activity gradually decreases up to JJA period. Instead, the SR shows a steady contribution of the seasonal lightning activity with a weak diurnal variation. The results clearly show that the contribution of the TR of SA to the GEC dominates over the SR contribution throughout all seasons. Despite the comparable magnitudes of the AFD (flashes $\text{km}^{-2}\,\text{yr}^{-1}$) in TR and SR, the TR contribution to the GEC is more significant than the SR contribution due to the fact that the surface covered by the TR is more than twice that covered by the SR. The current results are in accordance with those by *Blakeslee et al.* [2014], who found that the contribution of South America to the GEC is mainly during spring and summer seasons in the Southern Hemisphere (SH).

4. Conclusions

In this study the diurnal variation of seasonal lightning activity in South America was examined using data from the Lightning Imaging Sensor. Harmonic analysis was used to detect the spatial variations in the peak and strength of diurnal lightning activity across the studied area.

The results show that the tropical region of SA displays the maximum annual flash density in SON and JJA seasons, while the region located in the northeastern part of Argentina, southern Brazil, Paraguay, and Uruguay, including La Plata basin, presents a large, steady annual flash density ($>$20 flashes $\text{km}^{-2}\,\text{yr}^{-1}$) throughout all seasons of the year.

Generally, in the northern and central regions of South America, the time of maximum lightning activity was concentrated in the late afternoon to evening hours (between 14:00 and 18:00 LT), which may be associated with the peaking of the local convective activity associated with surface heating caused by daytime insolation. Meanwhile, in subtropical South America, particularly in the area limited by 25°S, 35°S of latitude and 50°W, 70° W of longitude, including the La Plata basin, the time of maximum lightning activity is not well defined and lightning can occur during any time of the day. This behavior can be associated to the presence of MCSs 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 the southern foothills of central Andes. The strength of the diurnal cycle was greater in the areas of the north, center, and east of South America, including the Amazon basin, stressing the relevance of the local-level convective processes in these regions. The cycle was weaker in general in subtropical South America (northeastern Argentina, southern Brazil, and Uruguay), where the MCSs predominate.

Annual flash densities (flashes $\mathrm{km}^{-2}\,\mathrm{yr}^{-1}$) in the tropical and subtropical part of the continent of South America were observed to have comparable magnitudes. However, the contribution of the continental tropics to the global electric circuit dominates over the continental subtropics' contribution throughout all seasons, due to the fact that the surface covered by the tropical region is more than twice the area covered by the subtropical region.

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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