Atmospheric Electrical Activity in central Argentina and its relationship with phenomena observed at the Auger Observatory

M G Nicora[1,2,4,5] D M Baissac[1,2,4,5], C I Villagran[1,2,4,5], Y Velazquez[1,2,4,5], F I Solari[1,2,4,5], M F Barle[1,2,4,5], L Pini[6] and F Bertone[3]

[1] DEILAP, Instituto de Investigaciones Científicas y Técnicas para la Defensa – CITEDEF, San Juan Bautista de La Salle 4397, Buenos Aires, Argentina
[2] Unidad de Investigación y Desarrollo Estratégico para la Defensa (CONICET-MINDEF), San Juan Bautista de La Salle 4397, Buenos Aires, Argentina
[3] Servicio Meteorológico Nacional. Buenos Aires, Argentina
[4.] Instituto Franco-Argentino para el Estudio del 4. Clima y sus Impactos (IRL3351 IFAECI).
[5] Facultad de Ciencias Astronómicas y Geofísicas de la Universidad Nacional de La Plata, Paseo del Bosque s/n, FWA, B1900 La Plata, Provincia de Buenos Aires, Argentina
[6] Departamento de Física, Universidad Nacional del Sur, Avenida Alem 1253, Bahía Blanca, Argentina

E-mail: gabriela@blueplanet.com.ar

Abstract. Thunderstorms in Argentina have great spatial variability explained by various mechanisms on different spatio-temporal scales, associated with the meridional extension and orography of the region. The Pierre Auger Observatory is located in Mendoza Province in central-western Argentina where the unique meteorological and geographical conditions result in a high spacial density of convective storms. **Atmospheric electrical activity (AEA)** produces Transient Luminous Events (TLEs) of which ELVES are the most prominent members of the extraordinary family that includes halos, jetstorms, and sprites. Northern Argentina and Southern Brazil are prolific producers of TLEs, which can be observed at the Pierre Auger Observatory by the Fluorescence Detector (FD) 24 UV telescope. In this work, we present the characterization of the AEA in the study region and the most important meteorological characteristics to aid in understanding which of the dynamical or microphysical processes could act in the formation of TLEs.

1. Introduction

South America (SA) is a continent with a wide meridional extension (12°N–55°S) and complex topography [1] including the Cordillera de los Andes, which is the longest cordillera in the world. The South American Low-Level Jet (SALLJ), located east of the Andes, is a crucial low-level circulation feature that is responsible for transporting moisture from the Amazon Basin towards southeastern SA.

The atmospheric electrical activity (**AEA**) pattern is in concordance with the meteorological processes, especially those of precipitation. [2] Found that precipitation over ocean basins and Amazonia is dominated by non-electrified-cloud precipitation, whereas thunderstorms greatly contribute to the total rainfall over the continent/SA; in particular, in northern Argentina and La Plata Basin, almost all precipitation comes from thunderstorms.

Figure 1 depicts the AEA diurnal cycle in SA [3]. On tropical SA, there is a clearly defined cycle with a peak around 17–19 LT. In northern Argentina, the maximum in AEA occurs at midnight while in the Pampa region the diurnal amplitude is very shallow and the data is disperse, which means that the AEA may occur at any time of day. Over the Central Andes slopes, the AEA is less than in the other regions and its occurrence is confined to the afternoon hours with no activity throughout the rest of the day.

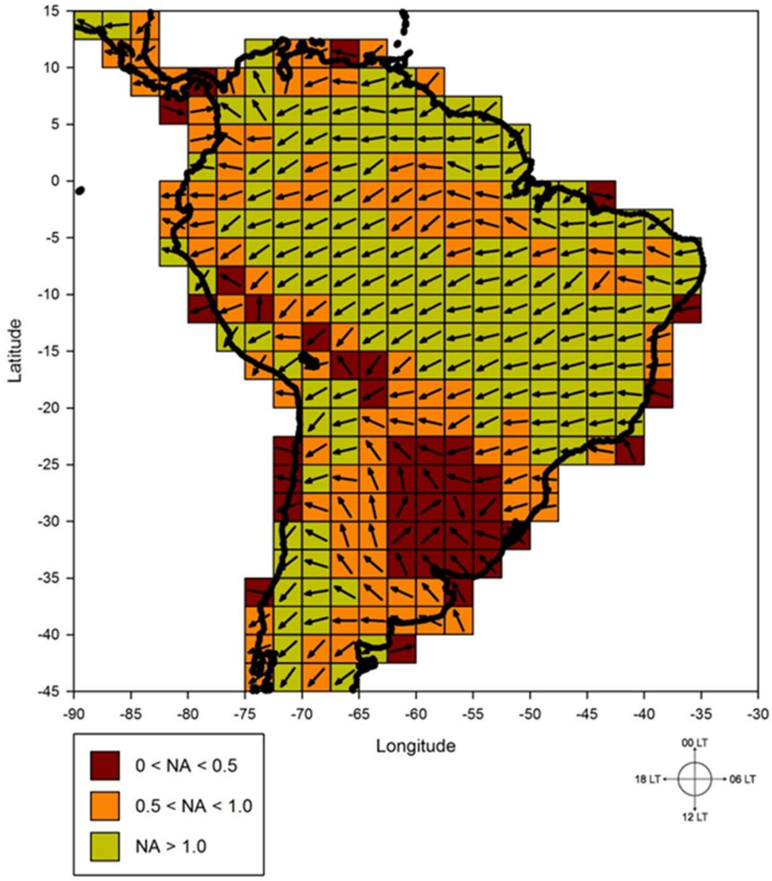


Figure 1. AEA diurnal cycle (adapted from [3]). NA <0.5 indicates the lack of a well-defined cycle in the AEA or the existence of a double maximum, 0.5 <NA <1.0 indicates a tendency to a daily cycle with a defined maximum, NA>1 indicates a well-developed daily cycle, with a well-defined maximum in the daily cycle of the AEA in that region. The vectors represent the time of maximum activity in local time (LT)

The Pierre Auger Observatory measures the properties of the most energetic particles known in the Universe and aims to discover their sources. It is located in Mendoza, Argentina, in a vast plain (centered at 35ºS, 70ºW) known as the Pampa Amarilla. The Observatory has a viewing footprint for atmospherics observations of 3·106 km2, reaching areas over the Pacific and Atlantic oceans, as well as the Cordoba region—which is known for its severe convective storms [4]—. As shown in Figure 1, the Observatory area has a marked diurnal cycle centered on a maximum of 18 LT.

Journal of Physics: Conference Series **2398** (2022) 012005 doi:10.1088/1742-6596/2398/1/012005

2. Data and methodology

The discharge data is provided by The World Wide Lightning Location Network (WWLLN, http://wwlln.net). The WWLLN is a worldwide network that became operational in August 2004 and has more than 70 stations over different continents; it detects very low-frequency radio waves (spherics) emitted by discharges. The overall efficiency of the WWLLN network in detecting discharges ranges from 5 to 10%, although recent studies estimate that the overall efficiency has reached values around 15% in 2017 [5].

The isokeraunic maps were made using the WWLLN data and the SYNOP data from the Servicio Meteorológico Nacional (Argentinian national weather service). The methodology can be found in [3, 5]. In this methodology the working grid is 0.2º.

We will work with three variables: **Thunderstorm Days (Td)** —defined as those days in which at least one discharge is detected in the grid—, **Lightning per Thunderstorm Day (L/Td)**—defined as the number of discharges per grid for each storm day—, and, finally, **Lightning/year (L/Y)**—that is the number of discharges in each grid per year.

3. Thunderstorms Days (Td)

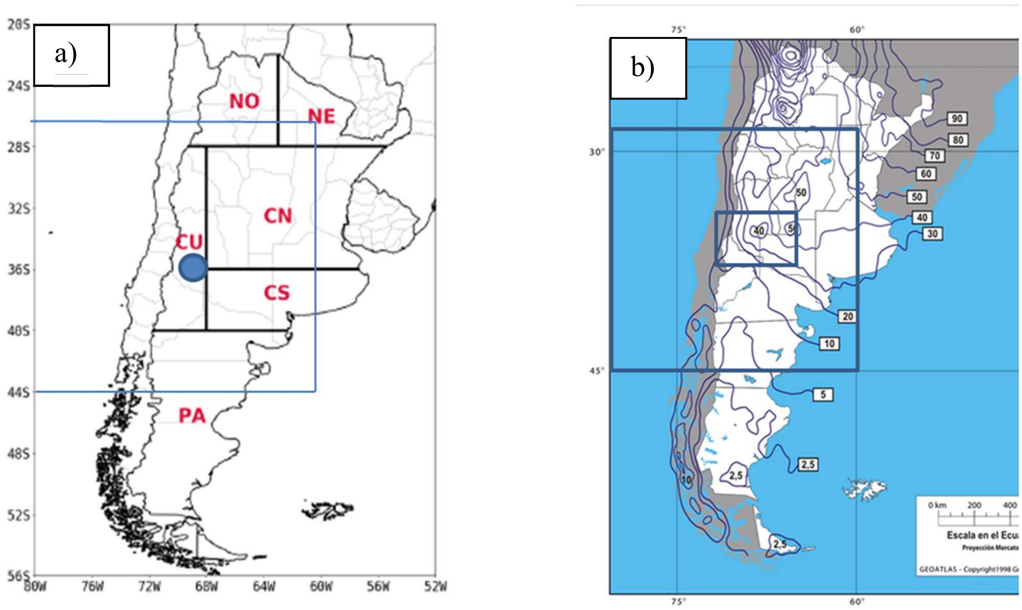
One of the first tools employed by humanity in monitoring weather and climate was the measurement or count of storm days. This variable is easy to quantify and it indicates the storm frequency and seasonal variation in the monitoring site; its trend over the decades contributes in understanding the atmospheric variations. Furthermore, the number of cloud-to-ground discharges—these are the discharges most dangerous to people, animals, and personal belongings—can be inferred from the storm days variable; then, protective measures can be enacted taking into account the electrical activity of the site.

The strict definition of "storm day", as given by the International Meteorological Committee (IMO) in 1878 is "A calendar day on which the observer heard thunder without discriminating whether the discharge was cloud-to-cloud or cloud-to-ground and regardless of the intensity of the storm and precipitation fall".

3.1. Isokeraunic maps

An isokeraunic map shows regions with equal number of thunderstorm days in a given time period. In Argentina, the first isokeraunic maps were elaborated using data from the Servicio Meteorológico Nacional manual observations. [3, 5] analyzed the relationship between manual thunderstorm observations (SYNOP reports) and lightning detected by the WWLLN network in Argentina.

Thunderstorms in Argentina have a great spatial variability associated with the country`s orography and meridional extension. In this study, the territory was divided into five regions according to [5]: **Northwest (NO)**, **Northeast (NE)**, **Cuyo (CU), Center**—which in turn was divided into north **(CN)** and south (**CS**)—, and **Patagonia (PA**). Figure 2 shows the maps made by [3] and the study regions in which the country was divided.



a) Regions into which the country was divided according to its meteorological features [5]

b) Annual isokeraunic map [3]

Figure 2. Annual isokeraunic map and the Observatory's coverage area for the measurement of phenomena observed in the atmosphere is shown in blue squares

The most important characteristics of each region, according to [5], are presented in this section. More references for each region can be found in their work.

- **Northwest Region NO.** This area, which is characterized by a very heterogeneous terrain with peaks of more than 6000 meters above sea level, has the highest values in the country in terms of storm days with **100 Td/year**. In addition, a very steep gradient is observed, especially over the province of Jujuy, with a north-south orientation. In this region, at low levels during the summer and intermittently during the winter, a very deep low pressure system forms over the Chaco region (25ºS, 60ºW) along with a depression of thermo-orographic origin—known as Depresión del Noroeste Argentino (DNOA)—present throughout the year, and a meridional jet stream from north to east of the Andes (SALLJ). The SALLJ transports warm and humid tropical air masses towards subtropical latitudes, providing favorable conditions for the generation of convective precipitation and storms in northern and central Argentina.
- **Northeast Region NE.** In this area, the annual isokeraunic map shows an increase of Td oriented towards the northeast that reaches values higher than **80 Td/year** covering the entire province of Misiones. Based on satellite observations, [6] identify this region as one of the regions where the highest density of electrical activity is observed worldwide. This area of maximums extends from the north to the center of the country.
- **Center Region CN/CS.** The annual isokeraunic map has a relative maximum over the Sierras de Córdoba (SCBA), with annual averages exceeding **50 Td/year**. Studies based on satellite observations have revealed that this region presents one of the most favorable natural scenarios for the onset of the most intense convective systems in the world. The unique characteristics of this region prompted the development of the RELÁMPAGO-CACTI Project (carried out in November 2018) with the objective of furthering the knowledge of the conditions that favor the

onset, generation and development of these extreme events as well as improving their forecasting [7].

- **Cuyo Region CU**. In this region, where the highest mountain peak of the Cordillera de los Andes is located, the annual isokeraunic map shows a west-east Td gradient. The highest values reach **45 Td/year** in the center and east of the Mendoza province. As in the NO and SCBA, the interaction between topography and atmosphere generates favorable conditions for the onset and intensification of severe storms. The Auger Observatory is located in this region, right at the highest longitudinal Td gradient..
- **Patagonia Region PA**. Towards higher latitudes, the isokeraunic map shows an increase in Td values in a SW-NE direction (from the center of Patagonia towards the central plains of the country), that becomes more intense south of the provinces of Mendoza and La Pampa, where values vary between **20 and 45 Td/year**

3.2. Thunderstorm Days series

Climate variability in Argentina has been extensively researched since it affects numerous human activities. However, few studies address the climate evolution in terms of changes in the Td frequency. This Td variable has been recently classified as an essential climatic variable (EVC) by the Weather Meteorological Organization (WMO).

A recent study [8] analyzed the Td temporal evolution using the data from 8396 weather stations around the globe. They found that Argentina is one of the places where the AEA is more frequent and that there is a significant increase in Td in the 1998–2017 period when compared to 1975–1994. Furthermore, for the 1975–2017 period, there is a significant increase (from 8% to 11%) on storm occurrence probability, with a growth rate of 2.6 Td/decade. Positive trends in Td were found in all four seasons; summer and spring had the greatest increases in Td, with rates of 1.2 and 1.0 Td/decade, respectively.

[9] Analyzed the temporal series from the five Argentinian centennial weather stations recognized by the WMO. The data up to 1956 was manually retrieved by the author by hand-processing more than 3500 weather notebooks and it has never been published before. The author found a significant increase in Td in four stations: Buenos Aires Observatory (1.2 Td/decade), Ceres Aero (1.1 Td/decade), La Quiaca Observatory (3.6 Td/decade), and Malargüe Aero (2.2 Td/decade). Figure 3 shows the temporal evolution of Malargüe station, which is the station closest to Auger Observatory.

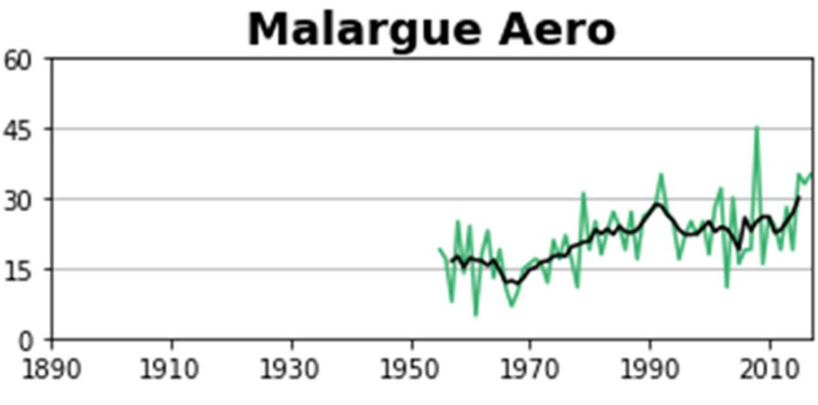


Figure 3. Malargüe Thunderstorm Days series. Black line is the moving averages (5 years), and green line is the annual series

4. AEA over and in the visual of the Observatory

In this study, we will present the Thunderstorm Days (Td), Lightning per Td (L/Td) and Lightning/year (L/Y) studies for the area north of the Auger Observatory and the southern coverage area of the Observatory.

4.1. Characterization of the AEA in the period 2010-2020 above the Auger Observatory

In this section, we use the WWLLN data to characterize the AEA by taking three parameters in a grid as mentioned in the methodology section. The figures include the location of the stations Loma Amarilla (LA), Coihueco (CO), Los Leones (LL), and Los Morados (LM), in which the reference values are plotted on the grid for each detector. Figure 4 shows the following features:

- **Lightning (L/Y).** The (Fig. 4a). There is a strong longitudinal variation of Lightning/year**. Los Morados has a value of 168 L/Y in the studied period (2011–2021) which is more than double than the 71 L/Y value found in Cohueco**. This highlights the variable inhomogeneity within the Observatory limits that are located in a transitional zone between the arid part of the mountain range and the large storm systems at the center of the country.
- **Thunderstorm Days (Td)**. (Fig. 4b). The same pattern of longitudinal variation is observed with Td, with maximum values in **Loma Amarilla with 27 Td** per year and a minimum is **Cohueco with only 18 Td**.
- **Lightning per Td (L/Td).** (Fig. 4c). This variable represents the average number of strokes in each grid per storm day, and helps us understand if there is any inhomogeneity (rivers, lakes, lagoons) that cause abrupt variations in the amount of discharges.

4.2. Characterization of the AEA in the period 2010-2020 *in the southern part of the Auger Observatory.*

As an example of a study in all the sites covered by the Observatory, we also analyze the southern area covered by the Observatory. This area encompasses the provinces of Rio Negro, Neuquen, La Pampa and part of Chubut and Buenos Aires- Figure 5 shows the following features

- **Lightning (L/Y).** (Fig. 5a). A clear increasing trend in a NW-SE direction is observed. This seems to be consistent with the formation of dry lines, which are borders between air masses characterized by a strong moisture contrast at low levels. Strong humidity gradients usually develop, in the absence of a well-defined front at low levels, between the arid elevations of the Patagonian Plateau and the Pampean Plain. These boundaries between air masses are frequently oriented in a NW-SE direction and are sometimes associated with the development of thunderstorms that, under favorable conditions, can lead to severe weather episodes [10].
- **Thunderstorm days (Td)**. (Fig. 5b). The same pattern is observed in the diagonal variations with values between 5 and 40 Td.
- **Lightning per Td (L/Td).** (Fig. 5c). This parameter shows certain homogeneity throughout the study area, although the observed variations might be determined by certain orographic variations.

.

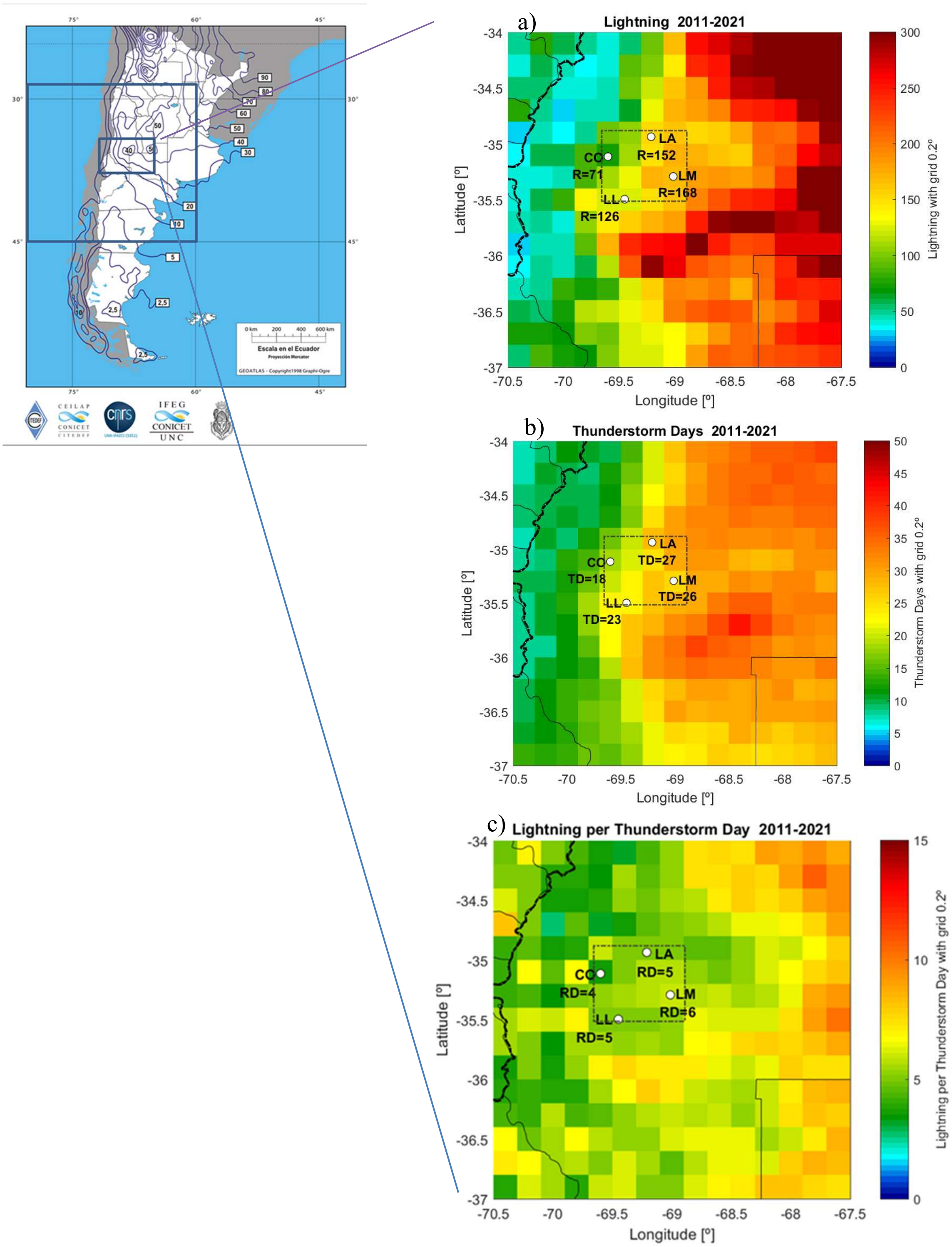


Figure 4. AEA characterized by three parameter in a grid (as mentioned in the methodology): (a) lightning per year, (b) thunderstorm days, and (c) lightning per storm day. The circles represent the stations Loma Amarilla (LA), Coihueco (CO), Los Leones (LL), and Los Morados (LM), with reference values are plotted on the grid for each detector.

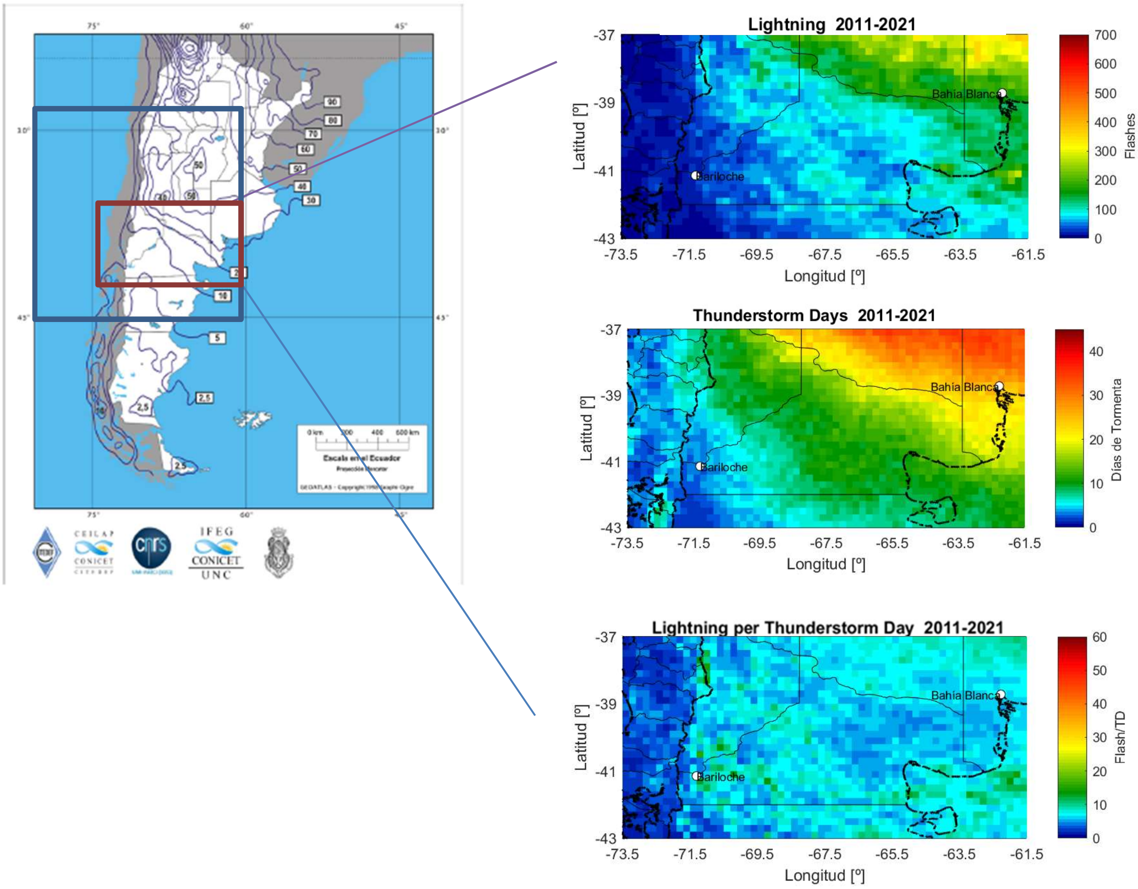


Figure 5. Same as Figure 4 but for the area south of the Auger Observatory.

5. Conclusions

To understand the AEA and its associated events, it is essential to understand the environment of storm generation in central Argentina, so in this study we present the AEA, Td and lightning in central Argentina using isokeraunic maps of the whole territory.

We show that Over the Observatory there are marked differences in the density of discharges, as well as in the Td. The authors believe that having the data of the electric field mills network at the Pierre Auger Observatory is important for future works.

Acknowledgments Servicio Meteorológico Nacional (Argentinian national weather service for providing SYNOP data, and the World Wide Lightning Location Network (http://wwlln.net) for providing the lightning location data used in this paper. This research was supported by GeoRayos II and CITEDEF with the Proyect GeoRayos II WEB and GINKGO 03 NAC 040/19. The authors would also like to thank the AHUEKNA Foundation their help in financing the presentation of this work, and .P Auger Cosmo-Geophysics group.

References

[1] Ferreira, G.W.S.; Reboita, M.S. A New Look into the South America Precipitation Regimes: Observation and Forecast. Atmosphere 2022, 13, 873. https://doi.org/10.3390/atmos13060873

[2] Liu, C., Williams, E. R., Zipser, E. J., & Burns, G. (2010). Diurnal variations of global thunderstorms and electrified shower clouds and their contribution to the global electrical circuit. Journal of the atmospheric sciences, 67(2), 309-323. https://doi.org/10.1175/2009JAS3248.1

[3] M. Gabriela Nicora. Actividad eléctrica atmosférica en Sudamérica. PhD thesis, 2014. URL https://doi.org/10.35537%2F10915%2F42231

[4] Aab, A., et al. "A 3-Year Sample of Almost 1,600 Elves Recorded Above South America by the Pierre Auger Cosmic-Ray Observatory." Earth and Space Science 7.4 (2020): e2019EA000582 https://doi.org/10.1029/2019EA000582

[5] Bertone, F., Nicora, G., & Vidal, L. Thunderstorm days over Argentina: Integration between human observations of thunder and the WWLLN lightning data. International Journal of Climatology. https://doi.org/10.1002/joc.7800

[6] Albretch Rachel I. Albrecht, Steven J. Goodman, Dennis E. Buechler, Richard J. Blakeslee, and Hugh J. Christian. Where Are the Lightning Hotspots on Earth? Bulletin of the American Meteorological Society, 97(11):2051–2068, nov 2016. https://doi.org/10.1175/BAMS-D-14-00193.1

[7] Nesbitt, S. W., Salio, P. V., Ávila, E., Bitzer, P., Carey, L., Chandrasekar, V.& Grover, M. A. (2021). A storm safari in subtropical South America: Proyecto RELAMPAGO. Bulletin of the American Meteorological Society, 102(8), E1621-E1644. http://DOI10.1175/BAMS-D-20-0029.1

[8] Lavigne, T., Liu, C., & Liu, N. (2019). How does the trend in thunder days relate to the variation of lightning flash density?. Journal of Geophysical Research: Atmospheres, 124(9), 4955-4974. https://doi.org/10.1029/2018JD029920

[9] Bertone., F. Estudio estadístico de series temporales de días de tormenta en Argentina y preparación de mapas isoceráunicos dentro de un contexto de cambio climático. Tesis de licenciatura DCAO UBA Nov. 2020.

[10] Bechis, Hernán . (2020). Estudio de los mecanismos que llevan a la formación y evolución de las líneas secas en la Argentina. (Tesis Doctoral. Universidad de Buenos Aires. Facultad de Ciencias Exactas y Naturales.). http://hdl.handle.net/20.500.12110/tesis_n6841_Bechis.