PROCEEDINGS OF SCIENCE

ONLINE ICRC 2021 THE ASTROPARTICLE PHYSICS CONFERENCE Berlin | Germany 37th International Cosmic Ray Conference 12–23 July 2021

Characteristics of near-earth thunderstorm electric fields at LHAASO observatory

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Abstract. Thunderstorms are common weather phenomena at high altitudes, accompanying with lightning, strong winds and other disasters. During thunderstorms, the strength of atmospheric electric fields could be up to 1000 V/cm or even higher. The intensity fluctuates violently and the polarity could change multiple times. So, direct measurement of the thunderstorm electric field is a quite challenging work. The Large High Altitude Air Shower Observatory (LHAASO), under the construction of a project at Daocheng (4410 m a.s.l., Sichuan, China), is featured with frequent thunderstorms, especially in summer. The distribution of thunderstorm parameters is presented by analyzing the near-earth atmospheric electric field of the LHAASO station in this work. The polarity and intensity variation characteristics of the electric field in the cumulus, mature and dissipating stages of thunderstorm are also discussed. The results show that the thunderstorms mainly occur in the period of a time from late afternoon to evening. They are more frequent and stronger in summer. During the mature stage, the field changes more dramatically. Our results could be helpful in understanding the variations of cosmic rays at LHAASO during thunderstorms, and provide valuable information for studying global thunderstorm activity.

Keywords: Near-earth thunderstorm electric fields, LHAASO observatory, Cosmic rays, Thunderstorm parameter

37th International Cosmic Ray Conference (ICRC 2021)
July 12th – 23rd, 2021
Online – Berlin, Germany

*Presenter

PoS(ICRC2021)286

1. Introduction

Thunderstorms are severe weather phenomena which can inflict immense death and property damage worldwide due to lightning, heavy rains, hail, and strong winds. During thunderstorms, the electric field strength could be up to 1000 V/cm, and the intensity or polarity changes dramatically. In 1921, physical model of GEC (the Global Electric Circuit) was first proposed by Wilson [1]. As it is well-known now, GEC is driven by thunderstorms and electrified rain clouds due to the separation of electric charge in the atmosphere, which distributes the large amount of current flow around the globe [2-4]. Namely, as current sources, thunderstorm plays the role of "generator" to maintain the balance of atmospheric electric field in fair days all around the world [3]. For years, scientists have studied the thunderstorm activity around the world and found it varies with location and time, which closely related to the activity of the sun. Qie et al. [5], Zhang et al. [6] and Yu et al. [7] reported the characteristics of thunderstorm over Tibetan Plateau. Their investigations showed that thunderstorms mainly occurred in summer season. Hripsime et al. [8] presented the atmospheric electric field variations during thunderstorms for several locations with different altitudes in Armenia. Their results indicate that the thunderstorm is more frequent from May to June and the most active part during the day is in the late afternoon and evening.

When there is a thunderstorm, the near-earth electric fields changes dramatically. Observations indicate that the electric field with strength of the order up to 1000 V/cm may appear [9]. In such strong fields, by accelerating or decelerating the charged particles in extensive air showers, the location, time, energy and flux of secondary cosmic rays will be considerably affected. The effects of thunderstorm electric fields on ground cosmic rays were studied by Chilingarian et al. [10, 11], Zhou et al. [12,13] and Bartoli et al. [14], and the acceleration mechanism was discussed in detail.

To learn more about the thunderstorm effects on the cosmic rays, further more investigations on the characteristics of thunderstorm activity are needed.

2. The atmospheric electric field mill at LHAASO

The Large High Altitude Air Shower Observatory (LHAASO) consists of three sub-arrays, an area of 1.3 km^2 array (KM2A), a 78,000 m^2 water Cherenkov detector array (WCDA), and 18 wide field-of-view air Cherenkov/fluorescence telescopes (WFCTA) [15]. It will carry out accurate measurements of the extensive air shower (EAS) by employing hybrid detecting technologies mentioned above. Because of its high altitude, LHAASO is characterized with frequent thunderstorms, especially in summer. So the count rates recorded by the detectors, the reconstructed shower rates and direction will be inevitably affected in a thunderstorm. Therefore, it is necessary to carry out thunderstorms monitoring at LHAASO station.

For thunderstorms monitoring at the LHAASO site, a Boltek EFM-100 field mill was installed at the roof of WCDA-2 pond in September 2019. The EFM-100 is a low cost, high quality atmospheric electric field monitor which can be directly connected to the exhibition computer to display and record data. The polarity and intensity of the near-earth electric field can be recorded every 0.5 s in real time. The measurement range of the electric field is in ±1000 V/cm and the measurement accuracy is 5%.

By using the atmospheric electric field data, we analyzed the active character of the thunderstorm at LHAASO observatory. The variation characteristics of the electric field during the thunderstorm are also discussed in this paper.

3. Data analysis and results

3.1 Data selection

Observation on thunderstorms at LHAASO was carried out since October 2019. In this work, we analyzed the atmospheric electric field data collected by EFM-100, covering a whole year from October 2019 to September 2020. We found that the direction of the electric field in fair weather is always downward, and the strength of the field is always less than 20 V/cm. While it is a disturbed weather, the electric field changes sharply. It may be a strong or a weak field, and may last a long or a short period. In order to study the thunderstorms activity, the first step is to filter and select the electric filed data that meet the thunderstorm conditions. In our work, as thunderstorm weather, the maximum strength of the near-earth atmospheric electric field is larger than 500 V/cm and lasts for at least 8 minutes, or it is higher than 900 V/cm at least 4 minutes. In fact, the measured electric field data will be affected by the environments, such as the meteorological conditions, height of the field mill above the ground, and so on. In our preliminary work the field value has not been calibrated yet and the measured data are relative ones. According to these criteria, 108 thunderstorms were analyzed in this paper.

3.2 Distributions of thunderstorm parameters

According to the climatic characteristics of LHAASO station, we use March to May, June to August, September to November and December to the following February to represent spring, summer, autumn and winter, respectively. We analyzed the characteristics of thunderstorm in LHAASO station from the aspects of thunderstorm day, thunderstorm number and thunderstorm duration.

3.2.1 Thunderstorm day

Thunderstorm day (TD in short) is defined as a local calendar day on which a thunderstorm occurs, regardless of how often it happens. It is one of the most important parameters in describing the characteristics of thunderstorms.

The monthly thunderstorm day distribution at LHAASO observatory was presented in Fig. 1. During the year (from October 2019 to September 2020), thunderstorms occurred on 81 days. The time of the initial thunderstorm is January 21, and the final thunderstorm occurs on November 20. More TDs are recorded from June to September. The highest peak was observed in July, with 17 TDs in this month. There are no thunderstorms in December. As seen from the figure, the TD distribution exhibits obvious seasonality. There are more than half of the TDs registered in summer, with a total of 42 days, which is the largest proportion among all seasons, contributing about 52% of the annual total of TDs. Spring (17 TDs) and autumn (20 TDs) follows, accounting for about 21% and 25%, respectively. Comparing to other seasons, thunderstorms is rarely occurring in winter.

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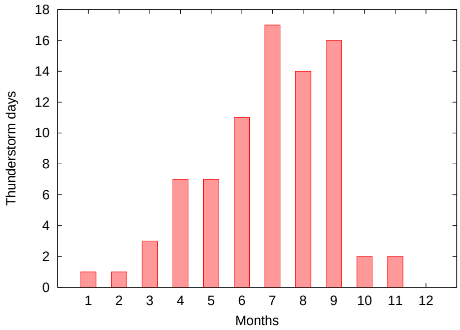


Fig. 1: The distribution of thunderstorm day over months.

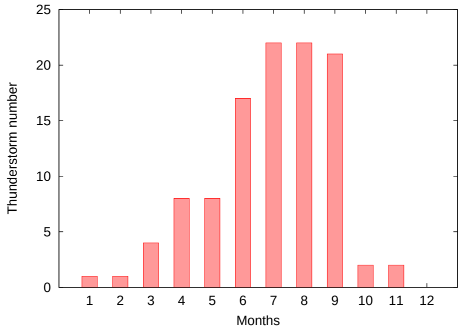


Fig. 2: The distribution of thunderstorm frequency over months.

3.2.2 Thunderstorm number

On a thunderstorm day, there may be only one thunderstorm, or there may be many. The number of thunderstorms in a day, or in a month, even in a year, is helpful to study the characteristics of thunderstorm activity. Fig. 2 shows the monthly distribution of thunderstorm number. From October 2019 to September 2020, there were 108 thunderstorms that met our filter criteria. The statistic results show that the thunderstorm is mainly recorded from March to September, and it is most active in July, August and September, exceeding 20 storms occurring in each of these months.

3.2.3 Thunderstorm duration

As we know, some thunderstorms last for a long time, some ones last for a short time. If a strong thunderstorm lasts for a long time, by accelerating or decelerating the charged particles, the effects on secondary cosmic rays cannot be ignored. The duration time is of great significance to study the thunderstorm characteristics and its effects on ground cosmic rays.

Based on the analysis of the 108 thunderstorms, Fig. 3 shows the monthly duration of the thunderstorms. The total duration of the thunderstorms throughout the year is more than 200 hours, and the mean of each thunderstorm is about 2 hours. In July, the total duration reaches the peak, up to about 50 hours.

According to the data, most of the thunderstorm weather lasts less than 2 hours and the number of thunderstorms decreases with the increase of duration time. The shortest thunderstorm lasts just over 10 minutes recorded on October 27, 2019. The thunderstorms with longer duration concentrate on the months from June to September. The thunderstorm with a maximum duration was observed on September 3, 2020, up to 7 hours.

3.3 Thunderstorm daily activity

The thunderstorm activity is related to the global and local climate. By learning the active periods of the thunderstorm in a day, the forecasting of thunderstorm weather can be improved greatly. We investigated the information on daily variability based on the analysis of 108 thunderstorm processes in LHAASO. It should be noted that the time in this article are all Local Time of Beijing which corresponds to Universal Time +8 h. From Fig. 4, we can see that there may be thunderstorm weather most of the time during the day. Thunderstorms are relatively rare from 00:00 to 15:00,

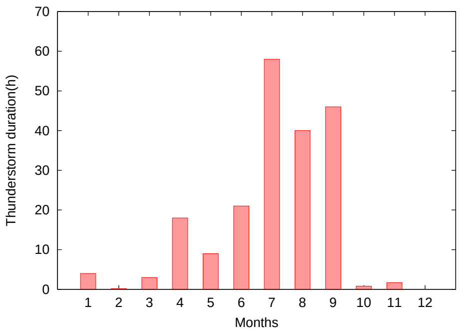


Fig. 3: Monthly total duration of thunderstorms.

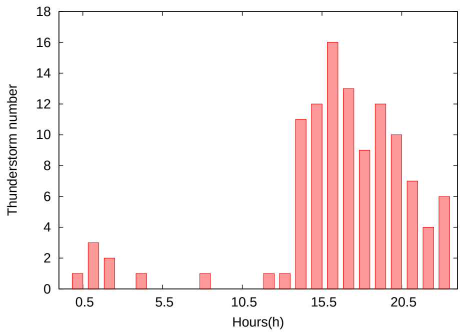


Fig. 4: Hourly mean total number of thunderstorms.

and most active in late afternoon to evening, even a few of them occurring at midnight. Between 15:00 and 22:00, the frequency increases sharply, with 77% of thunderstorms occurring during this period. After 22:00, it begins to decrease. From 22:00 to 24:00, a total of 17 thunderstorms occurred in this period, accounting for about16%.

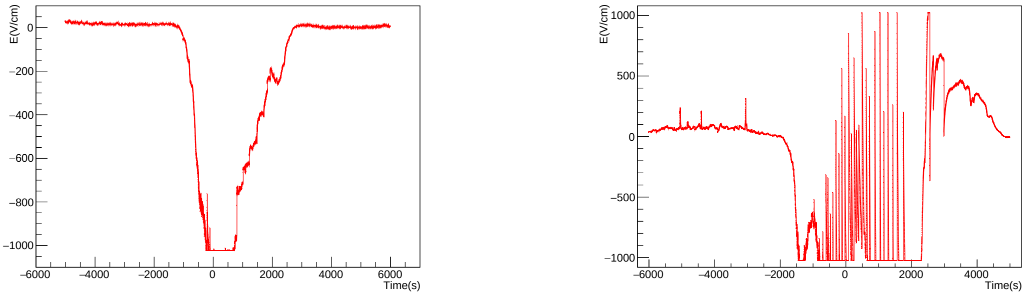
In fact, the diurnal variations are highly related to the formation of thunderstorms, which requires enough energy to form strong convection. In a day, from night to morning, atmospheric energy is consumed, and drops to its lowest level before sunrise. In the morning, the atmosphere starts to accumulate energy. And in the afternoon, enough energy and water vapor are accumulated to form convection. So it is the time when thunderstorms occur frequently. When there is no thunderstorm in the afternoon or the atmosphere consumes less energy, there is still sufficient energy to form convection at night, and then thunderstorm appears.

3.4 Variation of near-earth thunderstorm electric field

Fig. 5 shows the electric field evolution of two thunderstorm events. From the Fig. 5 (a), we can see that the thunderstorm occurred on August 23, 2020 is very strong. The absolute value of field is higher than the saturation value for about 20 minutes. According to the thunderstorm which occurred on July 12, 2020, seen from the Fig. 5 (b), the value of the field varies greatly, even jumping from one saturation value to the opposite saturation for many times. The field strength reaching the saturation value of the instrument lasts about 40 minutes. Unlike the electric field polarity in Fig. 5 (a), which never changes and remains negative throughout the thunderstorm, the polarity in Fig. 5 (b) changes multiple times. The field intensity variations and its polarity reversal are mainly affected by the charge structure in thunderclouds, which related to the charge-discharge process and the movement of thunderstorm clouds, as well as the occurrence of lightning. Therefore, the surface measurements of electric field and its characteristics analyses are helpful to study the charge structure of thunderstorm clouds, and then to monitor and forecast the thunderstorms more effectively.

3.4.1 The polarity variations of thunderstorm fields

By analyzing the atmospheric data of LHAASO, the polarity changing times are presented in Fig. 6. There are 12 thunderstorms with no polarity reversal, maybe the charge structure of



(a) August 23,2020 (b) July 12,2020

Fig. 5: The electric field evolution of the thunderstorms.

the thunderclouds is simple. Mostly polarity reversal times are less than 5. And the largest one occurring as many as 18 times in the afternoon of July12, 2020, as illustrated in Fig. 5 (b). We find that the lightning occurs frequently during this thunderstorm, up to 1373 times, which leads to the dramatic change in polarity of the electric field. Therefore, the charge structure in thunderstorm clouds is relatively complex.

3.4.2 Intensity variations of electric field during thunderstorms

In fact, the variation amplitude of the electric field intensity is closely related to the evolution process of the thunderstorm. In 1993, Byers-Braham [16] put forward a model of the thunderstorm cell life history. In his description, there are three stages in a typical thunderstorm cell life: cumulus, mature and dissipating stages. Different stage results in different field variation characteristics. Cumulus stage is the tower cumulus clouds forming stage and the strength of the field is small. The field will become stronger in the mature stage. When a thunderstorm is in its dissipating phase, there is often a small field with alternating polarities. Fig. 7 shows the intensity variation in the three stages. The red, blue and black lines represent cumulus, mature and dissipating stages, respectively. Evidently, in the mature stage, the field is stronger and it changes more dramatically, the mean variation amplitude is about 7.31 V/cm (within 0.5 seconds, same below). However, the variation amplitude in the cumulus and dissipating stage are 4.54 V/cm and 3.46 V/cm, respectively. Generally speaking, the variation of the field is associated with the distance of the thunderstorms away from the station. When the thunderstorms are moving towards the station, the field intensity becomes stronger. As the clouds are directly overhead, the field reaches its maximum strength. While the thunderclouds are leaving away from the station, it will decay to a normal fair weather electric field gradually.

When there is a strong thunderstorm, the measurement results of the detectors are bound to be affected due to the dramatic changes of the near-earth electric field. Therefore, the effects of strong field should be taken into account for the detector data analysis during severe thunderstorms.

4. Conclusion

During the year from October 2019 to September 2020, we observed 108 thunderstorms which met the filter criteria, occurring over 81 days. Thunderstorms are concentrated on June, July, August

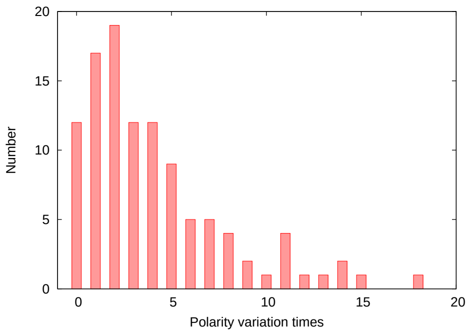


Fig. 6: The polarity variations of thunderstorm fields.

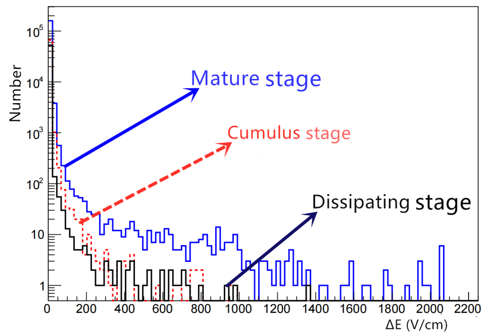


Fig. 7: The intensity variation at different stages.

and September. In terms of the duration, the total duration throughout the year is more than 200 hours, and the mean duration of each thunderstorm is about 2 hours. Thunderstorm at LHAASO station has diurnal variation characteristics. It tends to occur in period from late afternoon to evening, with relatively more at night and least in the morning. 77% of them are recorded in the interval from 15:00 to 22:00.

During thunderstorms, the electric field may fluctuate violently in its polarity and strength. The maximum polarity reversal times is up to 18. The variation amplitude is also related to the stage of thunderstorm development. In three stages of a thunderstorm cell life, the electric field is weak in the cumulus stage, stronger in the mature stage, and weaker again in the dissipating stage. At the mature stage, it is about 7.31 V/cm (within 0.5 seconds).

As mentioned above, the strong electric field brought by a thunderstorm will have an observable effect on the measurement data recorded by the detectors. Our results could provide a more complete assessment of the thunderstorm impacts on cosmic rays at LHAASO observatory. It is also helpful to study the charge structure in thunderstorm clouds and may give valuable information for studying global thunderstorm activity.

Acknowledgments

This work is supported by the National Natural Science Foundation of China (NSFC) under Grants No. U2031101, 11475141 and 12047576, the National Key R&D Program of China under the grant No.2018YFA0404201.The authors would like to express their sincere thanks to the members of the LHAASO collaboration.

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