Atmospheric Electric Field Effects on Cosmic Rays detected at Sierra Negra, Mexico

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Abstract

The effect of thunderstorms' atmospheric electric field (AEF) on secondary cosmic rays (CR) detected at high altitude was studied. We analyzed the data obtained during the period of October 2019 to March 2020 by the Solar Neutron Telescope (SNT) and a Boltek EFM-100 electric field monitor installed in the Sierra Negra Cosmic Ray Observatory (SNCRO) located at 4580 m a.s.l. in Puebla, Mexico. Based on the measurements of the EFM-100, 15 thunderstorms were identified in the established period. When ten of these thunderstorms occurred, fluctuations in the average counting rate of two SNT channels were observed.

On the basis of the general theory of AEF effects in the secondary CR components proposed by Dorman, we calculated as a first approximation the effect on the total charged component and the neutron component at the observation level of SNCRO. Simulations of air showers in the presence of a simplified electric field were performed with the CORSIKA code to complete the calculations. The observations were consistent with the calculated intensity variations.

Method

1. Identify thunderstorms through the Boltek EFM-100 measurements recorded from October 2019 to March 2020.
2. Select and analyze the data recorded on the dates of thunderstorms' occurrence by the SNT S1 (charged particles E ≥ 30 MeV) and $S2_{Anti}$ (neutral particles E ≥ 60 MeV) channels, due to their stability and low energy threshold.

CORSIKA Simulations

- Observation level at Sierra Negra's summit (4580 m, 579 g/cm^2).
- 2000 events generated by protons with energies of 10^2 - 10^6 GeV.
- Atmospheric electric field: Simple dipole as a first approximation (E = 20 kV/m)

Dorman's General Theory

Following a change of the AEF, the intensity variation of any CR secondary component *Ii* of type *i* observed at the level of atmospheric depth (h_0), with cut off rigidity (R_c), gravitational acceleration (*g*), and vertical distribution of air temperature (*T(h)*), humidity (*e(h)*) and AEF vector (**E**(*h*)) is given by:

$$\left(\frac{\Delta I_i(h_o,R_c,g_o,T_o(h),e_o(h),\mathbf{E}(h))}{I_i(h_o,R_c,g_o,T_o(h),e_o(h),\mathbf{E}_o(h))}\right)_E = \int_0^{h_o} W_{iE}(h,h_o,R_c)\Delta\mathbf{E}(h)dh$$

CORSIKA's multiplicity matrix output was used to complete calculations for the equation.

- For the total charged component:
  ± (0.81, 1.63, 2.44) % … With ΔE= ± (10, 20, 30) kV/m
- For the neutron component:
  ± (1.5, 3.01, 4.53) % … With ΔE= ± (10, 20, 30) kV/m

Results

Significant variations were observed for 10 thunderstorms in both SNT channels. The maximum percentage variation of the counting rate, for each thunderstorm, was calculated relative to the average. These percentage variations are shown in Table 1. The effect calculated on the basis of Dorman's theory is included.

Date (2019-2020)	Duration [Hrs]	AEF intensity [kV/m]	Channel S1 Variation [%]	Channel S2_Anti Variation [%]
17/10	6	(6, -20)	+0.9	+4.9
19/10	8	(20, -20)	+0.71	-2.45
21/10	6	(20, -20)	+1.39	-1.96
22/10	4	(20, -20)	+1.19	-2.84
26/10	3	(20, -20)	-1.27	-2
29/10	4	(20, -20)	-1.19	-1.93
30/10	7	(11, -20)	+1.27	+2.41
31/10	3	(20, -20)	-1.56	-2.89
19/01	2.5	(20, -20)	+1.41	-1.8
20/01	2.5	(20, -20)	-1.64	-2.6
Calculated AEF Effect [%]			±(0.81, 2.44)	±(1.5, 4.53)

Table 1. Thunderstorm properties and variations associated with them in the counting rate of the SNT's S1 and $S2_{Anti}$ channels.

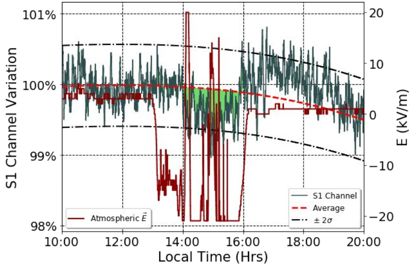

Figure 1. AEF and S1 Channel records for the thunderstorm of October 29th , 2020.

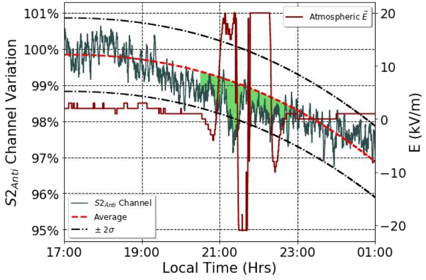

Figure 2. AEF and $S2_{Anti}$ Channel records for the thunderstorm of October 26th , 2020.

Discussion & Conclusions

There are two physical phenomena associated with AEF that could explain the results of Table 1: the muon mechanism and the electron mechanism. The SNT mainly detects the hadronic component of the secondary CR, however a fraction of the total counts is produced by muons, electrons and positrons. This fraction could be enough to cause the variations of around 1% observed in the S1 channel.

Although some processes have been established for the indirect influence of AEF on neutrons, they affect lower energy neutrons. Further research should be carried out to find if water molecules can absorb and moderate the neutrons detected by the $S2_{Anti}$ channel.

Based on the theoretical and experimental results, we conclude that the effect of the atmospheric electric field on the secondary CR flux is significant at the summit of Sierra Negra.

In addition, as future research, a higher number of thunderstorms will be analyzed to quantitatively validate the results and increase their statistical power. The measurement range of the EFM-100 will also be increased to ±100 kV/m.