ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE

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

CRI | Cosmic Ray Indirect: Poster(#1376)

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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 Boltek EFM-100, 15 thunderstorms were identified in the established period. When the majority of thunderstorms occurred, fluctuations in the average counting rate of 2 SNT channels were observed. On the basis of the general theory of atmospheric electric field 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.

Sierra Negra Cosmic Ray Observatory

- Located at Sierra Negra's summit at 4580 m a.s.l. (19.0° N, 97.3° W)
- Detectors:
  - Boltek EFM-100
  - Solar Neutron Telescope

Sierra Negra, Puebla, Mexico [1]

Methodology

- Measurements of the Boltek EFM-100 installed at Sierra Negra.
  - 15 Thunderstorms were identified from October 2019 to March 2020.
- Data analysis of two Solar Neutron Telescope channels: S1 (charged particles E$\geq$30 MeV) and $S2_{Anti}$ (neutral particles E$\geq$60 MeV).
  - Data normalization to the mean counting rate during fair weather.

Thunderstorm [2]

CORSIKA Simulations

- The hadronic interactions were modeled with QGSJET II-04 for high energies and FLUKA for low energies.
- Input parameters:
  - Observation level at Sierra Negra summit (4580 m, 579 g/cm^2).
  - Geomagnetic coordinates of Sierra Negra (27.345° N, 29.240° W).
  - 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

- According to Dorman [3], the intensity of any secondary CR component I_i of type i observed at the level of h_0 at the point with cut off rigidity R_c, gravitational acceleration g, and vertical distribution of air temperature $T(h)$, of humidity $e(h)$ and an AEF vector $\mathbf{E}(h)$ can be described by the equation:

$$I_i(h_o, R_c, g, T(h), e(h), \mathbf{E}(h)) = \int_{R_c}^{\infty} D(R) m_i(h_o, R, g, T(h), e(h), \mathbf{E}(h)) dR$$

where m_i is the integral multiplicity and $D(R)$ is the primary CR spectrum out of the atmosphere:

Supposing: $$\Delta\mathbf{E}(h) = \mathbf{E}(h) - \mathbf{E}_o(h)$$

$$\left(\frac{\Delta I_i(h_o, R_c, g_o, T_o(h), e_o(h), \mathbf{E}(h))}{I_i(h_o, R_c, g_o, T_o(h), e_o(h), \mathbf{E}_o(h))}\right)_E = \int_0^{h_o} W_{iE}(h, h_o, R_c) \Delta\mathbf{E}(h) dh \quad \text{... (1)}$$

In eq (1), the AEF coefficient W_{iE} is given by:

$$W_{iE}(h,h_o,R_c) = \int_{R_c}^{\infty} \frac{\delta m_i(h_o,R,g_o,T_o(h),e_o(h),\mathbf{E}(h))}{m_i(h_o,R,g_o,T_o(h),e_o(h),\mathbf{E}_o(h))\delta\mathbf{E}(h)} W_{iR_c}(h_o,R,g_o,T_o(h),e_o(h),\mathbf{E}_o(h))dR$$

Where W_{iRc} is a coupling function, described by:

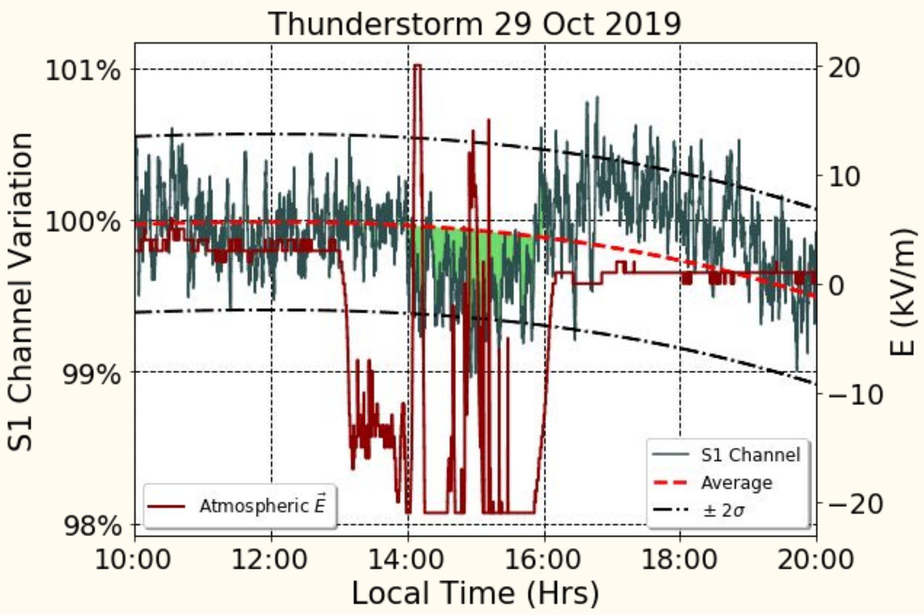
$$W_{iR_c}(h_o,R,g_o,T_o(h),e_o(h),\mathbf{E}_o(h)) = \frac{D_o(R)m_i(h_o,R,g_o,T_o(h),e_o(h),\mathbf{E}_o(h))}{I_i(h_o,R_c,g_o,T_o(h),e_o(h),\mathbf{E}_o(h))}$$

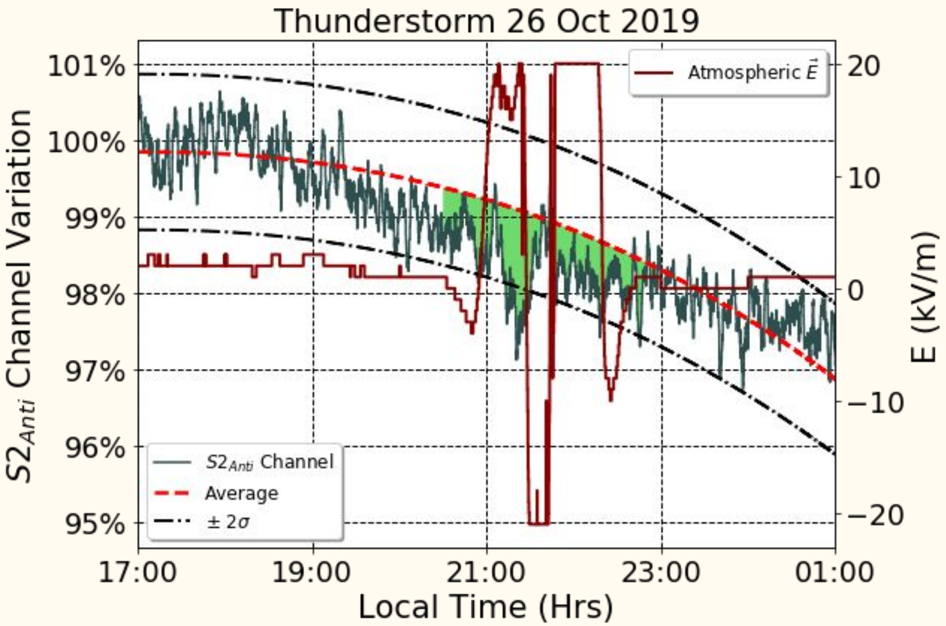
Dorman solves the equation for W_{iRc} for different CR components at a latitude of 30° with a cut off rigidity ~10 GV. As a first approximation, the values of W_{iRc} = 2.7% $(GV)^{-1}$ $(g/cm^2)^{-1}$ for the total charged component and W_{iRc}=5% $(GV)^{-1}$ $(g/cm^2)^{-1}$ for the neutron component were used.

Results

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.


Thunderstorm 29 Oct 2019
S1 Channel Variation
101%
100%
99%
98%
20
10
0
−10
−20
E (kV/m)
10:00
12:00
14:00
16:00
18:00
20:00
Local Time (Hrs)
Atmospheric $\vec{E}$
S1 Channel
Average
$\pm 2\sigma$


Thunderstorm 26 Oct 2019
$S2_{Anti}$ Channel Variation
101%
100%
99%
98%
97%
96%
95%
20
10
0
−10
−20
E (kV/m)
17:00
19:00
21:00
23:00
01:00
Local Time (Hrs)
Atmospheric $\vec{E}$
$S2_{Anti}$ Channel
Average
$\pm 2\sigma$

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 probably 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.

References

[1] Mexico’s Volcanoes. Sergio Luján Mora, 2009. http://deexpedicion.com/mexico2008/en/sierranegra

[2] Photos: Sky, Stormy Weather. 2020. https://www.pinterest.com.mx/pin/521854675553270027/

[3] Dorman, L. I. Cosmic rays in the Earth’s atmosphere and underground. Vol. 303. Springer Science & Business Media, 2013.