Influence of atmospheric electric fields on cosmic rays detected by the Solar Neutron Telescope at Sierra Negra

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POR MI RAZA HABLARA EL ESPIRITU

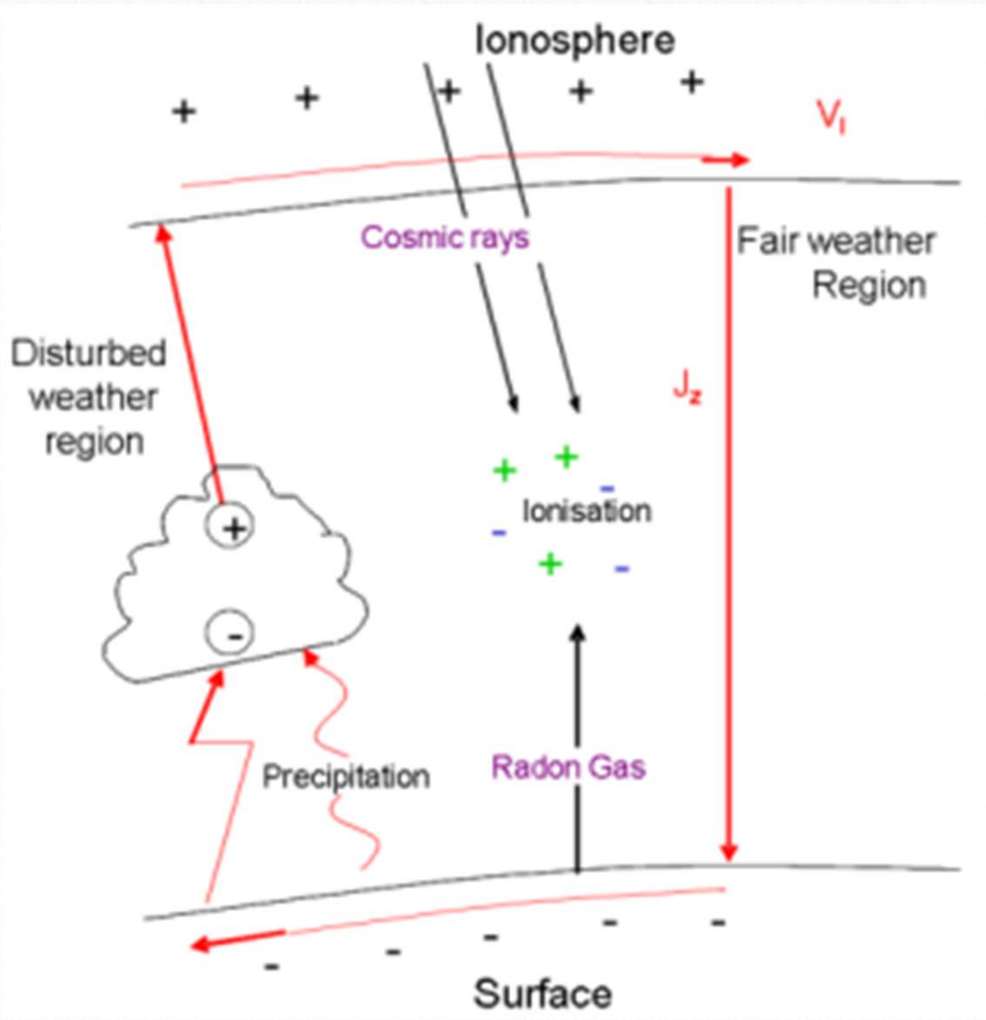
Introduction

- Atmospheric electric fields (AEF) produced by thunderstorms accelerate charged particles.
  - Sierra Negra Cosmic Ray Observatory (SN-CRO) installed at 4580 m should observe this effect.
- Objective:
  - Analyze the possible AEF effect on CR detected by SN-CRO.

Presentation Content

- AEF effects on CR
- Sierra Negra CR Observatory (SN-CRO)
- **Data Analysis**
- **Discussion**
- **Conclusions**

AEF Effects on CR


Ionosphere
+ + + + +
V_I
Cosmic rays
Fair weather
Region
Disturbed
weather
region
J_z
+
-
Ionisation
Precipitation
Radon Gas
Surface

Taken from [2]

Dorman's General Theory

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

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

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

- Where the AEF coefficient is given by:

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

- The coupling function W_{iRc} is given by:

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

- For the total charged CR component:

$$W_{iE}(h, h_0, R_c) = 2.938 \times 10^{-5} \,\% \,(g/cm^2)^{-1} (kV/m)^{-1}$$

- Substituting in equation 1:

$$\left(\frac{\Delta I_i \,(h_0, R_c, g, T(h), e(h), \overline{E}(h))}{I_i \,(h_0, R_c, g, T(h), e(h), \overline{E}(h))} \right)_E = \int_0^{h_0} 2.938 \times 10^{-5} \% \,(g/cm^2)^{-1} (kV/m)^{-1} * \Delta\overline{E}(h)\, dh$$

= ± (0.81, 1.63, 2.44) % … With ΔE= ± (10, 20, 30) kV/m.

- For the neutron component:

= ± (1.5, 3.01, 4.53) %

Sierra Negra Cosmic Ray Observatory

- It is located at 4580 m a.s.l.

(19.0°N, 97.3° O)

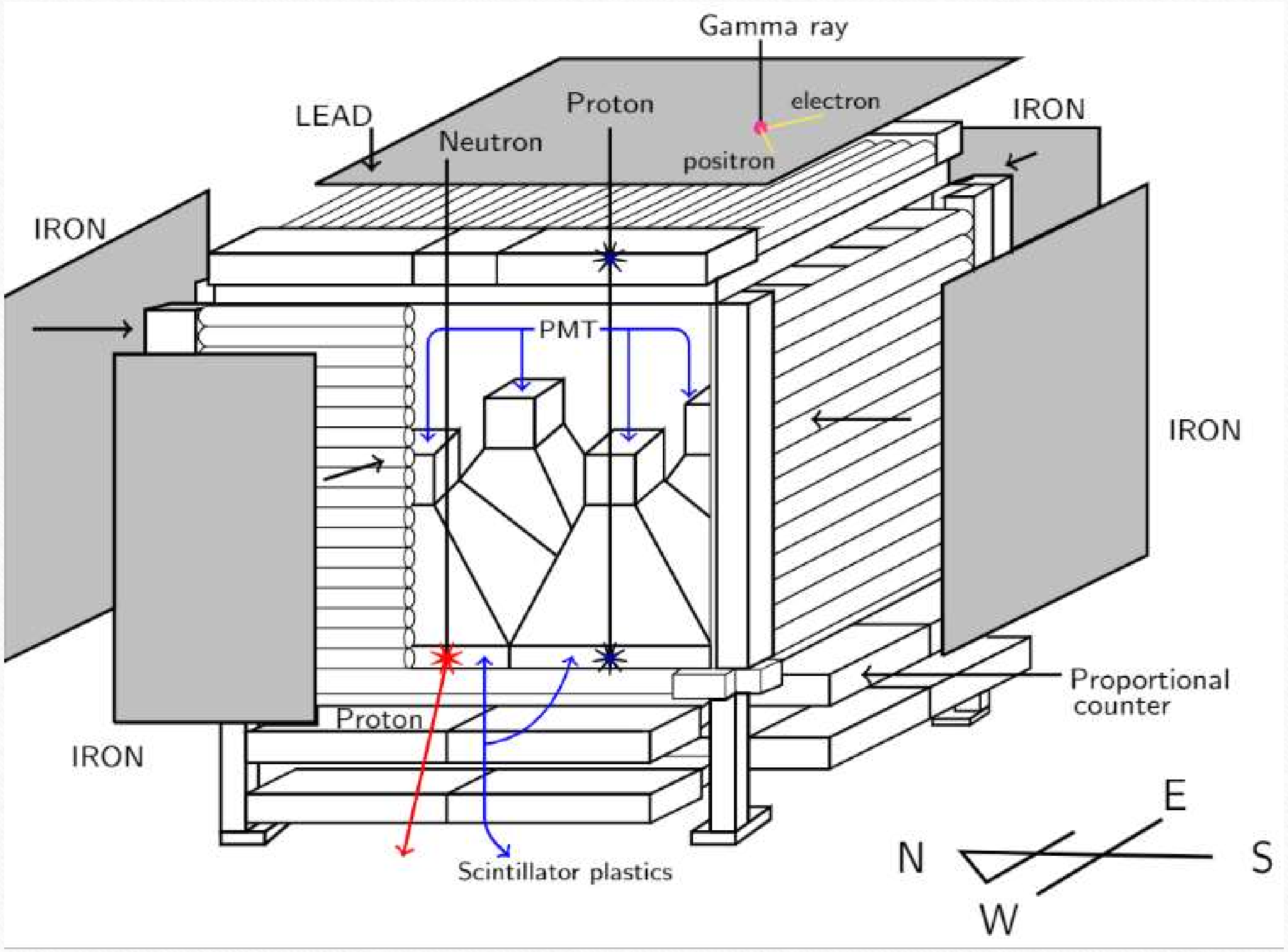
Detectors:

  - Boltek EFM-100
  - Solar Neutron Telescope (SNT)
  - SciBar CR Telescope (SciCRT)

Solar Neutron Telescope

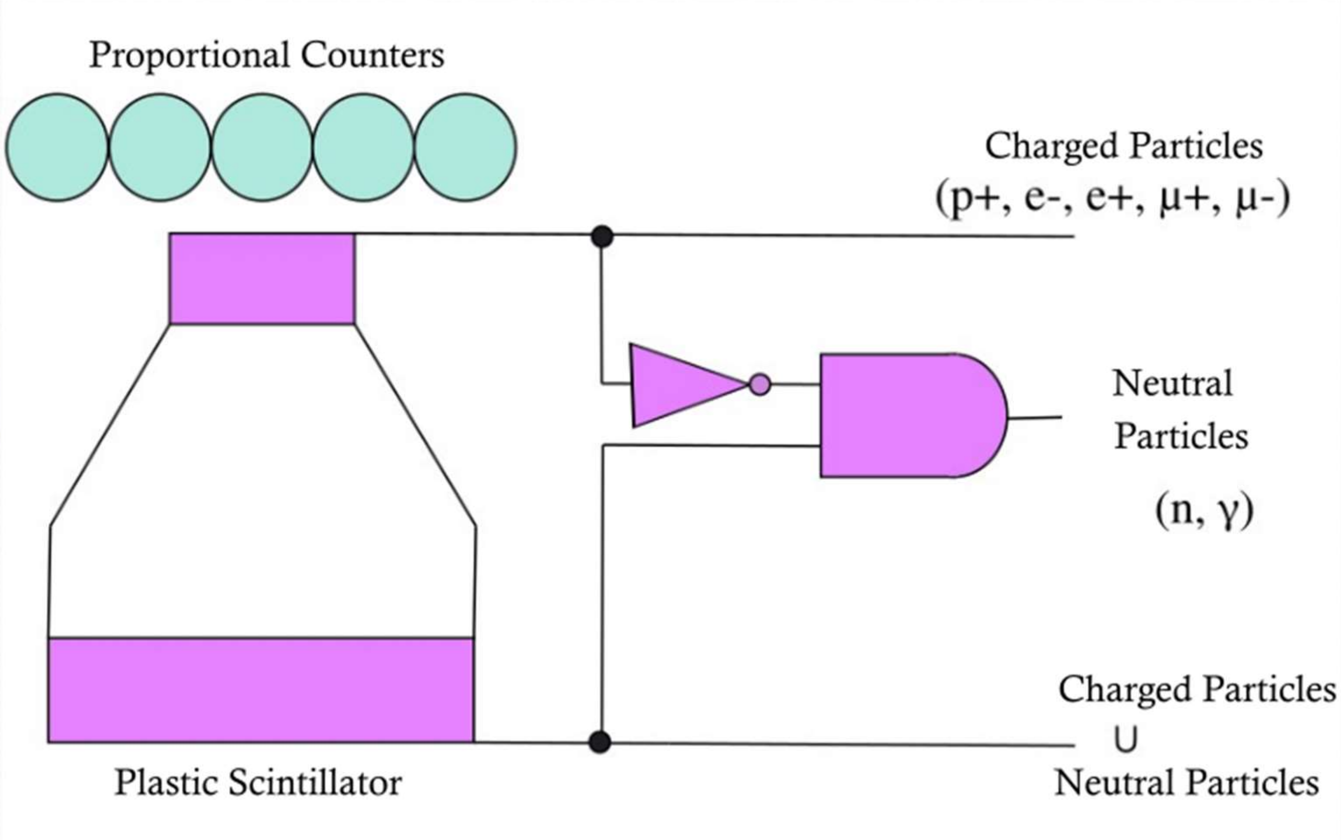
- Installed at Sierra Negra in March 2003.
- Part of a Global Network

SNT Global Network. Taken from [4].



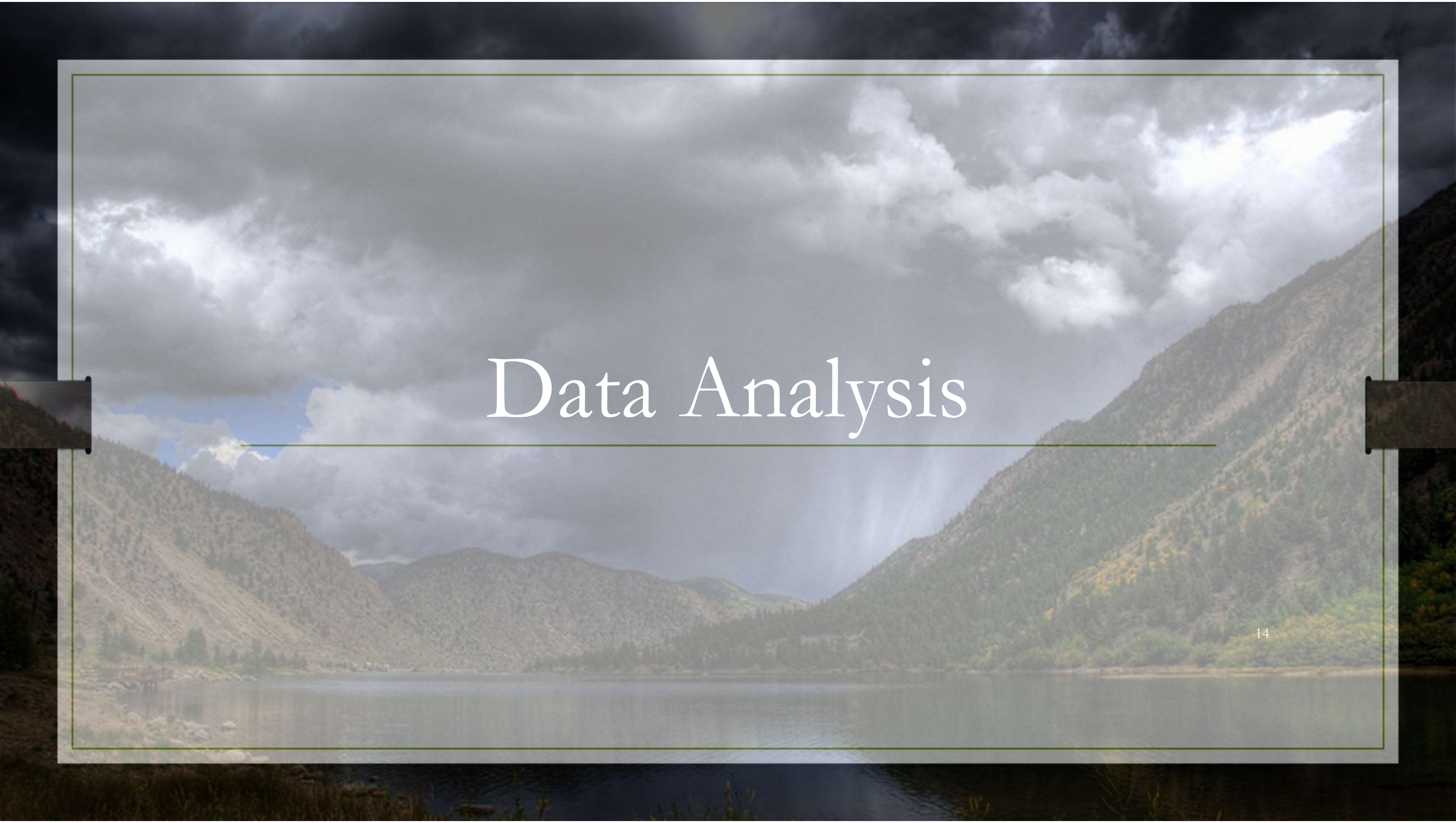
SNT Structure. Taken from [4]

Logical Detection System



SNT Main Channels (Energy Deposition Threshold)	
Charged Particles	**Neutral Particles**
S1 (E>30 MeV)	S1_Anti (E>30 MeV)
S2 (E>60 MeV)	S2_Anti (E>60 MeV)
S3 (E>90 MeV)	S3_Anti (E>90 MeV)
S4 (E>120 MeV)	S4_Anti (E>120 MeV)

Taken from [5]



Data Analysis

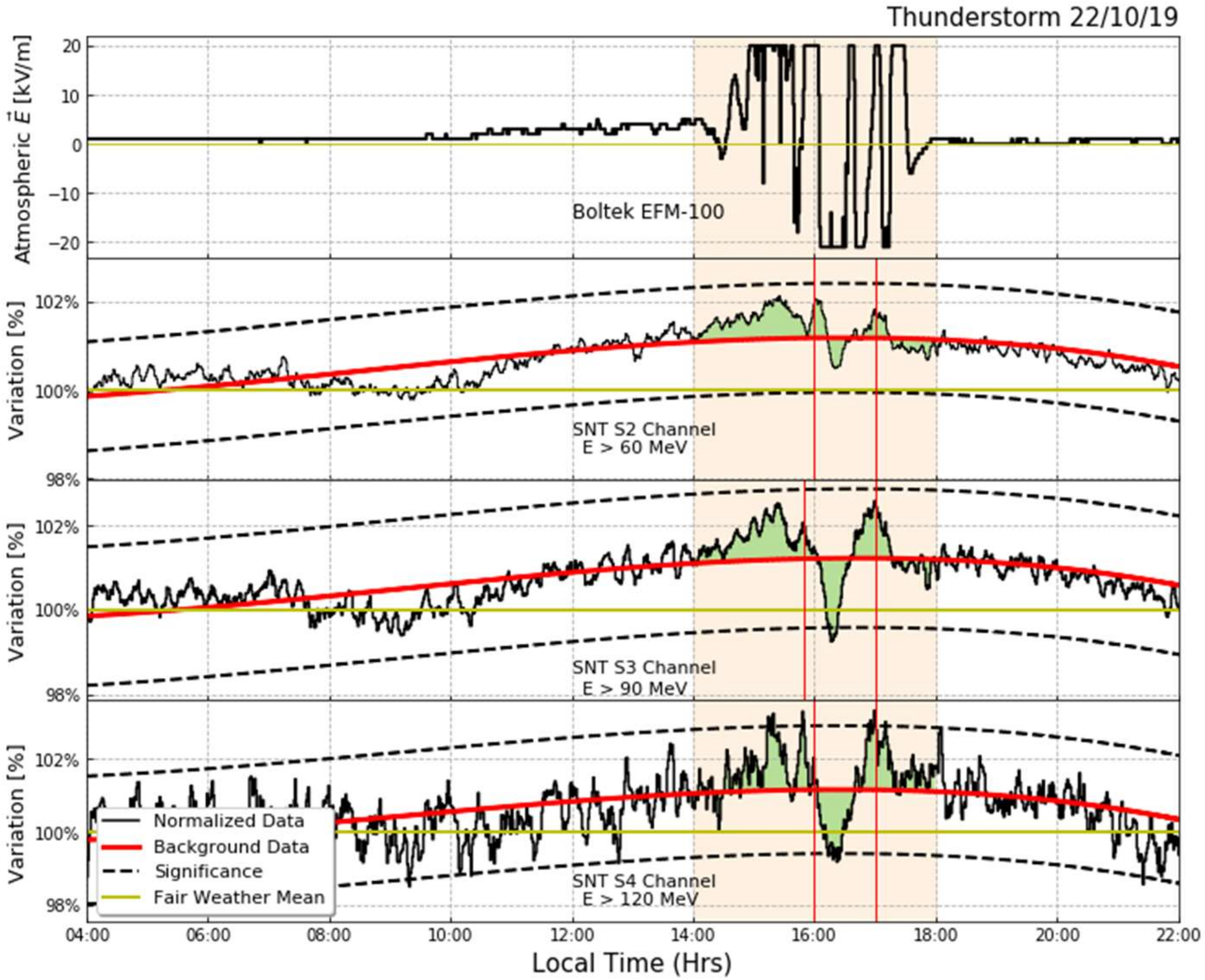
Thunderstorms (10/2019 - 03/2020)

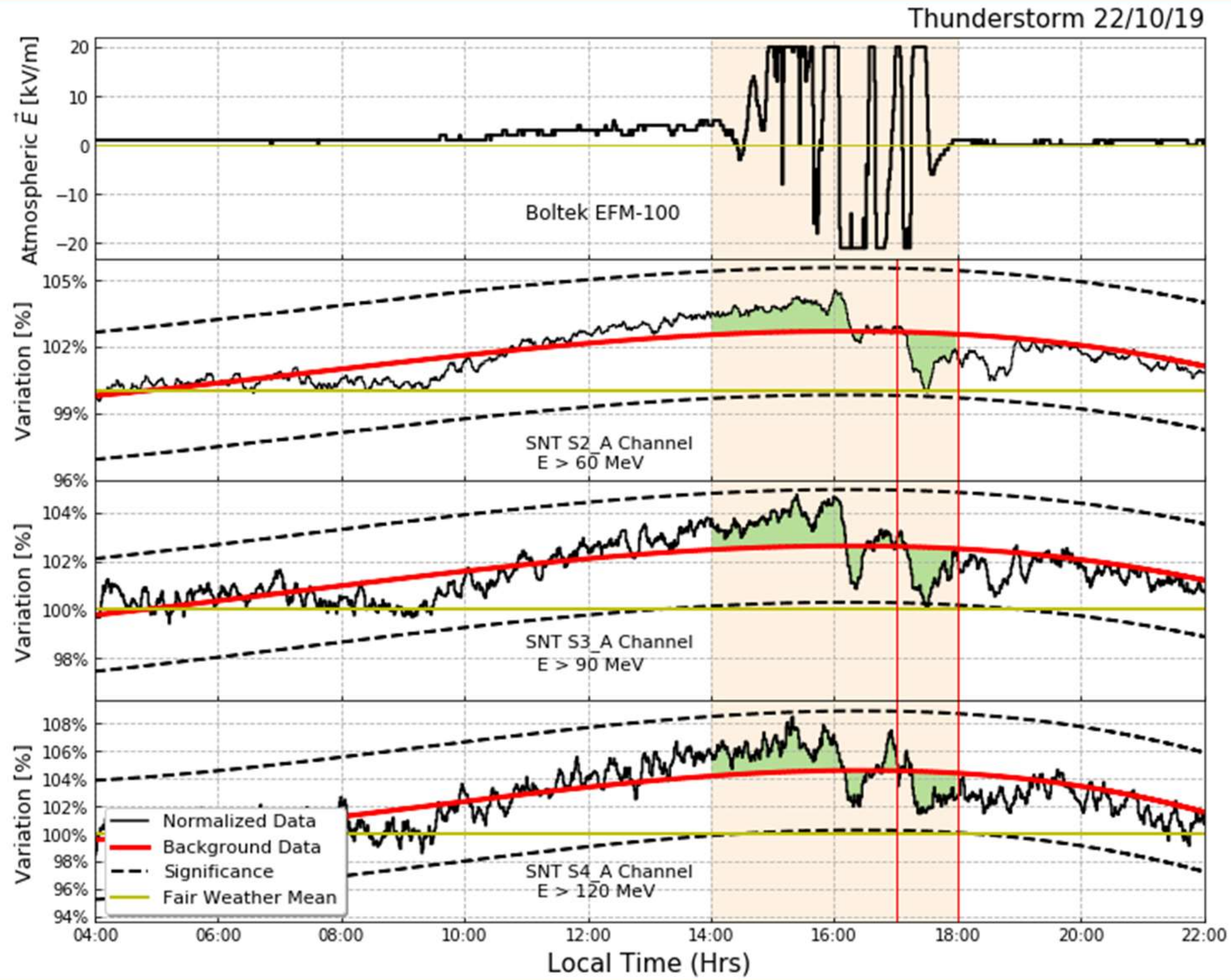
Date	Duration (Hr)	Interval (Local Time)	**E** (kV/m)
11/10/19	3	18:30 - 21:30	(20, -20)
17/10/19	6	12:00 - 18:00	(6, -20)
19/10/19	8	14:00 - 22:00	(20, -20)
21/10/19	6	15:00 - 21:00	(20, -20)
22/10/19	4	14:00 - 18:00	(20, -20)
24/10/19	5	16:00 - 21:00	(10, -20)
26/10/19	3	20:00 - 23:00	(20, -20)
29/10/19	4	13:00 - 17:00	(20, -20)
30/10/19	7	11:00 - 19:00	(11, -20)
31/10/19	2	07:00 - 10:00	(20, -20)
3/11/19	2.5	14:30 - 17:00	(12, -20)
19/01/20	2.5	16:00 - 18:30	(20, -20)
20/01/20	1.5	20:00 - 21:30	(20, -20)
17/03/20	3.5	15:30 - 19:00	(15, -20)
20/03/20	4	17:00 - 21:00	(20, -20)

Table 1. Observed thunderstorms and their properties.

Data Treatment for SNT Channels

1. Normalization to the fair weather mean.
2. Background data calculated adjusting a third degree polynomial.
3. Graph the data along with the Boltek EFM-100 measurements.
4. Calculate the percentage of observed variations.
5. Establish significance based on each channel's average diurnal variation.


Thunderstorm 22/10/19
Atmospheric $\vec{E}$ [kV/m]
20
10
0
−10
−20
Boltek EFM-100
Variation [%]
102%
100%
98%
SNT S2 Channel
E > 60 MeV
SNT S3 Channel
E > 90 MeV
SNT S4 Channel
E > 120 MeV
Normalized Data
Background Data
Significance
Fair Weather Mean
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Local Time (Hrs)


Thunderstorm 22/10/19
Atmospheric $\vec{E}$ [kV/m]
Boltek EFM-100
Variation [%]
SNT S2_A Channel
E > 60 MeV
SNT S3_A Channel
E > 90 MeV
SNT S4_A Channel
E > 120 MeV
Normalized Data
Background Data
Significance
Fair Weather Mean
Local Time (Hrs)

Charged Particle Channels Results (1)

Thunderstorm Date (2019)	S2 Channel Variation [%]	Approx. Duration [min]	S3 Channel Variation [%]	Approx. Duration [min]	S4 Channel Variation [%]	Approx. Duration [min]	Average Variation [%]	Average Duration [min]
11/10	+ 0.48 ± 0.24	17	+ 1.34 ± 0.32	12	+ 2.09 ± 0.65	12	+ 1.3 ± 0.44	13.66
17/10	+ 0.48 ± 0.31	32	+ 0.97 ± 0.38	32	+ 1.99 ± 0.66	19	+ 1.14 ± 0.47	27.66
19/10	+ 0.44 ± 0.28	15	No data	-	+ 1.71 ± 0.69	20	+ 1.07 ± 0.52	17.5
21/10	+ 0.95 ± 0.45	40	+ 3.35 ± 0.50	32	+ 3.14 ± 0.83	22	+ 2.48 ± 0.61	31.33
22/10	- 0.68 ± 0.31	60	- 1.95 ± 0.36	70	- 1.96 ± 0.61	60	- 1.53 ± 0.44	63.33
24/10	+ 0.66 ± 0.25	30	No data	-	+ 2.37 ± 0.70	40	+ 1.52 ± 0.52	35

Tabla 2. Tormentas eléctricas con porcentajes de variación significativos y su duración en los canales S2-S4 del TNS.

Charged Particle Channels Results (2)

Thunderstorm Date (2019-2020)	S2 Channel Variation [%]	Approx. Duration [min]	S3 Channel Variation [%]	Approx. Duration [min]	S4 Channel Variation [%]	Approx. Duration [min]	Average Variation [%]	Average Duration [min]
26/10	- 1.02 ± 0.22	30	- 1.33 ± 0.29	34	- 1.57 ± 0.70	26	- 1.3 ± 0.45	30
29/10	- 0.81 ± 0.20	100	No data	-	- 1.93 ± 0.64	30	- 1.37 ± 0.47	65
30/10	+ 0.8 ± 0.24	10	+ 0.99 ± 0.33	45	+ 1.70 ± 0.69	11	+ 1.16 ± 0.46	22
31/10	- 1.15 ± 0.41	112	- 1.45 ± 0.55	132	- 2.30 ± 0.72	50	- 1.64 ± 0.57	98
19/01	+ 1.23 ± 0.27	48	+ 1.47 ± 0.34	40	+ 2.10 ± 0.63	35	+ 1.60 ± 0.44	41
20/01	- 0.56 ± 0.19	60	- 0.57 ± 0.25	60	- 1.76 ± 0.67	30	- 0.97 ± 0.42	50

Tabla 2. Tormentas eléctricas con porcentajes de variación significativos y su duración en los canales S2-S4 del TNS.

Neutral Particle Channels Results

Thunderstorm Date (2019)	S2A Channel Variation [%]	Approx. Duration [min]	S3A Channel Variation [%]	Approx. Duration [min]	S4A Channel Variation [%]	Approx. Duration [min]	Average Variation [%]	Average Duration [min]
17/10	+ 3.86 ± 0.41	30	+ 6.50 ± 0.51	35	+ 5.39 ± 0.94	25	+ 5.25 ± 0.66	30
22/10	-2.62 ± 0.56	60	-2.43 ± 0.68	60	-2.94 ± 0.93	60	-2.66 ± 0.74	60
26/10	-1.32 ± 0.46	30	-1.61 ± 0.50	34	-2.66 ± 1.09	26	-1.86 ± 0.74	30
29/10	-1.44 ± 0.69	80	-1.72 ± 0.68	65	-2.80 ± 1.47	65	-1.99 ± 1.02	70
31/10	-2.46 ± 1.50	110	-2.83 ± 1.49	120	-4.20 ± 1.49	117	-3.16 ± 1.49	115

Discussion(1)

- Thunderstorms produce negative AEF pointing in the direction of the upper atmosphere.
  - Positive charges are decelerated on their way to the ground and negative charges are accelerated.
- The observed decrements in the counting rate of the charged particle SNT channels could be attributed to the muon mechanism (decrease in muon intensity due to the decay of positive muons that were decelerated by the AEF).
- The observed increments might be attributed to the runaway electron mechanism (acceleration of electrons by the AEF).
- Neutral particle channels show an important increment, which must be studied independently, and decrements that could be associated with the absorption of lower energy neutrons or muon noise (muon mechanism).

Discussion(2)

- The DV maximum coincides with the majority of thunderstorm occurrences. Significant increments were observed in these cases, so they could be associated with the DV instead of the AEF.
- The observed variations of the S2 channel's counting rate were not significant in a few cases, due to the low DV (>2%), but they are part of a systematic trend.
- The observed variations of the S4A channel's counting rate were not significant due to the high energy threshold (120 MeV) of the channel.

Conclusions

- The AEF effects on CR are significant at Sierra Negra, Mexico.
- The observed variations on the SNT charged particle channels have an average duration of 13-98 minutes and could be generally explained by the muon and runaway electron mechanisms.
  - The counting rate's increments may be attributed to runaway electrons, however, the majority of these thunderstorms occurred when the DV reached its máximum. Further research is needed.
  - The counting rate's decrements may be attributed to the muon mechanism, which was triggered by longer lasting thunderstorms that occurred when the DV wasn't at its maximum or minimum.
- The observed variations on the SNT neutral particle channels might be explained by neutron absorption due to water molecules or also by the muon mechanism, however, the fraction of muon counts for these channels must be calculated as further research. The increment can't be explained only by the AEF, additional space weather effects should be studied.
- The SNT is a reliable instrument for the study of the AEF muon mechanism.

Thank you

References

[1] CERN. Cosmic rays: particles from outer space. Revisado el 20/07/2020. https://home.cern/science/physics/cosmic-rays-particles-outer-space.

[2] https://www.semanticscholar.org/paper/Recent-advances-in-global-electric-circuit-coupling-Rycroft-Nicoll/c8fe7b6e98a7ceaa4d862393d1bfe4ae6c487231/figure/0

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

[4] González, L. X. (2010). El Telescopio de Neutrones Solares en Sierra Negra y Aceleración de Iones en la Atmósfera Solar (Tesis de Doctorado). Universidad Nacional Autónoma de México.

[5] Anzorena, M. A. (2014). Identificación de partículas neutras mediante análisis de forma de pulso en el Telescopio de Neutrones Solares en Sierra Negra, Puebla. (Tesis de Maestría). Universidad Nacional Autónoma de México.