COSMIC RAYS, THUNDERSTORM CLOUDS, AND POSSIBLE INFLUENCE ON CLIMATE, 2. ATMOSPHERIC ELECTRIC FIELD EFFECT IN DIFFERENT NEUTRON MULTIPLICITIES ACCORDING TO EMILIO SEGRE' OBSERVATORY ONE MINUTE DATA

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ABSTRACT

On the basis of cosmic ray and atmospheric electric field one minute data obtained by neutron super-monitor and EFS-1000 of Emilio Segre' Observatory on Mt. Hermon (33°18.3′N, 35°47.2′E, hight 2025 *m* above sea level, cut-off rigidity for vertical direction 10.8 GV) we determine the atmospheric electric field effect in CR for total neutron intensity and for multiplicities m≥1, m≥2, m≥3, m≥4, m≥5, m≥6, m≥7, and m≥8, as well as for m=1, m=2, m=3, m=4, m=5, m=6, and m=7. For comparison and excluding primary CR variations we use also data on neutron multiplicities obtained by NM of University "Roma Tre" and IFSI-CNR (about sea level, cut-off rigidity 6.7 GV). In February 2000 were observed 14 periods of thunderstorms with different durations (up to about 1000 min), the maximum strength of electric field was 110 kV/m. Thunderstorms were observed also in March 2000 (6 periods with maximal field 112 kV/m), in April 2000 (9; 70 kV/m), in May 2000 (4; 10 kV/m), in October 2000 (10; 70 kV/m), in November 2000 (5; 50 kV/m), in December 2000 (7; 88 kV/m), in January 2001 (12; 62 kV/m), in February 2001 (10; 88 kV/m). According to the theoretical calculations of Dorman and Dorman (2003) the electric field effect in the NM counting rate must be caused mainly by captchuring of slow negative muons by lead nucleus with escaping few neutrons. As it was shown in this paper, the biggest electric field effect is expected in the multiplicity m=1, much smaller in m=2 and negligible effect is expected in higher multiplicities. We control this conclusion on the basis of our experimental data. Obtained results give a possibility to estimate total acceleration and deceleration of CR particles by the atmospheric electric field. We consider also the possible influence of CR air ionization (especially by secondary energetic electrons) on thunderstorms and lightnings, and through this – on climate.

COSMIC RAYS AND ATMOSPHERIC ELECTRIC FIELD EFFECTS AS POSSIBLE LINKS IN SOLAR ACTIVITY INFLUENCE ON CLIMATE CHANGE

As we mentioned in Dorman and Dorman (2003), many authors considered cosmic rays and atmospheric electric field phenomenon as possible links in the solar activity influence on the Earth's climate: Ney (1959), Dickinson (1975), Markson (1978), Pudovkin and Raspopov (1992), Pudovkin and Veretenenko (1992, 1996), Tinsley (1996, 2000), Gurevich et al. (1992, 1999), Gurevich and Zybin (2000), Swensmark and Friis-Christensen (1997), Swensmark (1998, 2000), Marsh and Swensmark (2000a,b), Stozhkov et al. (1995, 1996, 2000, 2001), Price (2000), Schlegel et al. (2001), Stozhkov (2002). It was shown that there is some evidence of very important tendency: the increasing of cosmic ray intensity leads to increasing of atmosphere ionization what turns to increasing of low cloudiness, to increasing rain-fall and ground temeperature decresaing (see review in Swensmark, 2000; Stozhkov, 2002). The cosmic ray intensity increasing leads also to increasing of secondary relativistic electron fluxes which played a key role in formaton of thunderstorms and lightnings (see review in Gurevich and Zybin, 2000). So cosmic rays may influence on climat by two channels: through cloudiness and through atmospheric electric field effects (thunderstorms and lightnings). From this point of view the investigations of atmospheric electric field phenomenon connection with cosmic rays are especially important. In Dorman and Dorman (2003) was shown that not only charged particles of cosmic rays (primary and secondary of different types: muons, electrons, positrons, EAS and others detected by scintillators, ionization chambers, Gaiger-Muller, proportional and Cherenkov counters) are sensitive to the atmospheric electric field (what is natural), but also secondary component detected by world-wide network of neutron monitors and super-monitors must be sensitive to the atmospheric electric field. This sensitivity is caused by the process of lead mesoatoms formating by capturing of small energy negative secondary muons in neutron monitor and after few mikroseconds by emitting neutrons what are detected by neutron counters of monitor. It is important that this sensitivity of neutron monitor to the atmospheric electric field is expected to be very different for different neutron multiplicities: the highest is expected for the 1-st multiplicity, few times lower for the 2-nd, and negligible for $m \geq 3$. On the basis of cosmic ray and atmospheric electric field one minute data obtained by neutron super-monitor and electric field sensor EFS-1000 in Emilio Segre' Observatory on Mt. Hermon in Israel (33°18.3′N, 35°47.2′E, height 2025 *m* above sea level, cut-off rigidity for vertical direction 10.8 *GV*) was in the first time investigated the atmospheric electric field effect in cosmic rays for total neutron intensity and for different multiplicities. For comparison and excluding primary cosmic ray variations we used data obtained by Rome neutron supermonitor (about sea level, cut-off rigidity 6.7 *GV*). Obtained results give a possibility to estimate total acceleration and deceleration of cosmic ray particles by the atmospheric electric field.

MEASUREMENTS OF ATMOSPHERIC ELECTRIC FIELD ON MT. HERMON; CHARACTERISTICS OF THUNDERSTORM'S PERIODS

The sensor of atmospheric electric field EFS-1000 starts to work in Emilio Segre' Observatory on Mt. Hermon in February 2000. It made measurements on the top of Observatory each minute for negative field up to –160 kV/m and for positive field up to +16 *kV/m* (if the electric field has intensity near the ground $E > +16 kV/m$, EFS-1000 shows only the upper limit +16 *kV/m*). In Fig. 1 are shown examples of these measurements.

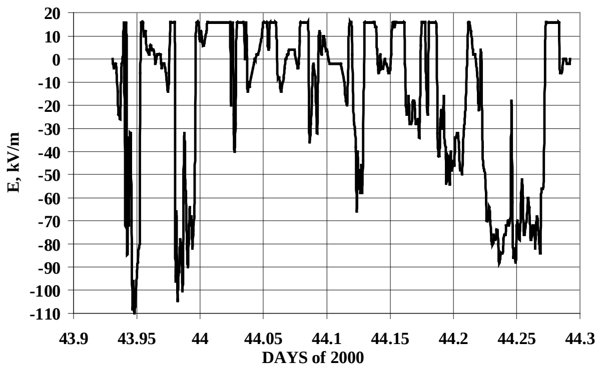

Fig. 1. One-minute data of atmospheric electric field on Mt. Hermon in one of periods of thunderstorms in February 2000.

In February-May, October-December 2000, and in January-May 2001 were observed by the sensor EFS-1000 of Emilio Segre' Observatory on Mt. Hermon 49 thunderstorm's periods.

REGRESSION RELATIONS BETWEEN ATMOSPHERIC ELECTRIC FIELD AND COUNTING RATES OF TOTAL NEUTRON INTENSITY AND DIFFERENT MULTIPLICITIES

Because the expected atmospheric electric field effect for measurements by NM on mountain heights is very small (Dorman and Dorman, 2003), it is necessary to decrease fluctuations in cosmic ray intensity caused by other causes than atmospheric electric field effects. Therefore we corrected data of total and different multiplicities on barometric effect (see in Dorman et al., 2001a), on snow effect (Dorman et al., 2001b), and on primary variations (by using Rome NM data for comparison). Our one-minute data characterized with statistical errors 0.98%, 1.45%, 2.76% and 4.74% for total intensity and multiplicities m=1, 2, and 3, correspondingly; therefore we used averaged data. We suppose that approximately $E(h_o,t)$ is in a good correlation with distribution function $E(h,t)$. In this case we obtain approximately

$$(\Delta I_m(t)/I_{mo})_E = \int_{h_3}^{h_o} W_{mE}(h)E(h,t)dh \approx \overline{W}_{mE} \times (h_o - h_3) \times E(h_o,t), \tag{1}$$

where h_3 means the air pressure on altitude of charged clouds caused thunderstorms, and we suppose that

$$\overline{W}_{mE} \approx \int_{h_3}^{h_o} W_{mE}(h)dh \Big/ (h_o - h_3) \,. \tag{2}$$

The expected values of $\overline{W}_{mE}$ were determined in Dorman and Dorman (2003). From other side, on the basis of described above experimental data on $E(h_o,t)$ and on $(\Delta I_m(t)/I_{mo})_E$ we can determine by Eq. 1 the regression coefficient $\overline{W}_{mE} \times (h_o - h_3)$.

As example, here we present results of regression analysis for 7 thunderstorms periods in February 2000 (total duration of thunderstorms periods more than 5000 minutes). Our EFS-1000 for all $E \geq +16$ *kV/m* gives the value $E = +16$ *kV/m*. Therefore we need to exclude from regression analyses all points with $E = +16$ *kV/m*. In Fig. 2 are shown total neutron intensity variations in dependence of atmospheric electric field E.

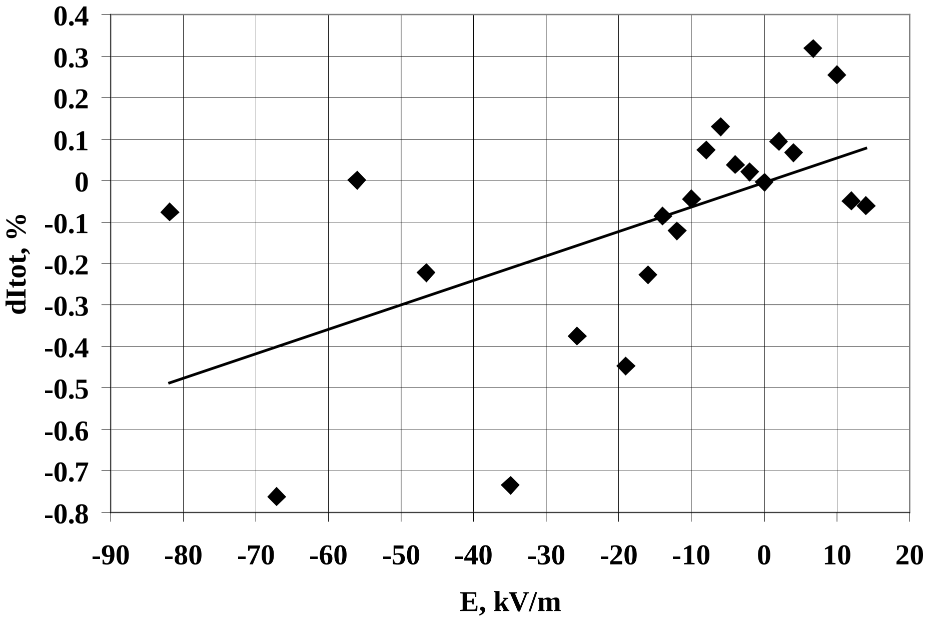

Fig. 2. Cosmic ray intensity variations *vs* atmospheric electric field E for total neutron intensity according to measurements on Mt. Hermon in February 2000. Straight line reflects the linear correlation between CR intensity and atmospheric electric field E according to Eq. 4.

According to data in Fig. 2, the statistical relation between variations of total neutron intensity and E is as following:

$$(\Delta I_t(t)/I_{to})_E \propto \overline{W}_{tE} \times (h_o - h_3) \times E(h_o,t) \tag{3}$$

with correlation and regression coefficients

$$R_t = 0.56 \pm 0.09;\ \overline{W}_{tE} \times (h_o - h_3) = (0.0059 \pm 0.0018)\ \%(kV/m)^{-1} \,. \tag{4}$$

In Fig. 3 - 4 are shown intensity variations of the multiplicities *m*=1 and 2 in dependence of atmospheric electric field *E*.

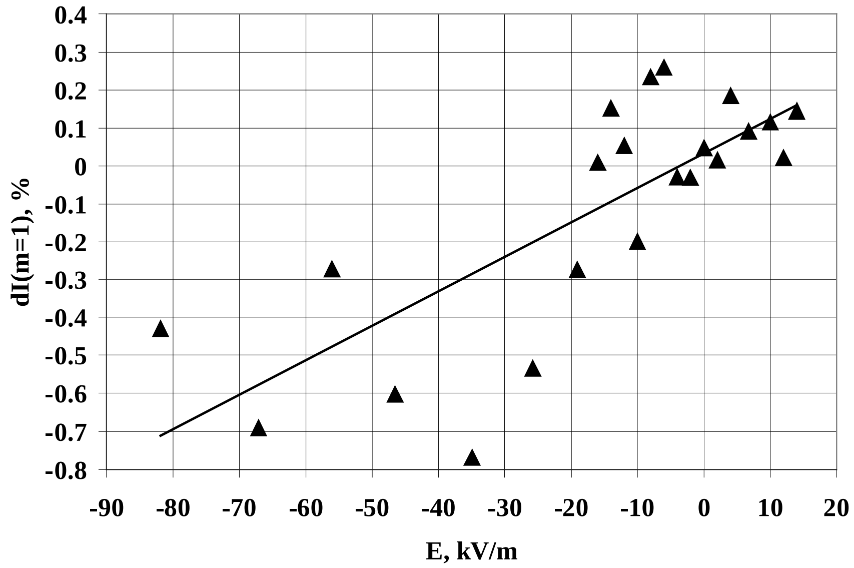

Fig. 3. The same as in Fig. 2, but for multiplicity *m*=1. Straight line reflects the linear correlation according to Eq. 6 with regression coefficient Eq. 7.

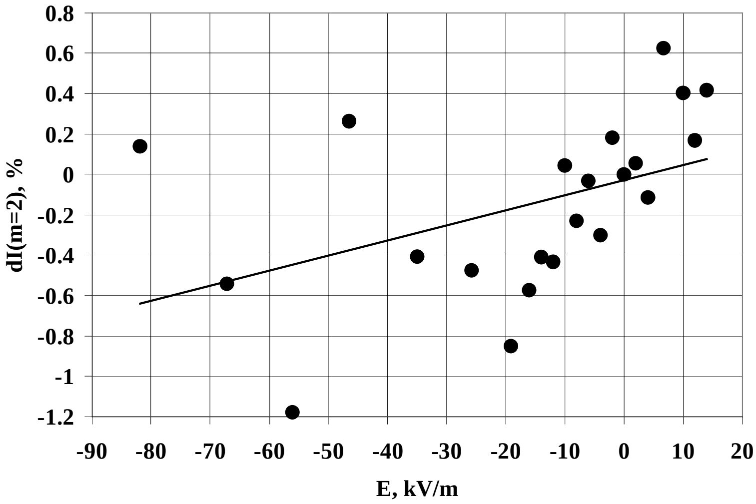

Fig. 4. The same as in Fig. 2, but for multiplicity *m*=2. Straight line reflects the linear correlation according to Eq. 5 with regression coefficient Eq. 8.

The statistical relations between variations of multiplicities m=1. 2, 3 and *E* are as following:

$$\left(\Delta I_m(t)/I_{mo}\right)_E \propto \overline{W}_{mE} \times \left(h_o - h_3\right) \times E\left(h_o, t\right) \quad (5)$$

with correlation coefficients

$$R_1 = 0.77 \pm 0.06,\ R_2 = 0.45 \pm 0.11,\ R_3 = -0.07 \pm 0.14, \quad (6)$$

and regression coefficients

$$\overline{W}_{1E} \times (h_o - h_3) = (0.0091 \pm 0.0016)\ \%(kV/m)^{-1},\ . \qquad (7)$$

$$\overline{W}_{2E} \times (h_o - h_3) = (0.0075 \pm 0.0032)\ \%(kV/m)^{-1}, \qquad (8)$$

$$\overline{W}_{3E} \times (h_o - h_3) = -(0.0016 \pm 0.0048)\ \%(kV/m)^{-1}, \qquad (9)$$

COMPARISON OF EXPERIMENTAL RESULTS AND THEORETICALLY PREDICTED OF ATMOSPHERIC ELECTRIC FIELD EFFECTS IN COUNTING RATES OF TOTAL NEUTRON INTENSITY AND DIFFERENT MULTIPLICITIES; DISCUSSION AND CONCLUSION

The comparison of experimental results reflected in Fig. 2-4 and Eq. 3-9 shows, that the best correlation with the biggest regression coefficient was observed for the multiplicity m=1, then smaller correlation and regression coefficients was observed for the total neutron intensity and for multiplicity m=2. Practically absent correlation and negligible regression coefficient was observed for the multiplicity m=3. These results are in good qualitatively agreement with predicted in Dorman and Dorman (1995), and recently calculated in details in Dorman and Dorman (2003).

To make quantitatively comparison of obtained experimental results with theory is much more difficult. From one hand, the influence of atmospheric electric field on charged energetic particles of cosmic rays has an integral character in vertical direction from the level of observations to the level of charged clouds and from great horizontal surface (neutron monitor detects particles arrived mostly from zenith angles smaller than about 30° that means from the surface about 10 km^2 on the height of charged clouds of few km). From other hand, the sensor of atmospheric electric field EFS-1000 gives information only on the local atmospheric electric field on the top of our Observatory on Mt. Hermon. Nevertheless we can try to do this comparison. Because February 2000, when was made observations, is a period of high solar activity, we will use for comparison theoretical prediction for Mt. Hermon, described by Eq. 18 in Dorman and Dorman (2003).

Let us in the first compare theoretical result for the multiplicity m=1 in Eq. 18 in Dorman and Dorman (2003) with experimental result described by Eq. 7, what was obtained with the smallest relative error. From this comparison follows

$$(h_o - h_3)_{m=1} \approx \frac{(0.0091 \pm 0.0016)\%(kV/m)^{-1}}{6.99 \times 10^{-5}\ \%(kV/m)^{-1}\left(g/cm^2\right)^{-1}} = (130 \pm 23)\,g/cm^2 \qquad (10)$$

From comparison of theoretical Eq. 18 in Dorman and Dorman (2003) for total intensity and multiplicity m=2 with experimental results described by Eq. 4 and 8, we obtain

$$(h_o - h_3)_{tot} \approx \frac{(0.0059 \pm 0.0018)\%(kV/m)^{-1}}{4.72 \times 10^{-5}\ \%(kV/m)^{-1}\left(g/cm^2\right)^{-1}} = (125 \pm 38)\,g/cm^2 \qquad (11)$$

$$(h_o - h_3)_{m=2} \approx \frac{(0.0075 \pm 0.0032)\%(kV/m)^{-1}}{4.66 \times 10^{-5}\ \%(kV/m)^{-1}\left(g/cm^2\right)^{-1}} = (160 \pm 68)\,g/cm^2 \qquad (12)$$

For multiplicity m=3 the expected effect is very small (see Eq. 18 in Dorman and Dorman, 2003)) in agreement with experimental result described by Eq. 9. The relative errors of determining $h_o - h_3$ by measurements of total intensity and multiplicities m=1 and m=2 are

$$\sigma_{tot} = \pm 38/125 = \pm 0.304;\ \sigma_1 = \pm 23/130 = \pm 0.177;\ \sigma_2 = \pm 68/160 = \pm 0.425; \qquad (13)$$

so the average value of $h_o - h_3$ with taking into account the relative weights of results described by Eq. 10-12 will be

$$\left(h_o - h_3\right)_{av} = \left\{\sigma_{tot}^{-2}\left(h_o - h_3\right)_{tot} + \sigma_1^{-2}\left(h_o - h_3\right)_{m=1} + \sigma_2^{-2}\left(h_o - h_3\right)_{m=2}\right\} \times \left(\sigma_{tot}^{-2} + \sigma_1^{-2} + \sigma_2^{-2}\right)^{-1} = 132\ g/cm^2; \quad (14)$$

with relative statistical error

$$\sigma_{av}^{-2} = \sigma_{tot}^{-2} + \sigma_1^{-2} + \sigma_2^{-2};\ \ \sigma_{av} = \pm 0.144, \quad (15)$$

so the final average result will be

$$\left(h_o - h_3\right)_{av} = (132 \pm 19)\ g/cm^2 \quad (16)$$

Obtained results show that the theory of atmospheric electric field effects in total neutron intensity and different multiplicities is in good agreement with experimental data obtained on Mt. Hermon. Determination of $\left(h_o - h_3\right)_{av}$ (see Eq. 16) shows that the average vertical distance from Emilio Segre' Observatory on Mt. Hermon to charged clouds caused atmospheric electric field is about 1.5–2.0 km (altitude above sea level 3.5–4.0 km) what is also in good agreement with meteorological observations. Obtained results show that with increasing of the accuracy of cosmic ray measurements it will be possible to estimate by cosmic rays the integral of electric field between ground and clouds (by measurements of total acceleration or deceleration of cosmic ray particles by atmospheric electric field between ground and clouds) what will give additional important continue information to the information on the the local atmospheric electric field what we have now.

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