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Research Article

Impact of High Energy Cosmic Rays on Global Atmospheric Electrical Parameters over Different Orographically Important Places of India

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Global atmospheric electrical parameters such as atmospheric conductivity, air-earth current density, atmospheric electric field, and atmospheric potential have been calculated for eighty different orographically important places of India under the influence of cosmic ray modulation factor due to Forbush decrease assuming fair weather conditions. The results have been compared with the earlier work of Kumar et al. (1998) and show that the correlation between cosmic rays and global atmospheric electrical parameters near the earth surface depends upon the relative magnitudes of galactic cosmic ray particles.

1. Introduction

Many investigators ([1–4] and others) suggest that the global atmospheric electrical parameters are influenced by the solar activity. Since the global electric circuit (GEC) describes the electrical environment of earth's near space, the solar activity is known to change the overall state of ionization [5]. The cosmic rays are one of the chief indicators of solar activity [6]. The solar activity influences the intensity of thundercloud electrification by changing the middle atmospheric conductivity above the top of the thundercloud [7]. The ionization rate of the atmosphere is the controlling element of the global electric circuit and is significantly affected by solar variability. Therefore, it is reasonable to expect that the atmospheric electrical parameters will be affected by solar activity.

In recent years, considerable attention has been paid to the GEC model that may provide better insight into the possible electrical coupling mechanism responsible for the observed variations. Hays and Roble [8] developed a quasistatic model using spherical harmonic functions, which include the geographical distribution of thundercloud activity, effect of earth's orography, and electrical coupling along geomagnetic field lines in the ionosphere and magnetosphere. Their calculations suggest that changes in conductivity due to solar flares are capable of affecting the global electric circuit on the global scale. However, their results did not explain the fact that both the atmospheric electric field and current increase after a solar flare. Tzur and Roble [9] used a two-dimensional model to calculate the atmospheric electrical response resulting from solar proton events and from Forbush decrease in cosmic ray flux following a solar flare. Makino and Ogawa [10] have developed a numerical model including earth's orography and global distribution of thunderstorm generators. Their results suggest that the decrease in cosmic ray flux has significant influence on the GEC parameters. Their calculations also explain the increase in both atmospheric electric field and air-earth current during solar flare events in high mountain stations. Also, Makino and Ogawa [11] improved their earlier model by incorporating the latitudinal, longitudinal, and height variations of conductivity. Sapkota and Varshneya [12] estimated the response of the global circuit to the Forbush decrease in cosmic ray flux. But the calculations of Makino and Ogawa [11] and Sapkota and Varshneya [12] were performed on the global basis in a grid of 5° both in latitude and longitude. Agarwal and Varshneya [13] made calculations for GEC parameters by taking the latitudinal variation factor due to cosmic rays as 0.4 for clean and clear atmosphere, but they took orography of Indian subcontinent.

Although many correlations of solar activity with global atmospheric electrical parameters at different geographic locations and altitudes are available in the literature, no theoretical details explaining all the observations for small-scale feature in response to solar activity are known. Therefore, the purpose of this paper is to determine the response of the global electric circuit in relation to decrease in cosmic ray flux. The global atmospheric electrical parameters, namely, atmospheric conductivity, air-earth current density, electric field, and atmospheric potential have been estimated by taking the height and latitudinal variations in cosmic ray flux due to Forbush decrease for 80 different cities of India assuming fair weather conditions.

2. Global Atmospheric Electrical Parameters

Makino and Ogawa [11] suggested that the atmospheric electric global circuit is a current system in which current flows upward from thunderstorm current generator through the ionosphere and down to the earth's surface in the fair weather regions, such that

$$\nabla \cdot \mathbf{J} = J_s, \tag{1}$$

where J_s is the point current source at the thundercloud centre and $\mathbf{J}$ is the current density in fair weather region.

Hays and Roble [8] divided the atmosphere into four coupled regions: lower troposphere, upper troposphere, mesosphere, and magnetosphere. The first region up to about 9 km is of much importance due to the earth's orography and varying electrical conductivity which increases exponentially with altitude [13], that is,

$$\begin{aligned} \sigma(z,\theta) &= \sigma_{sl} \exp\left[\frac{z}{2S_1(\theta)}\right] \ \mathrm{Sm}^{-1}, \quad z < z_1, \\ \sigma(z,\theta) &= \sigma_r(\theta) \exp\left[\frac{z}{2S_2(\theta)}\right] \ \mathrm{Sm}^{-1}, \quad z \geq z_1, \end{aligned} \tag{2}$$

where z is height from the sea level and θ is the colatitude. The colatitude is the complement of latitude. z_1 is height of the boundary separating lower troposphere from the upper troposphere (=9 km) and σ_{sl} is sea level conductivity (=2.2×10^{-14} Sm^{-1}).

$S_1(\theta)$ and $S_2(\theta)$ are the conductivity scale heights. The scale height $S_1(\theta)$ is given by

$$S_1(\theta) = \frac{z_1}{\{2\ln[(\sigma_r(\theta)/\sigma_{sl})\exp(z_1/2S_2)]\}} \ \mathrm{km}, \tag{3}$$

where $\sigma_r(\theta)$ is the reference conductivity and is given by

$$\begin{aligned} \sigma_r(\theta) &= \sigma_0\left[1+\left(\frac{F}{2}\right)\{1+\cos 3(\theta-30^\circ)\}\right] \ \mathrm{Sm}^{-1} \\ &\qquad \text{for } 30^\circ \leq \theta \leq 150^\circ, \\ \sigma_r(\theta) &= \sigma_0[1+F] \ \mathrm{Sm}^{-1} \quad \text{for } 30^\circ < \theta,\ \theta > 150^\circ, \end{aligned} \tag{4}$$

σ_0 is the reference conductivity at equator (1.1×10^{-13} Sm^{-1}), and S_2 is the scale height of vertical variation of conductivity (=3 km). F is the height and latitudinal variation in galactic cosmic ray modulation factor. F at an altitude (z from sea level) and colatitude (θ) is written as [14]

$$F = \begin{cases} F_{\min} \exp\left(-\dfrac{z}{S_{co}}\right), & z = 30\,\mathrm{km}, \\ F \ (\text{at } z = 30\,\mathrm{km}), & z > 30\,\mathrm{km}, \end{cases} \tag{5}$$

where S_{co} is the scale height calculated as

$$S_{co} = \frac{Z_{\max}}{\ln(F_{\max}/F_{\min})}, \tag{6}$$

where $z_{\max}$ is maximum value of height from sea level (30 km). $F_{\max}$ and $F_{\min}$ are the maximum and minimum values of galactic cosmic ray modulation factor.

$F_{\max}$ and $F_{\min}$ with $30^\circ \leq \theta \leq 150^\circ$ are given as

$$\begin{aligned} F_{\max} &= 0.05 + \alpha_{\max}\cos^4(\theta), \\ F_{\min} &= 0.03 + \left(\frac{\alpha_{\max}}{15}\right)\cos^4(\theta). \end{aligned} \tag{7}$$

Agarwal and Varshneya [13] reported that the galactic cosmic ray ion production rate is nearly constant at latitudes greater than 60°. Therefore, for all values of $\theta \leq 30^\circ$, we take $\theta = 30^\circ$, and for $\theta \geq 150^\circ$, we take $\theta = 150^\circ$.

$\alpha_{\max}$ is a constant which controls the height and latitudinal variations of cosmic ray flux. Based on the measurements of Neher [15], $\alpha_{\max}$ is found to lie in between 0.9 and 1.3. We have taken it 1.3 for maximum effect of F.

The columnar resistance, $R_{cl}(\theta)$, between the ionosphere and the earth surface is evaluated by

$$\begin{aligned} R_{cl_1}(\theta) &= \int_{z_g}^{z_1} \frac{1}{\sigma(z,\theta)} dz \ \Omega\mathrm{m}^2, \quad z_g \leq z \leq z_1, \\ R_{cl_2}(\theta) &= \int_{z_1}^{z_i} \frac{1}{\sigma(z,\theta)} dz \ \Omega\mathrm{m}^2, \quad z_1 \leq z \leq z_i. \end{aligned} \tag{8}$$

Therefore,

$$R_{cl}(\theta) = \left[R_{cl_1}(\theta) + R_{cl_2}(\theta)\right] \ \Omega\mathrm{m}^2, \tag{9}$$

where z_i is the height of the ionosphere (60 km) and z_g is the ground height from sea level.

The air-earth current density can be estimated as

$$J(z,\theta) = \frac{\Phi_i}{R_{cl}(\theta)}, \tag{10}$$

where Φ_i is the ionospheric potential (300 kV).

Then, the electric field $E(z,\theta)$ can be calculated as

$$J(z,\theta) = \sigma(z,\theta) \cdot E(z,\theta) \ \ \mathrm{Am}^{-2}. \tag{11}$$

The electrostatic potential $\phi(z,\theta)$ may be expressed by

$$\phi(z,\theta) = \int_{z_g}^{z} E(z,\theta)\, dz \ \mathrm{kV}. \tag{12}$$

This way, the calculations for the atmospheric electrical parameters were made for 80 different orographically important places of India. The results have been compared with the work of Kumar et al. [16] where they have taken a constant value (0.4) of galactic cosmic ray variation factor for the orography of the Indian subcontinent.

3. Results and Discussion

Figure 1(a) shows the variation of cosmic ray variation factor with height from sea level, whereas Figure 1(b) shows the plot of cosmic ray variation factor with latitude for 80 different orographically important places of India.

The atmospheric conductivity of hilly places (altitude > 2100 m) like Darjeeling, Shimla, and Kodaikanal has been found to be 4.68×10^{-14}, 4.80×10^{-14}, and 5.06×10^{-14} Sm^{-1} by taking F with $\alpha_{\max} = 1.3$ (Table 1), whereas for $F = 0.4$, the atmospheric conductivity for these places is 4.96×10^{-14}, 5.11×10^{-14}, and 5.39×10^{-14} Sm^{-1} (Table 2), respectively. For places very close to sea level (altitude < 12 m) like Vishakhapatnam, Kolkata, Thiruvananthapuram, and Mumbai, the conductivity is found to be 2.2×10^{-14} $\mathrm{Sm}^{-1}$for each place by taking F with $\alpha_{\max} = 1.3$ and $F = 0.4$. Agarwal and Varshneya [13] reported the value of atmospheric conductivity as 2.2×10^{-14} Sm^{-1} over oceans around the Indian subcontinent which is in full agreement with our calculated values for these places. Figure 2 shows a variation between atmospheric conductivity and height from sea level.

The calculated values of air-earth current density for mountainous regions such as Pachmarhi, Moun Tabu, Shillong Srinagar, Darjeeling, Shimla, and Kodaikanal have current density of the order of 3.20×10^{-12} Am^{-2}, 3.34×10^{-12} Am^{-2}, 3.82×10^{-12} Am^{-2}, 3.88×10^{-12} Am^{-2}, 4.54×10^{-12} Am^{-2}, 4.65×10^{-12} Am^{-2}, and 4.87×10^{-12} Am^{-2} by taking F with $\alpha_{\max} = 1.3$ (Table 1), whereas the current density for these places is 3.58×10^{-12} Am^{-2}, 3.74×10^{-12} Am^{-2}, 4.33×10^{-12} Am^{-2}, 4.42×10^{-12} Am^{-2}, 5.22×10^{-12} Am^{-2}, 5.35×10^{-12} Am^{-2}, and 5.62×10^{-12} Am^{-2}, respectively, for $F = 0.4$ (Table 2). Thus, the values of air-earth current density have been found to decrease for these mountainous places in comparison to the results of Kumar et al. [16]. But the values of each place increase at low and decrease at high latitudes which are in agreement with the work of Agarwal et al. [5]. Figure 3 shows a graph between air-earth current density and height from sea level. The places close to ocean like Kolkata and Vishakhapatnam have much less effect of cosmic ray flux which is quite obvious since the cosmic rays of the solar origin are known to cause the ionization at altitudes from 15 to 20 km onwards [17].

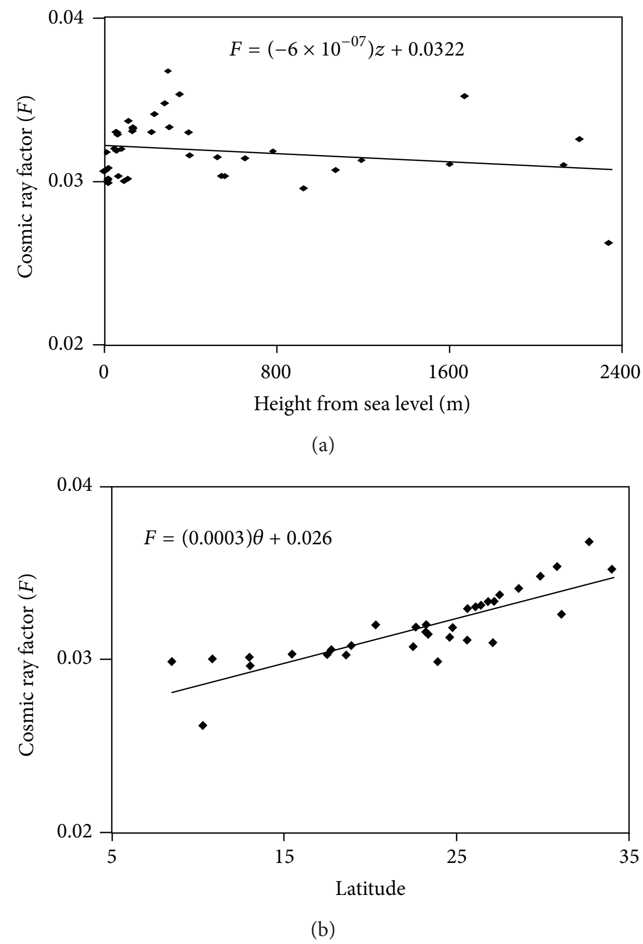

Figure 1: (a) Variation of cosmic ray factor (F) with hight from sea level. (b) Variation of cosmic ray factor with latitude.

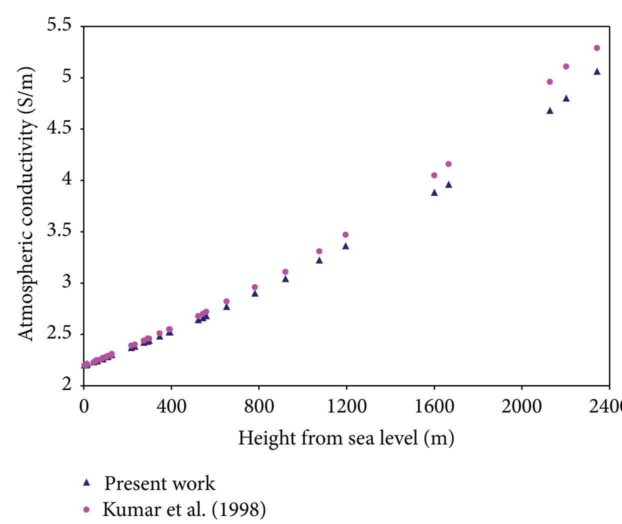

Figure 2: Atmospheric conductivity versus height from sea level.

It is estimated from calculations that the electric field over mountainous regions such as Pachmarhi, Moun Tabu, Shillong, Srinagar, Darjeeling, Shimla, and Kodaikanal having

Table 1: Calculated GEC parameters for F with $\alpha_{max} = 1.3$.

Sr no.	City	Conductivity ($\times 10^{-14}$ Sm^{-1})	Current density (10^{12} Am^2)	Electrical field (V/m)	Atmospheric potential (kV)
(1)	Agartala	2.21	2.24	101.43	274.68
(2)	Ahmedabad	2.24	2.27	101.38	274.35
(3)	Bangalore	3.04	3.04	99.92	265.80
(4)	Bhopal	2.64	2.66	100.65	270.02
(5)	Bhubanesware	2.23	2.26	101.39	274.43
(6)	Bhuj	2.26	2.29	101.34	274.13
(7)	Kolkata	2.20	2.23	101.44	274.76
(8)	Chandigarh	2.48	2.50	100.89	271.70
(9)	Chennai	2.21	2.24	101.43	274.68
(10)	Darjeeling	4.68	4.54	97.04	249.35
(11)	Dibrugarh	2.28	2.31	101.30	273.86
(12)	Gauhati	2.24	2.27	101.38	274.36
(13)	Goa	2.24	2.27	101.37	274.29
(14)	Hyderabad	2.66	2.68	100.61	269.80
(15)	Imphal	2.90	2.90	100.19	267.35
(16)	Jabalpur	2.52	2.55	100.86	271.29
(17)	Jaipur	2.52	2.54	100.87	271.32
(18)	Jammu	2.43	2.45	100.84	272.14
(19)	Jodhpur	2.37	2.40	101.14	272.92
(20)	Kanpur	2.30	2.33	101.27	273.72
(21)	Kodaikanal	5.06	4.87	96.40	245.75
(22)	Lucknow	2.30	2.33	101.27	273.72
(23)	Mangalore	2.28	2.31	101.31	273.94
(24)	Moun Tabu	3.36	3.34	99.37	262.58
(25)	Mumbai	2.20	2.24	101.44	274.72
(26)	Nagpur	2.44	2.46	101.01	272.18
(27)	New Delhi	2.38	2.41	101.11	272.78
(28)	Pachmarhi	3.22	3.20	99.62	264.02
(29)	Patna	2.24	2.27	101.37	274.31
(30)	Pune	2.68	2.69	100.58	269.66
(31)	Ranchi	2.77	2.78	100.42	268.71
(32)	Roorkee	2.42	2.44	100.95	272.34
(33)	Shillong	3.88	3.82	98.44	257.29
(34)	Shimla	4.80	4.65	96.75	248.08
(35)	Srinagar	3.96	3.88	97.98	256.17
(36)	Tiruchchirapalli	2.26	2.29	101.33	274.06
(37)	Thiruvananthapuram	2.20	2.23	101.44	274.75
(38)	Vishakhapatnam	2.20	2.23	101.45	274.79

altitudes 1075, 1195, 1600, 1666, 2128, 2202, and 2343 meters is 99.62, 99.37, 98.44, 97.98, 97.04, 96.75, and 96.40 V/m, respectively, by taking F with $\alpha_{max} = 1.3$ (Table 1), whereas for $F = 0.4$ (Table 2), the values of electric field for the above places have been found to be 108.11, 107.82, 106.72, 106.42, 105.05, 104.79, and 104.29 V/m, respectively. These results show that the values decrease in each case for all the hilly cities of India. But for an increase in cosmic ray flux, these values somewhat increase which is due to the increase in cosmic ray flux. The places very close to sea level have the average value of around 101.44 V/m. The mean value of electric field for these 80 different places is found to be 100.51 V/m, whereas for $F = 0.4$, this mean value of electric field is found to be 109.17 V/m. These results show that the average value of electric field is in agreement with previous works [18]. Figure 4 shows a variation of electric field with height from sea level. This graph clearly compares our results with Kumar et al. [16].

Calculations show that the average value of atmospheric potential for these 80 different places has been estimated to

TABLE 2: Calculated GEC parameters for $F = 0.4$.

Sr no.	City	Conductivity ($\times 10^{-14}$ Sm^{-1})	Current density (10^{12} Am^{2})	Electrical field (V/m)	Atmospheric potential (kV)
(1)	Agartala	2.21	2.43	110.02	278.67
(2)	Ahmedabad	2.24	2.46	109.89	278.33
(3)	Bangalore	3.11	3.31	106.64	269.52
(4)	Bhopal	2.68	2.92	109.04	274.31
(5)	Bhubaneswar	2.23	2.45	109.59	278.27
(6)	Bhuj	2.26	2.49	109.86	278.14
(7)	Kolkata	2.20	2.42	109.93	278.70
(8)	Chandigarh	2.51	2.75	109.68	276.04
(9)	Chennai	2.21	2.39	108.42	277.97
(10)	Darjeeling	4.96	5.21	104.99	254.59
(11)	Dibrugarh	2.29	2.52	110.07	278.01
(12)	Gauhati	2.24	2.47	110.11	278.44
(13)	Goa	2.25	2.45	108.81	277.81
(14)	Hyderabad	2.70	2.92	108.27	273.75
(15)	Imphal	2.96	3.22	108.61	271.85
(16)	Jabalpur	2.55	2.79	109.29	275.49
(17)	Jaipur	2.55	2.79	109.53	275.63
(18)	Jammu	2.46	2.69	109.74	276.50
(19)	Jodhpur	2.39	2.62	109.83	277.11
(20)	Kanpur	2.30	2.54	109.99	277.86
(21)	Kodaikanal	5.29	5.39	101.94	249.55
(22)	Lucknow	2.31	2.54	110.01	277.86
(23)	Mangalore	2.28	2.47	108.25	277.27
(24)	Moun Tabu	3.47	3.73	107.62	267.31
(25)	Mumbai	2.20	2.41	109.47	278.47
(26)	Nagpur	2.46	2.70	109.72	276.44
(27)	New Delhi	2.40	2.64	109.88	277.01
(28)	Pachmarhi	3.31	3.57	107.74	268.60
(29)	Patna	2.25	2.47	110.07	278.38
(30)	Pune	2.72	2.94	108.41	273.70
(31)	Ranchi	2.82	3.06	108.78	273.08
(32)	Roorkee	2.44	2.68	109.81	276.66
(33)	Shillong	4.05	4.32	106.59	262.27
(34)	Shimla	5.11	5.35	104.79	253.43
(35)	Srinagar	4.16	4.42	106.42	261.39
(36)	Tiruchchirapalli	2.27	2.45	107.80	277.17
(37)	Thiruvananthapuram	2.20	2.36	107.39	277.57
(38)	Vishakhapatnam	2.20	2.40	109.31	278.45

be 269.42, whereas from the investigations of Kumar et al. [16], it is clear that this average value of potential for $F = 0.4$ is 273.79 kV. Figure 5 compares our results of potential with height from sea level.

4. Conclusion

The results of present studies show that the variations in cosmic ray flux affect prominently the earth's environment. The calculated global electric circuit parameters have been found to vary in agreement with the clear response of solar activity. Whereas the solar cosmic ray particles are not able to penetrate to the lower atmosphere, the galactic cosmic ray particles create ionization up to ground surface at all altitudes. However, there is a less effect of cosmic rays to places very close to sea level. Kumar et al. [16] found that the orography of the earth surface plays an important role in the determination of global atmospheric electrical parameters. Therefore, it is concluded from the above study that the correlation between cosmic rays and atmospheric electrical

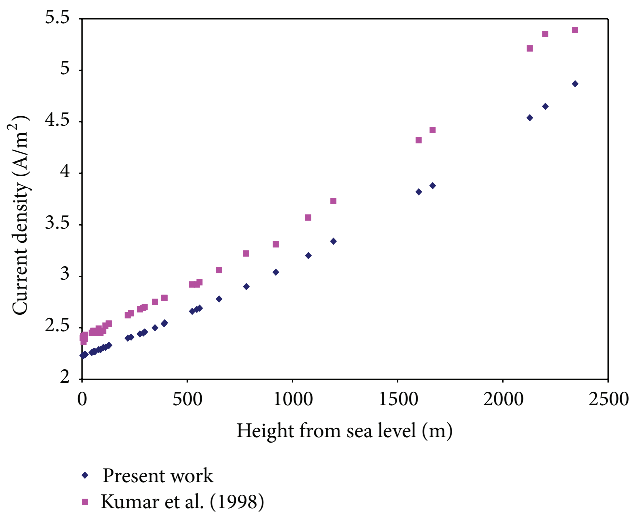

FIGURE 3: Current density versus height from sea level.

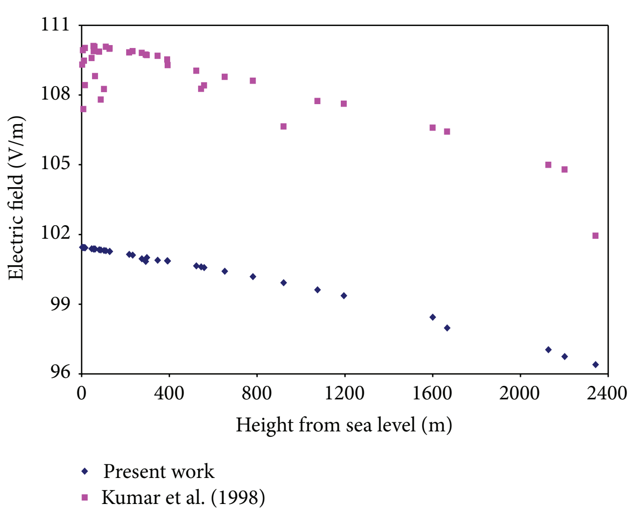

FIGURE 4: Atmospheric electric field versus height from sea level.

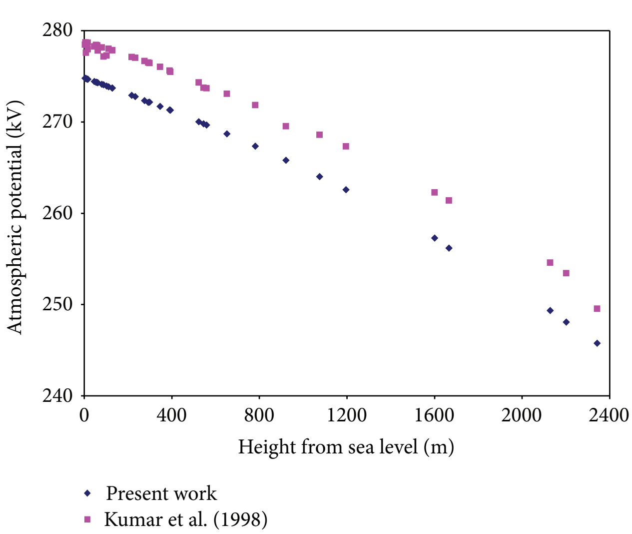

FIGURE 5: Atmospheric potential versus height from sea level.

parameters near the earth surface depends upon the relative magnitudes of galactic cosmic ray particles.

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