Is GCR induced ionization the prime driving force for Venus Lightning? V. R. Dinesh Kumar[1], Jayesh Pabari[2] and Kinsuk Acharyya[2], [1]Birla Institute of Technology and Science, Pilani (f20140771h@alumni.bits-pilani.ac.in), [2]Physical Research Laboratory, Ahmedabad.

Introduction: The lack of global magnetic fields on Venus has resulted in the formation of weak induced magnetic fields which give unrestricted access to Galactic Cosmic Rays (GCR) [1,2]. The ionization of lower atmosphere as a result of GCR has been a subject of many of the earlier studies and it has been considered as the primary source for cloud electrification on Venus [3,4]. In this work, we provide calculations that if GCR was indeed the prime driving mechanism for cloud electrification, then the intracloud discharges would be extremely long and results from earlier missions are not consistent with such discharges. We also show that even if we consider high altitude lightning initiation, where breakdown field is much lower, GCR induced charging still falls short and does not produce fields greater than breakdown field.

Methods: In terrestrial thunderstorms, the charged regions in the clouds have been approximated as a cylinder of radius 'R', thickness 't' and charge density 'ρ' [5,6]. The proposed geometry is as shown in Figure 1. It can be easily shown that the electric field due to this configuration at any point on the central axis is given by

$$\boldsymbol{E} = \frac{-\rho R}{2\varepsilon_0}\left[b_1 - \sqrt{1+{b_1}^2} - a_1 + \sqrt{1+{a_1}^2}\right]$$

where $a_1 = |z_0 - z_1|/R$ and $b_1 = |z_0 - z_2|/R$. Central axis if of interest because at any given altitude level, the maximum field produced by the cylinder will be at the point on the central axis. The maximum electric field produced by this unipolar charged cylinder as shown in Figure 1 is at altitude levels 'z_1' and 'z_2' on the central axis (i.e.) at cylindrical boundaries. The fields at these maxima points are equal and opposite and field is zero at the center of the cylinder. The effective electric field due to multiple charged regions, (i.e.) dipolar charged regions in atmosphere and their image charges due to Venus surface, is simply the vector sum of the fields due to each individual charge regions. Breakdown field is the field at which free electrons in the atmosphere gain sufficient kinetic energy to ionize a neutral molecule. Thus, lightning will initiate only when total field due to charged cylinders is greater than the breakdown field (i.e.) $|E_{tot}| \geq E_{br}$. The breakdown field of Venus atmosphere can be determined using the relation

$$E_{br}(z) = E_{br,0}\frac{n(z)}{n_0}$$

where $E_{br,0} = 6.95 \times 10^4\ kV/m$, $n(z)$ and n_0 are the atmospheric number density at an altitude 'z' and at the surface, respectively [7].

The Venusian middle clouds have high concentration of all modes of cloud particles [8]. It is shown in the work of Michael et al. [4] that the cloud particles in the regions of 48 – 55 km acquire negative charge as a result of electron attachment and charge transfer from ions. However, the typical charge density observed is in the order of pC/m^3 or lower in these regions. Beyond 55 km, appreciable amount of charge is not acquired by the cloud particles because of reduction in concentration of the cloud particles. At each altitude level, the remainder of positive ions and negative ions after the cascade of chemical processes are nearly equal. However, the concentration of free electron steadily increases from 10^6 m^{-3} at 45 km altitude level and attains a maximum concentration of 4×10^7 m^{-3} at about 60 km. Beyond that, it steadily continues to fall. We assume that the convective cells in the middle cloud [9,10] and gravitational segregation enable the formation of two distinct charge regions. Since breakdown field required for lightning initiation reduces with altitude [7], the breakdown field at upper cylinder is lower than that of the breakdown field at lower cylinder. Using the analytical expression and lower breakdown field at higher altitudes, we estimate the radius of the charged cylinders required to produce fields greater than breakdown fields. We also study the possibility of lightning initiation in higher altitudes due to the increased concentration of free electrons produced in higher altitudes as a result of GCR induced ionization.

Results: Free electrons produced by GCR induced ionization are not constrained to initiate lightning within convective cells and can initiate lightning at any higher altitude level. From a theoretical perspective, even a unipolar cloud charge region can produce fields greater than breakdown fields. Assuming a charged cylinder exists with its top face at 70 km (the boundary of upper clouds) and the charge density of this cylinder is 6.4 pC/m^3 (corresponding to maximum electron concentration), the resultant electric field at 70 km altitude due to various combinations of thickness and radius of cylinder is shown in Figure 2. Breakdown field at 70 km is 43 kV/m and even when assuming maximum possible thickness of 20 km (height of cloud layers) and extremely large radii, the maximum field produced is only 7.3 kV/m. Even under best possible condition, GCR produced free electrons are not capable of producing fields greater than critical fields.

We assumed that with the aid of convective cells and gravitational segregation, two distinct charge cells are formed with a thickness of few kms and have charge density in the order of pC/m^3.To cross breakdown fields, the radius of the charged cylindrical regions of these charge cells within middle clouds is required to be in the order of 1500 km and more. In the fractal modelling works of intracloud discharges, lightning usually initiates in the region between the charged cylinders and continues to grow in both directions till it reaches close to periphery of the charged cylinders [5,6]. The typical duration of one stroke of these extremely long discharges is in the order of 150 – 1500 ms (assuming propagation speeds of 10^7 and 10^6 m/s, respectively). For 'k' number of strokes, the length of the bursts recorded will be much longer. This results in whistler bursts in the order of few seconds. Statistical study of Venus Express Magnetometer datasets has shown that whistler bursts detected on Venus were typically 100 ms [11]. Such long discharges and time scales of these discharges are not consistent with spacecraft observations. Based on these results, we conclude that GCR induced ionization cannot be the prime driving mechanism for Venus Lightning.

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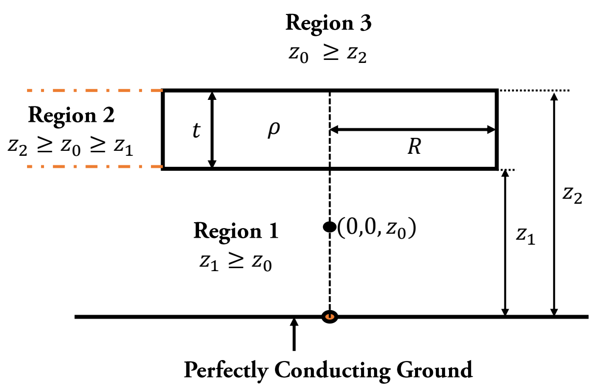

Figure 1: Side View of Proposed Geometry of Charged Cylinder in Venusian Atmosphere

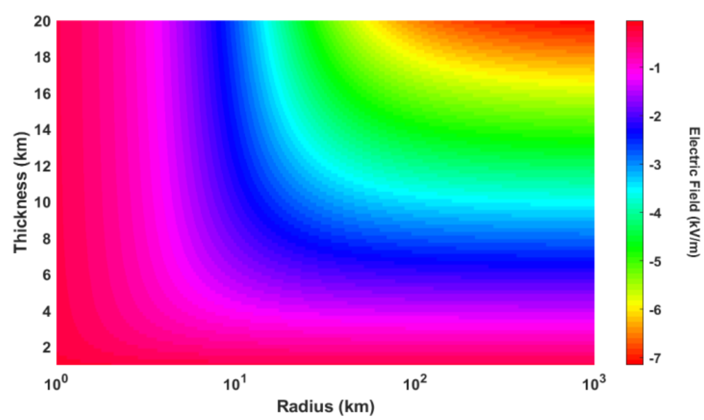

Figure 2: Parametric Sweep of radii and thickness of uniformly charged cylinder with charge density of 6.4 pC/m^3