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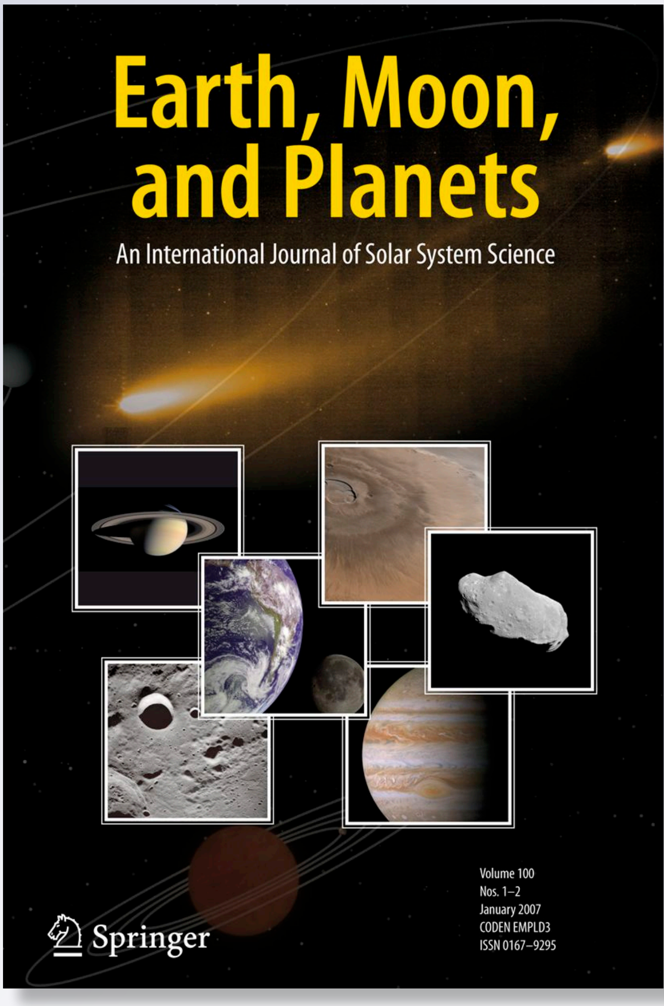


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# Studies on the Effects of 2009 Leonid Meteor Shower on Subionospheric Transmitted VLF Signals and Vertical Electric Potential Gradient

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**Abstract** The effects of 2009 Leonid Meteor Shower upon the two VLF subionospheric transmitted signals and vertical electric potential gradient from the ground surface have been studied from Kolkata (Lat: 22.56°N, Long: 88.5°E) on November 17, 2009. The received signals showed their peak values when *ZHR* (Zenithal Hourly Rate) was highest. Some typical variations in the outcome of these measurements during the meteor showers will be presented in this paper.

**Keywords** Leonid meteor shower · Zenithal Hourly Rate · VLF transmitted signals

## 1 Introduction

Meteors on their entry to the Earth's atmosphere, produce intense ionization in the lower ionosphere which are expected to affect appreciably the propagation of electromagnetic waves in the VLF range (Price and Blum 2000; Trautner et al. 2002; De et al. 2006a, b; Drobnock 2002). There is no conclusive evidence that major showers add significant ionization to the D or E layers so far, other than from individual trains. Due to which, the extra-ionizations produced at the ionospheric heights by major and minor meteor showers is felt to be the field of investigation. Most ionization in D and E layers is thought to be due to chemistry in presence of meteoric materials that were deposited by the sporadic meteoroids at much smaller sizes than those responsible for visible meteors. Different meteors produce ionization at various levels and at various times as they enter Earth's atmosphere with different velocities and different sizes. The Leonid meteor shower was

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formerly recognized as a strong periodic shower with periodicity of 33 years. Perturbations affected the orbit of the meteoroids ejected in prior returns of the comet in such a way that periodically dust trails wander in Earth's path and cause intense showers. On November 2009, a strong Leonid shower was predicted to occur because Earth was to encounter such a dust trail of comet 55P/Tempel-Tuttle (Jenniskens 2006). A significant shower was detected on that day (Koten et al. 2011).

Many geophysical events like the precipitation of energetic particles, occurrences of solar flares, lightning, earthquakes modify the ionization like the transient luminous events, e.g., sprites and elves. Fixed frequency VLF signals during their propagation through the Earth-ionosphere cavity are affected (Thomson and Clilverd 2001).

The ionization in the lower ionospheric region modifies the Earth-ionosphere waveguide parameters. As a result, the VLF signals, when recorded after their journey through a long distance, exhibit anomalous variations both in their amplitude and phase. For these reasons, it can be used as a tool to study the ionospheric perturbations and their association with the naturally occurring events.

Meteor showers introduce perturbation in ion composition, temperature and other physical parameters within the ionospheric medium at different levels of altitude extending from the lower D-region to the magnetosphere height (Garaj et al. 2000; Nickolaenko et al. 1999; Rodger 2003). This should have effect on vertical potential gradient due to variation of electron density on the lower surface of the ionosphere.

In this paper, some typical variation of amplitude of 16.4 and 19.8 kHz sub-ionospheric VLF signals during meteor showers will be presented using the recorded data from Kolkata, India (Lat: 22.56°N, Long: 88.5°E).

The transmitted signal frequencies at 16.4 and 19.8 kHz get attenuated at about 50–60 km height of the lightly ionized zone during their travel towards the ionospheric layers, due to which effective reception of the reflected signal at the ground will be weak. Higher signal strength is obtained when this type of ionized trail can contribute to the process of reflection of transmitted signals at the VLF receiver along with the reflected waves from the ionosphere.

Meteorological reports showed that the days from 15 to 21 November, 2009 had very clear sky and no serious 'thunder-bolt' related events were reported at Kolkata. So the period was comprised of an ideal situation for observing meteor showers through its effects on VLF radio propagation. The GOES 10 and GOES 12 satellites which continuously monitor solar activity reported (http://www.swpc.noaa.gov) no solar flare events around the period of occurrence of Leonid Meteor shower. During the peak activity period of the shower, there were no local lightning or flare generated perturbations in the ionosphere that could alter the amplitudes of the subionospheric transmitted signals received at Kolkata.

We also measured the vertical electric potential gradient in search of a signature from the meteor shower. The atmospheric electric potential gradient near the Earth's surface is governed by global thunderstorm and lightning activities (Bering et al. 1998; Rycroft and Price 2000). These put the Earth-ionosphere waveguide into resonance producing various characteristic spectra. Some specific variations of the atmospheric potential gradient as a possible precursor of earthquake have been reported (Kachakhidze et al. 2009). This potential gradient also depends on local environmental factors. There exists a correlation between the local potential gradient and worldwide thunderstorm distribution. But the value may be locally modulated by extra-ionization in the lower ionosphere during meteor shower (Price and Blum 2000). This is because the extra-ionization may create additional electric fluxes between the Earth and the ionosphere.

The outcome of our measurement of vertical electric potential gradient on November 17, 2009, will be presented where the variation of amplitude during the period of meteor showers is found.

## 2 Experimental Setup

In the area of Atmospheric Electricity, we are taking continuous records of atmospheric vertical electric potential gradient, Schumann resonance spectra from Kolkata (De et al. 2006a, b, 2009). The variation of air-temperature, electric field, current density and conductivity over the surface of the Earth at tropical latitudes (±25°) and temperate latitudes (±60°) are interrelated with the solar radiations, global lightning activity and concentration of the aerosol content in the lower ionosphere. The production of high potential difference between the Earth and the ionosphere due to the total number of thunderclouds acting together at any time drives the air-earth current downward from the lower region of the ionosphere to the surface of the Earth which varies in accordance with the ionospheric potential and columnar resistance. The potential gradient is recorded in the form of signals. These are processed and finally viewed in a computer through data acquisition system.

Round the clock measurements of the VLF transmitted signals at frequencies 16.4 and 19.8 kHz are regularly recorded at Kolkata, India (Lat: 22.56°N, Long: 88.5°E) over the past several years. The features of these signals are given in Table 1. The experimental set up is followed from an earlier paper (De et al. 2006a, b). For the reception of these signals, a straight horizontal copper wire of 8 SWG with 120 m length is used at the vertical height of 30 m from the ground in the form of an inverted-L type antenna. It is capable of receiving vertically polarized transmitted signals in the VLF bands from near and far sources. To record the signals, Gyrator-II VLF receivers were fabricated. The recordings of the VLF transmitted signals are made by computerized data acquisition system through a PCI 1050, 16 channel 12 bit DAS card. The data are sampled out after detection at the rate of 10 Hz. These are then processed and being stored in a computer. The RMS values of the filtered data are analyzed regularly using Origin 5.0 software.

The vertical electric field has been measured on a continuous basis with an ac field-mill. The alternating signal from the field-mill is being amplified using a signal processor having one-second time constant. IC LF356 N has been used at the input stage of the amplifier because of its high input resistance ($\sim 10^{12}\ \Omega$) and good signal to noise ratio. The sensitivity of the field-mill has been measured, which is $0.33 \pm 0.03$ V $m^{-1}$. The output is recorded by digital data acquisition system at a sample rate of one data per second.

**Table 1** Features of the sub-ionospheric signals

| | | |
|---|---|---|
| Frequency | 16.4 kHz | 19.8 kHz |
| Transmitter call sign | JXN | NWC |
| Location | Aldra Island, Norway | North-West Cape, Australia |
| Latitude | 66.42°N | 21.82°S |
| Longitude | 13.13°E | 114.16°E |
| Transmitting antenna | Omni-directional | Omni-directional |
| Power at radiation | Unknown | 1,000 kW |
| Operation | Continuous | Continuous |

## 3 Observational Results

The Leonids emanate from the trail of parent Comet, 55P/Tempel-Tuttle and the shower activity is significantly changing from year to year. Based on the reports of International Meteor Organization (IMO), Lyytinen and Nissinen (2009) estimated the combined effects of its two trails, i. e., 1,466 and 1,533, which enhanced the *ZHR* level to 113 from its lower level on November 17, 2009, at 20:20 h UT. Another secondary peak of *ZHR* level was found on the same date at 23:20 h UT with $ZHR = 71$, otherwise it shows normal value.

The present signals exhibit diurnal variations as shown in Fig. 1. The figure represents average over 14 distortionless days in the month of September, 2009. Thus sunrise and the sunset effects are clear in the figure.

Average of diurnal variation of the transmitted signal amplitudes at frequencies 16.4 and 19.8 kHz considered over 5 successive days prior to the peak of the Leonid meteor showers are shown in Fig. 2. The Zenithal Hourly Rate is a measure of Leonid shower activity measured from visual observations of the shower. *ZHR* value during this period was less than 10 and there were no remarkable variations in amplitude of the signals received at Kolkata, India, during this period (International Meteor Organization website: http://www.imo.net). Average of diurnal variations of the transmitted signal amplitudes at frequencies 16.4 and 19.8 kHz, considered over 5 successive days after the peak phase of Leonid meteor showers are shown in Fig. 3. A sudden increase in signal was measured coincident with the peak of the Leonid shower according to the measured *ZHR* values on November 17, 2009 (Fig. 4). The sudden enhancement in signal amplitude occurred when *ZHR* value was around 60. The enhancement of both the signals continued to a steady value until *ZHR* had decreased to the value around 60. In both the cases (Fig. 4), the signal level increased almost two times the normal value.

Figure 5 represents the temporal variation of vertical electric potential gradient on November 17, 2009, on the day of meteor showers by the continuous line curve and its values averaged over other 47 meteorologically clear days (11 days of August; 14 days of September; 13 days of October and 9 days of November, 2009), by dotted line curve. The error bars are also shown in the dotted graph. It is found that prior to meteor showers, vertical potential gradient starts to increase from about 16:30 h UT, while *ZHR* is around 60. The potential gradient reaches maximum value of 198 V $m^{-1}$ at about 20:20 h UT

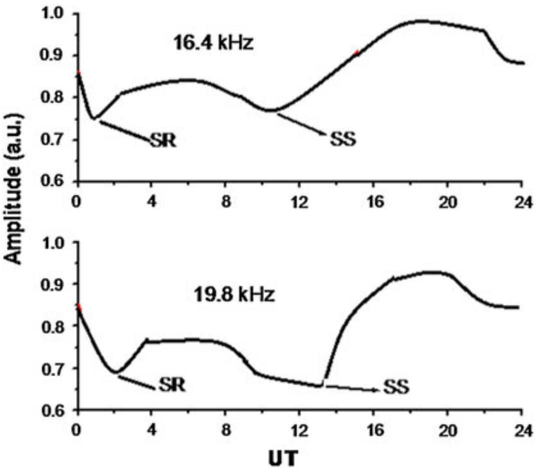


**Fig. 1** Diurnal variation of the signal amplitude of 16.4 and 19.8 kHz averaged over 14 meteorologically clear days in September, 2009. The time scale is shown in UT. *SR* Sunrise minimum, *SS* sunset minimum

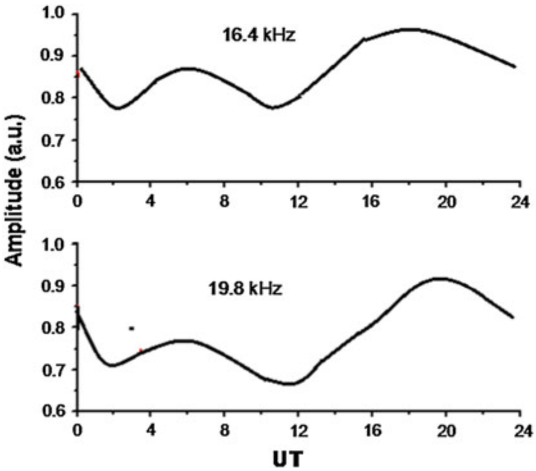


**Fig. 2** Average of diurnal variation of the transmitted signal amplitudes at frequencies 16.4 and 19.8 kHz during November 12–16, 2009, considered over 5 successive days prior to the Leonid meteor shower event

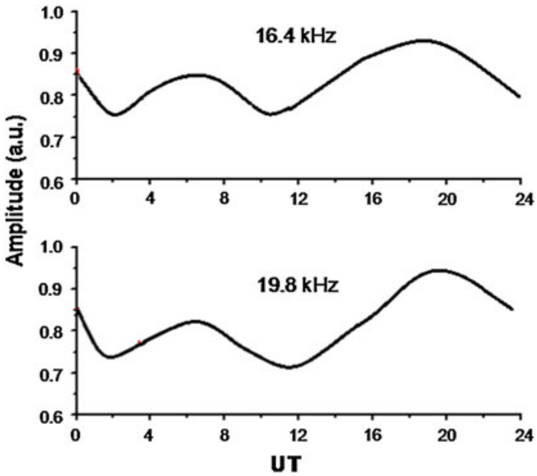


**Fig. 3** Average of diurnal variation of the transmitted signal amplitudes at frequencies 16.4 and 19.8 kHz during November 18–22, 2009, considered over 5 successive days after the Leonid meteor shower event

when *ZHR* is also maximum (about 140). Then it begins to decrease and continues up to midnight when the *ZHR* again attains the value 60. The maximum value on the average curve at 20:20 h UT is about 150 V $m^{-1}$. The continuous curve shows prominent variations from the average value during the period of showers since the variation is well beyond the error bars. During the other period of the day, the continuous curve follows almost the average plot that indicates the similar trend of changes. The peak value of potential gradient maintains its correspondence with the peak occurrence of *ZHR*.

## 4 Discussion

### 4.1 VLF Return

The coincidence between reported peak *ZHR* and the measured signals is evidence that the measured changes are due to the cause of extra ionization produced by the meteoroids during their entry and passage through the lower ionosphere. The duration of a meteor train

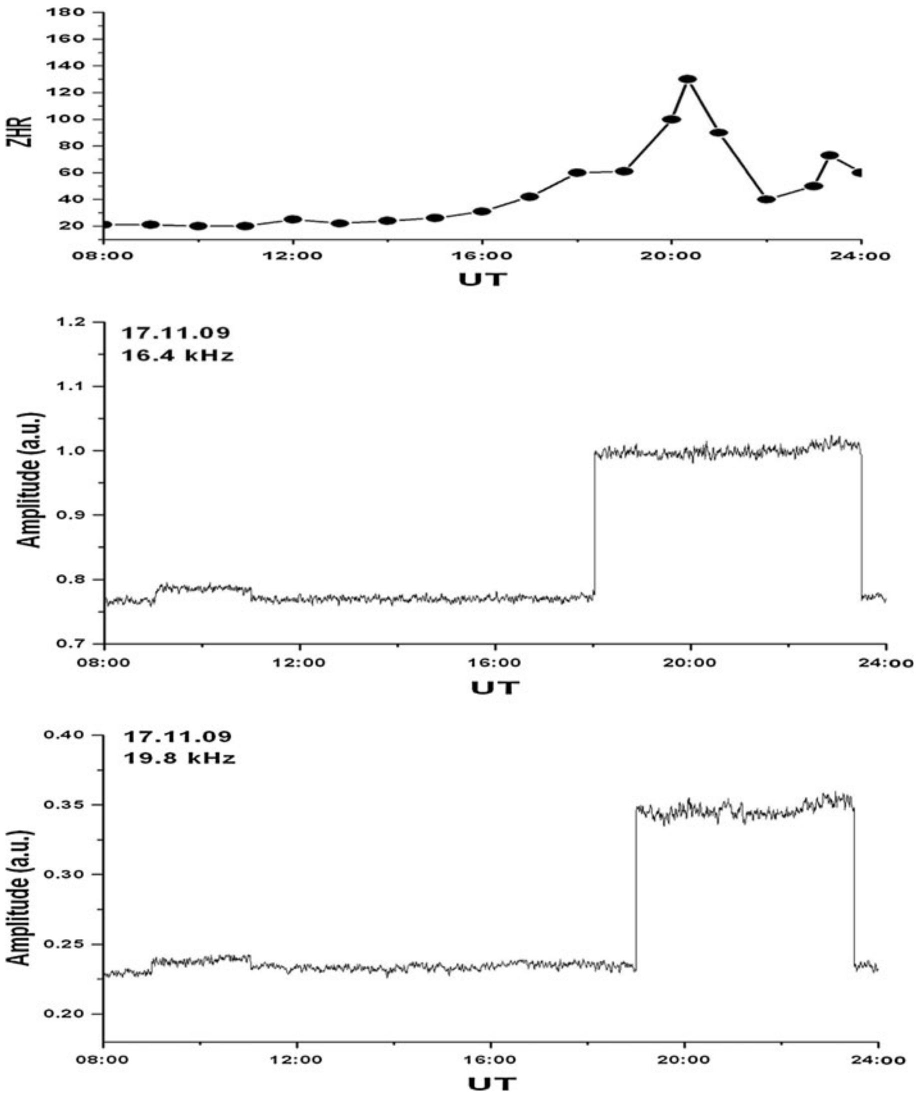


**Fig. 4** Variation of the transmitted signal amplitudes at frequencies 16.4 and 19.8 kHz on November 17, 2009, on the day of Leonid meteor shower event along with the variation of *ZHR*

is long enough for trains to merge and affect atmospheric ionization on a larger scale. As meteor particles enter into the atmosphere with tremendous speed, the air gets ionized. On entering the Earth's atmosphere, meteoric particles collide inelasticly with atmospheric constituents. Heat produced as a result of collision raises the temperatures of shower particles to such a high value that atoms distil-off the meteor. The process results in an ionized cylindrical column of appreciable initial radius along the path of meteor. The cylindrical ionized column expands radially due to ambipolar diffusion. After a meteor finished its role and produced a trail of initial radius $r_0$, the most important factors controlling its dissipation are attachment process by which electrons get attached to neutral

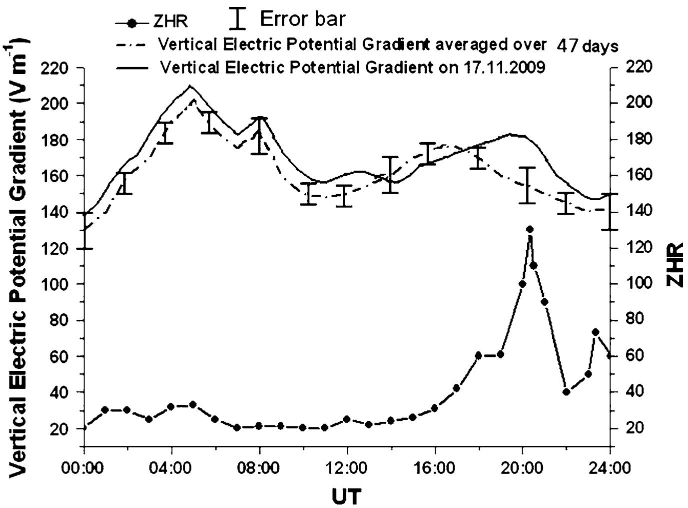


**Fig. 5** Diurnal variation of vertical electric potential gradient from the ground surface on November 17, 2009 (*continuous line curve*) along with its average value over 47 meteorologically clear days during August to November (*dotted line curve*). The diurnal variation of *ZHR* has been depicted by the *line curve* joining the *black dots*

molecules and ambipolar diffusion reduces the volume density of electrons without affecting line density. Considering these two processes, the volume density $N_e(r,t)$ at a radial distance $r$ from the axis of the cylindrical trail at a time $t$ after its formation may be given by (McKinley 1961).

$$N_e(r,t) = \frac{\lambda_0}{\pi\left(4Dt + r_0^2\right)} \exp\left[-\left\{\frac{r^2}{4Dt + r_0^2} + \beta_e N_m t\right\}\right] \tag{1}$$

where, $D$ is the diffusion coefficient; $\lambda_0$, the initial line density; $\beta_e$, attachment coefficient of electrons with neutral molecules and $N_m$ is the neutral molecular density participating in the attachment process.

The Atmospheric Radio Noise Field Strength (ARNFS) once changed from its normal value will not be restored until the electron density of the axis of trail attains the normal value. If $T$ is the time after which electron density at the axis ($r = 0$) of trail returns to the normal value, $N_e$ (0,$T$), then (1) yields

$$T = \frac{1}{\beta_e N_m} \ln\left[\frac{\lambda_O}{\pi(4DT + r_O^2) N_e(0,T)}\right] \tag{2}$$

The initial radius of a trail and rate of diffusion of electrons depend upon atmospheric pressure and hence on height, whereas the initial line density depends upon the height as well as the velocity of meteors. These values are given by (McKinley 1961):

$$\log r_0 = 0.075H - 7.9 \tag{3}$$

$$\log D = 0.067H - 5.6 \tag{4}$$

$$4.4 \log \lambda_0 = 82 - H + 49 \log V \tag{5}$$

here, height $H$ is in km, $r_0$ in m, $D$ in $m^2\ s^{-1}$, $\lambda_0$ in $m^{-1}$ and $V$ is in km $s^{-1}$. Daytime enhancement of ARNFS reveals that trails are formed at the reflection zone of ELF electromagnetic wave, i.e., at the lower surface of D-region at 70 km height. Using this value for $H$,

$$r_0 = 0.22\,\mathrm{m},$$

$$D = 0.12\,\mathrm{m^2\,s^{-1}},\ \text{and}$$

for all the observed values of duration ($T$) in our records, it is evident that $\frac{4DT}{r_0^2} \gg 1$, so that the (2) can be simplified to

$$T = \frac{1}{\beta_e N_m} \ln\left[\frac{\lambda_O}{\pi 4DTN_e(0,T)}\right] \qquad (6)$$

For Leonid meteoric particles, average velocity is 72 km $\mathrm{s^{-1}}$, and use of (5) gives $\lambda_0 = 2.6 \times 10^{23}\ \mathrm{m^{-1}}$. Taking nighttime normal electron density $N_e(0,T)$ at 110 km (lower E-region) to be $10^9\ \mathrm{m^{-3}}$, the value of $T$ may be of the order of several tens of minutes. The *ZHR* value is an index of intensity of meteor shower. *ZHR* is based on bright meteors, bright enough to be visible with the naked eye. They don't come much nearer to Earth's surface than the smaller particles. *ZHR* is related to influx of smaller particles through magnitude distribution index.

In fact, a number much larger than *ZHR* value are producing ionization in the ionospheric height. So, successive impinges by meteor particles may give rise to a situation such that dissipation of some ionized trails will be compensated by some new trails formed due to meteor particles which come next. Under this situation, electron density will be observed to be larger for a longer duration. Our observational results lead to assume that this situation arises when *ZHR* attains a value around 60 or greater. In 1999 Leonids, *ZHR* was around 3,000 to produce similar effect (Price and Blum 2000). So, this is a possible explanation for such sudden increase.

The sudden increase rather than gradual increase cannot be understood using wave-hop-theory. It requires the use of waveguide mode theory which considers the significant contribution from the second mode. One has to look for the effect of modal conversion. On both sides of the shower track, there is discontinuity in electron density. This discontinuity gives rise to so called modal conversion (Lynn 1973) in which sufficient energy may be transferred from the first mode to the second mode making the two modes comparable in their amplitudes. The reinforce of these two modes at the receiving station can produce sudden enhancement.

The step increase may also be explained as follows. It is apparent that step changes in signal amplitude cannot occur during a process in which there are gradual changes in the rate of production of electrons in the D-region. But continuous impinging by the meteor particles can give rise to increase in the reflection coefficient within several seconds to a few minutes. This kind of change in ionization can give rise to sudden increase in amplitude if electron density becomes greater than that required for total internal reflection of VLF radio waves. This is what happens in the case of meteor burst communications. The optimum level of ionization for total internal reflection of 16.4 and 19.8 kHz are not same due to variation in frequency. So it is obvious that the commencement of signal enhancement cannot be simultaneous in the case of two signals. The return of the signals from higher value to the ambient level should not occur simultaneously whereas present result shows that two signals returned to their normal levels simultaneously. This may be a case of mere coincidence jointly determined by frequency of the signals and obliquity of the meteor shower over the propagation path of radio wave. Once a signal gets total internal reflection (reflection coefficient = 1), the further increase in ionization will have nothing to do, i.e., the level will remain constant at the higher value.

We have explored our records for a period of 6 months. Five cases at 16.4 kHz and four cases at 19.8 kHz have been observed where there are small amount of sudden rises for smaller durations ($\sim$5–10 min). Also, there is another small increase in *ZHR* value just prior to the event on November 17, 2009 (Fig. 4). It can be said that this kind of event may be caused by random concentrations of meteors over the propagation path.

The Zenithal Hourly Rate can be expressed as (Jenniskens, 1994):

$$ZHR = \frac{N}{T_{eff}} \chi^{(6.5 - L_m)} C_p (\sin h_r)^{-1} \quad (7)$$

where, $N$ is the number of meteor showers seen in the period $T_{eff}$ (h); $L_m$, the star limiting magnitude when the faintest star becomes visible in the averted vision; $h_r$, the radiant elevation and $C_p$ is the personal correction co-efficient (=1.0).

We estimate the effective area of detection at the peak of the shower by

$$A = \frac{ZHR}{0.82 C_p} \chi^{(L_m - 6.5)} (\sin h_r) \quad (8)$$

here, 0.82 (km$^{-2}$ h$^{-1}$) is the peak influx of Leonids brighter than +6.5 magnitude (Gural and Jenniskens 2000); *ZHR*, Zenithal Hourly Rate (=60); $\chi$, the magnitude distribution index (approximately 3.5); $h_r = 70°$ and ($L_m - 6.5$), the magnitude difference between ELF/VLF limiting magnitude and +6.5 is the limiting factor for the optical meteors.

However, for the ELF/VLF meteors, the limiting magnitude may be higher (smaller meteors). Choice of a value of $L_m = 10.5$, the effective area of detection shows 10,318 km$^2$ and it is expected that a continuous sheet of ionization would be formed in the lower ionosphere.

### 4.2 Potential Gradient

Global lightning activity maintains a potential difference of about 250 kV between the Earth-ionosphere waveguide, which generates a vertical potential gradient of about 120 V m$^{-1}$ at the Earth's surface. During fair weather electricity, there would be no process of charge separation taking place in the atmosphere and the electrical phenomena are reasonably steady (Ogawa 1985). Atmospheric potential gradient is expressed as $E = \frac{V}{\lambda R}$, where $V$ is the potential difference between the Earth-ionosphere waveguide; $\lambda$, the conductivity of the air and $R$ is the columner resistance. For fair weather, $V$ and $R$ change very little. $E$ is then controlled mainly by $\lambda$.

During the entry of the leonid into the Earth's atmosphere, the free energy of the medium gets converted into random energy. The fluctuation of charge distribution increases the strength of velocity distribution and this increases the rate at which energy gets randomized, thereby producing intense ionization. In this situation, instability acts. Conductivity of the nearby medium increases to some extent but $\lambda$ is practically unaffected. But, due to the entry of the leonid, the enhancement of electron density in the lower ionosphere occurs. Ionization and recombination processes perturb the lower ionosphere for which an overall modulation in the space charge distribution may be attained. As a result, a continuous sheet of ionization is formed in the lower ionosphere (D-region) which lowers down the ionized region by several kilometers towards the Earth's surface. Due to which, the distance between the lower ionosphere and Earth's surface gets reduced and thereby potential gradient would increase.

### 4.3 Possible Explanation of the Ionized Path

Meteor particles during their entry with high velocity into the Earth's atmosphere collide with the medium particles. So long the kinetic energy of the particles will remain higher than the ionization energy of the medium particles, ionization would result. Also, the increase of the dissipation rate is attributed to turbulence generated microinstabilities in the shock produced in front of the meteors passing with high supersonic speed. For this, the relative electron–ion drift velocity exceeds the value for the onset of Kelvin–Helmholtz instability. The compressible ionospheric plasma driven by velocity shear and Earth's magnetic field at the frontal path of the meteor enhances the growth rate of Kelvin–Helmholtz instability. Strong turbulence is developed in which non-linear perturbation at the particle trajectories towards the rear zone of the meteor acts to stabilize the turbulent flow leaving a strongly ionized trail. The station signals at 16.4 and 19.8 kHz frequency gets depleted at this ionized zone during its travel towards the ionospheric layer for reflection and for this, the effective reception of the reflected signals at the ground will be weak. Such ionized trail can also contribute to the process of reflection of station signals at the ground receiver along with the reflected wave from the ionosphere and consequently the signal strength will be higher.

The detection of meteor shower by electromagnetic signals is very effective since the presence of a shower can also be detected during daytime unless there is severe thunderstorm activity. If the system is properly designed, it is also useful in detecting very weak or low *ZHR* meteor showers which are not detectable with visual observation even at night. It was the nighttime when the first shower occurred on November 17, 2009 at 18:00 h UT. Nevertheless, we successfully observed it by using electromagnetic waves from standard sources.

## 5 Conclusion

The results that are presented, show the enhancement of amplitudes of 16.4 and 19.8 kHz VLF signals during the entry of the showers into the Earth's atmosphere. The extra ionization produced by the supersonic meteoroids during their passage through lower ionosphere may have been the cause of high enhancement of signal level, which is about eight to nine times its normal value. The analyses of the data show that *ZHR* can be used as an index. When this value attains around 60 during the 2009 Leonid shower, VLF signals showed a sudden enhancement, i.e., meteors are responsible for such sudden increase. Thus, the enhancement of signal amplitude and the vertical potential gradient may be the two soul manifestations of the ionization effect of meteor particles. The explanation of the enhancement of VLF signals with the increase of *ZHR* value would be contemplated in future.

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