A Comparative Study on the Effects of Leonid Meteor Shower on the Propagation of Sferics and Transmitted Signal

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Abstract. The Leonid meteors are debris shed into face by the Tempel- Tuttle comet, which swings through the inner solar system at intervals of 33 years. The Leonid shower has now become an annual feature with its activity from 16\textsuperscript{th} November to 20\textsuperscript{th} November. In the Department of Physics of Tripura University two receivers, one sferics receiver tuned at 21.5 kHz and another transmitted signal receiver tuned at 40 kHz, were set up to study the effect of leonid meteor shower activity on propagation conditions during the period of Leonid meteor shower in 2004. We recorded the data of both the atmospherics and transmitted signal strengths during the meteor shower for several days. A typical zigzag pattern in the field amplitudes of both the sferics and transmitted signal are observed as a signature of meteor activity. During the peak activity of meteor shower enhancement in both sferics & transmitted signal level are observed ranging between 1 dB to 12 dB. Whereas, decrement in both the signal strengths are observed within 1 dB to 9 dB ranges. The calculated value of attachment co-efficient using 21.5 kHz sferics and 40 kHz signal is found to be different from each other. During day time the value of attachment co-efficient is found to be little higher in case of 21.5 kHz sferics while that during night the value is higher for 40 kHz transmitted signal.

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1 Introduction

Prediction for Leonid meteor shower 2004 has been centred on November 19th. According to three current models \cite{1}, comet experts – Jeremie Vaubaillon, Eako Lyytinen, Markku Nissinen, and David Asher – all have arrived at a common prediction for this year’s 2004 Leonids. It has been predicted that earth would
have to pass close to two dust trails, those of 1333 and 1733. Any outburst from the 1333 trail would peak at 12:12 IST, on November 19 with a potential Zenithal Hourly Rate (ZHR) of 10 at best. The second 1733 trail would arrive at 02:19 IST on November 20, when the rates can go up as high as ZHR = 65. That outburst has been expected to be seen best in Asia [2]. Even though rates will not be as high as in past Leonid storms, it is important to continue to observe these showers to learn how dust is distributed by the parent comet 55P/Tempel-Tuttle.

In the year 2004, the Leonid meteors enter into the earth’s atmosphere with a velocity of about 72 km/s [2] and mainly contribute near about 90 km [3] above the earth surface, thus producing some extra ionization in the D-region of ionosphere.

Different meteors produce ionization at different height as they centre the earth atmosphere with different velocities and sized. The Leonid shower with its characteristic velocity and size produces ionization in the D and E regions of the ionosphere. The extra-ionization produced at ionospheric heights due to major and sporadic meteor showers has been studied from time to time by various authors [3]. For low frequency propagation studies which are important for worldwide navigation as well as time and frequency dissemination, some work has been reported from 1960 onwards relating different meteoric showers viz. Geminid, Lyrid, δ-Acquird, Perseid etc. [4-14] however excluding the Leonid showers, possibly due to its irregular behaviour.

We are continuously recording the 40 kHz LF transmitted signal (Transmitter: Miyakoji station, Japan) and 21.5 kHz VLF atmospherics in the Physics Department of Tripura University. The continuous study of this sferics enables us to report various geomagnetic and solar activities from time to time. For Leonid meteor shower 2004 we have used the VLF-LF signal as a general tool. On the predicted period of shower there has been no solar flare occurred and moreover the sky was clear and no reports of thunderstorms have been obtained. Our observation shows the changes in ionization in the upper atmosphere due to meteor shower.

Various works have been made till now to see the effect of meteor shower on the propagation of both transmitted signal and natural signal (Sferics). But, the characteristics variation of the said effect on the transmitted signal and sferics is yet not being studied. This prompts us to carry out a comparative analysis between a transmitted signal and a natural signal.

2 Experimental Arrangement

Two receiving systems were developed at the Department of Physics, Tripura University (23°N, 91.4°E) to record natural atmospherics at 21.5 kHz and to receive 40 kHz LF signal transmitted from JJY station (37.4°N, 140.9°E), Japan, round the clock. The purpose of the deployment of these systems was to inves-
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Figure 1. Block diagram of the receiving system.

The measuring system consisted of an inverted L-type antenna having effective height of 7.85 m and terminal capacitance of 35.42 pF, a non-inverting amplifier having maximum gain of 20, a L-C series resonant circuit of Q-value 146 and bandwidth 200 Hz, a diode detector of RC time constant of 0.22 s, a quasi-

Figure 2. Propagation path between transmitter (T) and receiver (R).
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logarithmic amplifier to increase the dynamic range up to 35 dB and a 8 channel 12 bit ADC to store the data in the computer (Sampling rate 1 data per second) using Radio Sky Pipe software. The great circle path length between the receiving and transmitting stations in case of 40 kHz signal is 4944 km (Figure 2).

3 Observational Results

Firstly we have sighted whole day clear record of both the 40 kHz LF transmitted signal and VLF sferics at 21.5 kHz. A prolonged study shows that the general feature of these both signals are almost same. It is found that there is a gradual fall of these signal levels towards the sunrise and then signal levels again increase steadily up to afternoon period. During sunset both the signal levels are found to decrease and after sunset again rise. From November 18 to 21 of 2004, which is the period of the Leonid showers, Characteristic variations of the field strengths of both 40 kHz signal and 21.5 kHz sferics have been noticed form local midnight to the following afternoon hours. During the meteor activity, for both the signals, sudden decrease in field strength followed by sudden recovery was observed, whereas the inverse phenomenon i.e., sudden rises followed by sudden return to the normal value was also observed. In Figures 3 and 4, the variation of the 21.5 kHz sferics and 40 kHz signal level are shown during the peak activity of meteor shower and that during a clear day respectively.

![Figure 3](image-url)

Figure 3. Sferics (21.5 kHz) Level variation during a normal day (Upper panel) & during the day of peak activity of meteor shower (Lower panel).
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Figure 4. Signal (40 kHz) Level variation during a normal day (Upper panel) & during the day of peak activity of meteor shower (Lower panel).

It can clearly be seen from the figures that both the sferics and signal levels are completely different on 19th November 2004, i.e. on the day of peak activity of meteor shower, than that during a clear day. In both sferics and transmitted signal level sudden enhancement and sudden decrement/decrease events are studied carefully. The number of occurrences of sudden enhancement and decrease at

Table 1. Distribution of enhancements in different dB ranges for 21.5 kHz & 40 kHz

<table>
<thead>
<tr>
<th>Date</th>
<th>Frequency</th>
<th>Total no. of occurrences</th>
<th>Number of occurrences in between</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>21.5 kHz</td>
<td>11</td>
<td>1 to 3 dB 3 to 6 dB 6 to 9 dB 9 to 12 dB</td>
</tr>
<tr>
<td>18th Nov.</td>
<td></td>
<td></td>
<td>6 2 3 0</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>18</td>
<td>11 5 2 0</td>
</tr>
<tr>
<td>19th Nov.</td>
<td>21.5 kHz</td>
<td>22</td>
<td>11 4 6 1</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>35</td>
<td>17 9 6 3</td>
</tr>
<tr>
<td>20th Nov.</td>
<td>21.5 kHz</td>
<td>15</td>
<td>4 8 3 0</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>22</td>
<td>9 10 3 0</td>
</tr>
<tr>
<td>21st Nov.</td>
<td>21.5 kHz</td>
<td>14</td>
<td>7 3 4 0</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>17</td>
<td>10 5 2 0</td>
</tr>
</tbody>
</table>
Table 2. Distribution of decrements in different dB ranges for 21.5 kHz & 40 kHz

<table>
<thead>
<tr>
<th>Date</th>
<th>Frequency</th>
<th>Total no. of occurrences</th>
<th>Number of occurrences in between</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 to 3 dB</td>
</tr>
<tr>
<td>18th Nov.</td>
<td>21.5 kHz</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>19th Nov.</td>
<td>21.5 kHz</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>20th Nov.</td>
<td>21.5 kHz</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>21st Nov.</td>
<td>21.5 kHz</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>

different dB ranges \(20\log_{10}\left(\frac{E_{\text{decreased}}}{E_{\text{normal}}}\right)\) for 21.5 kHz and 40 kHz are shown in Tables 1 and 2, while Table 3 shows the distributions having different durations for both 21.5 kHz and 40 kHz.

The tables show that total number of enhancement and decrease events for 21.5 kHz lags the number of decreases for 40 kHz signal. But, most decreases for 21.5 kHz and 40 kHz both are of a magnitude of 1 to 3 dB and durations of 5

Table 3. Distribution of events for 21.5 kHz & 40 kHz having different durations

<table>
<thead>
<tr>
<th>Duration</th>
<th>Frequency</th>
<th>No. of enhancement</th>
<th>No. of decreases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 5 min.</td>
<td>21.5 kHz</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>5 to 10 min.</td>
<td>21.5 kHz</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>33</td>
<td>29</td>
</tr>
<tr>
<td>10 to 15 min.</td>
<td>21.5 kHz</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td>15 to 20 min.</td>
<td>21.5 kHz</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>20 to 25 min.</td>
<td>21.5 kHz</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Above 25 min.</td>
<td>21.5 kHz</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>40 kHz</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
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to 10 min. A comparison has been done to see the characteristics variation in the effects of the meteoric trails on sferics propagation and transmitted signal. It is clearly observed that for most of the dB ranges the number of enhancement and decreases for 40 kHz signal are greater but the respective numbers for sferics are greater in the range between 6 to 9 dB. It is also observed that the distribution of both the events for sferics mostly lags behind that for transmitted signal except that between 15 to 20 min. And the distribution of both the events is equal for the interval < 25 min.

On entering the earth’s atmosphere the meteoric particles collide unrealistically with the atmospheric constituents. Heat, produced as a result of collision, raises the temperature of shower particles to such a high value that the atoms distil off the meteor. The process results in an ionized cylindrical column of appreciable initial radius along the path of the meteor. After a meteor has 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 become attached to neutral molecules and ambipolar diffusion which reduces the column density of electrons without affecting the 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 is given by [3]

\[
N_e(r,t) = \frac{v_0}{\pi(4Dt + r_0^2)} \exp \left[ - \left( \frac{r^2}{4Dt + r_0^2} + \beta_e N_M t \right) \right],
\]

where \( D \) is the diffusion coefficient, \( v_0 \) is the initial line density, \( \beta_e \) is the attachment coefficient and \( N_M \) is the natural molecular density participating in the attachment process. The signal amplitude once changed from the normal value will not return to the previous level unless the electron density at the axis of the trail is restored. If \( T \) is the time after which the electron density at the trail axis \( (r = 0) \) returns to the normal value \( N_e(0,t) \), then equation (1) yields

\[
\beta_e N_M = \frac{1}{T} \log_e \left[ \frac{v_0}{\pi(4Dt + r_0^2)N_e(r,t)} \right].
\]

The initial radius of the trail and the rate of diffusion or the electrons depend upon atmospheric pressure and thus on height, whereas the initial line density depends upon the height as well as on the velocity of the meteoric particles. These values are given by [3]

\[
\log_{10}(r_0) = 0.075H - 7.9
\]

\[
\log_{10}(D) = 0.067H - 5.6
\]

\[4.4 \log_{10}(v_0) = 82 - H + 49 \log_{10} V,\]

where \( H \) is in km, \( r_0 \) in m, \( D \) in m\(^2\)/s, \( v_0 \) in m\(^{-1}\) and \( V \) in km/s.
Daytime enhancements on the signal strength reveal the fact that the trails are formed in the reflection zone at a height of about 70 km. Using this value for $H$, one gets

$$r_0 = 0.22 \text{ m and } D = 0.12 \text{ m}^2/\text{s}.$$  

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

$$\beta_e N_M = \frac{1}{T} \log_e \left[ \frac{v_0}{4\pi D t N_e(0, t)} \right].$$  

(6)

For Leonid shower particles possessing an average velocity of 72 km/s it is found that $v_0 = 2.6 \times 10^{23} \text{ m}^{-1}$. Moreover the meteoric trails are formed at a height of about 70 km during daytime as mentioned above. The height of ionization due to a meteor shower can be considered to be invariant at day and night. The ionization effect at 70 km height is, therefore, reasonable at night or in other words it is the fact that during meteor showers at day or night the electron density at 70 km is the decisive factor. Taking the daytime and nighttime normal electron density $N_e(0, T)$ at 70 km to be $10^8 \text{ m}^{-3}$ and $10^7 \text{ m}^{-3}$ respectively, values of $\beta_e N_M$ have been found. The distributions of events in different ranges of $\beta_e N_M$ are shown in Figures 5 and 6 for day and night respectively for both the signals. The respective point of maxima at day time for 21.5 kHz and 40 kHz are 0.067 s$^{-1}$ and 0.06 s$^{-1}$. At night time the respective point of maxima for 21.5 kHz and

Figure 5. Distribution of $\beta_e N_M$ values for 21.5 kHz.
Figure 6. Distribution of $\beta_e N_M$ values for 40 kHz.

40 kHz are found to be $0.083 \text{ s}^{-1}$ and $0.11 \text{ s}^{-1}$. In an atmosphere at 70 km height the attachment of electrons to oxygen molecules ($O_2$) is only considerable because of much lower proportion of oxygen atoms (O) relative to oxygen molecules. The attachment of electrons to nitrogen molecules ($N_2$) is also negligible [15]. The value of atmospheric density at 70 km is $8.7 \times 10^{-5} \text{ kg/m}^3$ [16]. Considering standard composition of $O_2$ and $N_2$ in the atmosphere at 70 km [17] and using Avogadro’s hypothesis, the number density of $O_2$ has been obtained as $3.7 \times 10^{21} \text{ m}^{-3}$. Now with the use of daytime and night time $\beta_e N_M$ values and considering the attachment only with $O_2$ we get the values of $\beta_e$ as $18 \times 10^{-23} \text{ m}^3/\text{s}$ and $22.5 \times 10^{-23} \text{ m}^3/\text{s}$ respectively for $21.5$ kHz. Whereas the values for 40 kHz at day and night are found to be $16 \times 10^{-23} \text{ m}^3/\text{s}$ and $29.7 \times 10^{-23} \text{ m}^3/\text{s}$ respectively.

4 Discussion and Concluding Remarks

Whenever a meteor enters into the earth’s atmosphere, various physical processes such as ionization, diffusion, recombination, attachment are associated with its journey. The inelastic collisions of shower particles with air molecules convert its kinetic energies into heat, light and ionization. Depending upon its initial mass and velocity a meteor can produce ionization before slowing down to thermal velocities. As the meteor penetrates more and more into the denser air the ionization increases and then falls off due to decreasing size. The ions
and electrons thus formed move rapidly in an electrically neutral cloud by the method of ambipolar diffusion. But the processes such as recombination of electrons with positive ions and attachment of electrons with neutral molecules to form stationary heavy negative ions contribute negatively towards the ionization process [10].

In the wake of the meteors thus a cylindrical ionized column – the trail is formed of certain initial radius which is far small compared to radio wavelength. The trail length is dependent on initial mass, initial velocity and zenith angle of the meteor particle. The brighter, faster meteors and moreover that coming out of the radiant near the horizon produce longer trails. Depending upon the volume density of electrons, the formed trails can be classified into under dense and over dense trails. Whenever atmospherics (the natural radio signal) from a distant source encounter either under dense or over dense trail created by shower particles, depending upon the ionization density and height of the interactions enhancement or absorption can occur.

In case of an under dense trail as shown in Figure 7, the volume density of electrons is not so large that it can reflect the incident radio wave. The electrons behave as individual oscillators and whenever a radio wave encounters an under dense trail zone of shower particles, some absorption occurs in the signal reducing its strength. The result of which is some decrement in signal level. Another case that may occur in the case of an interaction with under dense trail is that if the under dense trail zone is formed in that level of D-region from where the

![Figure 7. Under dense trail observed in 21.5 kHz sferics level and 40 kHz signal level.](image)
signal actually would get reflected, the additional meteoric ionization results in greater reflection coefficient for the signal and the result is some enhancement in sferics level.

If the volume density of electrons in the meteor trail is sufficiently large, then it results into an over dense trail shown in Figure 8. In this case the electrons are no longer independent oscillators and the incident radio wave can no longer penetrate it. The interaction of radio wave with over dense trail is much stronger compared to that with under dense one. An atmospherics interrupted in its path by an over dense trail zone of meteor when obtained at the receiver is slighted attenuated. But if the over dense zone is formed in the reflecting level of D-region for the signal then the interaction would cause a large enhancement in sferics level due to high reflection coefficient resulting from enhanced ion density. Another possibility that may happen is that if the over dense zone is formed at a height slightly lower than that required for reflection of the signal and provides sufficient ion density for signal reflection then the signal may get reflected from a lower level in D-region and the reduced path length can provide also small enhancement to the signal. Any under dense or over dense trail can affect the signal strongly whenever it blocks the Fresnel’s first half period zone of the receiver.

Now, the methodology used in the present approach to detect meteor shower indicates that during the activity of the Leonid meteor shower, the interactions of the natural sferics and transmitted signal with the ionospheric variations introduced due to the shower are slightly different. The calculated value of attach-
Figure 9. Comparison of attachment co-efficient values at day and night time obtained using sferics and transmitted signal.

ment co-efficient using 21.5 kHz sferics and 40 kHz signal is also found to be slightly different from each other. During day time the value of attachment co-efficient is found to be little higher in case of 21.5 kHz sferics while that during night the value is higher for 40 kHz transmitted signal. Figure 9 shows the comparison between the day and night time values of $\beta_e$ obtained using 21.5 kHz sferics and 40 kHz signal. This deviation in the observed results using completely different nature of signals may be effectively used in future for studying meteor shower. It is worth mentioning here that the use of electromagnetic signals for detecting and studying meteor shower is very effective. It is evident that during day time meteor showers cannot be visible. Infect, weak showers having low ZHR values are not even detectable visibly at night also. So, from the results of attachment co-efficient obtained both at day and night time using the two different signals it may be concluded that during day time sferics signals can be used for detecting meteor showers while transmitted signals may be used at night time for the same.

But still there remain doubts as different values of $\beta_e N_M$ are obtained due to the limitations of equation 6. It is not mandatory that during meteor shower the signals are reflected directly from the axis of the meteoric trail. The axis of the trail may be formed away from the ionospheric reflection point of the signals. So, the different values of $\beta_e$ obtained in case of sferics and signal may also
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be due to the same reason. So, further studies will also explore that how we may detect the formation of the axis of the meteoric trail using different signals. There may be two reasons why we have obtained higher values of $\beta_e N_M$ at night for both signals. Firstly, due to the fact that the neutral molecular density at 70 km ionospheric height is greater at night than at day time, secondly, at day time the value of $\beta_e$ decreases due to photo-detachment process [3] in the presence of solar radiation.

Now, the magnitude of the enhancement and decrement of the signal strength varies upon the inclination of the meteoric trail with the plane of the Fresnel’s first half period zone whereas the duration of the enhancement and decrement depends on the dissipation process of the ionized trail. The variation of the enhancement and decrement magnitudes with the duration may be due to the above mentioned fact.

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References
