Ground-based Radio Ducts in Northern India

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Received 4 June 1973; revised received 28 September 1973

Abnormal atmospheric conditions seriously affect a radio communication or radar system. In this paper an attempt has been made to study the percentage of occurrence of ducting conditions in northern India for different months of the year. The calculated values of the duct parameters like duct gradient, duct thickness, trapping angle and minimum frequency of trapping are presented. It is observed that the maximum percentage of duct occurrence in India is higher than the percentage in the United States and also, the minimum frequency of trapping in India is as low as 13.64 MHz whereas it is about 1000 MHz in USA.

1. Introduction

INHOMOGENEITIES of the earth's atmosphere produce changes in the speed of propagation of electromagnetic energy through different portions of the atmospheric envelope. Radio waves propagating within the earth's atmosphere are, therefore, generally bent or refracted due to the variations of refractive index of the atmosphere with height. The gradient of the refractive index determines the amount of bending suffered by the radio waves. In the case of a 'standard atmosphere', the refractivity (N) distribution in the troposphere is nearly an exponential function of height, reaching a certain constant value of N at the tropopause, regardless of the surface value. Nevertheless, the decrease in the refractivity with height, in general, could be considered as linear in the first one or two kilometres with a gradient of approximately —40N units per kilometre. The effect of standard atmosphere on low altitude radio propagation problems, where the ray-paths involved do not exceed 1 to 2 km above the earth's surface, is taken care of by the use of an effective earth's radius factor, K. However, deviations from the standard can cause abnormal propagation like super-refraction, ducting or sub-refraction of the radio waves which seriously affect a radio communication or radar system1.

Out of these different modes of abnormal propagation, a study has been made, in this paper, on the occurrence of ducting conditions in northern India. Ducting is a phenomenon of radio refraction, when a radio-ray originating at the earth’s surface is sufficiently refracted during its upward passage through the atmosphere so that it either is bent back towards the earth’s surface or travels in a path parallel to the earth’s surface. In order to study the occurrence of duct and the related properties, a ducting criteria2 based upon ray-tracing technique has been applied to 24 years of radiosonde observations from four meteorological stations located at Jodhpur, New Delhi, Lucknow and Guwahati, representing different climatic conditions in northern India from west to the east.

2. Theory

There are many instances when the refractive properties of the atmosphere depart from the exponential model. These situations are generally caused by the presence of steep negative vertical gradients of refractivity in layers of troposphere. The vertical gradient of the refractivity is a function of atmospheric temperature, humidity and pressure. Consequently, the surface layers, in which N-gradient is much steeper than —40 units/km or 12 units per 1000 ft, are caused by temperature inversions or humidity lapses due to cooling by nocturnal radiation, by subsidence, or by advection. Gradients ranging from —100 N/km to —156.9 N/km are considered to be super-refractive. Gradients ranging from 0 to positive values are considered to be sub-refractive and gradients equal to —157 N/km or less are considered to be ducting gradients1,9.

Bending of the radio waves due to atmospheric layer has been studied by utilizing the ray-tracing technique and Snell's law which may be written in cylindrical coordinates as

\[ n_r r_\theta \cos \theta_i = n_\rho r_\theta \cos \theta_d \]  \( \cdots (1) \)

where \( n_r = \) Radio refractive index at transmitter height

\( r_\rho = \) Radius of curvature of the ray at transmitter height

\( \theta_i = \) Elevation angle made by the ray with the tangent at the earth's surface at transmitter point
and \( n_1, r_d \) and \( \theta_p \) are the corresponding variables at the top of the trapping layer.

From the Snell’s law, Bean has derived the expression for the angle of penetration of the ray at the transmitter, \( \theta_p \), and the orders of magnitude of refractive index gradient needed for trapping of radio waves. They are

\[
\cos \theta_p = \frac{n_d r_d}{n r_t} \quad \ldots (2)
\]

and

\[
\frac{\Delta n}{\Delta r} = \frac{n}{a} - \frac{1}{a} \sim 157 N \text{ units/km} \quad \ldots (3)
\]

where \( a \) = earth’s radius

Another important parameter of the duct is the minimum frequency (or maximum wavelength) trapped. Kerr\(^4\) has stated that the physical situation in the presence of a duct is in many ways analogous to that in a waveguide and, depending upon the parameters of the duct, there is a minimum frequency \( f_{min} \), which will be trapped in the duct. The value of \( f_{min} \) is given by

\[
f_{min} = \frac{1.2 \times 10^8}{f^{1.2}} \left( -\frac{dn}{dt} - \frac{1}{a} \right) \quad \ldots (4)
\]

where \( t \) = thickness of the duct in km

and \( \frac{dn}{dt} \) = refractive index gradient.

3. Method of Analysis

Temperature and humidity profiles from daily radiosonde data, for 0000 and 1200 hrs GMT were studied from Jan. 1966 to June 1968, from surface to 700 mb (3 km). In total, about 250 profiles have been examined for the north Indian region. Significant level radiosonde data\(^6\) along with the surface data were examined for the occurrence of ground based ducts.

The refractivity values were computed using the formula:

\[
N = (n - 1) 10^8 = \frac{77.6}{T} \left( P + \frac{4810 \ e}{T} \right) \quad \ldots (5)
\]

where \( P, T, e, N \) and \( n \) stand for atmospheric pressure in millibars, absolute temperature, atmospheric vapour pressure in millibars, refractivity and refractive index respectively. The refractivity values at the surface and at the top of the layer were computed for all days and times when temperature inversions and humidity lapses are reported. From these \( N \) values, data for the gradients, \( \Delta N \), are computed. The days when these gradients equal or exceed -157 \( N \) are separated and further examined for ground based ducts. Using the expressions in Eqs. (2) and (4), angle of trapping and the minimum trapping frequency are computed.

4. Results

4.1 Duct Occurrence Percentages

Mean monthly variation of ducting conditions are presented in Fig. 1 for New Delhi, Jodhpur, Lucknow and Gauhati. The frequency of their occurrence is expressed as percentage of the number of days in a month. A summary of these results is given below:

4.1.1 Jodhpur—Ground based ducts have been found to occur in January, March to July, September to December with the exception of February and August. Maximum percentage of occurrence is 8% in the month of November.

4.1.2 New Delhi—Ground based ducts seem to be prevalent throughout the year except in the month of August. There is a summer maximum of 21% in April and another winter maximum of 15% in the month of October.

4.1.3 Lucknow—January to July and Sept. to Dec. are months during which ground-based ducts are found to occur at this station. Out of the four stations studied, this station is showing three maximum values of ducting percentages, one of 13% in April, the second of 16% in July and the third of 15% in November.

4.1.4 Gauhati—Mean monthly variation of ducting percentages show a much less variation in the
case of Gauhati during the period from January to June. However, the winter period shows a fluctuation in ducting percentage. A maximum value of 10% occurs in November.

4.2 Mean Monthly Ducting Gradient

Mean monthly variations of ducting gradients are presented in Fig. 2 for Jodhpur, New Delhi, Lucknow and Gauhati. The gradients are expressed in N units per km. A maximum value of 440 N/km was observed in the month of December at New Delhi.

4.3 Duct Thickness

Mean monthly variation of duct thickness for Jodhpur and New Delhi are presented in Fig. 3 and that for Lucknow and Gauhati are presented in Fig. 4. A maximum duct thickness of 600 m has been observed at Jodhpur during December.

There seems to be similarity in the trend of variation of duct thickness for Jodhpur and New Delhi, and also, there is a similarity in the case of Lucknow and Gauhati but this is different from that of Jodhpur and New Delhi.

4.4 Trapping Angle

Mean monthly variations of trapping angle are presented in Fig. 5 for Jodhpur and New Delhi and in Fig. 6 for Lucknow and Gauhati. The maximum value of 12.5 mrad has been observed at Jodhpur and Gauhati in the month of June. One finds an irregular variation of $\theta_p$ during summer and monsoon months and a systematic gradual change in $\theta_p$ during winter for all four stations. There is a
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similarity in the variations of Jodhpur and New Delhi, and also in those of Lucknow and Guwahati.

4.5 Minimum Frequency of Trapping

Table 1 presents the date of minimum frequencies trapped in different months for the four stations. The maximum and minimum values of trapped frequencies are observed at Lucknow, the minimum being 13·64 MHz in April and the maximum being 1714·28 MHz in January. Rest of the stations show values within these two limits. Of all the four stations, New Delhi shows a seasonal variation from VHF range to VHF from January to November. All the other stations show a random variation from month to month.

The maximum and minimum values of the above mentioned parameters like duct thickness and duct gradient are separately presented in Table 2. A minimum duct thickness of 750 m was observed at Jodhpur, and a maximum gradient of 613 N/km is found at New Delhi. A maximum trapping angle of 32·51 mrad was observed at the three stations, namely, Jodhpur, Lucknow and Guwahati.

An interesting feature is observed from these studies that all these parameters have practically the same values for all the four stations with only slight

Table 1 — List of Minimum Trapped Frequencies (MHz) for Duct Propagation

<table>
<thead>
<tr>
<th>Month</th>
<th>New Delhi</th>
<th>Jodhpur</th>
<th>Lucknow</th>
<th>Guwahati</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>540·12</td>
<td>300·00</td>
<td>1714·28</td>
<td>434·44</td>
</tr>
<tr>
<td>Feb.</td>
<td>754·03</td>
<td>—</td>
<td>444·44</td>
<td>315·70</td>
</tr>
<tr>
<td>March</td>
<td>432·57</td>
<td>124·62</td>
<td>114·13</td>
<td>196·70</td>
</tr>
<tr>
<td>April</td>
<td>198·75</td>
<td>56·89</td>
<td>13·64</td>
<td>159·95</td>
</tr>
<tr>
<td>May</td>
<td>143·75</td>
<td>440·00</td>
<td>114·80</td>
<td>64·51</td>
</tr>
<tr>
<td>June</td>
<td>116·35</td>
<td>651·03</td>
<td>138·00</td>
<td>116·50</td>
</tr>
<tr>
<td>July</td>
<td>226·00</td>
<td>282·59</td>
<td>134·80</td>
<td>—</td>
</tr>
<tr>
<td>Aug.</td>
<td>—</td>
<td>83·76</td>
<td>89·33</td>
<td>86·33</td>
</tr>
<tr>
<td>Sep.</td>
<td>255·31</td>
<td>98·30</td>
<td>98·33</td>
<td>250·00</td>
</tr>
<tr>
<td>Oct.</td>
<td>216·77</td>
<td>48·97</td>
<td>68·18</td>
<td>125·00</td>
</tr>
<tr>
<td>Nov.</td>
<td>265·41</td>
<td>48·97</td>
<td>91·60</td>
<td>292·68</td>
</tr>
<tr>
<td>Dec.</td>
<td>326·10</td>
<td>48·97</td>
<td>91·60</td>
<td>292·68</td>
</tr>
</tbody>
</table>

Table 2 — Maximum, Minimum Values of t and ∆N for Northern India

<table>
<thead>
<tr>
<th>Station</th>
<th>Maximum value</th>
<th>Minimum value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t N/km</td>
<td>t N/km</td>
</tr>
<tr>
<td>Jodhpur</td>
<td>750 295</td>
<td>90 130</td>
</tr>
<tr>
<td>New Delhi</td>
<td>600 611</td>
<td>90 130</td>
</tr>
<tr>
<td>Lucknow</td>
<td>450 341</td>
<td>100 170</td>
</tr>
<tr>
<td>Guwahati</td>
<td>420 460</td>
<td>105 061</td>
</tr>
</tbody>
</table>
difference between them. In particular, the minimum value for \( \theta_p \) is 5.53 mrad for all the four stations. It is interesting to compare these results with the results of Bean for three stations, viz. Fairbanks, Alaska, having arctic climate, Washington D.C., having temperate climate and Swan Island, West Indies, having a tropical climate. In contrast to the above observations for northern India that ground-based ducts are not formed during the month of August, it has been found that in Washington and Swan Island area percentage occurrence of ducts is maximum in the month of August. Also, the maximum angle of trapping is 4.8 mrad in America while it is 12.7 mrad for Lucknow. One of the most important differences observed is that the maximum duct thickness observed at Washington is 440 m as compared to 750 m observed at Jodhpur. The corresponding minimum frequency of trapping for America is 1000 MHz whereas for Indian conditions it is as low as 13.64 MHz.

5. Conclusions
This study has been based on radiosonde observations which are made only twice daily, viz. morning and evening. Also, the radiosonde is not a very sensitive instrument. However, bearing these limitations in our mind, the present study has shown that:

(a) Ground-based ducts are observed throughout the year except in August during monsoon season.
(b) A maximum of 21% ducts occur at New Delhi.
(c) The maximum refractivity gradient observed is \(-6.11 \text{ N units per km}\) at New Delhi.
(d) The maximum angle of penetration observed is 12.51 mrad.
(e) The minimum frequency of trapping is as low as 13.64 MHz.

Acknowledgement
Assistance given by Mr M. Sajid in the collection and analysis of data is acknowledged with thanks. The authors thank Dr E. Bhagiratha Rao for his interest in this work and permission to publish this paper.

References