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Radio ray refraction in the lowest three kilometres over India — Climatological aspects

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ABSTRACT. Seasonal variation of refraction at 0, 10 and 52·4 mr angles of elevation over inland and coastal stations of India has been studied. An examination has been made whether refraction could be used as a parameter for airmass identification for Indian stations during different seasons. Statistical regression method has been utilized to compute values of constants for predicting values of radio refraction from the surface values of radio refractive index.

1. Introduction

The object of the present paper is to study the seasonal and geographical variation of radio ray refraction in the lowest three kilometres over India based on the data of 5 years for twelve radiosonde stations and to attempt to classify them according to airmass properties. Linear regression equations between the surface value of radio refractive index N_s and bending of the ray τ have also been worked out to facilitate the prediction of the bending in the lowest three kilometres over India.

2. Data

The mean value of atmospheric pressure P, temperature T, and vapour pressure e, based on the afternoon data during the years 1956-1960 were utilized to compute the radio refractive index $N(h)$ from the equation —

$$N(h) = \frac{77\cdot 6}{T}\left(P + \frac{4810\,e}{T}\right) \qquad (1)$$

The values of $N(h)$ were obtained at surface, 900, 850 and 700-mb levels for all the twelve months and their seasonal means were worked out. $N\ (h)$ is used in the computation of τ as discussed below.

3. Computation of radio ray refraction

To compute the 'bending' the following method is used after Schulkin (1952). The bending for the whole profile of 3 km is given by —

$$\tau_n \simeq \sum_{k=0}^{n} \frac{2(N_k - N_{k+1})}{\theta_k + \theta_{k+1}} \qquad (2)$$

where θ_k is evaluated from the relation —

$$\theta_{k+1} = \sqrt{\theta_k^2 + \frac{2(\gamma_1-\gamma_0)}{\gamma_0} + 10^{6} - 2\,(N_S - N_1)} \qquad (3)$$

τ and θ are expressed in milli-radians and the symbols have usual meaning.

4. Results and Discussion

The values of τ in the lowest three kilometres computed from the above formula for 0, 10 and 52·4 mr ($\simeq 3°$) are given in Table 1.

4.1. *Seasonal and geographical variation of τ*

The radiosonde stations may be broadly classified into two groups (*i*) inland stations and (*ii*) coastal stations. Among the inland stations τ is lowest during summer and highest during southwest monsoon. An exception is, however, seen at Gauhati where the lowest value of τ occurs during winter and highest value during post monsoon season. Jodhpur also shows maximum value for 0° elevation in the post monsoon months. The coastal stations display only slight seasonal variation.

4.2. *τ versus elevation angle*

As the angle of elevation is increased from 0° to 3° the bending is reduced to about 25 per cent over inland stations and 20 per cent over coastal stations. This relationship shows little variation from season to season. Slight reduction over inland stations is, however, discernible during the southwest monsoon season.

TABLE 1

Values of total angular refraction from surface to 3 km for different seasons, for angles of elevation 0, 10 and 52·4 mr over India

Stations	Angle of elevation, 0 mr				Angle of elevation, 10 mr				Angle of elevation, 52·4 mr			
	Winter	Summer	Monsoon	Pre-monsoon	Winter	Summer	Monsoon	Pre-monsoon	Winter	Summer	Monsoon	Pre-monsoon
Inland												
Jodhpur	5·5	5·1	7·9	8·6	4·1	3·8	5·7	3·9	1·6	1·4	2·1	1·5
New Delhi	7·2	5·4	9·7	7·4	5·0	3·6	6·0	5·2	1·7	1·4	2·1	1·8
Nagpur	6·6	5·7	8·1	7·9	4·7	4·0	6·2	5·6	1·7	1 4	2·2	2·0
Allahabad	8·7	6·2	10·5	10·4	5·9	4·3	7·1	6·9	2·1	1·5	2·4	2·3
Gauhati	9·1	9·3	12·1	12·8	6·2	6·5	7·9	8·5	2·2	2·2	2·7	2·7
Coastal												
Dum Dum	10·6	12·2	12·4	12·3	7·0	7·9	8·2	8·2	2·3	2·6	2·7	2·7
Port Blair	12·9	12·6	13·2	12·1	8·7	8·3	8·6	8·1	2·9	2·8	2·7	2·7
Visakhapatnam	14·9	14·1	15·4	13·1	9·3	7·8	9·7	8·7	2·8	2·3	3·0	2·9
Madras	14·0	16·2	11·4	12·7	8·1	9·8	8·5	8·2	2·6	3·0	2·5	2·6
Trivandrum	12·2	13·1	13·5	12·8	7·7	8·6	8·8	8·3	2·7	2·8	2·8	2·7
Bombay	12·7	16·9	13·0	14·5	8·2	9·4	8·6	9·2	2·6	2·8	2·9	2·9
Veraval	12·5	18·8	15·5	14·7	7·9	11·8	9·8	9·3	2·5	3·6	3·1	2·9

TABLE 2

Coefficients, a and b and correlation coefficient γ for use in the statistical method of refraction prediction for $h-h_s=3$ km

θ_0 (mr)	Winter			Summer			Monsoon			Post-monsoon		
	γ	b	a	γ	b	a	γ	b	a	γ	b	a
Inland Stations												
0·0	·85	.0717	—14·75	·97	·0608	—11·94	·90	·0860	—21·26	·99	·0810	—16·93
10·0	·95	·0468	— 9·32	·96	·0474	— 9·87	·98	·0483	—10·58	·97	·0541	—11·55
52·4	·95	·0162	— 3·21	·98	·0125	— 2·15	·98	·0116	— 1·88	·98	·0147	— 2·67
Coastal Stations												
0·0	·78	·0814	—16·00	·47	·1430	—38·44	·80	·1288	—36·21	—·23	—·0429	+27·24
10·0	·95	·0590	—12·78	·53	·0952	—26·32	·63	·0405	—11·70	—·19	—·0168	+14·87
52·4	·95	.0147	—2·62	·67	·0291	— 8·00	·78	·0170	— 9·36	—·06	—.0016	+3·40

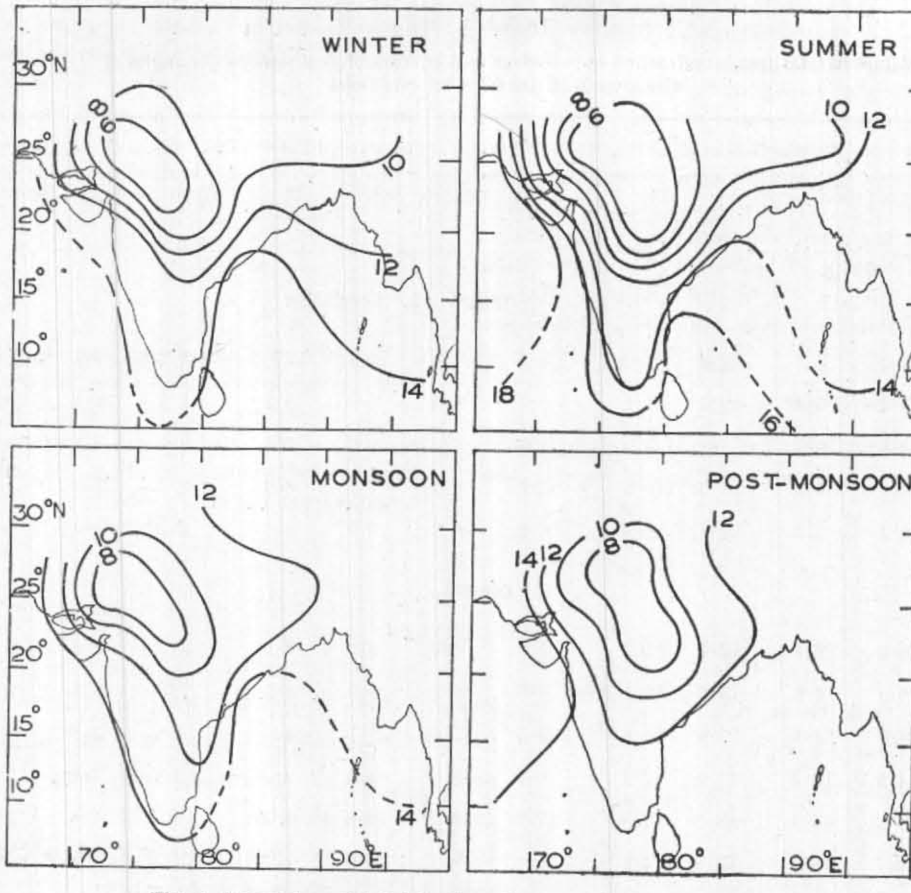

Fig. 1. Seasonal spatial distribution of mean τ (mr) over India (angle of elevation 0°)

4.3. τ *versus airmass characteristics*

An attempt has been made to correlate τ with various airmasses over India. It is well known that there are two predominant airmasses over India—continental and the monsoon. The influence of the southwest monsoon season is clearly reflected in τ values over inland stations of the country where the bending increases by 60 to 80 per cent as compared to summer season. High temperatures and low humidities make the values of τ lowest during summer as compared to winter. The coastal stations of the Peninsula remain under the moderating influence of the oceans and the small changes in the humidities of these airmasses mask any significant variation in τ values.

It is thus evident that in a tropical country like India airmass characteristics can be distinctly related with refraction over inland stations only and not over coastal stations. The surface values of radio refractive index N_s, however, showed rather distinct seasonal variation since highest values of N_s were observed during southwest monsoon all over the country (Maheshwari 1965, Srivastava 1967).

4.4. *Linear regression between* τ *and* N_s

Bean and Cahoon (1959) showed that the relation between $\tau_{1\cdot2}$ and N_s can be expressed as—

$$\tau_{1\cdot2} = b\, N_s + a \tag{4}$$

where, b and a are constants.

The values of the constants a and b for coastal and inland stations are given in Table 2 for the four seasons. The constant b which is the slope in equation (4) decreases rapidly with the increase in the angle of elevation, and shows slight seasonal variation. The other constant a comes out to be negative and varies in a similar manner as b. Correlation coefficients between τ and N_s are generally high for all the seasons over inland stations. The c.c. is highest during post monsoon and lowest during winter or southwest monsoon for inland stations at all the elevation angles. However, at coastal stations, the c.c. between

τ and N_s comes out to be negative during post-monsoon, but it is positive and highest during southwest monsoon. In general, the c.c. between τ and N_s decreases at coastal stations as compared to inland stations in the same season. The results may be utilised to point out the differences between average bending and that caused by synoptic weather situations, *e.g.*, western disturbances, tropical cyclones and monsoon depressions, since predominent variations in N occur in the lowest three km on account of these disturbances (Maheshwari 1962, Venkataraman *et.al* 1963, Srivastava 1965, 1968).

4.5. *Spatial distribution of* τ

The spatial distribution of τ at 0° in the lowest three kilometres is shown in Fig. 1 for all the seasons.

During summer season, the minimum values are obtained in the northern parts of the country and the maximum values over the west coast; the gradient of refraction is well marked over western parts of the country. The difference between summer and southwest monsoon values of refraction is also considerable at inland stations in the northern parts.

5. Conclusion

The above study which has shown the seasonal and geographical variation of τ in the lowest three kilometres at elevations of angles of 0, 10 and 52·4 mr enables one to estimate the extent to which the average bending may change with the seasons over India.

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