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Models of atmospheric refractive index with reference to coastal stations of India

R. B. PATHAK and H. N. SRIVASTAVA

Meteorological Office, New Delhi

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ABSTRACT. Based on the radiosonde data during the years 1957-1960, the effective earth's radius and the exponential model of atmospheric refractive index over coastal stations of India have been deduced. The correlation coefficient and the least squares straight line fit between the gradient of refractive index in the lowest one kilometre, $\triangle N$ and that near the ground surface, Ns has been studied and compared with the earlier studies based on the data of one year. The radio climatology of refractive index at 900-mb level and that of $\triangle N$ and their diurnal variation have also been briefly described.

1. Introduction

Since the installation of weather radars over the coastal stations of the country, angel activity associated with sea breeze has attracted the attention of several workers (Rai 1960, 1961; Datar and Sikdar 1964). The propagation characteristics when compared with that over inland stations are found to be distinctly different. It appears therefore, useful to evolve models of radio refractive index over the coastal stations rather than attempting a single model over the entire country as done hitherto (Srivastava 1968). It may also be mentioned that besides this aspect, the earlier study was based on one year data for the four months recommended by International Radio Consultative Committee (CCIR) and thus the results reported may not be truly representative for radio climatic purpose.

The object of this study is, therefore, to derive the various models of atmospheric refractive index over the coastal stations of India and to examine the seasonal and diurnal variation of the gradient in the lowest one kilometre so that transmission loss and refraction effects may be estimated. The radio climatology at 900-mb level has also been briefly described in the paper.

2. Models of radio atmospheres over coastal stations of India

Effective earth's radius model — The effective earth's radius model assumes an earth larger than the actual earth to the extent that the curvature of the radio ray may be absorbed in the curvature of the effective earth so that radio rays may be drawn as straight line over this earth rather than curved rays over the true earth. The effective earth's radius k is given by —

$$k = \frac{1}{1 + \frac{a}{n} \frac{dn}{dh} \cos\theta} \tag{1}$$

where a is the true radius of the earth, n is the refractiv index, ande dn/dh is the initial gradient with respect to height. The distance to the radio horizon, h of the radio ray leaving an antenna of height, h can be calculated from $\sqrt{2kha}$ for rays tangential to the earth ($\theta_o = 0$) and assuming n to be unity, equation (1) is approximated by

$$k \simeq \frac{1}{1 + a\frac{dn}{dh}} \tag{2}$$

The values of dn/dh computed from the gradient of radio refractive index in the lowest one kilometre (Table 1) was substituted in (2) for calculating the effective earth's radius k.

Exponential model of radio refractive index — The exponential model of radio refractive index is given by —

$$N(h) = A \exp(-Bh) \tag{3}$$

where $N(h)$ is the radio refractive index at height h and A and B are constants which can be determined by least squares method from the radio climatological data.

3. Estimation of the gradient of refractive index in the lowest 1 km from surface value

On account of availability of large number of surface weather observations several times a day, attempts are being made to estimate the gradient of radio refractive index $\triangle N$ from that near

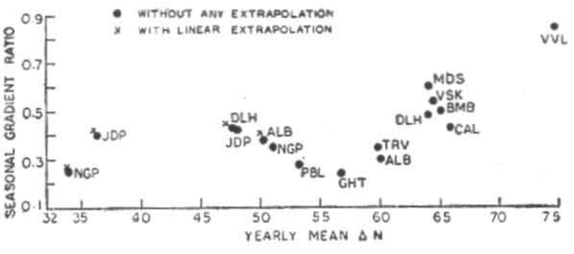

Fig. 1. Radio climatic classification of $\triangle N$ over India

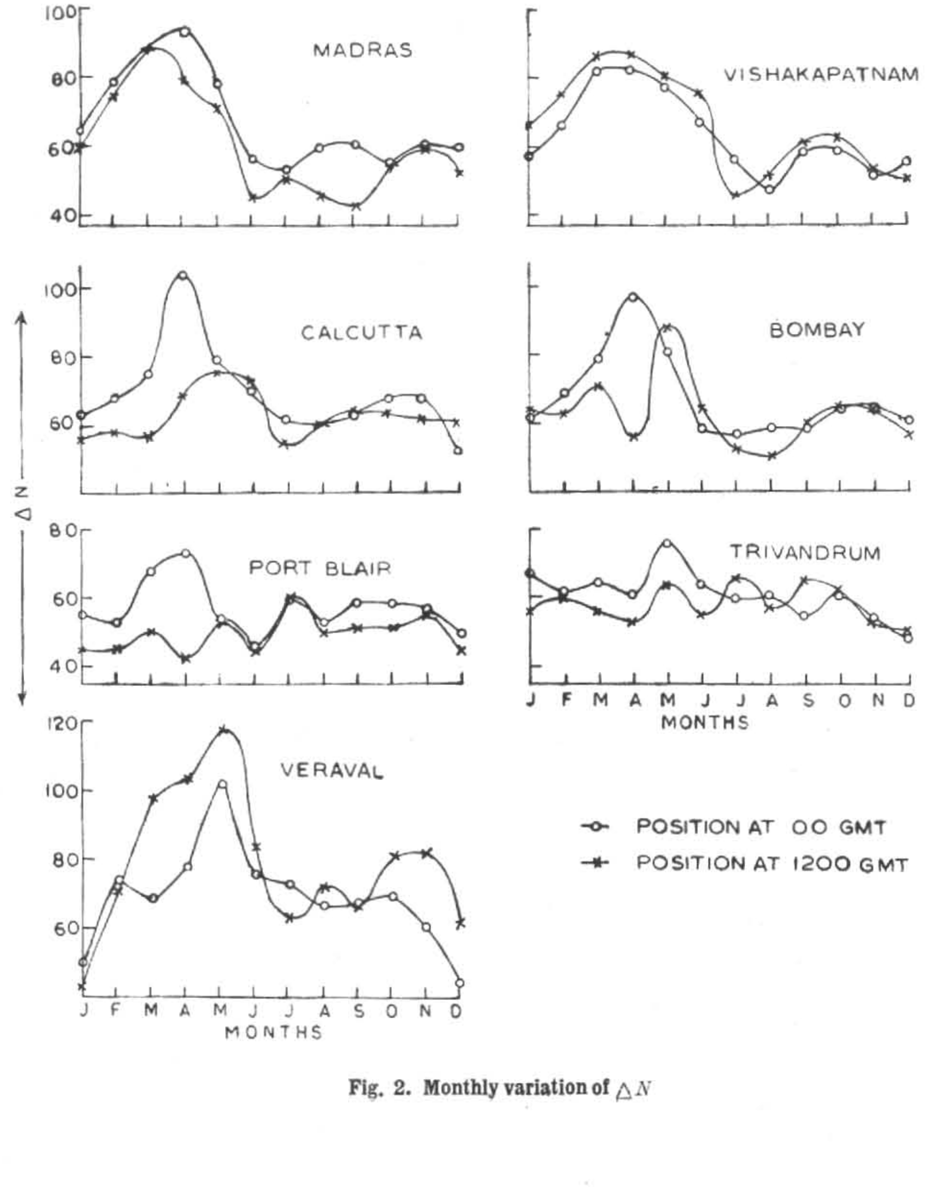

Fig. 2. Monthly variation of $\triangle N$

TABLE 1

Gradient of Radio Refractive Index ($\triangle N$) in the lowest 1 km over coastal stations of India (1957-1960)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bombay	63	66	75	76	84	62	55	54	59	64	64	58
Calcutta	59	62	65	85	82	71	58	60	63	65	64	56
Visakhapatnam	62	71	84	84	79	71	51	49	60	60	52	53
Veraval	47	77	84	91	110	80	68	69	67	76	72	54
Madras	63	77	89	87	75	51	52	52	51	60	60	53
Trivandrum	62	61	61	58	70	60	63	59	61	62	55	50
Port Blair	50	49	59	58	54	45	60	52	55	55	56	48

TABLE 2

Correlation Coefficient between $\triangle N$ *versus* Ns over India

	$\triangle N.N$ (1957-1960)	$\triangle N.Ns$* (1965)
February	0·71	0·97
May	0·66	0·83
August	0·77	0·43
November	0·61	0·83

*Srivastava and Chatterjee (1957)

the ground surface, Ns. The relation between Ns and $\triangle N$ is given by —

$$\triangle(N) = CNs + D \quad (4)$$

where C and D are constants which may be determined by least square method and neglecting the sign of $\triangle N$ which is negative.

4. Data

The daily values of atmospheric pressure, dry bulb temperature and dew point as obtained by 12 Indian radiosonde stations (Table 4) at 00 and 12 GMT for the years 1957-1960 were converted into mean monthly values of refractive index near the ground surface and at 900 mb. It is noticed from *Indian Daily Weather Reports* that the height of 900-mb surface remains close to 1 km throughout the year at all the coastal stations. However, for the inland stations of the country, height of 900-mb level shows well marked seasonal variation and may be as low as 850 m or so, after subtracting the station elevation, for some months.

Bean and Dutton (1966) suggested that the climatic variation of $\triangle N$ may be represented by plotting the ratio $R(\triangle N)$ of the highest and lowest values of $\triangle N$ *versus* the mean value of $\triangle N$. The results given in Fig. 1 show that the grouping of 12 radiosonde stations does not truly reflect the climatic characteristics at all the stations. In case $\triangle N$ values (Ns—N_{900}) at inland stations are linearly extrapolated for 1 km, a rather different type of classification is obtained for the same set of stations which again does not delineate the climatic characteristics besides showing unrealistically large values of $\triangle N$ for some inland stations. On this account, the correlation coefficient (CC) between $\triangle N$ *versus* Ns has been studied without any extrapolation but the limitations as mentioned above may be kept in view while interpreting the results.

5. Results and Discussion

The values of $\triangle N$ for seven coastal stations in India are given in Table 1.

TABLE 3

Effective earth's radius factor over coastal stations of India

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bombay	1·65	1·73	1·91	1·96	2·15	1·65	1·52	1·52	1·60	1·69	1·69	1·59
Calcutta	1·60	1·64	1·72	2·15	2·09	1·83	1·59	1·62	1·65	1·71	1·69	1·54
Madras	1·67	1·96	2·16	2·14	1·90	1·49	1·50	1·50	1·49	1·62	1·62	1·51
Trivandrum	1·65	1·64	1·64	1·57	1·81	1·62	1·65	1·60	1·64	1·65	1·54	1·47
Veraval	1·43	1·97	2·15	2·39	3·34	2·02	1·77	1·81	1·77	1·95	1·85	1·52
Visakhapatnam	1·65	1·83	2·15	2·15	2·01	1·83	1·49	1·45	1·62	1·62	1·50	1·51

TABLE 4

Radio climatology at 900 mb over India (1957-1960)

Station	Time (GMT)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Allahabad	00	275	265	264	259	264	286	340	341	321	298	270	270
	12	273	266	261	258	263	292	326	338	324	290	268	260
Bombay	00	275	272	274	278	304	329	329	326	326	306	290	284
	12	277	275	276	280	290	320	334	330	322	304	289	286
Calcutta	00	278	280	286	286	308	327	335	335	335	321	292	286
	12	280	281	283	296	314	317	338	332	333	317	294	288
Gauhati	00	287	286	287	310	314	328	334	335	340	318	312	295
	12	290	289	293	316	332	344	340	340	338	324	304	296
Jodhpur	00	268	259	261	260	272	311	330	326	316	283	270	270
	12	269	252	260	258	271	300	324	320	306	282	265	268
Madras	00	302	291	279	294	310	316	313	313	318	330	313	309
	12	296	282	280	296	310	326	320	324	324	320	316	312
Nagpur	00	281	272	269	273	275	304	328	327	322	304	284	280
	12	282	268	265	268	268	302	324	332	319	300	284	278
New Delhi	00	273	268	270	266	270	293	333	334	320	288	268	282
	12	271	265	270	262	265	290	331	339	315	286	272	273
Port Blair	00	318	322	306	312	336	336	322	329	324	325	321	322
	12	322	322	322	336	335	336	320	330	330	331	327	328
Trivandrum	00	300	303	305	314	316	320	316	316	316	316	316	316
	12	308	304	312	323	322	325	314	315	314	318	319	314
Veraval	00	273	284	273	286	282	318	323	324	314	296	280	279
	12	280	270	274	280	282	315	330	322	318	296	284	281
Visakhapatnam	00	293	288	284	301	309	319	322	331	322	318	303	293
	12	292	285	284	299	310	315	325	326	322	316	302	296

Diurnal variation of $\triangle N$ at coastal stations — It may be seen from Fig. 2 that in general, $\triangle N$ falls in the afternoon as compared to that in the morning at all the coastal stations over the country, except over Veraval and Visakhapatnam where $\triangle N$ varies in the reverse order. The diurnal changes from month to month do not vary uniformly.

Monthly variation of $\triangle N$ at coastal stations — In general, $\triangle N$ is maximum during the summer and decreases in the remaining months of the year. The largest values of $\triangle N$ are found at Veraval. The well marked difference in $\triangle N$ between Veraval and Bombay is partly attributed to the differences in the performance characteristics of C and F-type radiosondes*. The larger gradient observed at Veraval, north of Bombay in summer indicates predominant ducting conditions over north of Arabian Sea as compared to south. This has been supported by Srivastava and Mehrotra (*see* Ref.), who have found that *M*-inversions are more frequent at Bombay as compared to Trivandrum or Cochin.

The value of $\triangle$N is lowest at Madras during July to September which is in conformity with the climatic and geographical considerations. However, the monthly variation of $\triangle N$ does not show a significant decrease at all the coastal stations during southwest monsoon when the incidence of super-refracting conditions is found to be minimum. This indicates that ducting conditions for such stations will have to be studied in the light of stability parameters, eddy diffusivity and prevailing meteorological conditions over the oceanic areas for which instruments for measuring turbulence parameters in the lower layers of atmosphere and fine structure of radio refractive index as measured by microwave refractometers may be needed.

Correlation between $\triangle N$ versus Ns and regression equations — The seasonal variation of $\triangle N$ *versus* *Ns* as based on radio-climatic data is given in Table 2. It may be seen that a poor CC (0·40) between the surface value of refractive index and that in the lowest 1 km during southwest monsoon based on one year data may not be truly representative. It appears that the low value of CC in that year occurred partly due to lack of monsoon rainfall and consequent decrease of vapour pressure over the country.

The regression equations between $\triangle N$ *vs* *Ns* based on one year data for four representative months recommended by CCIR as reported earlier (Srivastava and Chatterjee 1967) get modified as follows—

$$\left.\begin{array}{ll} \triangle N=0\cdot4104\ Ns-80\cdot89 & \text{Feb} \\ \triangle N=0\cdot2870\ Ns-42\cdot32 & \text{May} \\ \triangle N=0\cdot6665\ Ns-200\cdot94 & \text{Aug} \\ \triangle N=0\cdot2861\ Ns-45\cdot28 & \text{Nov} \end{array}\right\} \quad (5)$$

Keeping in view the limitations of the correlation between *Ns* and $\triangle N$ over the inland stations of the country, it was desired to exclude them and study the CC between the quantities with reference to coastal stations of the country. It was rather surprising to find that except during southwest monsoon, the CC ($\triangle N$. *Ns*) was quite poor. It is thus difficult to estimate $\triangle N$ from *Ns* to a reliable degree from the regression equations for the coastal stations alone as given below —

$$\left.\begin{array}{ll} \triangle N=0\cdot083\ Ns+88\cdot30 & \text{Winter} \\ \triangle N.Ns=0\cdot24 & \\ \triangle N=0\cdot1645\ Ns+15\cdot32 & \text{Summer} \\ \triangle N.Ns=0\cdot30 & \\ \triangle N=0\cdot6776\ Ns-200\cdot53 & \text{SW monsoon} \\ \triangle N.Ns=0\cdot66 & \\ \triangle N=0\cdot1440\ Ns-104\cdot29 & \text{Post monsoon} \\ \triangle N.Ns=0\cdot24 & \end{array}\right\} \quad (6)$$

Effective earth's radius model over coastal stations — The values of effective earth's radius factor *k* which offer considerable simplification for radio propagation problems and prediction of ducting conditions over oceanic areas are given in Table 3. The results are self explanatory.

Exponential model over coastal stations —

$$\left.\begin{array}{ll} N(h)=Ns\ \exp\text{-}(0\cdot133\ h) & \text{Winter} \\ N(h)=Ns\ \exp\text{-}(0\cdot135\ h) & \text{Summer} \\ N(h)=Ns\ \exp\text{-}(0\cdot140\ h) & \text{SW monsoon} \\ N(h)=Ns\ \exp\text{-}(0\cdot136\ h) & \text{Post monsoon} \end{array}\right\} \quad (7)$$

This model has been found to hold good up to lowest 3 km as against the effective earth's radius model which holds good in general only up to 1 km above the ground surface.

Radio climatology at 900-mb level — The radio climatology and its diurnal variation are given in Table 4. It is seen that N_{900} is highest during

*On the performance characteristics of C and F-type Radiosondes Pt. I — Systematic C/F differences by R. Ananthakrishnan, R. Y. Mokashi and A. R. Ramakrishnan, Pre-publ. Sci. Rep. No. 21, India met. Dep., 1968 southwest monsoon and decreases in the other seasons. It is rather difficult to draw any definite conclusion regarding its diurnal variation from morning to evening hours. In general, however, the value of N_{900} falls in the afternoon as compared to that in the morning. It is also worth mentioning that the diurnal variation is quite small being of the order of 2 to 8 N units as compared to Ns when the range may be of the order of 25 to 30 N units at inland stations.

REFERENCES

Datar, S. V. and Sikdar, D. N.	1964	*Indian J. Met. Geophys.*, **15**, p. 459.
Rai, D. B.	1960	*Ibid.*, **11**, p. 412.
	1961	*Ibid.*, **12**, p. 307.
Srivastava, H. N.	1968	*Indian J. pure appl. Phys.*, **6**, p. 315.
Srivastava, H. N. and Chatterjee, S.	1967	*Indian J. Met. Geophys.*, **18**, p. 517.
Srivastava, S. S. and Mehrotra, S. M.	—	Super refracting conditions near Western Coast of India — Presented IERE Symp. on "Electronics in Industry", Sep. 1968 (under publ. Proc. IERE Indian Div).