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Radio-Climatology of India : II. Radio Refractive Index at 850-mb level

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ABSTRACT. Based on the five-year averages of the values of pressure, temperature and relative humidity at 850-mb level, the corresponding values of modified radio-refractive index have been computed for 13 stations in India. These data have been utilised to discuss the monthly and seasonal distribution of radio-refractive index at 850-mb level. A large number of radio-climatic charts have been prepared for this isobaric surface and the prominent features of the distribution of radio-refractive index at this level have been discussed.

1. Introduction

1.1. In the authors' recent paper dealing with the distribution of modified radio-refractive index near the ground surface over India (Kulshrestha and Chatterjee 1966), the monthly mean values of modified radio-refractive index near the ground surface were computed for 36 surface stations and an exhaustive set of radio-climatological charts were prepared. In that paper, the authors had also stressed the need for similar studies of the distribution and structure of radio-refractive index at upper levels over the country. The present paper deals with the structure of radio-refractive index distribution at 850-mb level which corresponds to an isobaric surface approximately 5000 ft above sea level.

1.2. The modified radio-refractive index (also termed radio-refractivity) of the atmosphere at 850-mb level has been denoted by N_{850} in this paper and is expressed in the usual N units. For a description of the definition of radio-refractivity or a discussion of the various parameters involved therein or for various methods of determination of radio-refractive index, a reference may be made to the authors' earlier paper (Kulshreshtha and Chatterjee 1966).

2. Scope of the present study

2.1. In the present study, the normal monthly and seasonal values of N_{850} have been computed and radio-climatic charts for monthly, seasonal, annual maximum, annual minimum and annual ranges of N_{850} have been prepared and discussed.

2.2. The east-west as well as the north-south cross-sectional distribution and annual range of N_{850} over the four representative months, *viz.*, February, May, August and November, have been discussed.

2.3. The month by month variations of N_{850} at the different stations in India have also been presented and discussed with a view to delineate homoclimes of upper air radioclimate in India.

3. Data

3.1. The present analysis is based on the 850-mb level data of 13 India Meteorological Department stations whose geographic positions are shown in the station locator map in Fig. 1. These 13 stations comprise of the 12 radiosonde stations and one high level station (Srinagar) whose surface pressure is itself of the order of 850 mb.

3.2. Mean monthly values of the 850-mb data of pressure P (mb), temperature t (°C) and relative humidity RH (per cent) for these 13 stations for the five-year period 1956 to 1960 were utilized for computation of radio-refractivity at 850-mb level from the well known expression for radio-refractivity as given by

$$N_{850} = (n-1) \times 10^6$$
$$= \frac{77 \cdot 6}{t+273} \left(P + \frac{4810\, e_s\, RH}{t+273}\right)$$

where, e_s = the saturation vapour pressure in mb.

3.3. As already mentioned in Section 2·1, the symbol N_{850} denotes the value of the modified radio-refractive index or radio-refractivity in N units at the 850-mb level.

4. Analysis of the data

4.1. The monthly mean values of N_{850} for all the 13 stations are given in Table 1.

4.2. Seasonal mean values of N_{850} have been worked out by taking average of the values of N_{850} for the months representing each of the four seasons. These seasonal means of N_{850} are given in Table 2. Maximum and minimum values, annual range and annual mean values of N_{850} for each of the 13 stations have also been worked out and are given in Table 2.

TABLE 1

Mean monthly values of N_{850} at various stations

S. No.	Station			Mean N_{850} (N units)											
	Name	Lat. (N)	Long (E)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Allahabad (ALB)	25°27′	81°44′	266	245	248	242	249	280	310	312	302	275	249	249
2	Bombay (BMB)	19°04′	72°06′	266	260	256	261	275	297	304	306	305	283	275	267
3	Calcutta (CAL)	22°39′	88°27′	261	260	265	268	288	305	312	313	308	295	267	259
4	Gauhati (GHT)	26°05′	91°43′	276	275	277	288	308	311	318	318	306	295	283	276
5	Jodhpur (JDP)	26°16′	73°03′	250	244	248	244	252	285	304	304	290	263	250	250
6	Madras (MDS)	13°00′	80°11′	270	259	256	265	285	292	302	302	299	296	289	275
7	Nagpur (NGP)	21°09′	79°07′	273	254	253	253	255	285	307	306	297	281	267	263
8	New Delhi (DLH)	28°35′	77°12′	254	248	256	249	252	276	310	310	300	268	253	250
9	Port Blair (PBL)	11°40′	92°43′	295	285	288	298	303	304	300	305	300	300	313	294
10	Srinagar (SRN)	34°05′	74°50′	256	267	269	274	280	283	300	300	283	273	265	264
11	Trivandrum (TRV)	08°30′	76°59′	284	288	296	298	294	296	293	293	292	297	292	288
12	Veraval (VVL)	22°55′	70°22′	266	255	256	259	258	288	292	301	296	277	274	263
13	Visakhapatnam (VSK)	17°42′	83°18′	274	268	267	270	280	300	302	305	303	296	273	266

TABLE 2

Seasonal mean, annual maximum, annual minimum, annual range and annual mean values of N_{850} for the various stations

S. No.	Station	Mean N_{850} (N units)							
		Winter Dec–Feb	Summer Mar–May	Monsoon Jun–Sep	Post monsoon Oct–Nov	Annual Max.	Annual Min.	Annual Range	Annual Mean
1	ALB	253	246	301	262	312	242	70	265
2	BMB	264	264	303	279	306	256	50	278
3	CAL	259	274	310	281	313	257	56	281
4	GHT	280	291	313	289	318	275	43	293
5	JDP	248	248	296	256	304	244	60	262
6	MDS	268	269	299	292	302	256	46	282
7	NGP	263	254	299	274	307	253	54	272
8	DLH	251	252	299	260	310	248	62	265
9	PBL	291	296	302	306	313	285	28	299
10	SRN	262	274	292	269	300	256	44	274
11	TRV	287	296	294	295	298	284	14	293
12	VVL	261	258	294	275	301	255	46	272
13	VSK	269	272	302	285	305	266	39	282

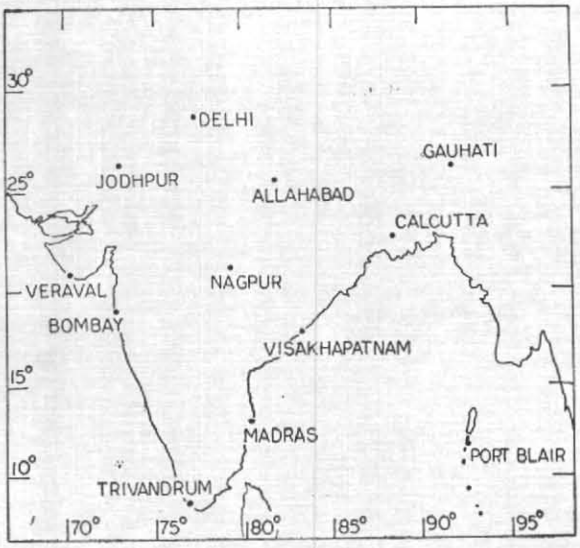

Fig. 1. Station locator map

TABLE 3

Monthly overall maximum and minimum values of N_{850} over India

Month	Overall Max. N_{850}	Station	Overall Min. N_{850}	Station
Jan	295	Port Blair	250	Jodhpur
Feb	288	Trivandrum	244	Jodhpur
Mar	296	Trivandrum	248	Jodhpur, Allahabad
Apr	298	Trivandrum, Port Blair	242	Allahabad
May	308	Gauhati	249	Allahabad
Jun	311	Gauhati	276	New Delhi
Jul	318	Gauhati	292	Veraval
Aug	318	Gauhati	293	Trivandrum
Sep	308	Calcutta	283	Srinagar
Oct	300	Port Blair	263	Jodhpur
Nov	313	Port Blair	249	Allahabad
Dec	294	Port Blair	249	Allahabad

4.3. The values of N_{850} for each of the 13 stations were plotted on maps for each month and isopleths were drawn at intervals of 10 N units. These charts may be seen in Figs. 2 (a) and 2 (b).

4.4. The seasonal means of N_{850} for the stations have also been plotted on maps and isopleths of seasonal means of N_{850} have been drawn at intervals of 10 N units (Fig. 3).

4.5. The annual maximum and annual minimum values of N_{850} as well as the values of the annual range of variation of N_{850} in N units as given in Table 2 have been plotted on maps and isopleths drawn at intervals of 10 units. These charts may be seen in Figs. 4-6.

4.6. The seasonal variation of N_{850} at the 13 stations is graphically shown in Fig. 7 (a).

4.7. In keeping with the technique adopted by the authors for radio-climatic classification of surface stations (Kulshrestha and Chatterjee 1966), the annual mean values *versus* the annual range of N_{850} at each of the 13 stations have been plotted and may be seen in Fig. 7 (b).

4.8. For each month, the values of overall maximum and minimum N_{850} have been picked up from Table 1 and are given in Table 3. These are also graphically shown in Fig. 8. The stations at which these monthly overall maximum and minimum values of N_{850} occur have also been indicated in Fig. 8.

4.9. The variation of mean monthly N_{850} for the selected stations along an east-west cross-section in the latitudinal belt of 20°–25° N has been shown in Fig. 9. In a similar manner, the variation of monthly mean N_{850} for five selected stations along a north-south cross-section in the longitudinal belt 75°—80°E is shown in Fig. 10. These cross-sectional variations have been studied for the four representative months in accordance with the recommendations of the CCIR, *viz.*, February (representing winter), May (representing summer), August (representing monsoon) and November (representing post-monsoon).

4.10. Similarly, cross-sectional variations of annual range of N_{850} at each of these stations is shown in Figs. 11 and 12 for the east-west and north-south cross-sections respectively.

4.11. The monthly variations of mean N_{850} at the 13 stations are graphically presented in Figs. 13-16. These stations have been grouped, in these diagrams, with a view to study the similarities of the monthly variations of N_{850}.

5. Discussions

5.1. *Monthly distribution of* N_{850}

5.1.1. *General features* — A careful study of the monthly patterns of N_{850} distribution over India (Figs. 2a and 2b) reveals the following general features.

5.1.1.1. Higher values of N_{850} occur over south Peninsula, Andaman Islands, West Bengal and Assam.

5.1.1.2. The location as well as the extent of the lowest N_{850} contour during winter, summer and partly post-monsoon months show a tendency to oscillate in a north-west to south-east direction. It is interesting to note that such a tendency was observed in the case of the pattern on the ground surface (Kulshrestha and Chatterjee 1966),

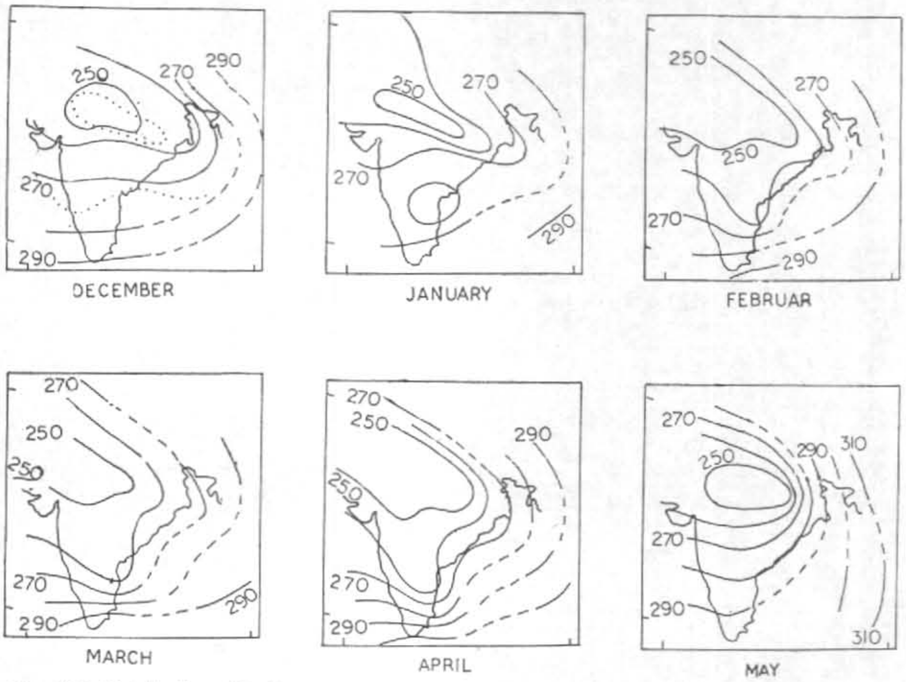

Fig. 2(a). Distribution of Radio Refractivity at 850 mb (N_{850}) over India during different months

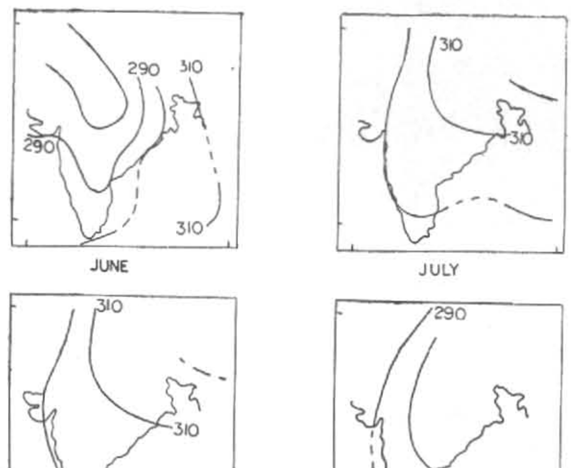

Fig. 2(b). Distribution of N_{850} over India during different months although in the latter case the tendency was in a north to south direction.

5.1.1.3. Though the annual highest and lowest values of N_{850} contours over the country are of the order of 320 and 240 N units respectively, but December through March the highest and lowest values of N_{850} contours are consistently of the order of 290 and 250 N units respectively.

5.1.2. *Month by month pattern* — When the monthly distribution patterns of N_{850} given in Figs. 2 (a) and 2 (b) are examined, the following additional facts are brought to light.

5.1.2.1. *December* — The area of the closed contour of the lowest value of N_{850} extends from Jodhpur to Allahabad. The maximum value of N_{850} over the country during this month is found to be 294 N units occurring over Port Blair while the minimum value of 249 N units occurs at Allahabad. The gradient is more or less uniform over the entire country.

5.1.2.2. *January* — The area of the closed N_{850} contour becomes narrow and elongated and extends more towards the southeast direction. An important feature is the appearance of another closed N_{850} contour around Madras. The N_{850} gradients over Rajasthan and the Gangetic plains of Uttar Pradesh are higher in comparison to the rest of the country. The maximum value of N_{850} during the month is 295 at Port Blair while the minimum value is 250 at Jodhpur.

5.1.2.3. *February* — The closed N_{850} contour of January is disrupted and the lowest N_{850} contour opens out in the west during February. The lowest N_{850} contour covers practically the whole of Rajasthan, Punjab and Uttar Pradesh. The maximum and minimum values of N_{850} during the month are 288 and 244 occurring at Trivandrum and Jodhpur respectively. Steep gradients prevail over the east coast and the sub-Himalayan regions of north India. The gradient is very much diffuse over Rajasthan and central India.

5.1.2.4. *March* — The lowest N_{850} contour remains open on the west but covers an area smaller than that covered in February and is confined to Rajasthan and west Uttar Pradesh. The N_{850} gradient becomes steeper over south peninsula and along the Madras coast. The gradient is, however, very flat in the central parts of the country and in the north peninsular regions. It is less steep in north and northeast as compared to February. The maximum value of N_{850} during the month is 296 at Trivandrum while the minimum value of 248 occurs at Allahabad and Jodhpur.

5.1.2.5. *April* — The lowest N_{850} contour continues to be open in the west but covers a larger area in this month. The N_{850} gradients over north peninsula, Rajasthan and Uttar Pradesh have become more diffuse while those over the rest of the country become steeper. The maximum value of N_{850} during the month is 298 at Trivandrum and Port Blair while the minimum value of 242 occurs at Allahabad.

5.1.2.6. *May* — The contour of the lowest N_{850} value becomes closed again and the area covered by it gets reduced. The axis of the closed contour, which had a southwest-northeast orientation upto April, assumed an east-west orientation. The closed contour lies mainly over east Rajasthan and Uttar Pradesh. The N_{850} gradient over south peninsula gets less steep while it becomes steeper over the rest of the country. The highest values of N_{850} which had been of the order of 290 N units December through March, gradually rise and become of the order of 310 N units during May. The maximum and minimum values of N_{850} during the month are 308 and 249 occurring over Gauhati and Allahabad respectively.

5.1.2.7. *June* — There is a general decrease in N_{850} gradient over the entire country. Although the highest values of N_{850} continue to be of the order of 310 N units, the lowest N_{850} values rise and become of the order of 280 N units. The contour of the lowest N_{850} values again opens up in the west and covers parts of Jammu and Kashmir, Punjab, north and east Rajasthan, west Uttar Pradesh and northern parts of central India. The gradient is diffuse in the entire country except in Bihar where it is moderately steep. The maximum and minimum values of N_{850} during the month are 311 and 276 at Gauhati and New Delhi respectively.

5.1.2.8. *July* — There is a complete change in the pattern. The N_{850} gradient is extremely diffuse, the difference between the highest and lowest N_{850} values during the month being of the order of 25 N units only. Even the orientation of the isopleths changes. While the axis of the contours was oriented northwest to southeast in the previous months, now the axis lies southwest to northeast. The maximum and minimum values of N_{850} during the month are 318 and 292 at Gauhati and Veraval respectively.

5.1.2.9. *August* — The distribution pattern is almost identical with that in July, the only difference being that the gradient over northeast India has become more diffuse as compared to July. The N_{850} gradient continues to be extremely diffuse. The axis of the contours is oriented southwest-northeast. The maximum and minimum values of N_{850} in this month are 318 and 293 at Gauhati and Trivandrum respectively.

5·1·2·10. *September*—The distribution pattern is similar to July and August. The trend of the N_{850} gradient in northeast India becoming further diffuse is maintained as much as there is no apparent gradient between central and eastern parts of the country. The gradient over the remaining parts of the country has become slightly accentuated as compared to July and August although still quite diffuse. The axis of the contours continues to be oriented in southwest-northeast direction. The maximum and minimum values of N_{850} during the month are 308 at Calcutta and 283 at Srinagar respectively.

5·1·2·11. *October*—With the withdrawal of the southwest monsoon, there is again a reversal in the distribution pattern. The axis gets oriented in northwest-southeast direction once again. The gradient starts building up again. The contour of the lowest N_{850} value, although not yet completely closed, assumes its characteristic shape and, in this month, is seen to cover parts of Jammu and Kashmir, Punjab, Rajasthan and Uttar Pradesh. The maximum and minimum values of N_{850} in this month are 300 and 263 at Port Blair and Jodhpur respectively.

5·1·2·12. *November*—The contour of the lowest N_{850} value gets closed and covers whole of Uttar Pradesh and parts of Punjab and Rajasthan. The gradient has further built up and is steeper over eastern parts of the country and the Bay of Bengal. The maximum and minimum values of N_{850} during this month are 313 and 249 at Port Blair and Allahabad respectively.

5·2. *Seasonal distribution of N_{850} over India*

5·2·1. *General features*

5·2·1·1. It will be seen from Fig. 3 that the seasonal distribution patterns for the seasons, summer (March to May) and post monsoon (October to November) are in many respects similar and the pattern for winter (December to February) is also not widely different. However, the seasonal distribution pattern for monsoon (June to September) is quite different from the rest of the seasonal patterns. The lowest seasonal values of N_{850} generally occur over Rajasthan and adjoining parts of the country while the highest values occur over the south peninsula, Andaman Islands and Assam.

5·2·1·2. The gradients are not very steep and are in fact quite diffuse in the north peninsula and central parts of the country.

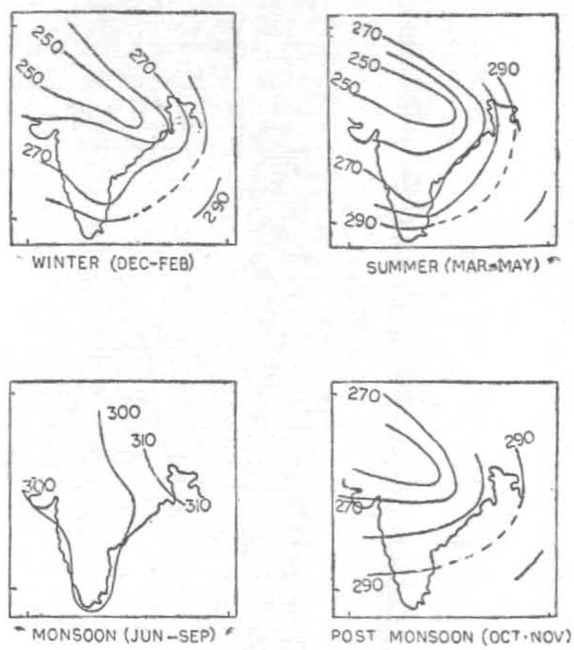

Fig. 3. Seasonal distribution of N_{850} over India

5·2·2. *Season by season pattern*

5·2·2·1. *Winter (December to February)*—The study of the seasonal pattern of N_{850} distribution during winter reveals that the lowest values of N_{850} occur over Rajasthan and Uttar Pradesh. The higher values occur over the extreme south peninsula, Andaman Islands and Assam. The highest values of N_{850} occur over Andamans. The gradient is extremely diffuse over north and central peninsula (Deccan plateau) but is relatively steeper over north India and along the Gangetic plain. As per CCIR recommendations, the month of February is the representative month of the season and it will be worthwhile to examine how the N_{850} isopleths of February compare with those for winter in India. A reference to Figs. 2(a) and 3 will show that the N_{850} contour pattern for winter compares more favourably with that for January rather than February. The highest and lowest N_{850} contours for winter and for January occur practically over the same regions and also have the same values. These facts indicate that the month of January, rather than February, is more representative month for winter for countries like India. It may be mentioned that similar observations become apparent if we examine the surface distribution of radio-refractivity over India during January and winter (Kulshrestha and Chatterjee 1966).

5.2.2.2. *Summer (March to May)* — During this season, there is a general increase in the gradient over the country. This results in a more gradual distribution of N_{850} gradient over Rajasthan and Deccan plateau and a general accentuation in the gradient over other parts of the country. Lower values of N_{850} occur over Rajasthan and adjoining areas and the higher values occur over south peninsula, Andaman Islands and Assam. The highest and the lowest values of N_{850} contours during the season are 300 and 250 N units respectively. According to the CCIR recommendations, the month of May is the representative month of the season. If we examine the monthly distribution of N_{850} with the seasonal distribution pattern for summer (Figs. 2a and 3), it is seen that the most striking similarity is the orientation of the contours in both the cases. The N_{850} gradients for May and summer also compare favourably. Thus the month of May is found to represent the summer season very well even in a tropical country like India.

5.2.2.3. *Monsoon (June to September)* — During this season, the contour pattern changes considerably. The N_{850} values over the entire country are relatively higher than those in the other seasons, but the gradient becomes very much diffuse. Only two isopleths could be drawn over the whole country. The axis of the contours is oriented in an almost north-south direction. According to CCIR recommendations, August is the representative month of the season. It is worthwhile to examine this aspect for India. The monthly distribution patterns for June, July, August and September (Fig. 2b) were examined to find out which of these monsoon months compared favourably with the seasonal distribution pattern during monsoon (Fig. 3). It is seen that June and September patterns do not at all resemble in any way with that for the season. However, both the July and August patterns, gradients, and other characteristics compare favourably with that for monsoon. July can, therefore, as well be the representative month for the season for India.

5.2.2.4. *Post Monsoon (October and November)* — The pattern and the orientation of the contours during this season is similar to that for summer but the N_{850} gradients in the post monsoon season are much more uniformly distributed over the entire country. The lower N_{850} values during the season occur over Rajasthan, west Uttar Pradesh and adjoining areas and the higher values occur over south peninsula, Andaman Islands and Assam. The highest and the lowest N_{850} contours are 300 and 260 N units respectively in this season. On comparing the contour orientation, highest and lowest isopleth values and range of variation of N_{850} for October and November with those for the post monsoon season, we find that the month of October would be a better representative of the season instead of the month of November as recommended by the CCIR.

5.3. *Distribution of annual maximum N_{850} values*

The contours of the annual maximum N_{850} over the various stations in the country are shown in Fig. 4. The highest and the lowest contours are 320 and 300 N units respectively. While the lowest values of annual maximum occur along the western boundaries of the country, and over extreme south peninsula, the highest values of annual maximum N_{850} are found to occur over Assam.

5.4. *Distribution of annual minimum N_{850} values*

The contours of the annual minimum N_{850} values over the various stations in the country are shown in Fig. 5.

The highest and the lowest minimum values are of the order of 280 and 240 N units respectively. While the lowest values of annual minimum N_{850} occur over west Uttar Pradesh, east Rajasthan and adjoining areas, the highest values of the annual minimum N_{850} are found to occur over the extreme south peninsula and the Andaman Islands.

5.5. *Distribution of the annual range of variation of N_{850}*

The distribution of the annual range of variation of the N_{850} values over India is shown in Fig. 6. The contours of the differences between the maximum and the minimum monthly means for each station for the entire year were plotted and isopleths were drawn as in Fig. 6. The smallest annual range of N_{850} variation is of the order of 20 N units and occurs over the extreme south peninsula and the Andaman Islands. The largest annual ranges of N_{850} variation are of the order of 70 N units and occur over a small region around central and sub-Himalayan Uttar Pradesh.

5.6. *Seasonal variation of N_{850} at various stations in India*

Fig. 7(a) shows the seasonal variation of N_{850} at the various stations. The tendency for many stations to group together and follow similar patterns of seasonal variation of radio-refractivity, which was noticed while examining the radio-refractivity data near the ground surface (Kulshrestha and Chatterjee 1966), is also reflected at the 850-mb level. We find that based on considerations of similarity of seasonal variations of N_{850} four distinct groups are easily discernible among these stations,

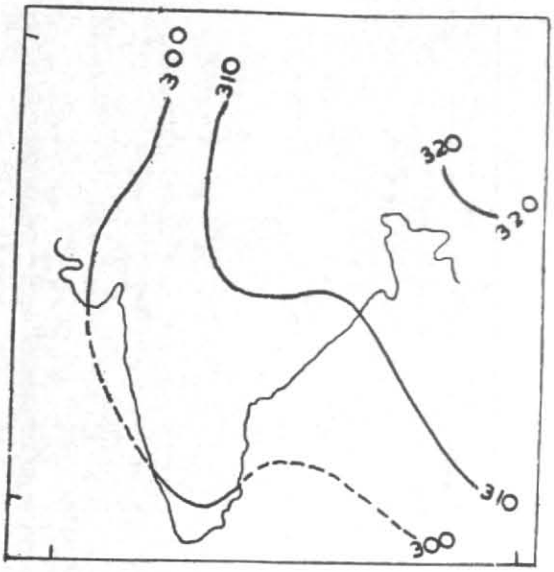

Fig. 4. Annual maximum N_{850}

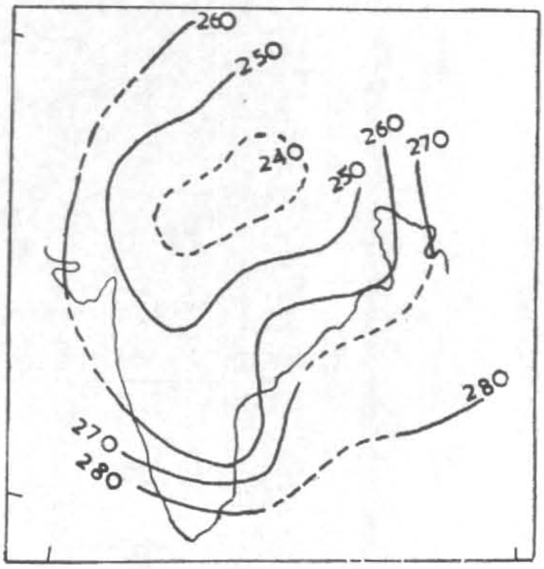

Fig. 5. Annual minimum N_{850}

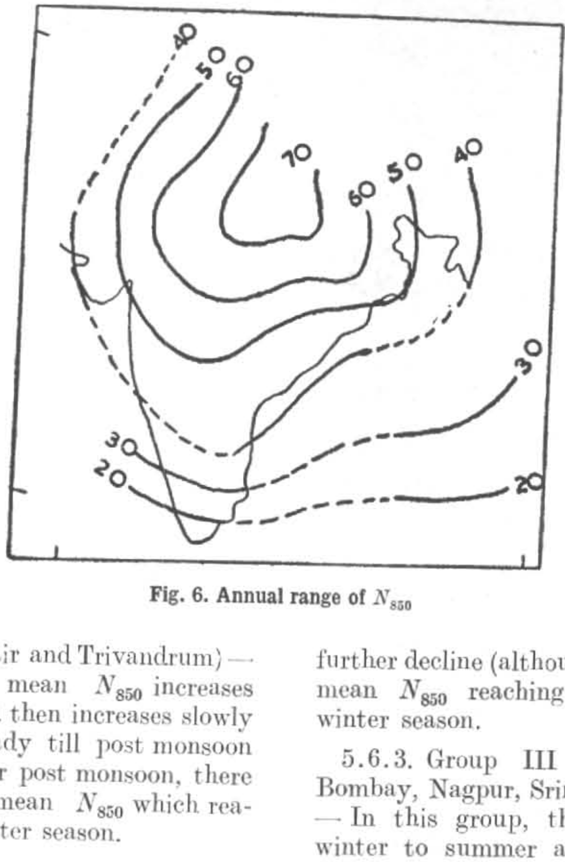

Fig. 6. Annual range of N_{850}

5.6.1. Group I (Port Blair and Trivandrum) — In this group, the seasonal mean N_{850} increases from winter to summer and then increases slowly or remains practically steady till post monsoon through the monsoon. After post monsoon, there is a decline in the seasonal mean N_{850} which reaches a minimum in the winter season.

5.6.2. Group II (Gauhati) In this group, the seasonal mean N_{850} increases with a fairly steep gradient from winter to monsoon (through summer) and then falls rapidly from monsoon to post monsoon. After the post monsoon season, there is a further decline (although less rapid) in the seasonal mean N_{850} reaching a minimum value in the winter season.

5.6.3. Group III (Visakhapatnam, Madras, Bombay, Nagpur, Srinagar, Veraval and Calcutta) — In this group, the seasonal variations from winter to summer are not all exactly similar. The seasonal mean values of N_{850} over Nagpur and Veraval decrease from winter to summer whereas those for Visakhapatnam, Madras and Bombay remain practically constant from winter to summer. The seasonal values over Srinagar and Calcutta show a steep rise from winter to summer.

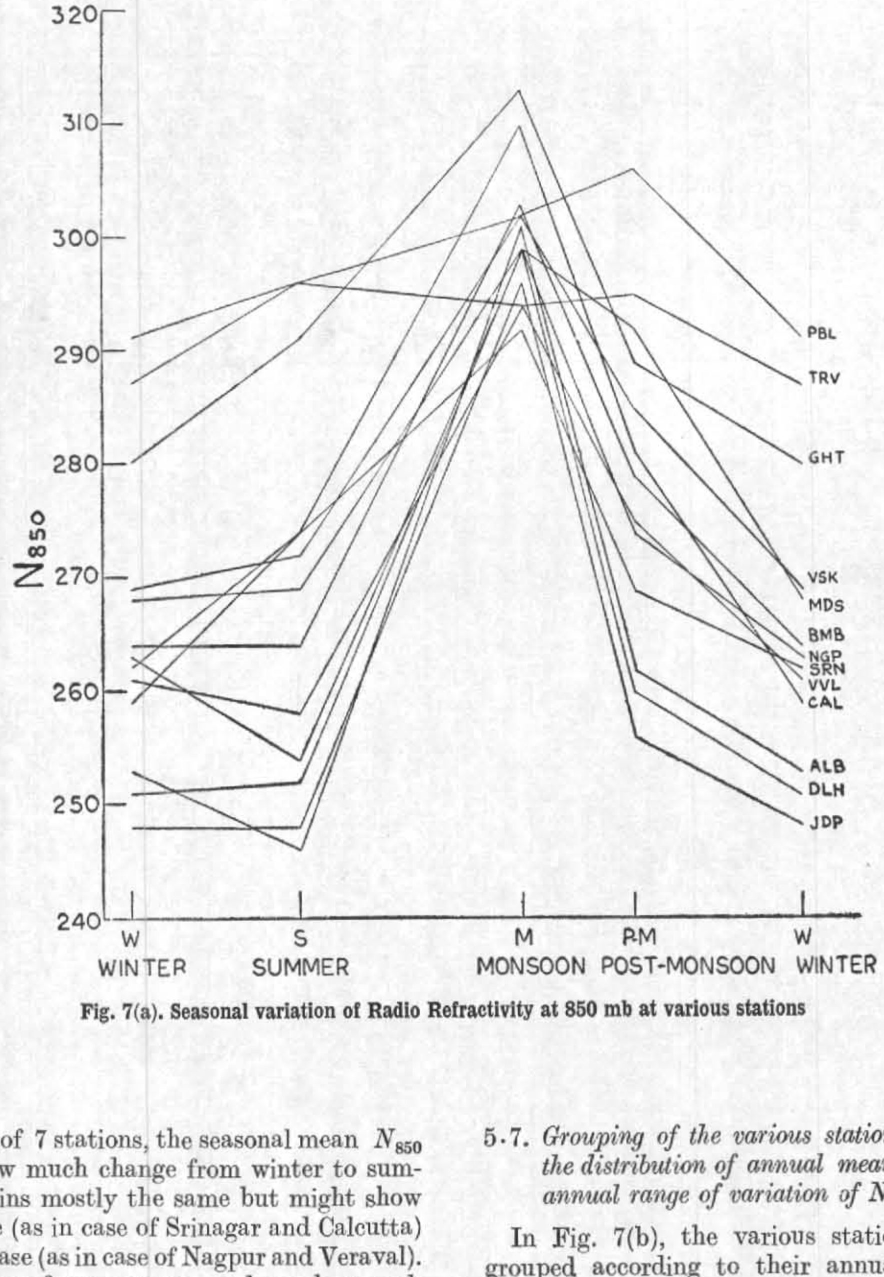

Fig. 7(a). Seasonal variation of Radio Refractivity at 850 mb at various stations

In this group of 7 stations, the seasonal mean N_{850} does not show much change from winter to summer. It remains mostly the same but might show some increase (as in case of Srinagar and Calcutta) or some decrease (as in case of Nagpur and Veraval). Values increase from summer and reach a peak during monsoon. After monsoon there is a decline in the seasonal mean N_{850} which mostly reaches a minimum in the winter season.

5·6·4. Group IV (Allahabad, New Delhi and Jodhpur) — One station in this group, *viz.*, Allahabad, exhibits a sharp decline in the mean seasonal N_{850} values from winter to summer but the seasonal values for New Delhi and Jodhpur remain practically constant from winter to summer. The seasonal variation of N_{850} from summer through monsoon, post monsoon and winter is exactly similar to that for the stations in Group III, *i.e.*, reaching the peak in monsoon.

5·7. *Grouping of the various stations according to the distribution of annual mean N_{850} and the annual range of variation of N_{850}*

In Fig. 7(b), the various stations have been grouped according to their annual mean N_{850} plotted against the annual range of variation of N_{850} observed at these stations. It is worthwhile to mention here that the surface radio-refractivity data for the Indian stations were also subjected to a similar treatment by the authors (Kulshrestha and Chatterjee 1966) and there we found that the stations arranged themselves in four distinct groups. We had, therefore, concluded there that the grouping was not entirely arbitrary but had a definite scheme of radio-climatic variation; specially because the same groupings were arrived at from two different considerations, *viz.*, the seasonal variation and the annual mean *versus* annual range of radio-refractivity. In the present case of

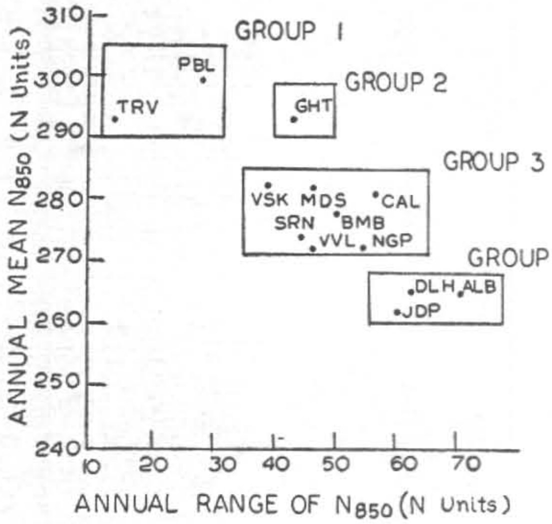

Fig. 7(b). Annual mean N_{850} *versus* annual range of N_{850} for the various stations

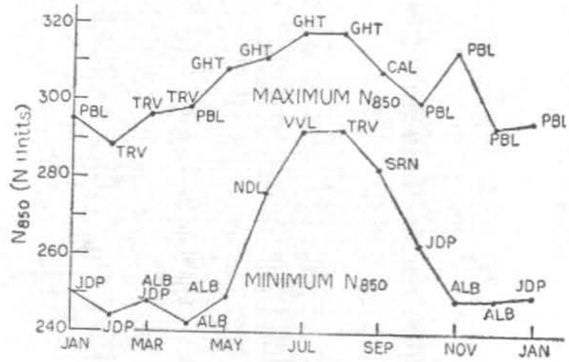

Fig. 8. Monthly maximum and minimum values of N_{850} over India

N_{850} also, we find that the stations arrange themselves in four distinct groups. Table 4 gives the details of the associated values of annual mean N_{850} and the annual range of N_{850} for these groups of stations.

It will be seen that these groups are the same as those discerned on the basis of seasonal variations of mean N_{850} (see section 5·6). This should prove that the grouping of the 13 stations in the four groups, as attempted here, is not entirely arbitrary but is in accordance with a definite scheme of variation of radio-climatic regimes as reflected in the seasonal variation of mean N_{850} and the distribution of annual mean N_{850} and the annual range of variation of N_{850}. This view is further strengthened by the fact that similar groups were discerned in the distribution of radio-refractivity near ground surface (Kulshrestha and Chatterjee 1966). These groups delineate the existence of what we might call as homoclimes of upper air radio-climate at 850-mb level over India. But it should be noted that these groupings are based on certain gross radio-climatic features such as seasonal mean, annual mean, or annual range of variation of N_{850} for each station. It is natural to expect that many of the finer features of radio-climate at any particular station are likely to be lost in these gross averages.

5·8. *Monthly maximum and minimum values of N_{850} over India*

For each month, the maximum and minimum values were picked up from Table 1 and graphically plotted in Fig. 8. The stations over which these values occur have also been indicated in this figure; which depicts the month by month variation of maximum and minimum N_{850} values over India. An examination of Fig. 8 reveals the following interesting points.

5·8·1. *Variation of monthly maximum N_{850} over India*

5·8·1·1. The monthly maximum values of N_{850} range between 318 and 288 N units.

5·8·1·2. The highest maximum N_{850} value (318 N units) occurs over Gauhati during July and August and the lowest maximum N_{850} (288 N units) occurs over Trivandrum in February.

5·8·1·3. It is interesting to note that May through August the monthly maximum N_{850} occurs consistently over Gauhati. Similarly, October through January the monthly maximum N_{850} occurs consistently over Port Blair. February through April the monthly maximum N_{850} occurs over Trivandrum although in April Port Blair also simultaneously exhibits monthly maximum value of N_{850}. In September, the monthly maximum N_{850} takes place over Calcutta. In general, we find that during the post monsoon, winter and summer, the monthly maximum N_{850} occurs over the extreme south peninsula and Andaman Islands. During monsoon, however, it occurs over the eastern parts of the country.

5·8·2. *Variation of monthly minimum N_{850} over India*

5·8·2·1. The monthly minimum value of N_{850} varies between 300 and 242 N units. It will be seen that the difference between the maximum and minimum values of N_{850} for any month, ($N_{850\,max} - N_{850\,min}$), has highest value in November and the lowest value during July and August.

TABLE 4

Groups of distinct radio-climatic regimes at 850-mb level over India

Group	Stations	Location	Radio-climatic characteristics	
			Annual mean N_{850}	Annual range of N_{850}
I	Port Blair, Trivandrum	Coastal or island stations below 15°N	290—300	10—30
II	Gauhati	Inland station in northeast India	290—295	40—50
III	Visakhapatnam, Madras, Calcutta, Bombay, Srinagar, Veraval, Nagpur	Mainly coastal stations	270—285	30—60
IV	New Delhi, Allahabad, Jodhpur	Land-locked stations in north and northwest India	260—270	60—70

5.8.2.2. The monthly minimum values of N_{850} reach a peak in August over Trivandrum. While they remain practically constant during July and August, they decline rapidly on both sides of this flat peak. While there is one flattened peak during July and August, there are two distinct minima, one in April and the other in November, both occurring over Allahabad.

5.8.2.3. The highest monthly minimum occurs over Trivandrum in August followed closely by Veraval in July, while the lowest minimum N_{850} occurs over Allahabad in April.

5.8.2.4. If we examine the places of occurrence of monthly minimum N_{850}, many interesting radio-climatological aspects are revealed. January through March (*i.e.*, the later part of winter and early summer), the monthly minimum N_{850} occurs over Jodhpur in the semi-arid region of Rajasthan. During the entire summer months (*viz.*, March through May), the monthly minimum N_{850} occurs over Allahabad. It may be noted that during March, the minimum N_{850} is exhibited simultaneously by both Jodhpur and Allahabad. It is Allahabad again during November and December. During the monsoon months of June, July, August and September, the monthly minimum N_{850} occurs over New Delhi, Veraval, Trivandrum and Srinagar respectively. During the post monsoon month of October, it occurs over Jodhpur.

5.9. *Variation of* N_{850} *along an east-west cross-section*

Variations of N_{850} over Calcutta, Allahabad, Nagpur, and Veraval along an east-west cross-section in the latitudinal belt of 20° – 25°N for the four representative months (February, May, August and November as per CCIR recommendations) have been shown graphically in Fig. 9. During February, May and November, the N_{850} values reach minima over Allahabad and reach maximum over Calcutta except for November when the N_{850} maximum occurs over Veraval. In these three representative months, N_{850} decreases rather gradually from Veraval to Nagpur and then fairly steeply upto Allahabad where it reaches the lowest value for the stations in this east-west cross-section. Thereafter the values of N_{850} start rising rapidly upto Calcutta. This east-west cross-sectional picture changes completely during August due to the effects of the monsoon. The value of N_{850} along the cross-section increases rather steadily from Veraval to Calcutta through Nagpur and Allahabad. The cross-sectional gradient in this month is less steep. The range of variation of N_{850} in this cross-section is maximum in May (39 N units) and minimum in August (12 N units). The N_{850} values are highest in August (of the order of 310 N units) and lowest in February (of the order of 250 N units).

5.10. *Variation of* N_{850} *along a north-south cross-section*

Variations of N_{850} over Srinagar, New Delhi, Nagpur, Madras and Trivandrum, *i.e.*, stations along a north-south cross-section in the longitudinal belt of 75°–80°E, for four representative months of February, May, August, and November have been graphically shown in Fig. 10. The variations of N_{850} during February, May and November follow an almost identical trend. During all these three months, the N_{850} value reaches a peak at Trivandrum and has the smallest value at New Delhi. The value of N_{850} decreases from Srinagar to New Delhi where, as already mentioned, it reaches the lowest value for the cross-section in these three months. The N_{850} values then start rising and continue to rise upto Trivandrum through Nagpur and Madras. During February, the increase in N_{850} from New Delhi to Madras (through Nagpur) is gradual and then it rises rapidly upto Trivandrum. In May, the N_{850} value increases gradually upto

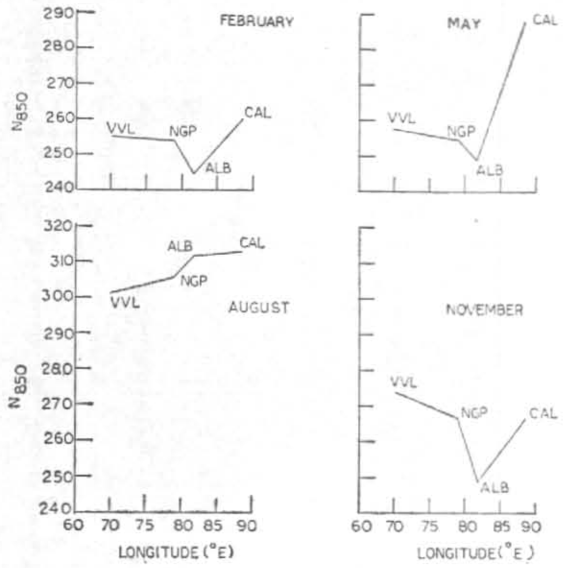

Fig. 9. East-West cross-section of N_{850} over India for four representative months

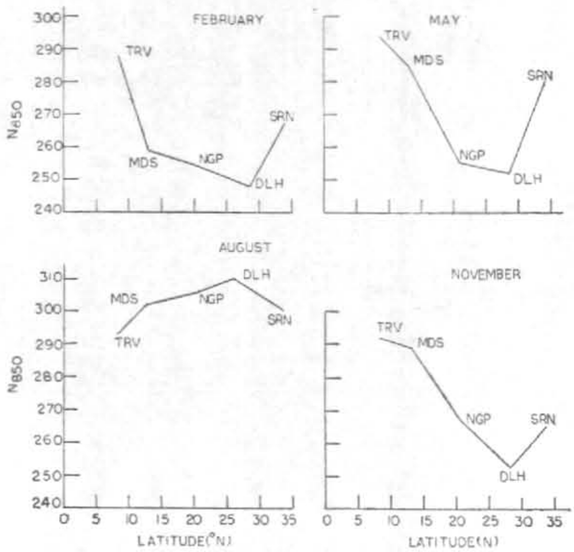

Fig. 10. North-South cross-section of N_{850} over India for four representative months

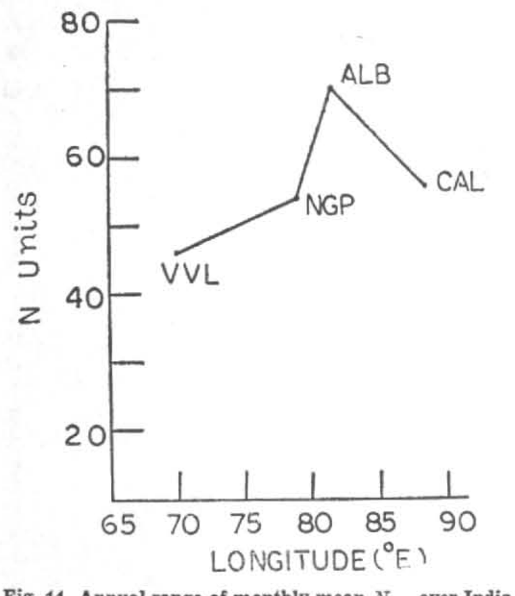

Fig. 11. Annual range of monthly mean N_{850} over India (East-West cross-section)

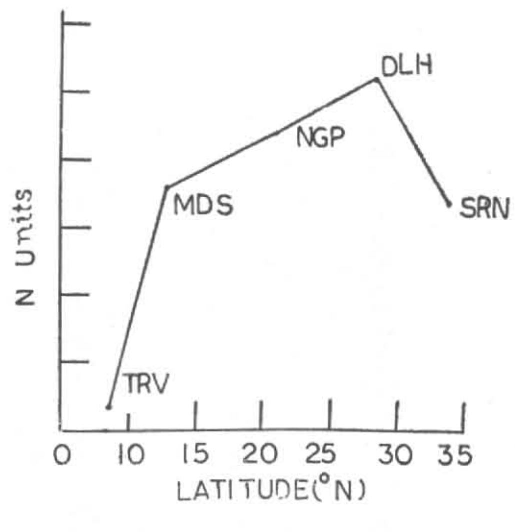

Fig. 12. Annual range of monthly mean N_{850} over India (North-South cross-section)

Nagpur and then rapidly upto Trivandrum through Madras. In November, the N_{850} starts rising rapidly, right from New Delhi and this trend is continued upto Madras (through Nagpur), after which the rise is rather gradual up to Trivandrum. The trend of N_{850} variation along this cross-section during August is entirely different. During this month, the N_{850} reaches a maximum over New Delhi. The N_{850} increases from Srinagar to New Delhi and then gradually decreases upto Trivandrum through Nagpur and Madras. Along this cross-section, the range of N_{850} variations are between 288 – 248 (40 N units) in February, between 294 uad 252, *i.e.*, 42 N units in May, between 310 and 293, *i.e.*, 17 N units in August and between 292 and 253, *i.e.*, 39 N units in November. The range of variation of N_{850} along this cross-section is maximum (42 N units) during May and is minimum (17 N units) during August. The values of N_{850} are highest during August (of

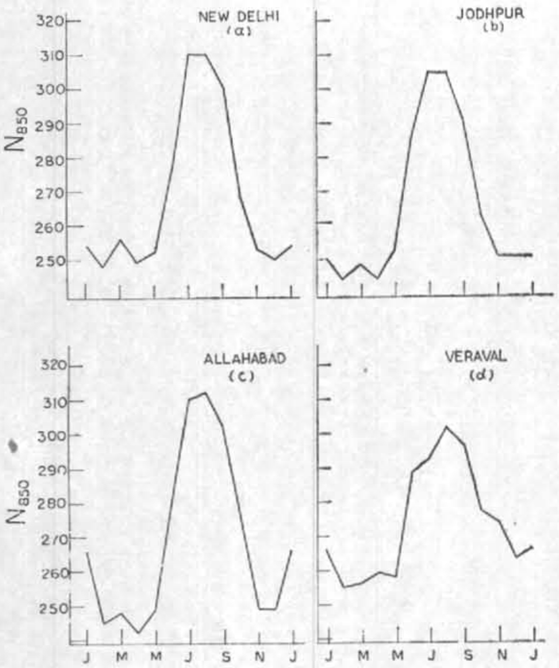

Fig. 13. Monthly variation of mean Radio-refractivity at 850 mb over various stations

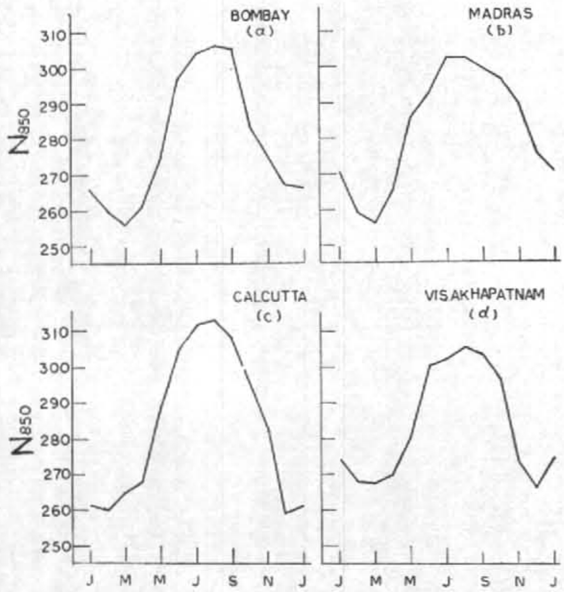

Fig. 14. Monthly variation of mean Radio-refractivity at 850 mb over various stations

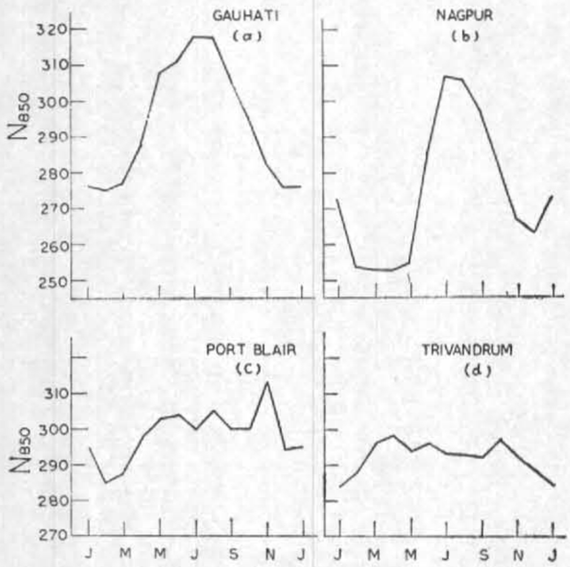

Fig. 15. Monthly variation of mean Radio-refractivity at 850 mb over various stations

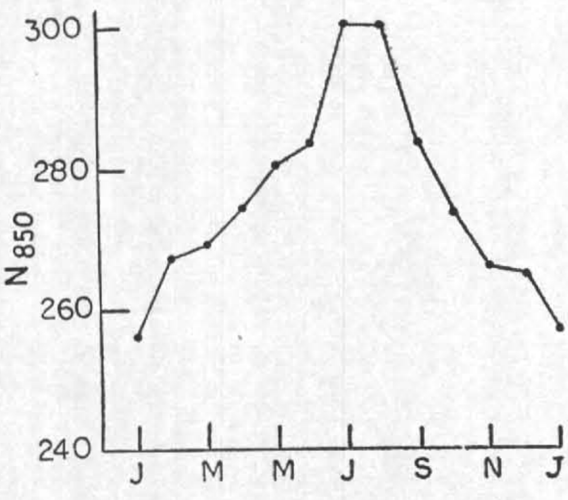

Fig. 16. Monthly variations of N_{850} at Srinagar

the order of 300 N units) and the lowest in February (of the order of 270 N units).

5.11. *Variation of annual range of N_{850} along the East-West cross-section (Fig. 11).*

The maximum variation of annual range of N_{850} in this east-west cross-section occurs over Allahabad and minimum variation over Veraval; the values of annual ranges extending between 70 and 46 N units. From Calcutta the annual range increases and reaches a peak over Allahabad. The annual range decreases rapidly between Allahabad and Nagpur and then gradually to Veraval. It may be mentioned that the annual range over Allahabad (70 N units) is the highest over India.

5.12. *Variation of annual range of N_{850} along the North-South cross-section (Fig. 12)*

The maximum variation of annual range of N_{850} in the north-south cross-section occurs over New Delhi and the minimum variation over Trivandrum; the values of annual ranges extending between

62 and 14 N units. The annual range increases from Srinagar to New Delhi when it reaches the peak and then starts falling rather gradually upto Madras through Nagpur. Between Madras and Trivandrum, the decrease of annual range of N_{850} is very steep. It will be worth mentioning that the annual range over Trivandrum (14 N units) is the lowest over India.

5.13. *Monthly variation of N_{850} at the 13 stations in India*

The monthly variations of N_{850} at the 13 stations have been given in Figs. 13-16. On a careful examination on the basis of the similarity in monthly variations of N_{850} at the various stations, it is observed that these stations can be classified into the following seven distinct types —

Type 1	New Delhi Jodhpur	Allahabad Veraval	Fig. 13
2	Bombay Calcutta	Madras Visakhapatnam	Fig. 14
3	Gauhati		Fig. 15 (a)
4	Nagpur		Fig. 15 (b)
5	Port Blair		Fig. 15 (c)
6	Trivandrum		Fig. 15 (d)
7	Srinagar		Fig. 16

It may be recalled that in Section 5·7, we had attempted groupings of these 13 stations based on considerations of certain gross radio-climatic averages and had remarked that many of the finer features of radio-climate at the individual stations might have been masked in the gross averages. However, Figs. 13-16 depict the fine structure of the radio-climate over the country at 850-mb level in as much as they exhibit the month by month change in N_{850} values over the various stations and thereby bring to light many distinct and characteristic features in the monthly variations. These typical regimes of monthly variation of N_{850} may be regarded to represent seven types of homoclimes of upper air radio-climates at 850-mb level over India. Each of these upper air homoclimes are characterised by a distinct and characteristic N_{850} regimes of monthly variation as shown in Figs. 13 to 16.

6. Conclusions

6.1. The complete radio-climatology of the distribution and structure of the atmospheric radio-refractivity of upper air at 850-mb level over the entire country has been worked out. A large number of maps and diagrams showing different aspects of the 850-mb radio-climatology have been presented. An attempt has been made to delineate homoclimes of upper air radio-climate over the country.

6.2. It is hoped that this study will provide the much desired data to radio-physicists and radio-engineers in radio measurements, propagation studies, frequency planning and allied investigations.

7. Acknowledgements

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