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# Radio-Climatology of India: III. Radio Refractive Index at 700-mb level

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ABSTRACT. Based on the 5-year averages of the values of pressure, temperature and relative humidity at 700-mb level, the corresponding values of modified radio-refractive index have been computed for this level over 12 Indian stations. These data have been utilised to discuss the monthly and seasonal distribution of radio-refractive index at 700-mb level. Various radio-climatic charts, dealing with the horizontal distribution of radio-refractive index at this isobaric surface over India, have been prepared and their prominent features have been discussed.

## 1. Introduction

1.1. In their earlier two papers (Kulshrestha and Chatterjee 1966a, 1966b), the authors have dealt with the distribution of modified radio-refractive index near the ground surface and at 850-mb level. In those papers, radio-climatological charts were prepared for the two levels and were discussed in detail. The present paper deals with the horizontal structure of modified radio refractive index distribution at the 700-mb isobaric surface (corresponding approximately to 10,000 ft above sea level) over India.

1.2. In the present paper, the authors present the radio-climatology for this isobaric surface over the country. To enable a proper comparative study of the structure of modified radio-refractive index at 700-mb level with those near the ground surface and at the 850-mb level, the data in the present paper have also been subjected to a similar treatment as was done in the authors' earlier two papers (Kulshrestha and Chatterjee, *op. cit.*).

## 2. Scope of the present study

2.1. The present paper is the third in the authors' projected series of studies on the radio-climatology of India and deals with various aspects of the distribution and horizontal structure of the modified radio-refractive index at 700-mb level. This modified radio-refractive index (also termed as radio-refractivity) of the atmosphere at 700-mb level has been denoted by $N_{700}$ 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 the various methods of determination of radio-refractive index, a reference may be made to the paper by Kulshrestha and Chatterjee (1966a).

2.2. In the present study, the normal monthly and seasonal values of $N_{700}$ have been computed from the available radiosonde data and radio-climatic charts for monthly, seasonal, annual maximum, annual minimum and annual range of $N_{700}$ have been prepared and studied.

2.3. The east-west and north-south cross-sectional distribution and annual range of variation of $N_{700}$ have been discussed for four representative months (*viz.*, February, May, August and November).

2.4. The month by month variations of $N_{700}$ at the different stations in India have been presented and discussed with a view to delineate homoclimes of upper air radio-climate over India.

## 3. Data

3.1. The present analysis is based on the 700-mb data of 12 India Meteorological Department radiosonde stations whose geographic positions are shown in the station locator map in Fig. 1.

3.2. Mean monthly values of the 700-mb pressure $p$ (mb), temperature $t$ (°C), and relative humidity $RH$ (%) for these 12 stations for the 5-year period 1956 to 1960 were utilised for evaluation of radio-refractivity at 700-mb level from the conventional expression for radio-refractivity as given by—

$$N_{700} = (n-1) \times 10^6$$

$$= \frac{77 \cdot 6}{(t+273)} \left\{ p + \frac{4810\, e_s RH}{(t+273)} \right\}$$

where, $n$ is the atmospheric radio-refractive index, and $e_s$ is the saturation vapour pressure in mb.

## 4. Analysis of the data

4.1. The computed monthly mean values of $N_{700}$ for all the 12 stations are given in Table 1.

4.2. Seasonal mean values of $N_{700}$ have been worked out by taking average of the values of $N_{700}$ for the months representing each of the four seasons. These seasonal means of $N_{700}$ are given in Table 2. Maximum and minimum values, annual

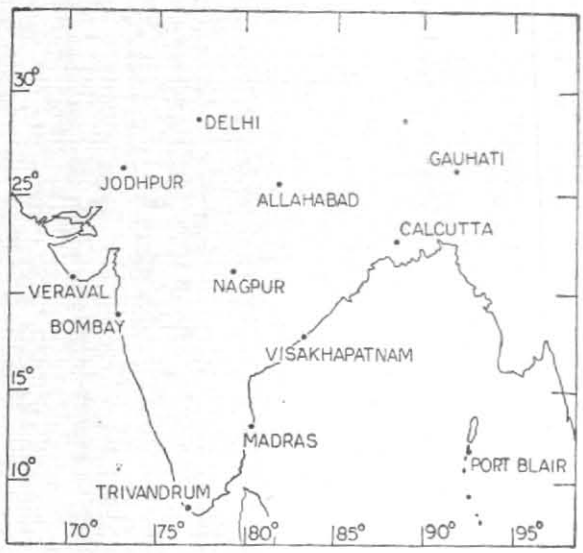


**Fig. 1. Station locator map**

range and annual mean values of $N_{700}$ for each of the 12 stations have also been worked out and are given in Table 2.

4.3. The values of $N_{700}$ for each of the 12 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 $N_{700}$ for the stations have also been plotted on maps and isopleths of seasonal means of $N_{700}$ have been drawn at intervals of 10 $N$ units (Fig. 3).

4.5. The annual maximum and annual minimum values of $N_{700}$ as well as the values of the annual range of variation of $N_{700}$ in $N$ units, as given in Table 2, have been plotted on maps and isopleths drawn at intervals of 10 $N$ units. These charts may be seen in Figs. 4 to 6.

4.6. The seasonal variation of $N_{700}$ at the 12 stations is graphically shown in Fig. 7(a).

4.7. In keeping with the technique adopted by the authors for radio-climatic classification in case of data for the ground and 850-mb level (Kulshrestha and Chatterjee, *op. cit.*), the annual mean values *versus* the annual range of $N_{700}$ at each of the 12 stations have been plotted and may be seen in Fig. 7(b).

4.8. For each month, the values of overall maximum and minimum $N_{700}$ 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 $N_{700}$ occur are also indicated in Fig. 8.

4.9. The variation of mean monthly $N_{700}$ for 5 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 $N_{700}$ for four 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 the Post-monsoon).

4.10. Similarly, cross-sectional variations of annual range of $N_{700}$ at each of these stations are shown in Figs. 11 and 12 for the east-west and north-south cross-sections respectively.

4.11. The monthly variations of mean $N_{700}$ at the 12 stations are graphically presented in Figs. 13 to 15. These stations have been grouped, in these diagrams, with a view to study the similarities of the monthly variations of $N_{700}$.

## 5. Discussions

5.1. *Monthly distribution of* $N_{700}$

5.1.1. *General features* — A study of the monthly patterns of $N_{700}$ distribution over India (Figs. 2a and 2b) reveals the following general features —

5.1.1.1. Higher values of $N_{700}$ occur over the south peninsula, Bay Islands, and Assam; while lower values occur over the central parts of the country.

5.1.1.2. October through May, the lowest isopleth of $N_{700}$ appears as a closed contour and the orientation of its axis shows a tendency to oscillate from NE—SW direction to E—W direction. There is no closed contour during the monsoon months.

5.1.1.3. The highest and the lowest values of $N_{700}$ contours over the country during the entire period of 12 months are of the order of 240 and 200 $N$ units respectively.

5.1.2. *Month by month pattern* — When the monthly distribution patterns of $N_{700}$ are examined further month by month, the following additional facts come to light.

5.1.2.1. *December* — The area of the closed contour of the lowest value of $N_{700}$ extends from Jodhpur to practically up to the Orissa coast near about Cuttack. The maximum value of $N_{700}$ over the country during this month is found to be 221 $N$ units occurring over Port Blair while the minimum value of 202 $N$ units occurs over Allahabad as well as over Jodhpur. The gradient is diffuse over the entire country.

5.1.2.2. *January* — The closed contour of the lowest value of $N_{700}$ continues to be practically over the same region and oriented in the

**TABLE 1**

**Mean monthly values of $N_{700}$ at various stations**

| Serial No. | Station | | | $N_{700}$ ($N$ 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 | 205 | 201 | 203 | 202 | 207 | 222 | 243 | 238 | 230 | 210 | 199 | 202 |
| 2 | Bombay (BMB) | 19 04 | 72 06 | 209 | 209 | 211 | 218 | 224 | 230 | 232 | 235 | 228 | 217 | 210 | 207 |
| 3 | Calcutta (CAL) | 22 39 | 88 27 | 206 | 204 | 210 | 216 | 225 | 236 | 242 | 242 | 230 | 216 | 207 | 204 |
| 4 | Gauhati (GHT) | 26 05 | 91 43 | 214 | 216 | 219 | 220 | 232 | 242 | 242 | 246 | 240 | 228 | 215 | 214 |
| 5 | Jodhpur (JDP) | 26 16 | 73 03 | 206 | 203 | 208 | 211 | 218 | 234 | 230 | 232 | 222 | 213 | 204 | 202 |
| 6 | Madras (MDS) | 13 00 | 80 11 | 207 | 205 | 208 | 213 | 222 | 234 | 234 | 234 | 232 | 229 | 216 | 212 |
| 7 | Nagpur (NGP) | 21 09 | 79 07 | 208 | 208 | 214 | 216 | 218 | 233 | 240 | 240 | 231 | 219 | 209 | 205 |
| 8 | New Delhi (DLH) | 28 35 | 77 12 | 207 | 204 | 206 | 207 | 212 | 221 | 234 | 238 | 227 | 211 | 203 | 205 |
| 9 | Port Blair (PBL) | 11 40 | 92 43 | 220 | 216 | 220 | 228 | 233 | 234 | 232 | 235 | 232 | 235 | 228 | 221 |
| 10 | Trivandrum (TRV) | 08 30 | 76 59 | 213 | 212 | 225 | 223 | 230 | 221 | 223 | 224 | 224 | 229 | 231 | 218 |
| 11 | Veraval (VVL) | 22 55 | 70 22 | 210 | 209 | 211 | 212 | 214 | 222 | 228 | 228 | 225 | 213 | 209 | 209 |
| 12 | Visakhapatnam (VSK) | 17 42 | 83 18 | 211 | 211 | 222 | 223 | 222 | 233 | 234 | 236 | 237 | 232 | 215 | 209 |

**TABLE 2**

**Seasonal mean, annual maximum, annual minimum, annual range, and annual mean values of $N_{700}$ for the various stations**

| | | Mean $N_{700}$ ($N$ units) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Winter | Summer | Monsoon | Post-monsoon | Annual | | | |
| | | (Dec-Feb) | (Mar-May) | (Jun-Sep) | (Oct-Nov) | Max. | Min. | Range | Mean |
| 1 | ALB | 203 | 204 | 233 | 205 | 243 | 199 | 44 | 211 |
| 2 | BMB | 208 | 218 | 231 | 213 | 235 | 207 | 28 | 217 |
| 3 | CAL | 205 | 217 | 237 | 211 | 242 | 204 | 38 | 217 |
| 4 | GHT | 215 | 224 | 243 | 222 | 246 | 214 | 32 | 226 |
| 5 | JDP | 204 | 212 | 229 | 209 | 234 | 202 | 32 | 213 |
| 6 | MDS | 208 | 214 | 233 | 223 | 234 | 205 | 29 | 219 |
| 7 | NGP | 207 | 216 | 238 | 225 | 240 | 205 | 35 | 221 |
| 8 | DLH | 205 | 208 | 230 | 207 | 238 | 203 | 35 | 213 |
| 9 | PBL | 219 | 227 | 233 | 231 | 235 | 216 | 19 | 227 |
| 10 | TRV | 214 | 226 | 223 | 230 | 231 | 212 | 19 | 223 |
| 11 | VVL | 209 | 212 | 226 | 211 | 228 | 209 | 19 | 215 |
| 12 | VSK | 210 | 222 | 235 | 223 | 237 | 209 | 28 | 223 |

same northwest-southeast direction as was during December. The maximum and minimum values of $N_{700}$ are 220 and 205 occurring over Port Blair and Allahabad respectively. The gradient over the central parts of the country is very much diffuse. There is, however, some steepening of the gradient over the Orissa and the Circar's coasts.

5.1.2.3. *February* — The location, extent and orientation of the closed contour of the lowest value of $N_{700}$ remain practically the same as during the earlier two months. Even the general distribution of the isopleths, during this month, does not show much change from that in December and January. The maximum $N_{700}$ value of 216 $N$ units occurs over Port Blair and Gauhati while the minimum $N_{700}$ value of 201 $N$ units occurs over Allahabad. The gradient is about the same as in January.

**TABLE 3**

**Monthly overall maximum and minimum values of $N_{700}$ over India**

| | Overall Max. $N_{700}$ | Station | Overall Min. $N_{700}$ | Station |
|---|---|---|---|---|
| January | 220 | Port Blair | 205 | Allahabad |
| February | 216 | Gauhati, Port Blair | 201 | Allahabad |
| March | 225 | Trivandrum | 203 | Allahabad |
| April | 228 | Port Blair | 202 | Allahabad |
| May | 233 | Visakhapatnam | 207 | Allahabad |
| June | 242 | Gauhati | 221 | Trivandrum, New Delhi |
| July | 243 | Allahabad | 223 | Trivandrum |
| August | 246 | Gauhati | 224 | Trivandrum |
| September | 240 | Gauhati | 222 | Jodhpur |
| October | 235 | Port Blair | 210 | Allahabad |
| November | 231 | Trivandrum | 199 | Allahabad |
| December | 221 | Port Blair | 202 | Allahabad, Jodhpur |

5.1.2.4. *March* — Though the orientation of the closed $N_{700}$ contour remains in the same northwest-southeast direction, but the area has diminished in size and lies over east Rajasthan and west Uttar Pradesh during this month. The general contour pattern remains the same except for the fact that during the month, another closed contour having the same value as that of the lowest contour appears near the Madras coast. The $N_{700}$ gradient over the south peninsula, eastern part of the country and Bay Islands has generally increased from the previous months. The maximum and minimum values of $N_{700}$ are 225 and 203 $N$ units occurring over Trivandrum and Allahabad respectively during the month. It is interesting to note that the $N_{700}$ isopleth of value 210 $N$ units, which was running practically along the boundaries of the country during February, has diminished in area in March and lies entirely to the north of the Deccan Plateau and shows a tendency to form a closed contour.

5.1.2.5. *April* — The closed $N_{700}$ contour practically lies over the same region as in March. The area of the $N_{700}$ isopleth of value 210 $N$ units has decreased still further during this month and has formed into a semi-closed $N_{700}$ contour. The maximum and minimum values of $N_{700}$ during the month are 228 and 202 $N$ units occurring over Port Blair and Allahabad respectively. There is an increase in the gradient over the central and the northern parts of the country while it gets diffuse over the rest of the country.

5.1.2.6. *May* — The $N_{700}$ contour of the value of 210 $N$ units which had gradually become semi-closed by April has finally assumed a close configuration during May and is oriented in the east-west direction. This contour is now located between Kota and Allahabad. The maximum and minimum values of $N_{700}$ during the month are 232 and 207 $N$ units occurring over Gauhati and Allahabad respectively. There has been a decrease in the $N_{700}$ gradient over all parts of the country.

5.1.2.7. *June* — The closed isopleth which was persisting from December through May over northern parts of the country gets disrupted and the pattern and orientation of $N_{700}$ contour over the country gets completely changed during the monsoon months. Practically a single isopleth of value 230 $N$ units runs through the entire country except over the foot of Himalayas in the north and over Assam. Higher values of $N_{700}$ are seen to occur over Assam and the lower values occur over the extreme south peninsula. The maximum and minimum values of $N_{700}$ are 242 and 221 $N$ units occurring over Gauhati and Trivandrum respectively. The $N$ gradient is quite diffuse over the entire country.

5.1.2.8. *July* — The $N_{700}$ contour of value 240 $N$ units, which was lying over Assam in June, has extended towards southwest further into the country. The contour of value 230 $N$ units runs practically along the west coast, south peninsula and the Bay Islands. The gradient is very flat. The maximum and minimum values of $N_{700}$ are 243 and 223 $N$ units occurring over Allahabad and Trivandrum respectively.

5.1.2.9. *August* — Only two contours of values 240 and 230 $N$ units are running over the country during August. The $N_{700}$ contour of 240 $N$ units lies practically over the same parts of the country where it was during July and the same is also the case for the contour of 230 $N$ units. The gradient has become further diffuse over the entire country. The maximum and minimum values of $N_{700}$ are 246 and 224 $N$ units occurring over Gauhati and Trivandrum respectively.

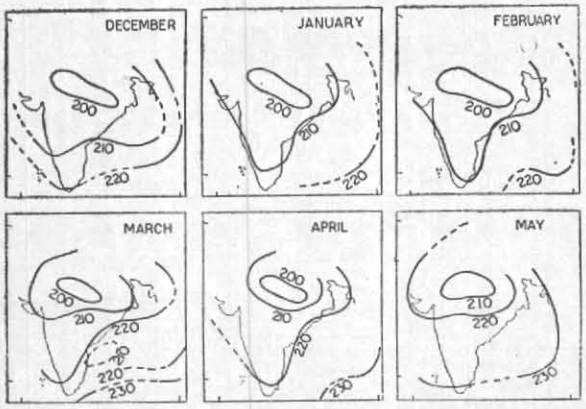


**Fig. 2(a). Distribution of radio-refractivity at 700 ($N_{700}$) over India during different months**

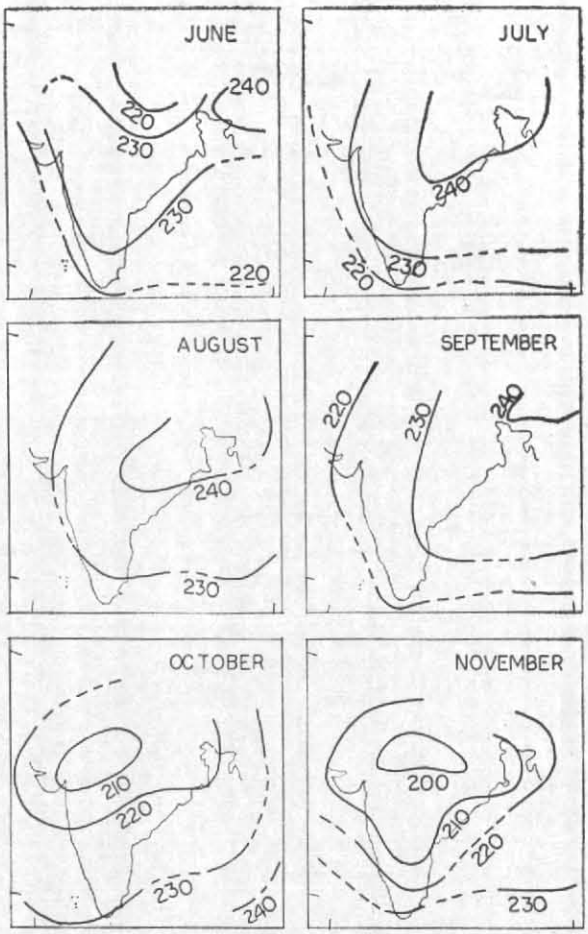


**Fig. 2(b). Distribution of $N_{700}$ over India during different months**

5.1.2.10. *September* — During this month, when the southwest monsoon retreats, the 240 *N* contour lies over Assam as was the case in June at the start of the monsoon season. The maximum and minimum values of $N_{700}$ are 240 and 222 *N* units occurring over Gauhati and Jodhpur respectively during this month. The gradient continues to be diffuse.

5.1.2.11. *October* — With the retreat of the southwest monsoon, there is an abrupt change in the $N_{700}$ contour pattern during this month. It will be interesting to note that the orientation of the $N_{700}$ contours is very similar to that we have seen during the months prior to June. Another interesting feature is the reappearance of the closed contour. This closed contour lies over Gujarat and Rajasthan and some parts of Uttar Pradesh. Its axis is oriented in a northeast-southwest direction. The gradient over the Peninsula is flat. The maximum and minimum values of $N_{700}$ are 235 and 210 *N* units occurring over Port Blair and Allahabad respectively.

5.1.2.12. *November* — The closed contour of 200 *N* units lies over Rajasthan, Uttar Pradesh, and west Bihar; and its axis is oriented in an east-west direction. It may be mentioned that the axis of this closed contour was in the northeast-southwest direction during October. The gradient is higher along the coasts and the south peninsula during November. It is, however, quite diffuse in the central parts of the country. The maximum and minimum values of $N_{700}$ are 231 and 199 *N* units occurring over Trivandrum and Allahabad respectively. It is worth mentioning that 199 is the lowest minimum value of $N_{700}$ for the entire year.

5.2. *Seasonal distribution of $N_{700}$ over India : Season by season pattern* (Fig. 3)

5.2.1. *Winter (December to February)* — The study of the seasonal pattern of $N_{700}$ distribution during winter reveals that the lowest values of $N_{700}$ occur over Rajasthan, Uttar Pradesh and Bihar. The higher values of $N_{700}$ occur over the Bay Islands during this season. The gradient over the entire country is diffuse. The maximum and minimum seasonal values of $N_{700}$ are 219 and 203 *N* units occurring over Port Blair and Allahabad respectively.

5.2.2. *Summer (March to May)* — During this season, there is a general increase in the value of $N_{700}$ over the entire country; this increase being of the order of 10 *N* units. Lower values of $N_{700}$ occur over parts of Rajasthan, Punjab, Uttar Pradesh and Bihar. Higher values occur over the Bay Islands during this season. The maximum and minimum seasonal values of $N_{700}$ are 227 and 204 *N* units occurring over Port Blair and Allahabad respectively.

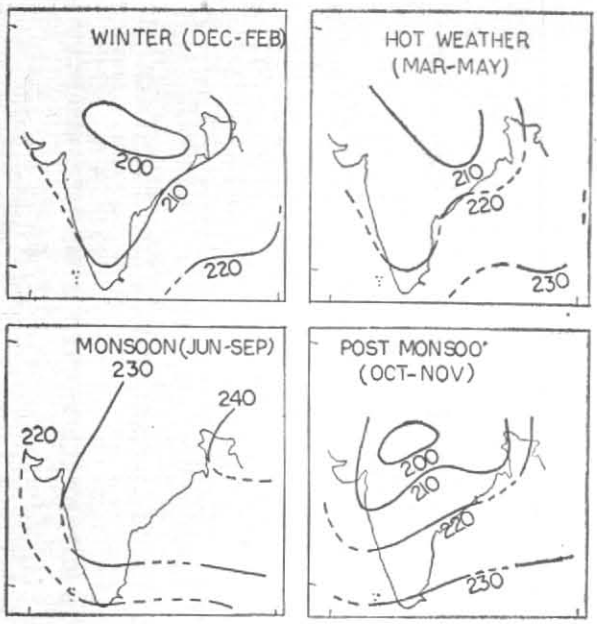


Fig. 3. Seasonal distribution of $N_{700}$ over India

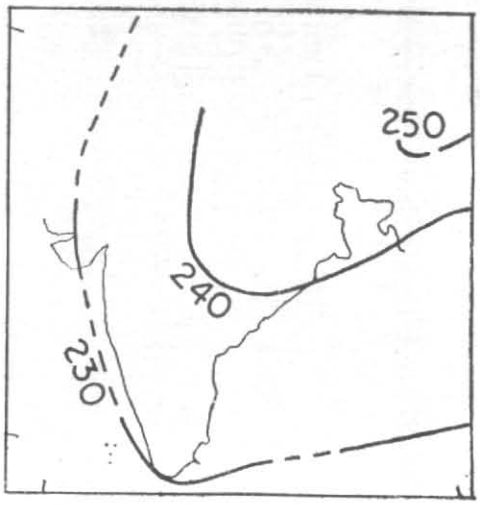


Fig. 4. Annual maximum $N_{700}$

5.2.3. *Southwest monsoon (June to September)* — In this season, the distribution pattern is entirely different from that in the other seasons. The $N_{700}$ gradient is extremely diffuse over the entire country except over the south peninsula. Higher values of $N_{700}$ occur over Assam and adjoining areas whereas lower values occur over the extreme peninsula during this season. The seasonal maximum and minimum values of $N_{700}$ are 243 and 223 $N$ units occurring over Gauhati and Trivandrum respectively.

5.2.4. *Post-monsoon (October and November)* — During this season, the closed contour of the lowest value of $N_{700}$, *viz.*, 200 $N$ units, appears over west Uttar Pradesh and Rajasthan. The contour pattern undergoes a complete change from that in the monsoon season. The higher values of $N_{700}$ occur over the extreme south peninsula and the Bay Islands; whereas the lower $N_{700}$ values occur over the central and northern parts of the country. The maximum and minimum values of $N_{700}$ during this season are 231 and 205 $N$ units occurring over Port Blair and Allahabad respectively. It is interesting to note that among all the four seasons, the $N_{700}$ gradient during this season is the highest over the entire country.

5.3. *Distribution of annual maximum* $N_{700}$

The contours of the annual maximum $N_{700}$ over the various stations are shown in Fig. 4. The highest and the lowest values for the isopleths are 250 and 230 $N$ units respectively. While the lowest values of the annual maximum occur along the western boundaries of the country, over the extreme south peninsula and the Bay Islands, the highest values of annual maximum $N_{700}$ are found to occur over Assam.

5.4. *Distribution of annual minimum* $N_{700}$

The contours of the annual minimum values of $N_{700}$ over the various stations are shown in Fig. 5. The highest and the lowest values of the annual minimum $N_{700}$ isopleths are 220 and 200 $N$ units respectively. While the lowest values of annual minimum $N_{700}$ occur over Uttar Pradesh, Rajasthan and adjoining areas, the highest values occur over the Bay Islands.

5.5. *Distribution of the annual range of variation of* $N_{700}$

The distribution of the annual range of variation of the $N_{700}$ over India is shown in Fig. 6. The contours of the differences between the maximum and the minimum monthly means for each of the twelve stations for the entire year were drawn. The annual range is seen to vary between 20 and 40 $N$ units. Higher values of the annual range occur over Uttar Pradesh, Bihar and parts of Madhya Pradesh and West Bengal; while the lower values occur along the western boundaries of the country, south peninsula and the Bay Islands. The maximum value of the annual range of $N_{700}$ is 44 and occurs over Allahabad while the minimum value of 19 $N$ units occurs over Port Blair, Trivandrum and Veraval.

5.6. *Seasonal variation of* $N_{700}$ *at the various stations*

Fig. 7 (a) shows the seasonal variation of $N_{700}$ over the various stations. The tendency for a

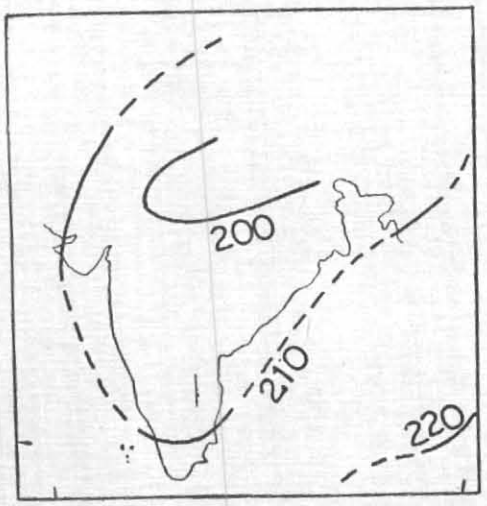


Fig. 5. Annual minimum $N_{700}$

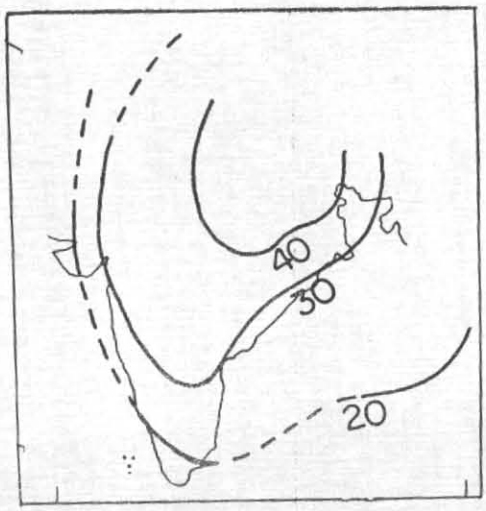


Fig. 6. Annual range of $N_{700}$

number of stations to group together and to 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 1966a) and at the 850-mb level (Kulshrestha and Chatterjee 1966b), is also reflected at the 700-mb level. We find that based on the considerations of similarities in the seasonal variation of $N_{700}$, four distinct groups are easily discernible in Fig. 7(a). It may be of interest to note that these groups come out to be very nearly the same as in case of the radio-refractivity distribution at the 850-mb level.

5.6.1. Group I (Port Blair and Trivandrum)

In this group, the seasonal mean $N_{700}$ increases from winter to summer. Thereafter upto monsoon, there is a decrease in the rate of rise or an actual fall in the value of the seasonal mean $N_{700}$. The post-monsoon season has a value of mean seasonal $N_{700}$ which in any case is higher than that during summer or pre-monsoon period. Seasonal values of $N_{700}$ again decrease from post-monsoon to winter which exhibits the lowest seasonal $N_{700}$. There is no distinct maxima. $N_{700}$ maintains high values in summer through post-monsoon seasons.

5.6.2. Group II (Gauhati)

In this group, the seasonal mean $N_{700}$ 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 gradual decline in the seasonal mean $N_{700}$ reaching a minimum value in the winter season. The highest value is reached in monsoon. It is interesting to note that the seasonal $N_{700}$ value during monsoon at this station (Gauhati) is the highest for all the stations for which the data have been presented in this paper.

5.6.3. Group III (Visakhapatnam, Madras and Nagpur)

In this group, the seasonal values of $N_{700}$ gradually increase from winter to summer. After summer, the seasonal variation of $N_{700}$ increases quite fast upto monsoon when it reaches a peak at all the stations. After monsoon, the seasonal values of $N_{700}$ maintain their fairly steep rate of decrease upto winter which exhibits the lowest values. The highest values of seasonal mean $N_{700}$ are attained in monsoon for the stations in this group also.

5.6.4. Group IV (Veraval, Bombay, Calcutta, New Delhi, Jodhpur and Allahabad)

In this group, the seasonal variations of $N_{700}$ from winter to summer are not similar for all the stations. The seasonal mean $N_{700}$ increases steadily from winter to summer in the cases of Bombay, Calcutta and Jodhpur; while in the cases of Veraval, New Delhi and Allahabad the seasonal mean values of $N_{700}$ increase very little and remain practically constant. The seasonal variations from summer to winter (through monsoon and post-monsoon seasons) are, however, similar for all the stations in this group. Values of seasonal mean $N_{700}$ increase steeply from summer to monsoon where the values reach a peak. After monsoon season, the values decrease rapidly upto post-monsoon reaching about the same values as in summer. From post-monsoon to winter, there is a slow but definite decrease in the values of seasonal mean $N_{700}$ which exhibit the lowest values in winter.

5.7. *Grouping of the various stations according to the distribution of annual mean $N_{700}$ and the annual range of variation of $N_{700}$*

In Fig. 7(b), the various stations have been grouped according to their annual mean $N_{700}$ plotted

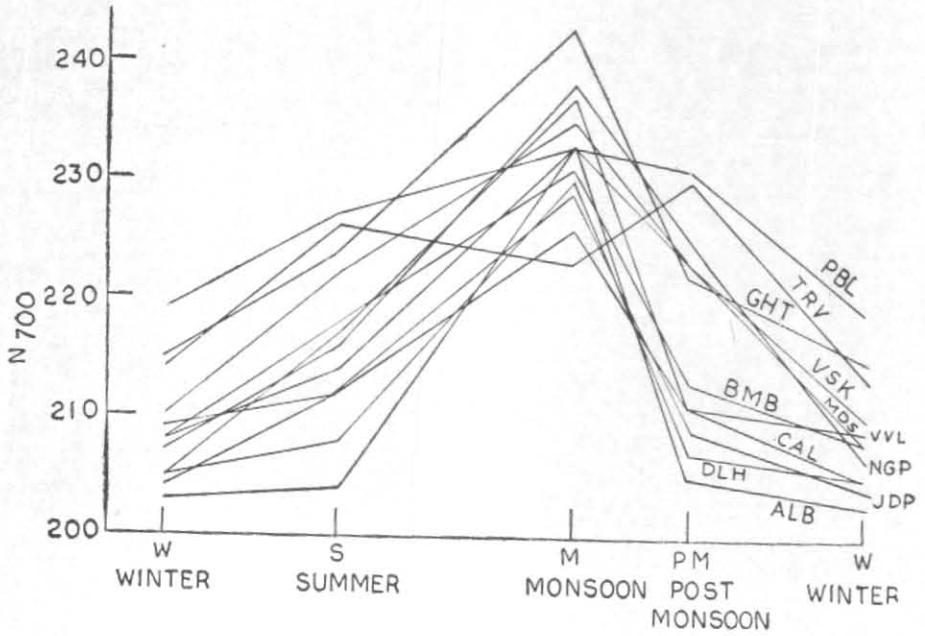


**Fig. 7(a). Seasonal variation of radio-refractivity at 700 mb at various stations over India**

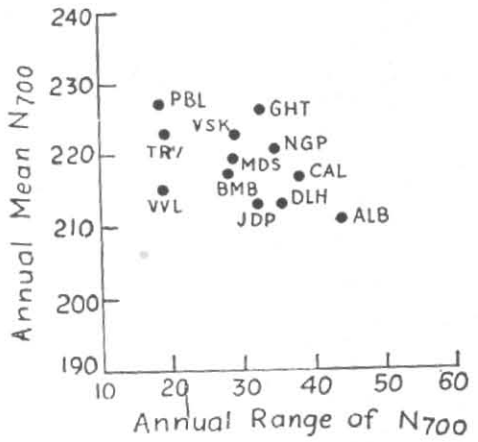


**Fig. 7(b). Annual mean *vs* annual range of $N_{700}$ ($N$ units) for the various stations**

against the annual range of variation of $N_{700}$ observed over those stations. It is worthwhile to mention that the data of radio-refractivity near the ground surface and for the 850-mb level was subjected to similar treatment in the authors' earlier two papers (*op. cit.*) and it was found that the stations arranged themselves in four distinct groups. We had, therefore, concluded 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 $N_{700}$ also, we find that the stations arrange themselves in four distinct groups. Table 4 gives the details of the associated values of annual mean $N_{700}$ and the annual range of variation of $N_{700}$ for these groups of stations.

These groups delineate the existence of homoclimes of upper air radio-climate at 700-mb level over India. These groupings are, however, based on certain gross radio-climatic features such as seasonal mean, annual mean, or annual range of variation of radio-refractivity at 700-mb level over the country. It is, therefore, likely that finer details of radio-climatic variation over any particular station are lost in these gross averages.

### 5.8. *Monthly maximum and minimum values of $N_{700}$ over India*

For each month, the overall maximum and minimum values of $N_{700}$ among the 12 stations are given in Table 3. These are graphically plotted

**TABLE 4**

**Groups of distinct radio-climatic regimes at 700-mb level over India**

| Group | Station | Radio-climatic characteristics | |
|---|---|---|---|
| | | Annual mean $N_{700}$ ($N$ units) | Annual range of $N_{700}$ ($N$ units) |
| I | Port Blair<br>Trivandrum | 220–230 | 15–20 |
| II | Gauhati | 220–230 | 30–35 |
| III | Visakhapatnam<br>Madras<br>Nagpur | 215–225 | 25–35 |
| IV | Veraval<br>Bombay<br>Calcutta<br>New Delhi<br>Jodhpur<br>Allahabad | 210–220 | 15–45 |

in Fig. 8. The stations over which these values occur have also been indicated in Fig. 8 which depicts the month by month variation of overall maximum and minimum values of $N_{700}$ over India. This figure also gives a better idea of the monthly overall range of variation of $N_{700}$ over the country. In addition to all this, Fig. 8 highlights the following features.

5.8.1. *Variation of monthly overall maximum $N_{700}$*

5.8.1.1. The monthly overall maximum values of $N_{700}$ range between 216 and 246 $N$ units occurring over Gauhati during February and August respectively. The lowest value of 216 $N$ units for the overall maximum $N_{700}$ also occurs over Port Blair during the month of February.

5.8.1.2. The monthly overall maximum values of $N_{700}$ during the monsoon months (June to September) occur over the inland stations, *i.e.*, over Gauhati during June, August and September and over Allahabad during July.

5.8.1.3. During the post-monsoon, winter and summer months (October to May), the monthly overall maximum values of $N_{700}$ occur over the coastal and island stations (Trivandrum or Port Blair). However, exception to this trend occurs during February when the overall maximum value of $N_{700}$ also occurs over Gauhati in addition to Port Blair.

5.8.2. *Variation of monthly overall minimum $N_{700}$*

5.8.2.1. The monthly overall minimum value of $N_{700}$ varies between 199 and 224 $N$ units. It will be seen that the difference between the overall maximum and minimum values of $N_{700}$ for the country for any month, *i.e.*, $N_{700\ \max} - N_{700\ \min}$ has the highest value in November (32 $N$ units) and the lowest value during January and February (15 $N$ units).

5.8.2.2. The monthly overall minimum values of $N_{700}$ reach a peak in August over Trivandrum. While the variation of monthly overall minimum remains practically constant during the monsoon months June to September, it declines rapidly on both sides of this semi-flattened peak. The lowest value of the overall minimum occurs over Allahabad in November.

5.8.2.3. It is interesting to note that the monthly overall minimum value of $N_{700}$ occurs consistently over Allahabad during the post-monsoon, winter and summer months (October to May), while it occurs over Trivandrum during the monsoon months (June to September). Besides, the overall minimum $N_{700}$ also occurs over New Delhi in June, over Jodhpur in September and December months.

5.9. *Variation of $N_{700}$ along an east-west cross-section*

Variations of $N_{700}$ over Gauhati, 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. The variations of $N_{700}$ along this cross-section for the representative months, February, May and November are very much similar. In each of these three months, the $N_{700}$ value is highest over Gauhati in the eastern part of the country and is lowest over Allahabad in the central part of the country. The variation of $N_{700}$ between Gauhati and Allahabad and between Allahabad and Nagpur is very much pronounced; whereas there is practically no variation in $N_{700}$ values between Nagpur and Veraval during these three representative months of February, May and November. The overall fall of $N_{700}$ between Gauhati and Allahabad during February, May and November is 15, 25 and 16 $N$ units respectively. The variation of $N_{700}$ during the representative month of August in this cross-section is quite different from that in the other three representative months. During August, the $N_{700}$ value decreases steadily from Gauhati to Veraval, except for the section between Allahabad and Nagpur. Moreover, the $N_{700}$ values are generally higher during the month of August in this cross-section in comparison to the other representative months.

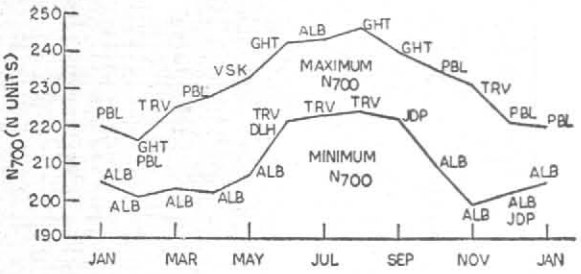


Fig. 8. Monthly maximum and minimum values of $N_{700}$ over India

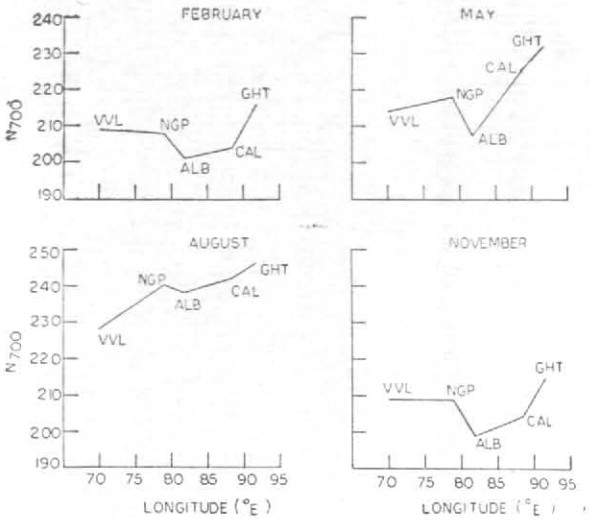


Fig. 9. East-West cross-section of $N_{700}$ over India for four representative months

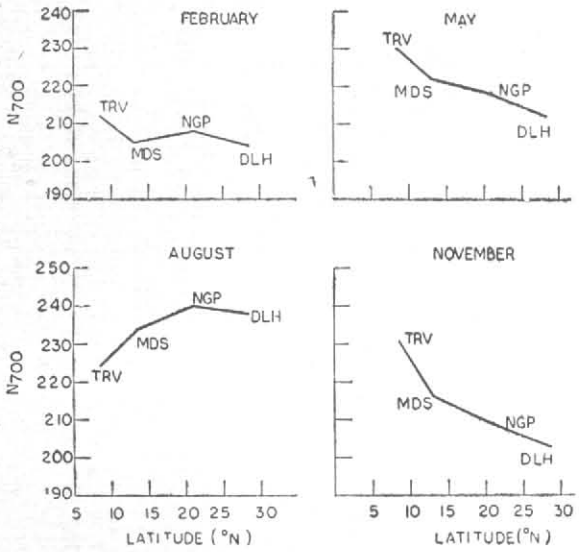


Fig. 10. North-South cross-section of atmospheric radio-refractivity at 700 mb over India for four representative months

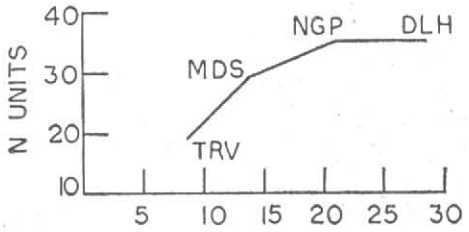


Fig. 11. Annual range of monthly mean of $N_{700}$ ($N$ units) over India (North-South) cross-section

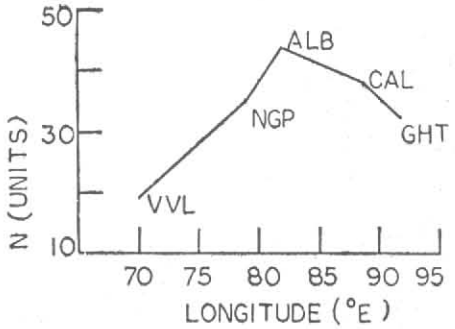


Fig. 12. Annual range of monthly mean $N_{700}$ ($N$ units) over India (East-West) cross-section

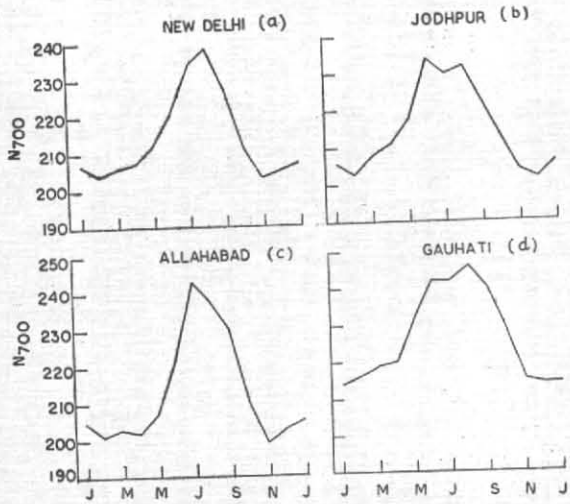


Fig. 13. Monthly variation of mean radio-refractivity at 70C mb over various stations

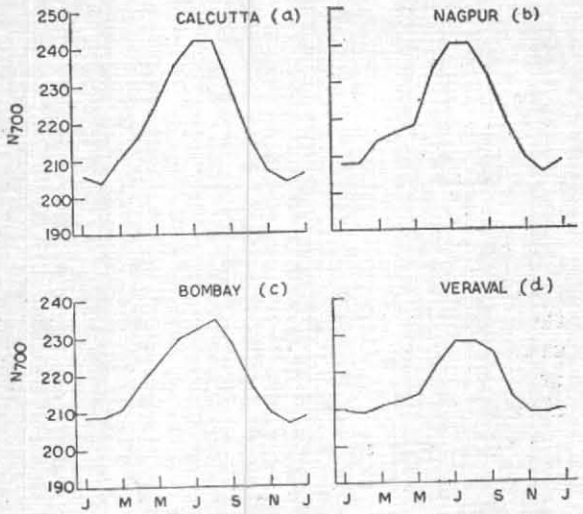


Fig. 14. Monthly variation of mean radio-refractivity at 700 mb over various stations

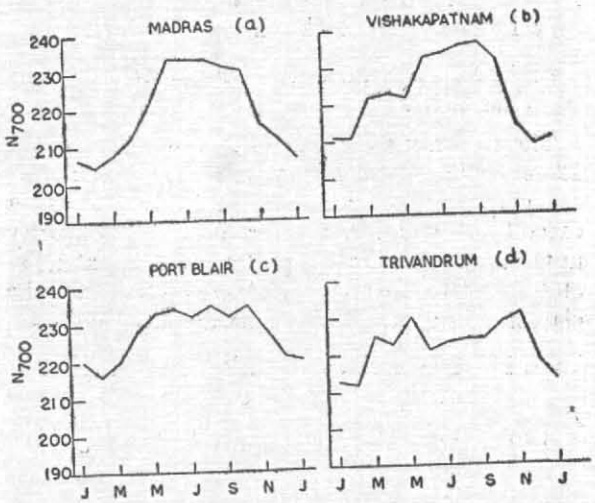


Fig. 15. Monthly variation of mean radio-refractivity at 700 mb over various stations

5.10. *Variation of $N_{700}$ along a north-south cross-section*

Variations of $N_{700}$ over New Delhi, Nagpur, Madras and Trivandrum along a north-south cross-section in the longitudinal belt of 75°-80°E for the four representative months (February, May, August and November) have been graphically shown in Fig. 10. During February, May and November, the trend of variations in this cross-section is very much similar. The $N_{700}$ value increases steadily from north to south in this cross-section during February, May and November, except during February when there is slight fall between Nagpur and Madras. In February, the overall increase in radio-refractivity between New Delhi and Trivandrum is 8 $N$ units. The same for May and November are 18 and 28 $N$ units respectively. The trend of variation along this cross-section during August is quite different. During this representative month of August, the $N_{700}$ increases by only 2 $N$ units between New Delhi and Nagpur. After Nagpur, $N_{700}$ decreases gradually upto Trivandrum in the south. The overall fall in $N_{700}$ value between New Delhi and Trivandrum during August is 14 $N$ units. The range of variation of $N_{700}$ along the cross-section is maximum in November (28 $N$ units) and minimum in February (8 $N$ units).

5.11. *Variation of annual range of $N_{700}$ along the north-south cross-section* (Fig. 11)

The highest variation of annual range of $N_{700}$ in this north-south cross-section occurs over Nagpur and New Delhi and lowest over Trivandrum; the values of annual ranges extending between 35 and 19 $N$ units. The annual range in this cross-section between New Delhi and Nagpur remains steady and then starts decreasing gradually upto Trivandrum.

5.12. *Variation of annual range of $N_{700}$ along the east-west cross-section* (Fig. 12)

The maximum variation of annual range of $N_{700}$ in this cross-section occurs over Allahabad and minimum over Veraval; the values of annual range extending between 44 and 19 $N$ units. From Gauhati, the annual range increases reaching a peak over Allahabad. The annual range then declines rapidly between Allahabad and Veraval. It is worthwhile to mention that the annual range over Allahabad (44 $N$ units) is the highest over India at 700-mb level.

5.13. *Monthly variation of $N_{700}$ over the individual stations*

The monthly variations of $N_{700}$ at each of the 12 stations, chosen for the present study, are graphically shown in Figs. 13 to 15. On a careful examination on the basis of similarity in the monthly variation patterns of $N_{700}$ at these stations, it is observed that these stations may be classified into the following six distinct types—

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

It may be mentioned that in Section 5.7, we had attempted groupings of these 12 stations on the basis of the 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. Figs. 13 to 15, however, depict the fine structure of the radio-climate over the country at 700-mb level bringing to light many distinct and characteristic features in the month by month variations. These typical regimes of monthly variation of $N_{700}$ may be regarded to represent six types of homoclimes of upper-air radio-climate at 700-mb level over India. Each of these upper-air homoclimes are characterised by a distinct and characteristic $N_{700}$ regime of monthly variation as shown in Figs. 13 to 15.

## 6. Conclusions

6.1. The complete radio-climatology of the distribution and structure of the atmospheric radio-refractivity of upper air at 700-mb level over India has been worked out. A large number of maps and diagrams showing different aspects of the 700-mb radio-climatology have been presented. An attempt has also been made to delineate homoclimes of upper-air (700-mb) radio-climate over the entire country.

6.2. It is felt that the present study will provide the much desired to radio-physicists and communication engineers in radio/radar measurements, propagation studies, frequency planning and allied investigations.

## 7. Acknowledgements

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1966b *Ibid.*, **17**, 4, pp. 545-558.