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Radio climatology of Gauhati

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ABSTRACT. An attempt has been made to study the pattern of radio-refractivity of air over Gauhati from the surface to the 700-mb level. It is noticed that the variations in the surface values of refractivity do not reflect and are not correlated with the changes in the vertical profile of refractivity. Fluctuations in refractivity are not always the highest at the surface, steadily decreasing upwards. Ideas about models of refractivity derived from studies in the temperate countries need to be modified before they can find application in tropical countries like India. The occurrence of super-refraction and sub-refraction in the layers near the ground over Gauhati has been studied and the frequency distributions of the values of vertical gradients of refractivity have been worked out.

1. Introduction

Extensive radio climatological studies have been done in certain countries of the temperate climatic regions to understand the pattern of radio refractivity in the lower troposphere and its influence on radio propagation (Bean and Dutton 1966). Variations off refractivity near the ground surface have been studied in detail and attempts have been made to correlate the surface pattern with the vertical profile of refractivity in order to deduce the vertical structure from surface measurements at places where upper air observations are not available. Based on statistical correlation studies, several models of the vertical profile of refractivity (linear, exponential, bi-exponential etc) have been enunciated and numerous formulae and mathematical expressions put forward to describe the radio climatology of different areas. These studies have largely been confined to the temperate regions of the world and not much work has been done on the radio climatology of places in the tropical and equatorial regions. Some studies made in India and elsewhere indicate that the conclusions drawn from studies of temperate climates are not applicable to tropical and equatorial regions. On account of the substantially higher water vapour content of the air in the warmer climates, the refractivity pattern is necessarily different in such areas.

Kulshrestha and Chatterjee (1966, 1967) have calculated the surface refractivity values for 36 stations in India from the 5-year monthly means (1959-63) given in the *Climatic Data of the World*. They have also calculated the monthly mean values of refractivity at 850 mb and 700-mb levels for twelve radiosonde stations from the mean data for the period 1956-60. Srivastava and Pathak (1970) have computed values of refractivity for upper levels upto 100 mb from radiosonde data for the same period. Venkiteshwaran and others (1970) have worked out the refractivity values at surface from normals given in the Climatological Tables of the India Meteorological Department, reduced them to sea level values (N_0) and drawn chart of (N_0) for each month of the year. In the present study an attempt has been made to bring out the main features of refractivity over Gauhati, a station which in climatic characteristics, is fairly representative of large areas of Assam, particularly the Assam valley. Normals of surface refractivity have been worked out from the data given in the climatological tables by making use of the Smith and Weintraub formula.

$$N = 77.6\,(P/T) + 3{\cdot}73 \times 10^5\,(e/T^2)$$

Upper air refractivity values have been calculated from the normals of radiosonde data for the period 1956-60. In addition, daily upper air data from the morning and evening radiosonde observations were extracted from the *Indian Daily Weather Reports* for the year 1966 and a study of the vertical profile of refractivity in the lower troposphere has been made.

2. Discussion

The monthly normals of surface refractivity of Gauhati are given in Table 1. The highest value occurs in the mid-monsoon month of August while the lowest occurs in February. The annual range of variations based on the monthly means is of the order of 60 N-units but is as much as 80 N-units if the highest maximum and the lowest minimum values reached during the year are taken into consideration. The annual range of variations is largely due to the variations in the wet term (70) and considerably less due to the variations of the dry term (20) as can be seen from

TABLE 1

Surface refractivity at Gauhati

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Normals of Surface (N_s)							
Morning	337	336	340	354	373	386	389	392	389	387	360	346
Evening	338	329	333	347	371	384	389	390	388	382	360	348
Mean Max.	346	346	350	362	379	391	394	397	395	384	366	355
Mean Min.	327	325	330	345	366	381	383	386	383	371	350	336
Highest Max.	350	351	356	369	385	396	397	400	399	392	373	359
Lowest Min.	323	320	323	338	358	374	379	381	378	356	346	332
					Normals of Dry term (D)							
Morning	272	269	264	261	259	257	257	257	258	260	267	270
Evening	269	264	260	257	256	255	255	255	257	260	265	268
Mean Max.	278	275	270	266	263	260	259	259	261	265	270	276
Mean Min.	265	261	258	255	255	254	254	254	255	258	261	264
Highest Max.	281	279	274	269	265	262	261	261	263	268	274	279
Lowest Min.	263	258	254	252	251	251	252	251	252	255	259	261
					Normals of Wet term (W)							
Morning	65	68	76	93	114	129	133	135	131	127	93	76
Evening	69	65	73	90	115	129	134	135	131	122	95	80
Mean Max.	68	71	79	97	117	131	135	138	134	120	96	79
Mean Min.	62	64	72	89	111	127	130	132	128	114	89	72
Highest Max.	70	73	82	99	120	134	137	140	136	123	99	81
Lowest Min.	61	62	70	87	107	123	127	130	126	111	88	71

TABLE 2

	Dry Season (Nov-Apr)	Wet Season (May-Oct)
Mean	345	385
Range	30	20
Av. diurnal variation	20	10

Table 1. With the inflow of humid monsoon air in the month of May, there is a steep rise in the value of refractivity, which remains at a higher level during the entire monsoon period of 5 to 6 months. The refractivity value falls rapidly with the withdrawal of the monsoon and remains at a lower level during the remaining six months of the year. The use of the annual mean and the annual range of refractivity to describe the radioclimate (as has been done in the temperate countries and suggested in documents like the CCIR) does not give a correct picture of the pattern of refractivity prevailing during the year. It would be more appropriate to divide the year into two periods—the dry and the wet seasons—and describe the mean level and variations of refractivity during the two periods separately. The two periods have their own distinct patterns of refractivity as indicated by the average values given in Table 2.

The distinction between the seasons may be even more sharp if the wet season is reckoned from the actual date of onset to the date of withdrawal of the monsoon instead of taking the whole of the calendar months.

3. Upper air refractivity

The mean values of refractivity for every month of the year 1966 worked out from the morning and evening radiosonde observations are given in Table 3 for levels upto 700 mb. It will be seen that the variations of refractivity at a height of 1 km (900-mb level) are even more than at the surface and it is only above the 850-mb level that there is a gradual decline in the range of variations. This would mean that the commonly held view that the variations of refractivity are larger at the surface and diminish with height is not strictly valid in the lower levels upto 1 or 2 km above ground.

TABLE 3

Mean refractivity in the upper air over Gauhati

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Surface	M	338	340	340	360	378	384	389	388	364	368	357	338
	E	340	332	337	351	372	386	390	388	377	373	361	348
900 mb	M	288	291	277	297	306	335	342	338	335	318	311	298
	E	283	285	282	307	324	333	342	345	335	320	307	295
850 mb	M	268	257	261	281	293	311	317	311	309	286	273	273
	E	265	262	263	285	298	313	317	316	309	297	284	267
800 mb	M	247	248	245	258	273	289	296	283	286	267	260	252
	E	243	250	247	269	277	286	293	294	287	268	262	248
700 mb	M	202	209	214	220	229	245	249	248	239	228	214	212
	E	208	206	205	221	231	244	248	245	239	222	219	204

TABLE 4

Mean monthly diurnal variation of refractivity

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(a) Surface refractivity (Mean Max–Mean Min)												
N_s	19	21	20	17	13	10	11	11	12	13	15	19
D	13	14	12	11	8	6	5	5	6	7	9	12
W	6	7	7	8	6	4	5	6	6	6	7	7
(b) At different levels (Morning—Evening)												
Surface	−02	+08	+03	+09	+06	−02	−01	00	+07	−05	−04	−10
900 mb	+05	+06	−05	−10	−18	+02	00	−07	00	−02	+04	+03
850 mb	+03	−05	−02	−04	−05	−02	00	−05	00	−11	−11	+06
800 mb	+04	−02	−02	−11	−04	+03	+03	−11	−01	−01	−02	+04
700 mb	−06	+03	+09	−01	−02	+01	+01	+03	00	+06	−05	+08

4. Diurnal variation of refractvity

The mean monthly values of the diurnal variation of surface refractivity and its dry (D) and wet (W) terms are given in Table 4(a). These represent the difference between the mean maximum and mean minimum monthly values given in Table 1.

To compare the diurnal variations at different heights, the mean difference between the morning and evening observations is tabulated in Table 4(b). It will be apparent that the variations at the upper levels are not guided by those at the surface. A statistical study of the morning and evening data for all the days of the year 1966 reveals that the correlation between the diurnal variation at surface and that at 900-mb level is poor. The correlation coefficient is 0·5 in winter, 0·3 in the monsoon season and 0·4 for the rest of the year.

5. Vertical gradient of refractivity

The mean values of the vertical gradient of refractivity in the layers upto 700-mb level worked out from the daily morning and evening radiosonde observations are given in Table 5. The gradient in the first kilometre (DN1) is usually taken to represent the characteristic of the vertical profile of refractivity and its variations are supposed to be in tune with the variations of surface refractivity. But this is not borne out from the data presented in Table 6. The months of the highest DN1 values do not coincide with the months of the highest N_s values; nor are the months of the lowest DN1 values the same as the months of the lowest N_s values. A statistical study of all the daily values of N_s and DN1 shows that the correlation between the two parameters is poor; the correlation coefficient is 0·2 during monsoon and 0·3 during the other months of the year. Srivastava (1969) has also reported poor correlation between N_s and DN1 in the monsoon months for Indian stations in general and has also found that the distribution of DN1 need not necessarily be the same as that of N_s over India.

The last column DN5 in Table 5 gives the average gradient of refractivity from the surface to the 700-mb level. Dennis (1962) found that

TABLE 5

Mean values of gradient of refractivity —Gauhati 1966

	0530 IST						1730 IST					
	N_s	DN1	DN2	DN3	DN4	DN5	N_s	DN1	DN2	DN3	DN4	DN5
Jan	338·2	50·3	41·9	42·4	37·5	43·2	340·1	56·3	45·5	42·2	32·4	43·1
Feb	340·4	58·7	40·7	32·9	36·3	42·9	332·3	52·8	36·3	27·7	38·9	41·3
Mar	339·9	67·1	35·3	31·4	27·8	41·3	336·5	53·9	36·7	29·8	32·0	38·8
Apr	359·8	63·7	38·0	42·9	34·0	45·8	351·2	48·0	42·8	45·1	37·2	42·0
May	377·8	63·4	47·0	39·5	41·2	48·3	372·2	53·6	52·1	39·7	40·6	46·0
Jun	383·9	55·5	49·8	42·0	42·4	45·7	386·4	57·3	47·4	43·4	40·2	47·0
Jul	389·5	54·4	51·3	38·8	40·0	46·1	390·1	54·3	56·1	41·9	39·2	47·1
Aug	388·3	53·7	63·3	41·1	41·6	47·0	387·9	55·0	54·1	41·9	43·5	48·5
Sep	384·0	56·6	55·3	42·7	47·7	48·5	376·8	56·5	53·8	42·5	41·2	48·5
Oct	367·7	52·0	57·4	45·0	35·6	45·2	373·0	56·3	50·3	50·1	41·5	48·6
Nov	356·9	49·4	58·3	43·1	41·3	46·3	361·0	55·3	48·3	43·9	39·3	45·6
Dec	337·7	41·2	52·9	40·1	38·8	41·9	347·7	55·9	47·9	42·9	37·8	46·1

TABLE 6

Diurnal variation of refractivity gradient (Morning—Evening)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
N_s	—2	8	3	9	6	—3	—1	0	7	—5	—4	—10
DN1	—6	6	13	16	13	—2	0	—1	0	—4	—6	—15
DN2	—3	4	—1	—5	—5	2	—5	9	1	7	10	5
DN3	0	5	2	—2	0	—1	—3	—1	0	—5	—1	—2
DN4	5	– 3	– 4	—3	1	2	1	—2	6	—6	2	1
DN5	0	2	2	4	2	—1	—1	—1	0	—3	1	—4

Ns — Surface refractivity values

DN1 → Gradient between surface and 900 mb level (*N*-units/km)
DN2 → Gradient between 900 and 850 mb level (*N*-units/km)
DN3 → Gradient between 850 and 800 mb level (*N*-units/km)
DN4 → Gradient between 800 and 700 mb level (*N*-units/km)
DN5 → Average gradient between surface and 700-mb level (*N*-units/km)

on a microwave link of 85 miles the basic transmission loss was approximately a function of DN1, while on a longer path of 300 miles the relationship between the transmission loss and DN1 was non-linear and better results were obtained by averaging the refractivity gradient over 5000 ft. In many of the tropo-scatter links where the radio path traverses upto a height of 3 km, DN5 may give a better idea of the average refraction effects of the atmosphere. It would be noticed from Table 5 that the values of DN5 are much less than those of DNI and also that the variations from month to month are considerably subdued. The larger range of variations in the surface refractivity may possibly give an exaggerated picture of the variations in the actual refraction effects of the atmosphere. The pattern of diurnal variation in the refractivity gradients is shown in Table 6. It will be seen that the diurnal variation of DN1 (the gradient in the first kilometre) is much more than the diurnal variation of the surface refractivity. The mean diurnal variation of DN5 is considerably smaller.

6. Super-refraction, ducting and sub-refraction

It is known that temperature inversions at the ground or in the upper air cause ducting gradients. But temperature inversions alone are seldom strong enough to produce ducting gradients in the tropical countries and an accompanying large humidity lapse is often a necessary condition to such steep gradients. The daily radiosonde observations of Gauhati for the year 1966 were examined to study the occurrence of ground inversions and the refractivity gradients in the corresponding layer. It is found that ducting gradient (157 *N*-units or more per km) occurred on 31 days in the layer of about 200-300 metres above ground although ground inversion of temperature has been reported on as many as 204 days in the year. The gradient

TABLE 7

Frequency (No. of days) of gradient of refractivity in the first layer above ground of Gauhati

N	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
						(a) Morning (0530 IST)							
35 or less	2	1	—	2	—	2	5	—	2	2	2	3	21
36-50	3	—	—	1	1	—	—	1	3	4	—	6	19
51-100	15	13	4	8	10	11	9	11	7	12	13	14	127
101-156	9	6	17	10	8	4	7	1	6	5	10	2	85
157 or more	1	4	6	5	3	2	—	2	4	—	3	1	31
No. of days of temp inversion	29	25	28	22	12	5	2	2	10	18	24	27	204
						(b) Evening (1730 IST)							
35 or less	2	1	3	1	4	4	2	1	1	1	2	—	22
36 to 50	1	—	—	1	1	2	1	3	1	1	2	2	15
51 to 100	11	9	9	10	9	10	7	6	11	15	11	9	117
101 to 156	6	8	8	9	2	6	4	1	6	3	9	8	70
157 or more	5	6	5	3	1	—	3	2	5	5	3	7	45

TABLE 8

Frequency of gradient of refractivity in the second layer above ground of Gauhati

(Significant level to 900 mb)

N	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
						(a) Morning (0530 IST)							
35 or less	10	5	11	3	2	4	1	2	5	1	9	10	63
36-50	8	9	6	8	7	3	3	3	3	7	7	8	72
51-100	10	9	9	13	11	7	15	10	13	15	11	11	135
101-156	2	—	1	2	2	5	2	1	1	1	1	—	18
157 or more	—	1	—	—	—	—	—	—	—	—	1	—	2
						(b) Evening (1730 IST)							
35 or less	10	12	14	11	2	7	4	3	3	9	8	11	94
36 to 50	5	7	5	8	3	2	3	1	4	6	6	5	55
51 to 100	7	5	6	3	9	13	13	7	14	8	12	7	104
101 to 156	2	—	—	1	2	—	—	1	2	1	—	2	11
157 or more	1	—	—	1	1	—	1	1	—	—	1	—	6

values have however been above normal on 243 days including several days on which no temperature inversion was reported. Table 7 (a) gives the frequency of occurrence of different ranges of gradients of refractivity in the first layer above ground, that is, between surface of the ground and the first significant pressure level reported below the 900-mb pressure level in the morning radiosonde observations. The first row of Table 7(a) reveals that 'sub-refractive' or below normal gradients occurred on 21 days in the year. The lowest value of observed gradient is zero and there is no case of inverse gradient (that is, refractivity increasing with height) in the morning observational data. The possibility of abnormal gradients in the air immediately above the ground layer has also been examined. Table 8(a) gives the frequency of occurrence of gradient values in this second layer worked out from the data pertaining to days on which a significant level was reported below the 900 mb pressure level in the morning radiosonde observations. It is seen that sub-refractive gradients occurred within this layer on 59 days and ducting gradients on 2 days only. Tables 7(b) and 8 (b) give the frequencies of gradients in the first and second layers for the evening observations (1730 IST). It may be seen that the gradient of refractivity in the ground layer is often quite high and ducting gradients occur on 45 days in the year. This is because of the steep lapse of humidity in the first 100 or 200 metres above ground. Table 8(b) shows a high frequency of occurrence of sub-refractive gradient in the second layer above ground.

7. Models of refractivity

Most workers in the field have shown an excessive preoccupation with the idea of 'models of refractivity'. In an attempt to simplify the problem of describing the vertical profile of refractivity, the linear, exponential and bi-exponential models have been propounded and statistical studies carried out to determine the degree of validity of these models. To a large extent this approach can be of practical value in the temperate regions, where stratification and horizontal homogeneity within the air masses permit such a classification. Srivastava and Pathak (1970, 1969 a and b) have taken refractivity data of Indian stations and tried to fit them into these tailored models, but the results have not been conclusive. Convective activity, lack of horizontal homogeneity and high moisture content in the air over the Indian region, may probably account for this. The frequent occurrence of cumulus clouds would also affect the pattern of refractivity. Crain *et al.* (1954) have reported refractivity differences of 40 to 50 N units between cumulus clouds and the ambient air. It would therefore appear that no single model of refractivity can adequately represent the variations of refractivity with height over Indian stations.

8. Conclusions

1. The increase of refractivity values caused by high moisture content of the air in the monsoon season does not necessarily result in proportionately higher refraction effects since the gradient values do not increase correspondingly.

2. The annual range of surface refractivity does not reflect a correspondingly large range in the values of the vertical gradient of refractivity.

3. The monthly and seasonal variations in refractivity are not a maximum at the surface but at some height (say, 1 km) above ground.

4. There is no correlation between the diurnal variations of refractivity values at the surface and 900 mb (1 km) level.

5. There is no correlation between the surface refractivity and the gradient in the first kilometre above ground.

6. The gradient of refractivity in the first kilometre above ground is a highly variable quantity and is not representative of the vertical profile of refractivity. The average gradient over a larger layer of say, upto 3 km may perhaps give a better idea of the average refraction effects of the atmosphere. This can be verified only by propagation measurements.

7. Super-refractive (above normal) gradients occur on many days in the morning hours and ducting gradients occur on about 30 days in the year in a layer of about 200 to 300 m above ground. Slightly sub-refractive gradients occur on 30 to 40 days in the ground layer but is more common in the layer immediately above the ground layer.

8. Super-refraction occurs on several days in the evening hours also on account of a setep lapse in humidity within a layer of 100 to 200 m above ground.

9. Sub-refractive gradients occur frequently in the evening hours in the second layer above ground, that is, approximately between half and one kilometre above the surface level.

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