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Radio-climatology of the sea areas adjoining the Indian sub-continent

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ABSTRACT. Based on the climatological data provided by the International Indian Ocean Expedition (1959-1965), radio-climatology of the sea areas adjoining the Indian sub-continent has been worked out in this paper. Monthly and seasonal mean values of radio refractivity are given for the sea level, 850 mb and 700 mb levels. Vertical gradients of radio refractivity are also presented.

1. Introduction

In recent years, many studies have been published describing the radio-climatology over the Indian land mass. No detailed investigation seems to have been made of the distribution of the atmospheric radio refractivity over the vast sea areas adjoining the Indian sub-continent. Radio-climatological data over these sea areas are of vital importance in the study of propagation problems and effective planning of appropriate telecommunication links between the mainland, numerous islands and ocean-going vessels. In this paper, an attempt has been made to present the radio-climatology of the sea areas lying between the equator and the Indian sub-continent.

2. Data for the present study

The sea areas adjoining the Indian sub-continent have lacked in regular meteorological observations except from a few island stations. A very large volume of meteorological data, both for the surface and the upper air, were however collected as part of the International Indian Ocean Expedition (I.I.O.E.) using coastal stations, island stations, ships, aircraft and satellites. The I.I.O.E. was active during 1959-1965 and was a joint project of the India Meteorological Department and the U.S. National Science Foundation. After careful processing, these data were published in 1972 by the National Science Foundation, Washington, D.C., U.S.A., as two volumes of the Meteorological Atlas of the International Indian Ocean Expedition.

The surface meteorological data in the I.I.O.E. Atlas are based on about 194000 standard weather observations recorded by ships of various types voyaging in the Indian Ocean during 1963 and 1964. From these observations, averages (by individual month and by five-degree latitude-longitude squares) of the meteorological parameters were worked out by a computer programme which was designed to remove various possible errors and inconsistencies. As the data in case of upper air observations could not be so extensive, upper air climatological information obtained before, during, and after the I.I.O.E. were incorporated together. These data were mainly from the radiosonde stations on coasts, islands and research ships. Monthly averages by 5° latitude-longitude squares were worked out generally based on about five aerological soundings per 5° square.

Thus averaged values of meteorological parameters, both for surface and upper air, are given for each 5° square in the I.I.O.E. Atlas. The present author has used these basic climatological data for computing the corresponding values of atmospheric radio refractivity given in this paper. The atmospheric radio refractivity, N, was computed using the standard expression $N=77.6/T\ (P+4810\,e/T)$, where T, P and e denote the temperature in degrees Absolute, atmospheric pressure and vapour pressure in millibar respectively.

3. Presentation of the radio-climatological data

The present study is confined to the sea area delimited by the equator and the coast-lines of Somalia, Arabia, Pakistan, India, Sri Lanka Bangladesh, Burma, Thailand, Malaysia and Indonesia. This vast sea area has been divided into 5° squares of latitude and longitude (Fig. 1). Most of the presentation of data is done here in the form of Tables. This necessitates the designation of each 5° square by a suitable indicator number for the sake of uniformity of reference in the various tables. Hence each of the forty squares in

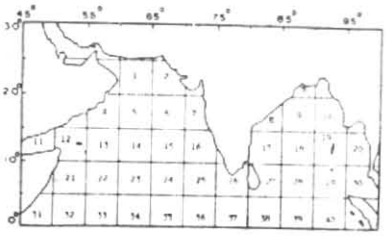

Fig. 1. Designator numbers of the 5° squares

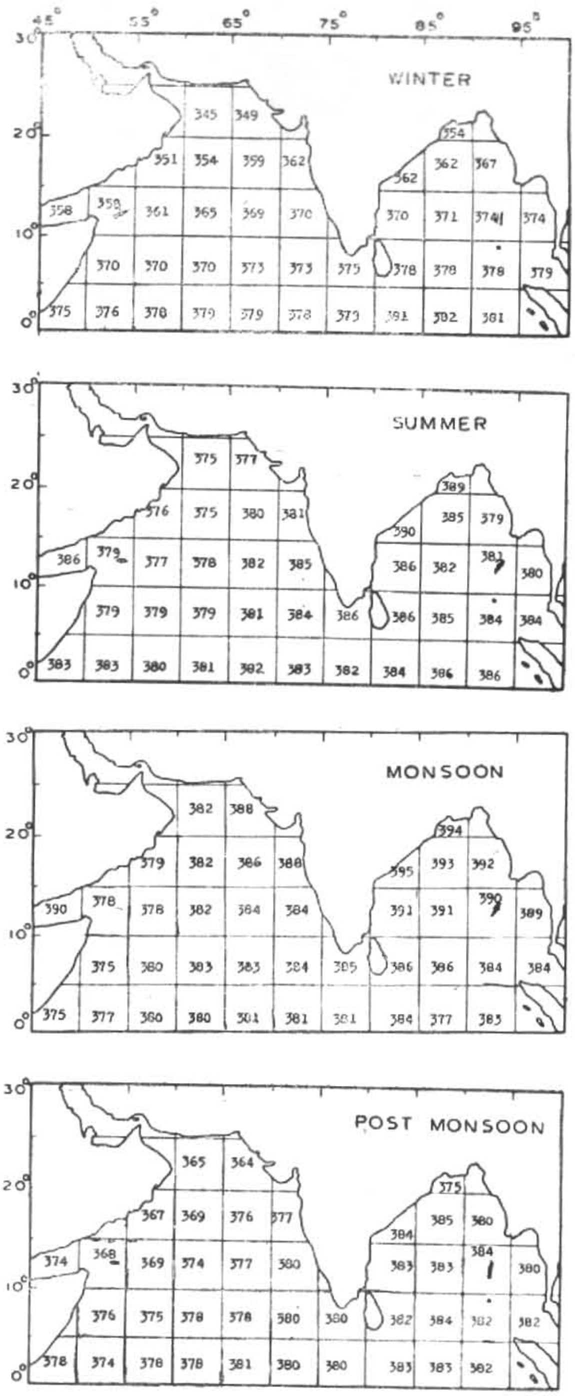

Fig. 2. Seasonal averages of radio refractivity for sea level

Fig. 1 has been assigned a specific serial 'Designator Number'. Tables 1 to 4 follow this scheme of designator numbers of 5° latitude-longitude squares given in Fig. 1.

Table 1 gives the mean values of atmospheric radio refractivity at sea level (N_0) for each of the 40 squares for each month and the average values for each season. In computing the seasonal averages, the following conventional classification is followed.

Winter season : December, January and February

Summer season : March, April and May

Monsoon season : June, July, August and September

Post monsoon season : October and November

Similarly, Tables 2 and 3 present the mean values of atmospheric radio refractivity at 850 mb and 700 mb levels respectively for each month and the averages for the four seasons.

Figs. 2, 3 and 4 present, in the form of maps, the *seasonal* averages of radio refractivity for the sea level, 850 mb and 700 mb respectively.

From the seasonal averages in Tables 1, 2 and 3 for the three levels (*viz.*, sea level, 850 mb and 700 mb), the gradients of radio refractivity existing (*i*) between sea level and 850 mb level and (*ii*) between 850 mb and 700 mb levels were computed for each season for those 5° squares for which data were available. These values of gradients are presented in Table 4. As the 850 mb level isobaric surface is, on the average, 1.5 km above sea level and the radio refractivity can well be taken to decrease linearly with height in the free air above sea upto this relatively short height of 1.5 km above sea level, the value of the radio refractivity gradient between sea level and 850 mb level can be utilized to compute the radio refractivity gradient over the first one kilometre above the sea surface. This is denoted by $\triangle N$. These value of $\triangle N$ are also given in Table. 4.

4. Discussion of the computed radio-climatological data

4.1. *Radio refractivity at sea level* (N_0)

A study of Table 1 and Fig. 2 brings out the following characteristics of the N_0 regime.

(*i*) N_0 varies between 342 and 398 N_0 units.

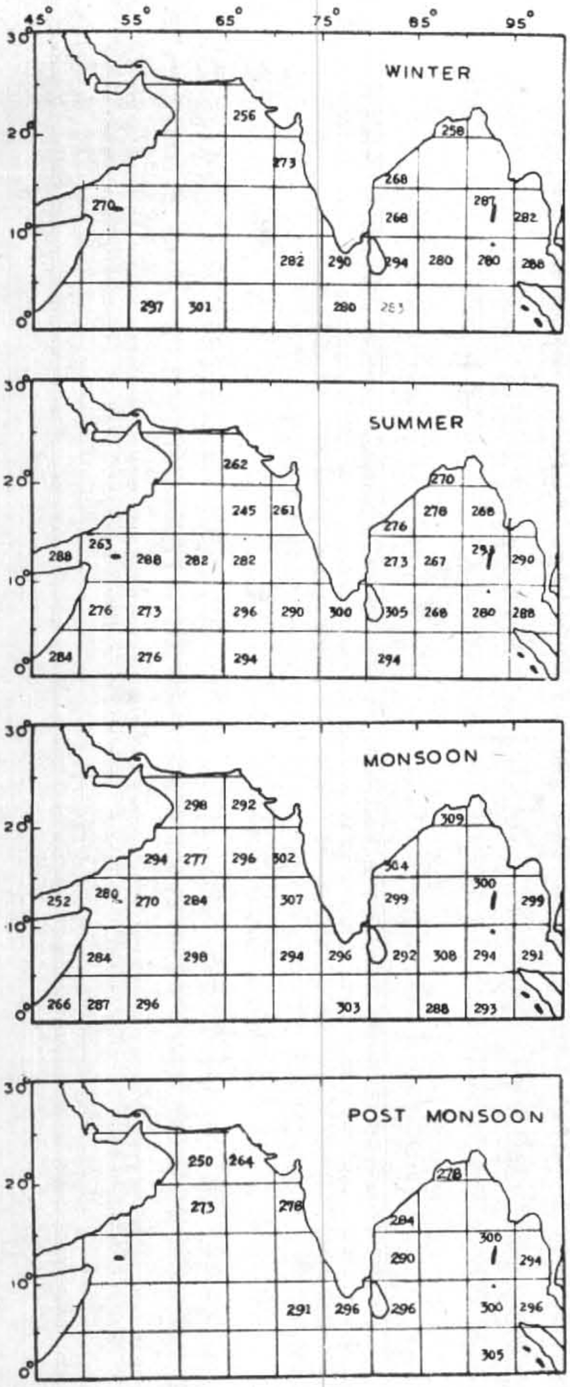

Fig. 3. 850 mb

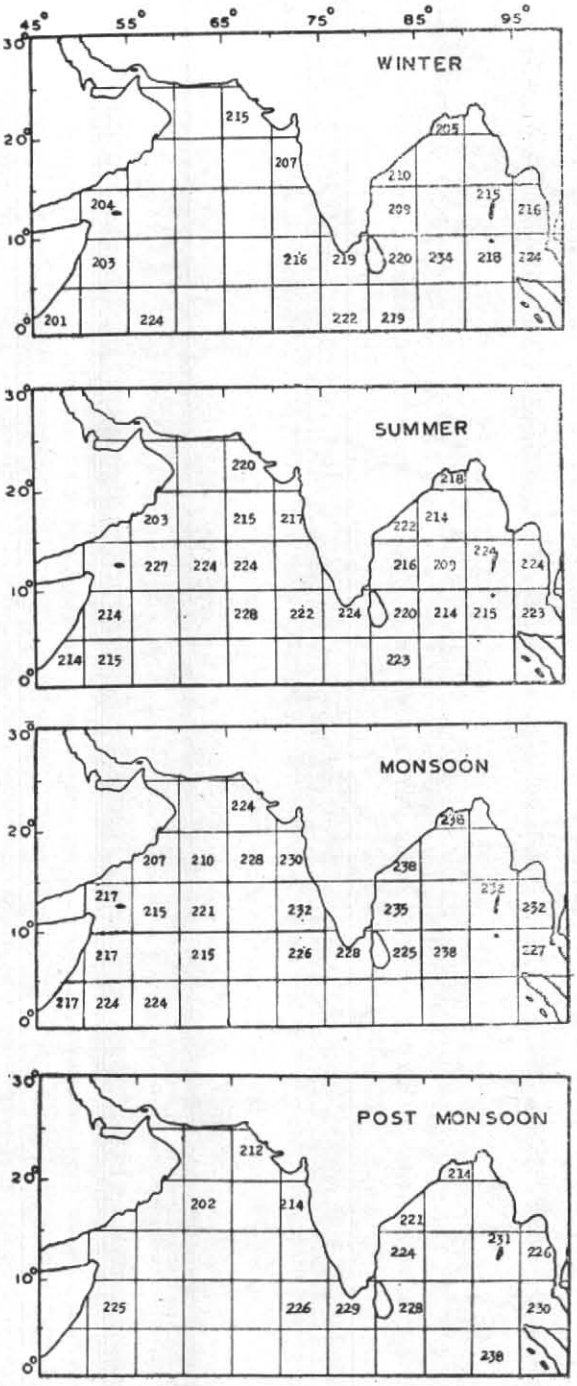

Fig. 4. 700 mb

Seasonal averages of radio refractivity

(*ii*) Generally, N_0 is the highest during the monsoon months but could be of the same order in the summer months also for coastal areas. N_0 is the lowest in winter months.

(*iii*) In any season the lowest values of N_0 occur in the northern and central parts of the Arabian Sea.

(*iv*) In the Bay of Bengal, N_0 generally decreases from west to east except in winter months when it increases from west to east.

TABLE 1

Monthly mean and seasonal mean values of radio refractivity at sea level (N_0) over the sea areas adjoining the Indian sub-continent

No.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Summer	Monsoon	Post Monsoon
1	342	348	360	378	388	390	380	382	377	372	358	346	345	375	382	365
2	344	348	368	375	389	395	391	385	380	368	361	356	349	377	388	364
3	343	368	378	394	395	393	391	396	398	390	360	352	354	389	394	375
4	348	355	364	377	388	389	376	376	376	372	362	350	351	376	379	367
5	352	354	364	377	385	392	382	378	374	372	366	356	354	375	382	369
6	354	356	372	380	388	396	389	382	376	381	372	367	359	380	386	376
7	354	361	374	382	388	392	393	385	383	380	374	370	362	381	388	377
8	358	369	380	389	401	396	396	392	396	386	382	358	362	390	395	384
9	354	370	374	389	391	396	392	392	392	386	384	361	362	385	393	385
10	359	376	375	382	380	398	390	389	389	386	373	366	367	379	392	380
11	351	362	372	391	395	393	392	387	387	377	371	362	358	386	390	374
12	357	362	366	382	388	382	376	376	378	369	366	354	358	379	378	368
13	356	364	370	376	385	382	377	376	376	369	369	362	361	377	378	369
14	362	364	372	376	385	385	380	385	378	371	374	369	365	378	382	374
15	366	368	378	378	389	388	382	384	380	374	380	372	369	382	384	377
16	365	371	383	384	388	386	390	382	380	380	380	374	370	385	384	380
17	366	375	380	388	390	396	388	390	390	382	384	368	370	386	391	383
18	370	375	373	384	388	396	389	390	389	382	384	368	371	382	391	383
19	369	378	377	382	385	393	386	390	390	387	380	375	374	381	390	384
20	370	378	376	378	385	389	386	391	391	386	374	375	374	380	389	380
21	368	372	374	382	382	377	371	376	376	376	376	370	370	379	375	376
22	366	371	374	378	386	380	381	379	382	372	378	372	370	379	380	375
23	368	371	377	378	382	386	380	384	381	374	382	372	370	379	383	378
24	370	374	376	378	389	386	380	383	384	374	381	374	373	381	383	378
25	370	374	379	384	388	386	384	383	384	380	380	374	373	384	384	380
26	374	378	382	388	388	386	387	383	384	380	381	374	375	386	385	380
27	378	381	383	384	392	389	386	386	382	384	380	374	378	386	386	382
28	374	380	383	384	388	390	386	386	383	384	384	381	378	385	386	384
29	374	380	383	385	385	386	382	383	383	384	380	381	378	384	384	382
30	374	382	384	382	385	386	382	383	383	384	380	381	379	384	384	382
31	372	378	384	382	384	374	371	378	377	379	378	376	375	383	375	378
32	372	381	380	382	386	378	372	376	383	378	374	374	376	383	377	374
33	374	381	380	378	382	377	381	382	382	374	382	378	378	380	380	378
34	378	380	383	378	382	379	380	384	376	374	381	378	379	381	380	378
35	377	380	379	382	386	382	383	382	376	381	381	380	379	382	381	381
36	377	380	376	385	389	382	383	380	379	378	381	377	378	383	381	380
37	377	380	379	381	385	382	383	380	380	381	380	380	379	382	381	380
38	380	383	383	384	384	386	383	386	380	384	382	380	381	384	384	383
39	384	382	383	389	385	382	382	364	380	385	381	380	382	386	377	383
40	380	382	382	389	386	382	382	383	384	382	381	381	381	386	383	382

*Designator number of the 5°-square

TABLE 2

Monthly mean and seasonal mean values of radio refractivity at 850 mb level (N_{850}) over the sea areas adjoining the Indian sub-continent

No.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Summer	Monsoon	Post monsoon
1	..	..	..	..	..	..	..	298	..	250	..	..	..	..	298	250
2	258	251	260	259	266	286	302	294	288	264	264	260	256	262	292	264
3	258	260	264	264	283	304	311	311	308	292	265	256	258	270	309	278
4	..	..	..	..	..	..	..	294	..	..	..	..	..	..	294	..
5	..	..	..	..	..	..	262	280	288	..	273	..	..	..	277	273
6	..	..	..	..	245	326	273	290	..	..	..	..	..	245	296	..
7	298	255	256	258	270	299	305	304	298	284	272	266	273	261	302	278
8	268	268	267	275	286	302	304	304	304	294	274	267	268	276	304	284
9	..	..	..	..	278	..	..	..	..	..	..	..	..	278	..	..
10	..	..	268	..	..	..	..	..	..	..	..	..	..	268	..	..
11	..	..	..	288	..	..	..	252	..	..	..	..	..	288	252	..
12	..	262	..	263	..	..	..	280	..	..	..	277	270	263	280	..
13	..	..	..	..	288	..	..	270	..	..	..	..	..	288	270	..
14	..	..	..	..	282	..	..	284	284	..	..	..	..	282	284	..
15	..	..	..	..	282	..	..	..	..	..	..	..	..	282	..	..
16	..	..	..	..	..	..	314	..	300	..	..	..	..	..	307	..
17	270	259	267	266	286	295	300	302	300	296	285	276	268	273	299	290
18	..	..	267	..	..	..	..	..	..	..	..	..	..	267	..	..
19	288	282	284	295	300	302	300	301	299	300	299	290	287	293	300	300
20	280	284	282	288	300	300	297	298	300	299	288	282	282	290	299	294
21	..	..	262	290	..	..	..	284	284	..	..	..	..	276	284	..
22	..	..	273	..	..	..	..	..	..	..	..	..	..	273	..	..
23	..	..	..	..	..	..	..	..	298	..	..	..	..	..	298	..
24	..	..	..	..	296	..	..	..	..	..	..	..	..	296	..	..
25	280	282	280	298	293	294	294	294	294	292	290	284	282	290	294	291
26	290	290	298	302	300	297	297	294	295	298	295	290	290	300	296	296
27	294	292	318	299	298	294	292	292	291	293	298	296	294	305	292	296
28	..	280	245	..	291	..	..	..	308	..	..	..	280	268	308	..
29	..	280	..	280	..	294	..	..	..	..	300	..	280	280	294	300
30	292	282	284	286	295	287	289	295	292	299	294	289	288	288	291	296
31	..	..	..	284	..	..	..	266	..	..	..	..	..	284	266	..
32	..	..	..	..	..	..	..	287	..	..	..	..	..	..	287	..
33	..	297	276	..	..	295	..	298	..	..	..	..	297	276	296	..
34	..	301	..	..	..	..	..	..	..	..	..	..	301	..	..	..
35	..	..	..	..	294	..	..	..	..	..	..	..	..	294	..	..
36	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
37	..	280	..	..	..	..	303	..	..	..	..	..	280	..	303	..
38	..	283	..	..	294	..	..	..	..	..	..	..	283	294	..	..
39	..	..	..	..	..	288	..	..	..	..	..	..	..	..	288	..
40	..	..	..	..	..	293	..	..	..	..	305		..	..	293	305

* Designator number of the 5°-square

TABLE 3

Monthly mean and seasonal mean values of radio refractivity at 700 mb level (N_{700}) over the sea areas adjoining the Indian sub-continent

No.*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Winter	Summer	Monsoon	Post monsoon
1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
2	222	212	234	214	214	220	228	224	222	213	212	211	215	220	224	212
3	206	206	212	218	223	235	240	242	236	224	205	204	205	218	238	214
4	..	..	203	..	..	..	..	207	..	..	..	..	..	203	207	..
5	..	..	..	..	..	..	209	211	..	..	202	..	..	..	210	202
6	..	..	..	..	215	..	..	..	228	..	..	..	..	215	228	..
7	207	208	212	217	222	229	235	227	229	218	210	206	207	217	230	214
8	209	211	218	223	225	236	235	238	242	229	213	210	210	222	238	221
9	..	..	..	..	214	..	..	..	..	..	..	..	..	214	..	..
10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
12	..	204	..	..	..	..	..	217	..	..	..	..	204	..	217	..
13	..	..	..	..	227	..	..	215	..	..	..	..	..	227	215	..
14	..	..	..	..	224	..	..	221	..	..	..	..	..	224	221	..
15	..	..	..	..	224	..	..	..	..	..	..	..	..	224	..	..
16	..	..	..	..	..	..	232	..	..	..	..	..	..	..	232	..
17	208	207	208	218	223	235	236	236	233	230	219	211	209	216	235	224
18	..	..	209	..	..	..	..	..	..	..	..	..	..	209	..	..
19	219	208	216	224	231	231	233	233	231	234	228	218	215	224	232	231
20	214	219	219	222	231	231	233	230	234	228	224	215	216	224	232	226
21	..	..	207	220	..	..	..	217	225	..	..	203	203	214	217	225
22	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
23	..	..	..	..	..	..	..	..	215	..	..	..	..	..	215	..
24	..	..	..	..	228	..	..	..	..	..	..	..	..	228	..	..
25	212	219	217	222	227	225	227	226	228	226	226	217	216	222	226	226
26	218	219	217	225	229	226	229	228	229	230	228	219	219	224	228	229
27	220	217	215	222	224	220	226	228	226	228	228	224	220	220	225	228
28	..	234	..	..	214	..	..	..	238	..	..	..	234	214	238	..
29	..	218	..	215	..	..	..	..	..	..	..	..	218	215	..	..
30	223	225	222	220	228	226	226	227	229	232	229	224	224	223	227	230
31	201	..	..	214	..	..	..	217	..	..	..	..	201	214	217	..
32	..	..	215	..	..	..	..	224	..	..	..	..	..	215	224	..
33	..	224	..	..	..	224	..	223	..	..	..	..	224	..	224	..
34	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
35	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
36	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
37	..	222	..	..	..	..	..	..	..	..	..	..	222	..	..	..
38	..	219	..	..	223	..	..	..	..	..	..	..	219	223	..	..
39	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
40	..	..	..	..	..	..	..	..	..	..	238	..	..	..	..	238

*Designator number of the 5°-square

TABLE 4

N-gradients over the sea areas adjoining the Indian sub-continent

No.*	△Surface-850 mb				△850-700mb				△N			
	W	S	M	P	W	S	M	P	W	S	M	P
2	93	115	96	100	41	42	68	52	62	76	64	66
3	96	119	85	97	53	52	71	64	64	79	57	65
4	..	..	85	..	..	..	87	..	..	..	57	..
5	..	..	105	96	..	..	67	71	..	..	70	64
6	..	135	90	..	..	30	68	..	..	90	60	..
7	89	120	86	99	66	44	72	64	60	80	58	66
8	94	114	91	100	58	54	66	63	63	76	61	66
9	..	107	..	..	..	64	..	..	..	72	..	..
12	88	..	98	..	66	..	63	..	59	..	66	..
13	..	89	108	..	..	61	55	..	..	60	72	..
14	..	96	98	..	..	58	63	..	..	64	66	..
15	..	100	..	..	..	58	..	..	..	66	..	..
16	..	..	77	..	..	..	75	..	..	..	52	..
17	102	113	92	93	59	57	64	66	68	76	62	62
18	..	115	..	..	..	58	..	..	..	76	..	..
19	87	88	90	84	72	69	68	69	58	58	60	56
20	92	90	90	86	66	66	67	68	62	60	60	58
21	..	103	91	..	..	62	67	..	..	69	61	..
23	..	..	85	..	..	..	83	..	..	..	57	..
24	..	85	..	..	..	68	..	..	..	57	..	..
25	91	94	90	89	66	68	68	65	61	63	60	60
26	85	86	89	84	71	76	68	67	57	58	60	56
27	84	81	94	86	74	85	67	68	56	54	63	58
28	98	117	78	..	46	54	70	..	66	78	52	..
29	98	104	..	..	62	65	..	..	66	70	..	..
30	91	96	93	86	64	65	64	66	61	64	62	58
31	..	99	109	..	..	70	49	..	..	66	73	..
32	..	..	90	..	..	..	63	..	..	..	60	..
33	81	..	84	..	73	..	72	..	54	..	56	..
37	99	..	..	..	58	..	..	..	66	..	..	..
38	98	90	..	..	64	71	..	..	66	60	..	..
40	..	..	..	77	..	..	..	67	..	..	..	52

*Designator No. of the 5°-square W—Winter S—Summer M—Monsoon P—Post Monsoon

4.2. *Radio refractivity at 850 mb level* (N_{850})

N_{850} regime exhibits the following pattern as seen from Table 2 and Fig. 3.

(*i*) N_{860} lies between 250 and 318 N units.

(*ii*) Generally, N_{850} is the highest in the monsoon months and is the lowest in winter months. But over the waters around Sri Lanka, N_{850} is the highest during summer months.

(*iii*) While the lowest values in any season appear to occur over the central Arabian Sea, no definite pattern is discernible over the Bay of Bengal.

4.3. *Radio refractivity at 700 mb level* (N_{700})

A study of Table 3 and Fig. 4 reveals the following characteristics of the N_{700} regime.

(*i*) N_{700} varies between 202 and 242 N units.

(*ii*) N_{700} is the highest in the monsoon months and is generally the lowest in the winter months.

(*iii*) By far in any season the values of N_{700} over the open parts of the sea areas are lower than those over the coastal areas.

4.4. *Vertical gradients of N*

Table 4 gives the seasonal averages of vertical gradients of N between (*i*) sea level and 850 mb level (*ii*) 850 and 700 mb levels and (*iii*) sea level and 1 km above sea level. It will be seen that while (△ sea level-850 mb) is generally the highest in summer season, (△850-700 mb) is generally the highest during monsoon months.

Seasonal values of △N vary between 52 and 80 N units. For many parts of the sea area under study, △N is the highest in summer months but for many others, it is the highest in monsoon months. While over most of the coastal waters, △N is the highest in the summer months, the same is not true for many other coastal waters, *e.g.*, those adjoining Somalia and Sri Lanka.

5. Conclusions

N values at sea level, 850 mb and 700 mb levels over the sea areas adjoining the Indian sub-continent have been computed and presented in the form of tables and maps. Values of N gradients between sea level and 850 mb level, 850 and 700 mb levels, and sea level and 1 km above sea level have also been presented. This radio-climatological data should be useful to radio-meteorologist and telecommunication engineers.