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Elevated ducting of radiowaves in association with trade wind inversion along the coasts of India

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सार – इस शोधपत्र में जून से सितम्बर तक भारत के पूर्वी और पश्चिम तटों की ओर समुद्र के ऊपर से होकर आने वाले व्यापारी पवनों के साथ उन्नत रेडियो वाहिनियों का अध्ययन किया गया है। जून से सितम्बर 1974 की अवधि में, जब करांची दूरदर्शन से प्रसारित संकेत बम्बई एवं पूणें के दूरदर्शन सेटों पर दिखाई पड़ते हैं, असामान्य अति अपवर्तन एवं वाहिनीकृत परिघटन की कुछ रिपोर्टों के बाद यह अध्ययन विशेष रूप से शुरू किया गया है। जून से सितम्बर 1974 के प्रातः (00 ग्री० मा० स०) और शाम (12 ग्री० मा० स०) के तीन तटवर्ती स्टेशनों के सतह से 500 मि० बार (5.8 कि०मी०) तक के रेडियोसोन्दे आंकड़ों को वर्तमान अध्ययन के लिए उपयोग में लाया गया है। ये स्टेशन हैं —पूर्व तट पर कलकता और विशाखापतनम और पश्चिम तट पर बम्बई।

इस अवधि में इन स्टेशनों पर रेडियो अपवर्तनता (N) की उर्ध्वाधर परिच्छेदिका को ज्ञात कर आरेखित किया गया है और उन्नयित रेडियो वाहिनियों की पहचान कर गणना की गई है। इस शोधपत्र में भारत में पूर्वी एवं पश्चिमी तटों के रेडियो प्रसारण की दशाओं का भी विवेचन किया गया है।

ABSTRACT. The present paper deals with the study of elevated radio ducts over seas along the east and west coasts of India in association with trade wind inversion during the months June through September. This study was specially undertaken after a few reports of abnormal super-refraction and ducting phenomena near the Bombay coast during June-September 1974 when signals of Karachi T.V. station could be received by T.V. sets around Bombay and Pune. Morning (00 GMT) and evening (12 GMT) radiosonde data from surface to 500 mb (5.8 km) for the three coastal stations, *viz.*, Calcutta and Visakhapatnam on the east coast and Bombay on the west coast during June to September 1974 were utilised in the present study.

Vertical profiles of radio refractivity (N) over these stations during this period were workedout, plotted and layers of elevated radio ducts were identified, tabulated and radio propagation conditions over the east and west coasts of India were discussed in the paper.

1. Introduction

The path followed by radioray in the atmosphere is dependent upon the vertical gradient of the refractive index along the path. The vertical gradient of the index of refractivity depends upon the vertical distribution of atmospheric pressure, temperature and humidity. Tropospheric ducting phenomenon has been studied by a number of workers in the past. On the basis of three years of radiosonde data Bean & Dutton (1966) determined the statistical occurrence characteristic of surface ducts in area typical of Arctic, temperate and tropical maritime climates. The maximum occurrence observed by them for the above areas were 9.2 per cent in Feb, 4.6 per cent in summer and 13.8 per cent in August. They also observed that ducts were associated in Arctic with temperature inversions; in temperate zones with radiation inversions and accompanying humidity lapse and in tropics with moderate temperature and humidity lapse. Wickerts (1970) observed that around 60 per cent of ducts over the sea occurred within a height of 500 m from surface while their thicknesses were generally no more than 100 m; they also observed excellent correlation between temperature inversions and ducting over the sea.

In India early investigations relating to formation of ducts and unusually high refraction of radiowaves were made from Calcutta and Bombay areas and were reported by Durst (1946). These studies were based on observations by radars operating at wavelengths 1.5 and 7 m. During the period January-May 1943 super-refraction observed over Calcutta during night varied from 20 to 30 occasions per month at $\lambda = 1.5$ m and 3 to 14 occasions per month at $\lambda = 7$ m.

Highest number of super-refraction was observed at wave length, λ, is equal to seven metres in April and May. Kulshrestha and Chatterjee (1966) studied the vertical structure of radio refractivity distribution in the lower troposphere over the country and prepared composite refractivity profiles

TABLE 1

Date (1974)	Ht. of base (m amsl)	N at base	Thickness of layer (m)	N at top	Gradient of N	Weather
			(a) West coast (Bombay)			
			00 GMT			
Jun						
12	1500	304	310	241	203	Cu, Cs, Sc 3/8
12	2430	263	150	225	253	3/8 Cu, Cs, Sc
14	700	351	150	321	200	4/8 Sc, Cu, Ci
15	4330	188	70	171	243	4/8 Cu, Sc, Ac, Ci, Cs
16	1600	317	310	229	284	4/8 Cu, Cs, Ac, Ci
16	2120	272	260	217	212	4/8 Cu, Cs, Ac Ci
18	2270	279	260	236	165	1/8 Cu, Ac, Ci, Cs
20	2490	278	470	202	162	5/8 Cu, Sc, Cs
20	2490	278	110	240	380	5/8 Cu, Sc, Cs
			12 GMT			
Jun						
3	2420	262	300	211	170	3/8 Cu, Sc
4	2270	284	340	214	206	5/8 Cu, Sc
5	540	339	170	312	159	4/8 Sc, Cu, Ac
9	1530	295	120	254	342	4/8 Sc, Cu
11	1580	297	310	264	161	5/8 Sc, Cu, Ac
16	1630	283	160	234	306	4/8 Cu, Sc, Ci, Ac
17	1680	274	310	224	161	5/8 Cu, Sc, Cs, Ac
			(b) West coast (Bombay)			
			00 GMT			
Jul						
13	2150	270	160	242	175	4/8 Cu, Ac, Cs, Sc
14	2460	253	230	216	161	6/8 Cu, Sc, As, Ns, Ci
18	2500	268	300	213	184	1/8 Cu, Cs
26	2430	259	300	208	170	3/8 Cu, Sc, Ac
			12 GMT			
Jul						
4	10	386	40	376	250	4/8 Cu, Sc, As
20	2730	252	170	224	165	5/8 Cs, Cu, Sc, St
			(c) West coast (Bombay)			
			00 GMT			
Aug						
8	5430	172	50	155	340	6/8 St, Cu, As, Ci
28	2640	254	140	218	257	3/8 Cu, Ac
			12 GMT			
Aug						
5	10	396	100	361	350	4/8 St, Cu, Ac, Cs
25	2730	253	190	213	211	3/8 Cu, Sc, Ac
26	2560	251	220	206	205	3/8 St, Cu, Ac
30	2900	247	190	202	237	7/8 St, Cu, Ac
31	2980	245	130	219	200	2/8 Cu, Ac
			(d) West coast (Bombay)			
			00 GMT			
Sep						
28	10	390	140	367	164	5/8 St, Cu, Ac, Ci
			12 GMT			
Sep						
5	630	325	180	296	161	1/8 Cu
14	10	395	150	268	180	5/8 Cs, Cu, Sc
			(e) East coast (Calcutta)			
			00 GMT			
Jun						
4	670	353	260	313	157	5/8 Cu, Cb, Ci
8	10	285	15	380	333	1/8 Sc, Ac
13	10	400	25	346	216	3/8 Cu, Sc
14	10	398	300	342	187	6/8 Cu, Sc
			12 GMT			
Jun						
1	1100	349	300	290	197	6/8 Ac, Cu
			380	285	167	
			East coast (Visakhapatnam)			
			00 GMT			
Jun						
1	40	389	320	327	194	Ci
			12 GMT			
Jun						
20	40	389	270	345	194	Ci
			(f) East coast (Calcutta)			
Jul			**00 GMT (*Nil*)**			
Jul			**12 GMT (*Nil*)**			
			East coast (Visakhapatnam)			
Jul			**00 GM T (*Nil*)**			
			12 GMT			
Jul						
2	40	416	310	346	249	2/8 Cu, Sc, Ac
19	40	404	310	333	236	5/8 Sc, Ci
22	40	404	90	352	578	1/8 Cu, Ci
			(g) Calcutta			
			00 GMT			
Aug						
20	10	409	16	406	187	3/8 Cu, Ac, Ci
			12 GMT			
Aug						
9	1907	287	33	280	212	4/8 Cb, Cu, Sc, As
12	10	406	255	362	172	3/8 Cb, Cu, Sc, As
			Visakhapatnam			
Aug			**00 GMT (*Nil*)**			
			12 GMT			
Aug						
21	40	387	120	341	383	5/8 Sc, Ac
			(h) Calcutta			
Sep			**00 GMT (*Nil*)**			
Sep			**12 GMT (*Nil*)**			
			Visakhapatnam			
			00 GMT			
Sep						
4	1500	339	420	269	167	5/8 Sc, Ac
28	40	398	110	380	164	1/8 Cu, As, Ci
Sep			**12 GMT (*Nil*)**			

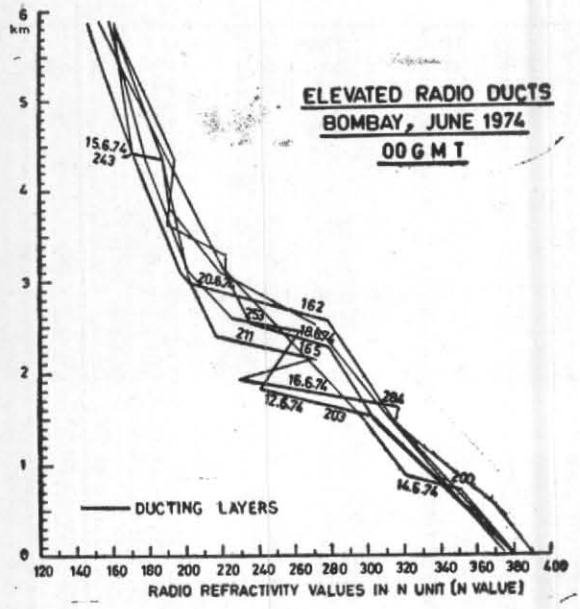

Fig. 1

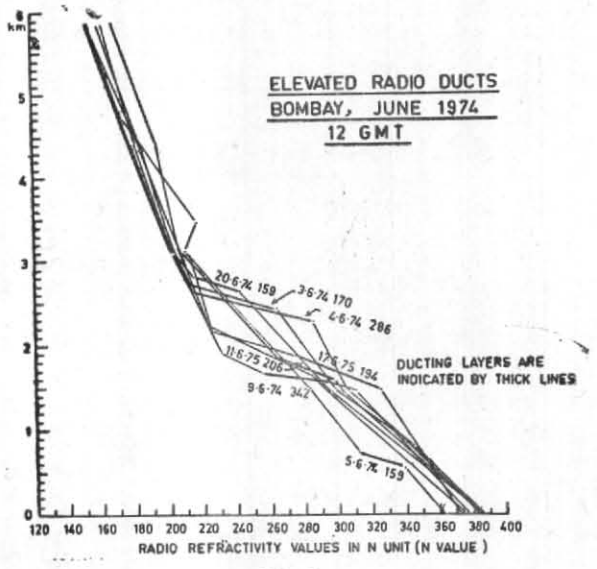

Fig. 2

for ground to 10,000 ft (a.s.l.) and also presented and discussed the vertical N profiles upto 10,000 ft (a.s.l.) for all the twelve months over India and worked out the vertical N gradients between ground surface and 5,000 ft (a.s.l.) and between 5,000 ft and 10,000 ft (a.s.l.). Chatterjee (1971) studied the atmospheric super-refraction over India based on five years radiosonde data for twelve Indian radiosonde stations. In the paper he calculated the vertical gradient of radio refractivity over the Indian stations and prepared maps showing zones of refractivity conditions between ground and 5,000 ft (a.s.l.). Chatterjee and Gerrish (1970) also studied the refractivity profiles and corresponding temperature and dew point structure over Miami during July 1970 showing that ground based super-refractive layers are produced primarily by moisture lapse and are essentially independent, whether temperature inversion exists or not. Majumdar (1964) studied the surface ducting phenomenon over the east coast of India and Assam valley and plains of northern and central India based on two-year period radiosonde and V.H.F. propagation data over the three V.H.F. radio paths.

The present paper deals with the study of elevated ducts over the seas along the east and the west coasts of India in association with trade wind inversion during the months June to September. This study was specially undertaken after a few reports of abnormal super-refraction and ducting phenomena near the Bombay coast during trade wind inversion regimes when signals of Karachi T.V. station could be received by T.V. sets around Bombay and Pune.

2. Data

As already discussed, the path followed by radioray in the atmosphere is dependent upon the vertical gradient of the atmospheric radio refractivity. The radio refractivity N is given by:

$$N=(n-1)\times 10^6=77.6PT^{-1}+3.73\times 10^5\, eT^{-2} \quad (1)$$

where n is the atmosphere radio refractive index, P is pressure, T is temperature and e is vapour pressure. e is given by :

$$\ln e = 21.64 - 5418\, T_d^{-1} \quad (2)$$

an integrated form of Clausius-Clapeyron equation where T_d is the dew point temperature.

The present study of elevated radio ducts along the east and west coasts of India in association with the trade wind inversion regimes is based on 00 and 12 GMT radiosonde data from surface to 500 mb (5.8 km) for the three coastal stations, *viz.*, Calcutta and Visakhapatnam on the east coast and Bombay on the west coast during June-September 1974. Daily 00 and 12 GMT values of pressure, dry bulb and dew point temperature values for the four monsoon months have been utilised for computation of radio refractivity values. Refractivity values can be computed by using the Eqns. (1) & (2) above but in practice it is much easier to use nomograms such as the project Arowa refractive index nomogram. Therefore, in the present study the N values have been computed by using the above nomogram.

The microwave refractivity profiles for the three coastal stations for the period June-September 1974 for days on which ducting occurred, have been plotted (Figs. 1-7). The heights of bases, and thicknesses of the ducting layers and the refractivity gradients have also been worked out and given in Table 1 (a-h).

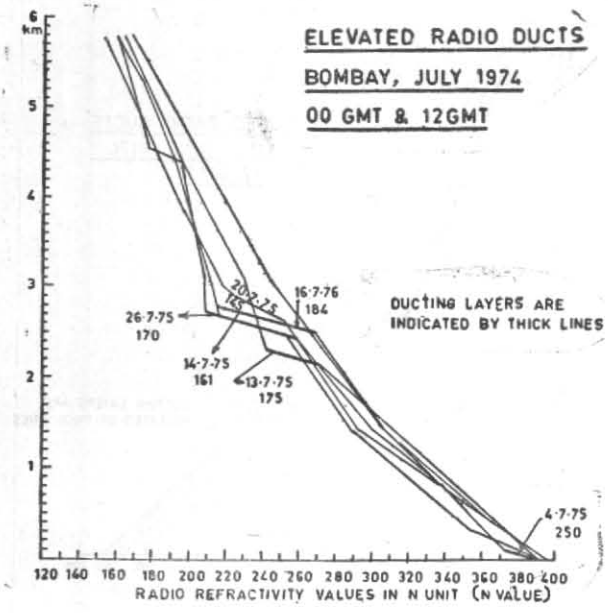

Fig. 3

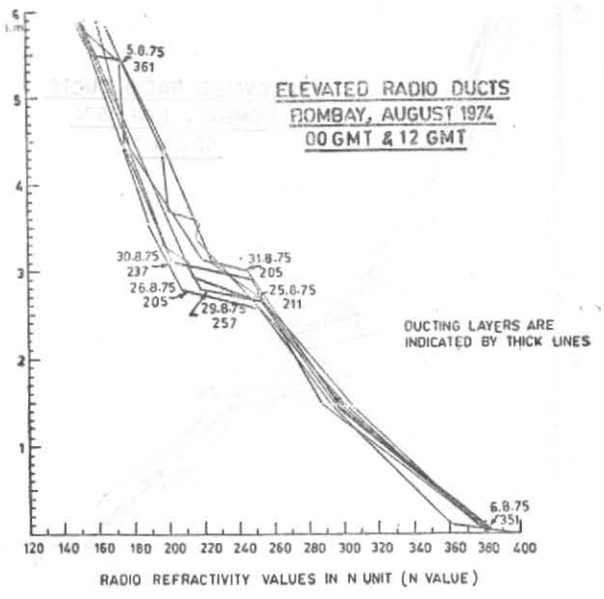

Fig. 4

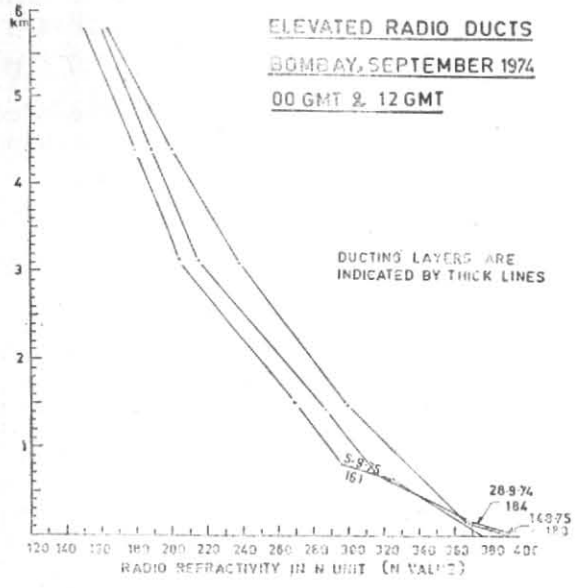

Fig. 5

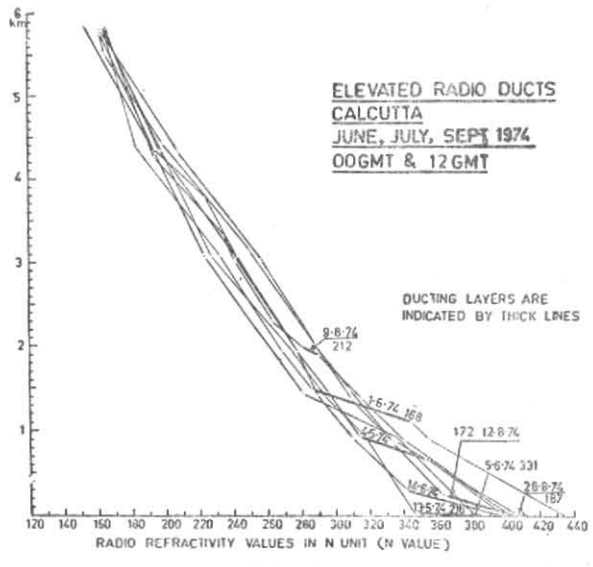

Fig. 6

3. Discussion of results month by month

3.1. *For west coast — Over Bombay*

3.1.1. *June 1974* — Table 1 (a) gives dates and other particulars of radio ducts formed during the month of June 1974 over the west coast around Bombay. Ducting occurred on as many as nine occasions during the early morning hours and the height of base of ducting layers varied between 700 and 2490 m above the sea surface and the thickness of the elevated duct varied between 70 and 470 m and the vertical gradient of refractivity per thousand metres (km) varied between 162 and 380 *N* units. During afternoon, radio ducts occurred on seven occasions. The base height ranged from 540 to 2420 m above sea surface and thickness of ducts varied between 120 and 340 m and gradient of refractivity per thousand metres varied between 161 and 342 *N* units.

A scrutiny of weather over Bombay on these occasions reveals that the elevated ducts were formed mostly in association with stratocumulus and fair weather cumulus clouds, indicating that the atmosphere was stable enough for formation of sharp vertical gradients of radio refractivity

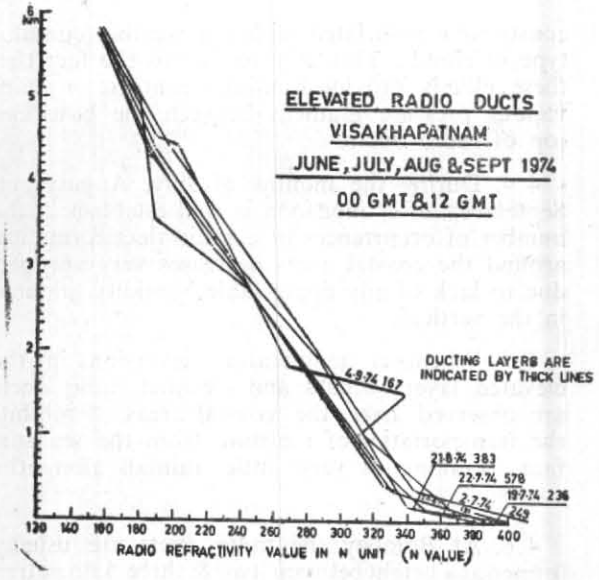

Fig. 7

caused by high lapse rate of humidity. Figs. 1 and 2 show the plots of vertical gradient of refractivity from surface to 500 mb, for 00 and 12 GMT, thick lines showing ducting layers.

3.1.2. *July 1974* — Table 1(b) gives dates and other particulars of radio duct formation during July 1974. Ducting occurred on four occasions during morning hours and the base height varied from 2150 to 2500 m above the sea surface and thickness varied from 160 to 300 m and vertical gradient of refractivity varied between 161 & 184 *N* units per km. In the afternoon radio ducts occurred on the two occasions, the base height varying between 10 m (surface) and 2730 m. The thickness of ducting layers varied from 40 to 170 m and gradient of refractivity varied from 165 to 250 *N* units per km. The gradient of refractivity in one layer with base at 2730 m and 70 m thickness was as high as 400 *N* unit/km. In July also ducting gradients were found to be associated with stratocumulus and the fair weather cumulus clouds and high lapse rate of humidity.

3.1.3. *August 1974* — Table 1(c) gives the details of radio duct formation for the month of August 1974. During morning hours, ducting occurred on two occasions only with base heights at 5430 and 2460 m, thickness 50 and 140 m and refractivity gradients 340 and 257 *N* unit/km respectively. In the afternoon ducting occurred on as many as five occasions with bases ranging from surface to 2980 m above sea surface and thickness ranging from 100 to 220 m and gradient of refractivity varying from 200 to 350 *N* unit/km. The incidences of ducting again being markedly associated with cumulus, stratocumulus and altocumulus clouds.

3.1.4. *September 1974* — Table 1(d) gives the details of radio duct formation during the month of September 1974. There is only one occasion when ducting occurred in the morning, the base being at the surface and thickness being 140 m and a *N* gradient of 164 *N* unit/km. Ducting occurred on two occasions during the evening one with base at 630 m, thickness 180 m and refractivity gradient 161 *N* unit/km and the other with base at surface, thickness 150 m and *N* gradient 180 *N* unit/km.

3.2. *For east coast*

3.2.1. *June 1974* — Table 1(e) gives height of base, thickness and refractivity gradient for ducting layers for the month of June 1974 over Calcutta and Visakhapatnam.

Calcutta — Ducting occurred on four occasions in the morning hours during the month but elevated duct formed only once. The other three ducts were ground based. The elevated duct had a base at 670 m and a thickness of 270 m and a *N* gradient of 157 *N* unit/km. The thickness of ground based ducts vary from 15 to 300 m and ducting *N* gradients vary from 187 to 333 *N* unit/km. In the afternoon ducting occurred on one occasion and it was an elevated duct with a base at 1100 m and a thickness of 380 m and refractivity gradient of 167 *N* unit/km. Here again, like the west coast, the ducts were formed in association with cumulus clouds.

Visakhapatnam — Only two incidences of duct formation were observed during the month, one each in the morning and evening hours and both of these were ground based ducts. The two ducts have thickness of 320 & 270 m respectively and both of them have a refractivity gradient of 194 *N* unit/km.

3.2.2. *July 1974* — Table 1(f) gives the height of base, thickness and refractivity gradients of radio ducts formed over the east coast during the month of July 1974.

Calcutta — Incidence of duct formation was not observed during July 1974. The duct formation, which may be attributed primarily to humidity lapse in the vertical has not taken place due to the setting up of monsoon current over the area and a more or less uniform distribution of humidity in the vertical.

Visakhapatnam — No ducts formed during the morning hours, while in the evening hours, ducts formed on three occasions and all the three were ground based having thickness varying from 90 to 300 m and refractivity gradients from 236 to 578 *N* unit/km.

3.2.3. *August 1974* — Table 1(g) gives the details of height, thickness and refractivity gradients etc over the east coast — Calcutta and Visakhapatnam during the month of August 1974.

Calcutta — The only duct that formed was ground based with a thickness of 16 m and a refractivity gradient of 187 N unit/km and no elevated duct was observed in the morning hours. In the afternoon, ducts were observed to have formed on two occasions, one of them was an elevated duct with a base at 1910 m, thickness 30 m and refractivity gradient 212 N unit/km. The other was a ground based duct with a thickness of 255 m, refractivity gradient 172 N unit/km. Both these ducts formed an association with cumulus and stratocumulus clouds.

Visakhapatnam — No ducting layer formed during morning hours and only one ground based duct could be detected during evening hours. Thickness of the duct was 120 m and gradient of refractivity in this layer was 383 N unit/km.

3.2.4. *September 1974* — Table 1(h) gives the details of height, thickness and the gradient of refractivity etc for the east coast (Calcutta and Visakhapatnam) for September 1974.

Calcutta — No ducting layers were observed to have formed during the month of September 1974.

Visakhapatnam — Two ducting layers with bases at 1500 and 40 m were observed. The first one, an elevated duct, had a thickness of 420 m and gradient of refractivity 167 N unit/km while the other, a ground based duct, had a thickness of 110 m and refractivity gradient of 164 N unit/km. Both the ducting layers were observed during morning hours. No ducting layers were observed during evening hours.

4. Conclusion

4.1. The range of refractivity gradient($-\triangle N/\triangle H$) during the monsoon months, over the west coast vary from 159 to 380 N unit/km and is practically equal to those over the east coast which range from 159 to 383 N unit/km during the same period.

4.2. The frequency of occurrence of radio duct over the coastal belt around Bombay are more than those over Calcutta and Visakhapatnam month wise.

The total number of occasions when radio duct formation could be located from the anyalysis are 32 during the monsoon months around Bombay, 9 around Calcutta and 8 around Visakhapatnam.

4.3. The present study indicates that there are preferred months of radio duct formation along the coasts during the monsoon months. The month of June is considered to be the most favoured month for the elevated radio duct formation along the coasts, than the subsequent months of July, August and September. This may be due to the fact that before the onset of monsoon, there is a high humidity gradient in the vertical resulting in high radio refractivity gradient. It is seen that weather associated with the occurrences of elevated radio ducts has some definite pattern. On most of the occasions radio duct formation, along the coasts were associated with fair weather cumulus type of clouds. This may be due to the fact that these clouds provide humidity contrast or sharp vapour pressure gradient between the base and top of radio ducts.

4.4. During the months of July, August and September, after monsoon is well established, the number of occurrences of a radio duct formation around the coastal areas decreases very abruptly due to lack of any appreciable humidity gradient in the vertical.

4.5. Whenever temperature inversion in the elevated layers occurs and elevated radio ducts are observed over the coastal areas, it inhibits the transportation of moisture from the sea surface, resulting in very little rainfall along the coasts.

4.6. At Bombay the radio ducts are usually formed at a height between two & three kilometres above sea surface/ground surface. This may be due to the orographic lifting of the moist air over the Western Ghats. This is in contrast to the radio duct formation over Calcutta and Visakhapatnam, where it is normally near the ground surface.

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