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Tropospheric radiowave propagation over the Bay of Bengal

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ABSTRACT. It is known since World War II that supernormal radio wave propagation occurs frequently in the VHF and UHF bands along the east coast of India. This paper presents a study of abnormal propagation observed along the Bay of Bengal coast as well as across the Bay with an S-Band radar located at Madras. Spectacular displays of the Bay coast from Sri Lanka to Orissa and occasionally of the Sundarbans, the Burma coast and Sumatra have been obtained. The seasonal and diurnal variation of such long distance anomalous propagation has been studied in relation to the meteorological conditions and refractive index profiles. The synoptic meteorological features provide a qualitative explanation of the phenomena. The refractive index profiles are however based on routine radiosonde data which do not have sufficient resolution to detect spatial variations over small scales. Hence the utility of the refractivity data to predict the abnormal propagation is found to be limited. To provide guidance to radar and radio engineers, it is necessary to have accurate data of refractivity. In the absence of such data, compiled statistics of observed abnormal propagation may be the most useful data source for the engineer.

1. Introduction

Propagation of VHF radio waves far beyond the horizon, along the east coast of India was first noticed during World War II by the RAF who were operating 1.5 metre radars (Durst 1946, Hatcher and Sawyer 1947). In a subsequent study with an X-band radar of the India Meteorological Department limited to a radius of 300 km around Madras (Raghavan and Soundararajan 1962) the seasonal variations were examined and explained in a qualitative manner.

The present paper reports a more comprehensive study with an S-band meteorological radar at Madras, in which abnormal propagation extending frequently all along the coast from Sri Lanka to West Bengal and occasionally across the Bay to the Andamans, Burma, and Sumatra were observed. Frequent reception of VHF T.V. signals over similar distances has been reported in the press and elsewhere. The seasonal and diurnal variation of such extremely long distance propagation is examined with reference to meteorological conditions.

A knowledge of the occurrence of abnormal propagation and its diurnal and seasonal variation is of great importance to radar and communication engineers for the proper interpretation of radar echoes and for ensuring reliable and interference free reception of radio and T.V. signals. Hence many workers have tried to construct maps of refractivity from available radiosonde data and tried to predict the occurrence of abnormal propagation therefrom. In view, however, of the coarseness of radiosonde data for this purpose, and the nonavailability of refractive index data with high spatial resolution the utility of such maps is limited in practice. It will, therefore, be useful to compile statistics of actual occurrence of abnormal propagation for the practical use of radar and radio engineers.

2. Radar observations

The S-band (2890 MHz) 500 KW Cyclone Warning Radar at Madras has been in use since December 1972, for tracking of cyclones and observation of other echoes of meteorological origin. It is here proposed to discuss only echoes produced by superrefraction or duct formation over distances of several hundred kilometres in the context mentioned above.

The radar is a pulsed radar scanning in azimuth or in elevation. It has a conical beam of 2 degrees width (between 3 dB points). There is a choice of 2 pulse widths of approximately 1 and 4 microseconds with corresponding p.r.f. of 590 and 160 p.p.s. respectively. At the latter p.r.f. the radar has an unambiguous range of 940 km which in conditions of normal propagation, is well beyond the radar horizon.

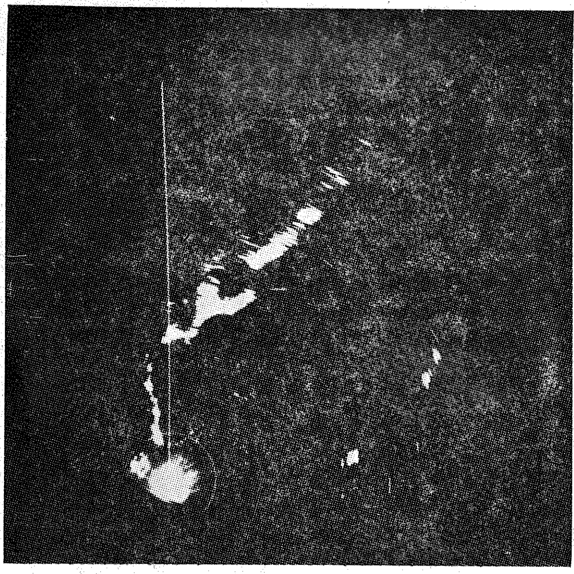

Fig. 1. Radar PPI Photograph at 1738 IST of 24 February 1973. This is an off centred picture. Range markers are at 100 km intervals. Andhra Pradesh and Orissa coasts and part of the Burma Coast are seen

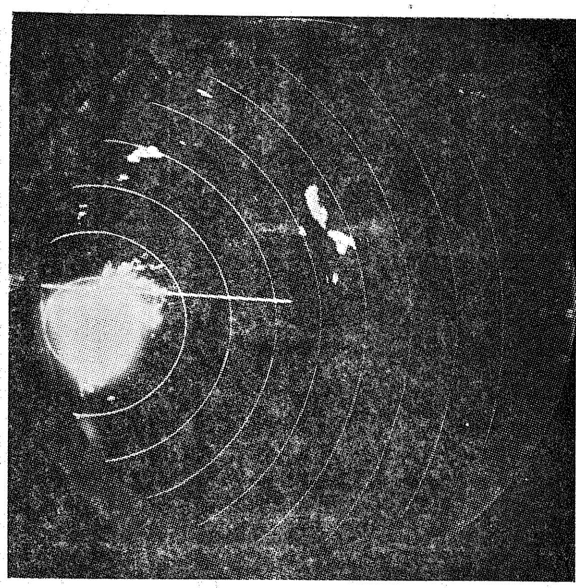

Fig. 2. Burma Coast displayed as a second time around echo

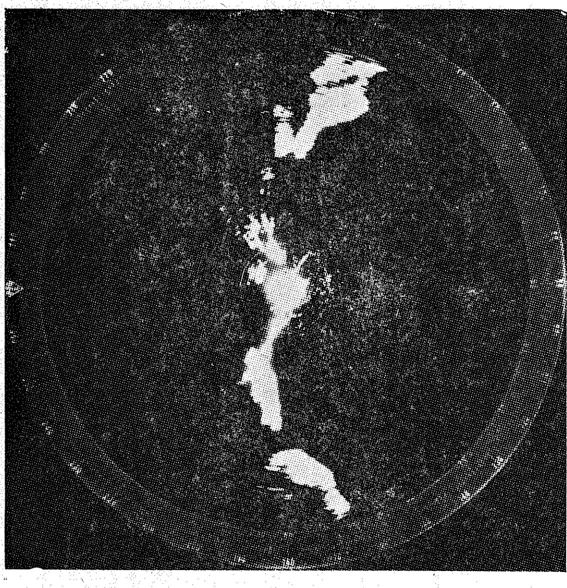

Fig. 3. Parts of Andhra Pradesh, Tamil Nadu and Sri Lanka Coasts are visible

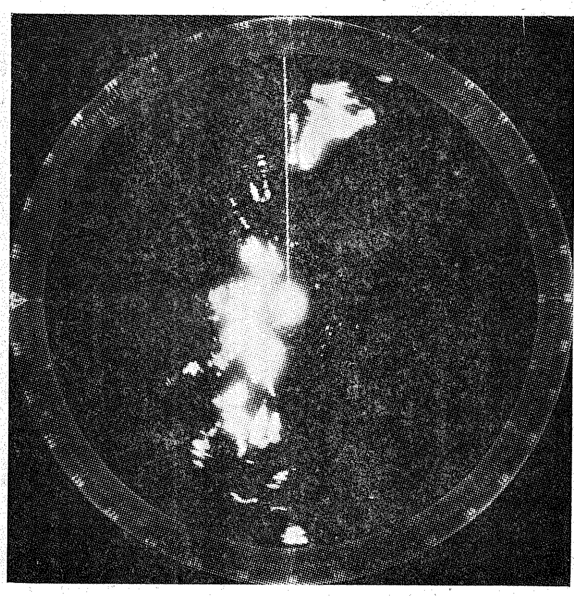

Fig. 4. Land area over Tamil Nadu (including Pamban Peninsula) is seen

Figs. 1 to 4 are radar PPI pictures showing some spectacular echoes due to anomalous propagation. Fig. 1 shows the entire Bay coast from Madras to Puri, the Godavari delta being prominently seen. The rangemarkers are at 100 km intervals. The echo in this picture at a range of 600 to 700 km and azimuth about 065 deg. is from the Burma coast. Its real range is about 1600 km and it is displayed at 1600-940, *i.e.*, about 650 km as a 'second-time-around' echo. Fig. 2 shows the Burma coast from the Bangladesh border to Sandoway more prominently. The presentation of such multiple-time around echoes is subject to shape distortion due to apparent elongation in the radial direction as compared to the tangential. Great care in identification is therefore necessary. Fig. 3 displays parts of the Andhra Pradesh and Tamil Nadu coasts and the northern parts of Sri Lanka. In Fig. 4, a considerable land area in Tamil Nadu can be seen

TABLE 1

Refractivity gradients from surface to 900 mb (1 km) at Madras for 1973

	Mean difference per km						Highest	
	N_s-N_{900}		D_s-D_{900}		W_s-W_{900}		N_s-N_{900}	
	(GMT)		(GMT)		(GMT)		(GMT)	
	00	12	00	12	00	12	00	12
Jan	72	65	27	21	44	42	115	109
May	71	66	23	21	48	45	97	94
Jul	51	49	22	19	28	29	95	95
Nov	68	62	24	21	44	42	91	84

N=Refractivity, D='Dry' part, W='Wet' part
Suffixes s and 900 stand for surface and 900 mb levels.

including the Pamban peninsula. Occasionally the Sundarbans coast, some of the Bay Island and the northwestern tip of Sumatra are also visible. The actual patterns seen and the intensities of echoes vary widely from time to time apparently as a function of changing refractive index distribution. But even from long distances considerable power can be returned. For instance the received power from the echo in Fig. 2 was about −92 dBm representing a loss of only about 180 dB over a path length of 3000 km.

3. Frequency of occurrence and seasonal variation

Abnormal propagation of the type shown above has definite seasonal and diurnal patterns. We shall consider four seasons, *viz.*, winter (late December to February), pre-monsoon (March to May), monsoon (June to September) and post-monsoon (October to early December) with four characteristic patterns of propagation.

3.1. *Winter* — Abnormal propagation is frequently witnessed in late night and early morning hours and not only along the coast but over land areas as well (Fig. 4). It is rare at other times of the day.

3.2. *Pre-monsoon* — From the latter part of February abnormal propagation usually starts in the afternoon and persists continuously till late in the evening. It is seldom encountered in the morning hours. In this season propagation is supernormal almost every day and the longest distances are also seen.

3.3. *Monsoon* — When the southwest monsoon advances over the Bay in June, superrefraction becomes infrequent. From late June to September, propagation is normal or often subnormal. The latter conclusion is inferred from an observation of the apparent heights and seeing distances of precipitation echoes in this season.

3.4. *Post-monsoon* — In this season the propagation is mostly normal and sometimes subnormal. Super refraction is rare and if it occurs it does so only for short periods.

4. Refractive index profiles

To see if one can predict this seasonal and diurnal variation, we shall look at the refractive index data. Refractive index data are computed from routine radiosonde observations of pressure, temperature and humidity which are available for 00 and 12 GMT for four stations on the coast and one in the Andamans. The utility of these data, however, is limited as the radiosonde derived profile is coarse and smooths out the fine structure which may really be responsible for superrefraction and duct formation. To illustrate this, data of the refractivity [$N=(n\text{-}1)\times 10^6$, where n is the refractive index] gradients in the first one kilometre [$(N_s - N_{900})$, where N_s is the surface refractivity and N_{900} is that at 900 mb] are presented in Table 1 for the months of January, May, July and November representing respectively the four seasons mentioned above.

These values are for Madras but data of other stations along the coast are not very different. It will be seen that although abnormal propagation occurs almost everyday in May and seldom in November there is hardly any difference in the mean refractivity gradients for the two months. Even the highest values in May and July are almost the same. The only clear feature is that the mean refractivity gradient in July a 'normal' month is clearly less than in the other three seasons. Hence there are no significant differences in N gradients in various seasons.

We may also consider the 'dry' and 'wet' components of the refractivity separately (Table 1). The gradient of the dry component has practically no seasonal variation. The morning values are slightly higher than the evening in January because of the temperature inversion found in the mornings. The wet component has a smaller gradient in July, but the other three seasons have almost identical gradients.

Vertical profiles of refractivity (N) and refractive modulus [$M=N+Z/a\times 10^6$, where Z is the altitude and a is the effective earth's radius] for individual dates in the surface to 700 mb (3km) layer have also been examined, though these are too numerous to be presented here. Except for occasional cases of steep 'N' gradients or shallow elevated 'M' inversions, the profiles do not exhibit characteristics particularly different on days of 'abnormal propagation'.

We may also consider the "initial refractivity lapse rate" $\triangle Ni$ (the difference between N_s and N at a nominal altitude of 250 metres above the surface). As this refers to a shallower layer than $N_s - N_{900}$ considered above, one should expect this to correlate better with observed abnormal propagation. However, it may be seen from Table 2 that the monthly and diurnal variations of this quantity do not correspond to the variations of abnormal propagation.

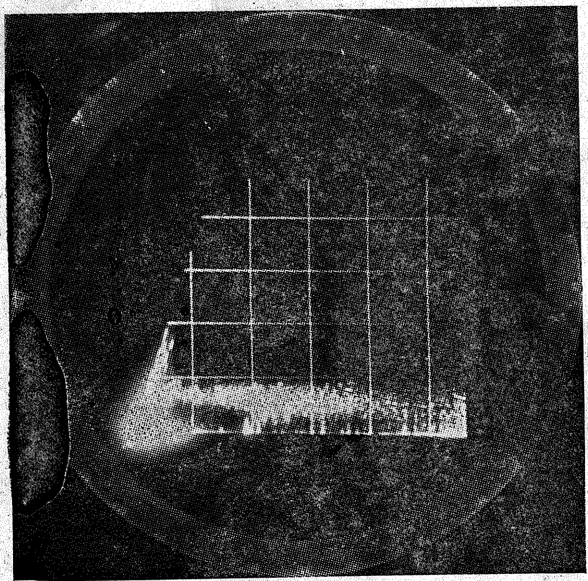

Fig. 5. Range Height Indicator picture—Height markers at 2.5 km intervals. Elevated horizontal layer echo at about 2 km altitude in clear weather

TABLE 2

$\triangle Ni$ at Madras

Time (GMT)	Months J	F	M	A	M	J	J	A	S	O	N	D
00	65	65	93	110	120	80	80	100	75	65	70	50
12	50	65	70	58	75	55	45	75	55	65	50	50

The variation of the effective earth's radius factor is shown in Table 3. While the large values in some months clearly show that the usual 4/3 earth assumed in routine work can be greatly in error, the seasonal and diurnal variations exhibited by the data in Table 3, obviously do not correspond very well to the abnormal propagation observed. The high value for August mornings when no abnormal propagation occurs and the relatively low values for April evenings when extensive abnormal propagation occurs, illustrate this point.

Thus the refractive index data derived from radiosonde observations do *not* help us to explain the observed phenomena quantitatively. The refractivity data, are only a rough guide falling short of the radio engineers requirements. This may be the result of the layers involved in the abnormal propagation being small in thickness and, therefore, not apparent in the radiosonde data. This suggestion is supported by the fact that the radar (Fig. 5) often shows shallow reflecting layers close to the coast at the 1 or 2 km levels due to refractive index discontinuities which are not detectable from the radiosonde data. A quantitative verification is possible only by accurate low level ascents or direct measurements of refractive index. Such measurements are essential for providing reliable guidance to the radio engineer.

5. Synoptic features

An explanation of the observed anomalous propagation is possible albeit qualitatively by an examination of the synoptic weather charts and certain characteristic patterns of the tephigrams. We shall consider these seasonwise.

5.1. In winter (January and February) there is an anticyclone over the Indian Peninsula in the lower troposphere even in the mean chart (India Met. Dept. 1943). The winds along the coast are dry northelies or northeasterlies coming round the anticyclone. This subsiding dry air flowing over the moist sea surface, gives rise to a tephigram exhibiting a very sharp lapse of humidity with height. A typical tephigram is shown in Fig. 6. The refractivity gradient will be further increased in the morning hours when the surface temperature inversion encourages stabilization. Abnormal propagation, therefore, occurs mainly in the mornings and extends over land areas (Fig. 4). The conditions favouring super refraction in this case are also favourable to mist or fog formation which, of course, is very common in these months especially in the northern parts of the Bay coast. The anticyclonic subsidence does not, however, extend well out into the Bay and this may explain the absence of abnormal propagation across the Bay towards Burma on winter mornings.

5.2. *The pre-monsoon season* — In March and April the anticyclone at low levels (surface to 1.5 km) lies over the sea in the mean chart (India met Dept. 1943). Winds in the surface to 850 mb layer are light easterly, southeasterly or southwesterly. There is no surface inversion in the mornings. However, by afternoon the sea breeze sets in producing a large lapse of humidity with height, and abnormal propagation along the coast and across the Bay starts in the afternoon and persists for several hours. As the sea-breeze advances, the humidity lapse is confined to a very shallow layer and this explains why the refractive index profile does not show it.

5.3. *Monsoon season* — With the advance of the monsoon over the Bay in June, the anticyclonic circulation disappears. Winds at lower tropospheric levels over the Peninsula become westerly and increase in velocity. The sea breeze effect is suppressed. High humidity extends upto higher levels. The air temperature and dew point curves are quite close even in Madras which does not have much rain. Hence propagation is normal or subnormal at all hours of the day.

5.4. *Post-monsoon season* — In the post-monsoon or north-east-monsoon season a diffuse low

TABLE 3

Effective earth's radius factor (K) for Madras

Hour (GMT)	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
00	1.7	1.7	2.5	3.3	2.8	2.0	2.0	2.8	2.0	1.7	1.8	1.4
12	1.4	1.7	1.8	1.5	1.9	1.5	1.35	1.8	1.4	1.7	1.6	1.4

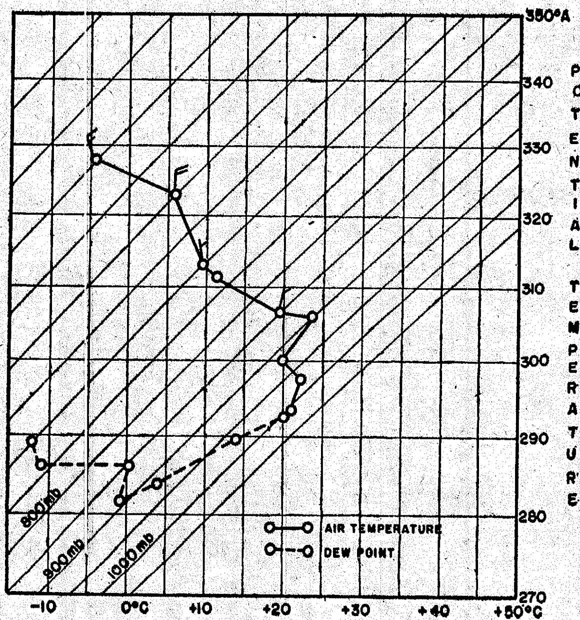

Fig. 6. Tephigram of Madras. 15 January 1973 0520 IST

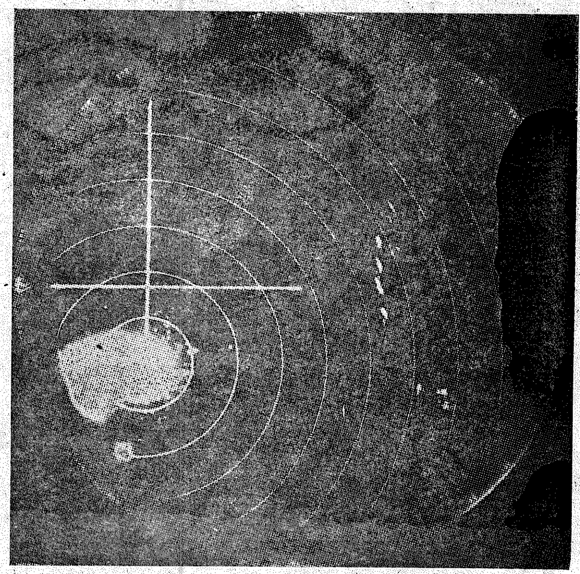

Fig. 7. Spiral rain band associated with a cyclone seen at a range of about 600 km east of the radar site. Range markers are at intervals of 100 km

pressure area is established over the Bay. Northeasterly winds blow along the Bay coast. Moisture extends to considerable heights but there are wide variations in humidity profile from day to day. Because of the low pressure area which often accentuates, the atmosphere is well mixed and the occurrence of strong refractivity gradients is discouraged.

6. Consequences of the propagation patterns

Thus the meteorological features explain the seasonal and diurnal variation of propagation conditions in a qualitative but satisfactory manner. The broad pattern is that along the Bay coast frequent long distance abnormal propagation can be expected in the mornings in winter and in the afternoons and evenings from late February to early June. In the rest of the year the propagation is normal or subnormal.

The distances over which propagation occurs over the Bay are often far more than those reported from many other parts of the world. As far as TV, FM broadcasting and other VHF systems are concerned, it is therefore necessary to take into account the persistent abnormal propagation in certain seasons in order to overcome interference. Bacause of congestion of frequency bands, identical frequencies are often allotted in VHF, UHF or microwave bands to stations far apart, on the assumption that propagation is mostly limited to line of sight. This assumption is not valid for the Bay of Bengal area in the clear season. To avoid interference the frequencies need to be offset even if the stations are far apart. The use of highly directional aerials will also solve the problem in certain cases.

The most important effects of abnormal propagation on operational work may be found in the working of radars. Taking meteorological radar in particular the variation of propagation conditions increases the effective range of the radar in some seasons and decreases it in others. For instance, while a radar at Madras can often detect precipitation in May even beyond 500 km, it can rarely do so beyond 300 km in November. Fig. 7 shows a case of a spiral rainband associated with a cyclone detected at a range of 600 km due to a rare case of abnormal propagation in November. The eye of the cyclone of May 1979 (which hit Andhra Pradesh) was seen by Madras radar at a range of 425 km owing to abnormal propagation. This has to be kept in view while trying to locate storms or in interpreting radar pictures. Secondly the height of clouds evaluated from radar assuming the well known 4/3 earth's radius formula will often be in error by a few kilometres being overestimates in May and underestimates in November (*see* Table 3). This is a serious operational difficulty for the radar meteorologist in assessing the heights of convective clouds associated with severe weather. Thirdly serious difficulties of indentification of echoes arises. Normally the radar operator is familiar with the permanent echoes and the usual pattern of abnormal propagation echoes and is able to distinguish them from precipitation echoes. However, there are several occasions (*e.g.*, in May in Madras) when the two types coexist on the radarscope. Owing to extreme amount of refraction the echoes due to anomalous propagation sometimes exhibit apparent height of several kilometres and appear on the RHI similar to cumulonimbus clouds. Only careful observation over several minutes looking for growth and movement can enable the operator to distinguish the two. The possibility of long distance propagation also enables multiple time around echoes to superpose themselves on real precipitation echoes and cause confusion. This possibility increases at high p.r.f.'s. The problem is more serious when intensity measurements are attempted in order to evaluate rainfall rates. When this is done manually the operator ignores the areas over which he knows or suspects anomalous propagation or other nonprecipitation echoes to be present. In the case of an automated video processor-rainfall computer system, all echoes will be taken by the system to be rainfall and evaluated accordingly. To prevent this it is possible to store the information on permanent echoes and reject their contribution (Aoyagi 1978, Tatehira and Shimizu 1978); but in the case of anomalous propagtion echoes this becomes difficult as the pattern will not remain constant. One method of distinguishing abnormal propagation from precipitation is from the differences in spectral distribution of the echo (Johnson *et al.* 1975) but this technique does not appear to have been developed sufficiently for operational use.

In the case of radars for other applications, *e.g.*, aviation or shipping other difficulties would probably arise. The use of variable p.r.f. and Doppler facility may minimise some of the problems but not completely eliminate them. Hence the documentation of actual abnormal propagation over all times of day and various seasons will be of great practical help to the radar and radio engineers.

7. Conclusions

Abnormal propagation over distances of hundreds of kilometres is very frequent along the Bay of Bengal coast and across the Bay in the afternoons and evenings of the pre-monsoon season. On winter mornings it extends to land areas in the Peninsula. The seasonal and diurnal variation is qualitatively explained by the synoptic meteorological charts but a quantitative treatment may be possible only from more accurate measurements of refractive index profiles than is available from radiosonde data.

Abnormal propagation over the Bay frequently occurs over much longer distances than many other areas of the world and should, therefore, be taken into account in planning TV and communication systems in VHF, UHF and microwave bands. In the operation of radars the effects due to abnormal propagation should be carefully considered to avoid misinterpretation of radar pictures.

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References

Aoyagi, J., 1978, Proc. 18th Conf. Radar Meteorology, Am. Met. Soc., 1978, p. 358.

Durst, C. S., 1946, Meteorological Factors in Radiowave propagation, Phys. Soc. and Royal Met. Soc., p.193.

Hatcher, R. W. and Sawyer, J. S., 1947, *Quart. J. R. met. Soc.*, **73**, 317-318, pp. 391-406.

India Met. Dept., 1943, *Climatological Atlas for Airmen.*

Johnson, G. N., Smith, P. L., Nathanson, F. E. and Brooks L.W., 1975, Proc. 16th conf. Radar Meteorology, Am. Met. Soc., p. 374.

Raghavan, S. and Soundararajan, K., 1962, *Indian J. Met. Geophys.*, **13**, 4, pp. 501-509.

Tatehira, R. and Shimizu, T., 1978, Proc. 18th Conf. Radar Meteorology, Am. Met. Soc., 1978, p. 364.