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A study of abnormal Radar Propagation around Madras

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ABSTRACT. Occurrence of supernormal radar propagation in the 3-cm band around Madras has been investigated. The results generally agree with the findings of Durst (1946). The temperature and humidity distribution giving rise to favourable Refractive Index gradients in the various seasons and the wind distribution and synoptic features aiding the setting in of super-refraction are discussed.

The occurrence of super-refraction prior to formation of mist or fog has also been discussed in relation to its forecasting value.

1. Introduction

Supernormal radar propagation over the coasts of India was first noticed during the war by the RAF who were operating 1·5 metre radars at several sites close to the coasts. Propagation conditions over the Indian Seas in various seasons in relation to the climatology of the area have been summarised by Durst (1946). An intensive study of formation of radioducts near the Madras coast in relation to sea-breeze structure has been made by Hatcher and Sawyer (1947) working at Madras aerodrome. The conclusions reached in these studies were—

(*i*) Super-refraction over the Bay of Bengal was very pronounced during the period March to May when the coast south of Visakhapatnam could be seen from Madras, but not the south coast towards Ceylon.

(*ii*) Propagation is generally orthodox in the monsoon season but in October it occasionally becomes supernormal.

(*iii*) In winter, super-refraction is very frequent.

With the establishment of a storm warning radar (3-cm wave length) at Madras airport an opportunity to undertake the study of super-refraction is once more available and the results of a study for a period of one year are presented.

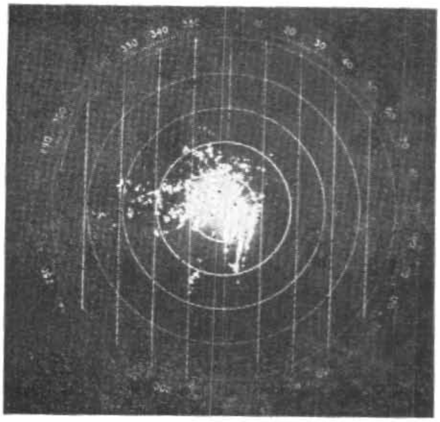
2. The observations

The radar is generally operated about once in an hour at all hours of the day mainly with a view to detect weather echoes, but any other phenomena observed have been generally recorded and photographed. Most* of the echoes (other than normal ground clutter) seen at times when there was definitely no precipitation or thunderstorm activity, have been identified as cases of ground objects being seen owing to super-refraction. The only other possibility is that they are 'angels'. This is however, most unlikely for the following reasons—

(*i*) The echoes were visible invariably at antenna elevations of 0 to 2° and disappeared at higher angles. It appears unlikely that the gradients of temperature and humidity necessary for back reflections at these angles would have existed, and they can be more readily explained by a bending of the ray towards ground objects.

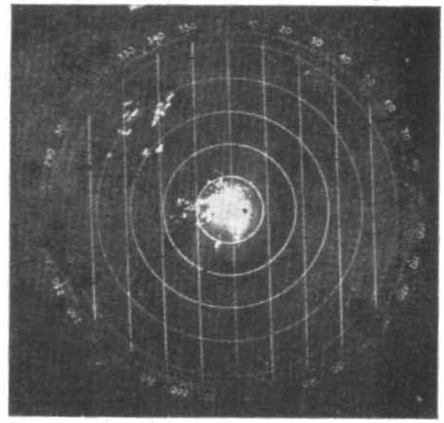
(*ii*) The echoes were in all cases stationary and only increased or decreased in number or intensity.

*A few exceptions, which cannot be explained on the basis of super-refraction, have been recorded and are under study



Range 25 n. miles Elev 1°

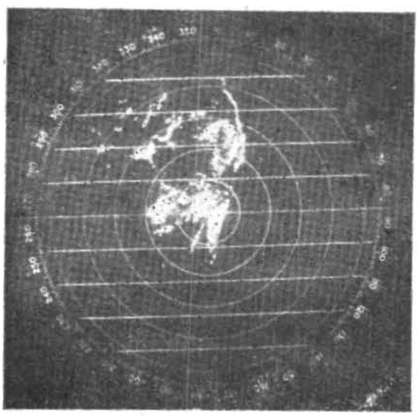
Fig. 1a



Range 50 n. miles Elev. 1°

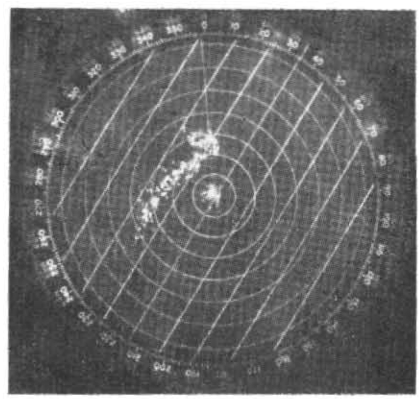
Fig. 1b

Fig. 1. Permanent ground clutter



0535 IST Range 50 n. miles Elev. 0°

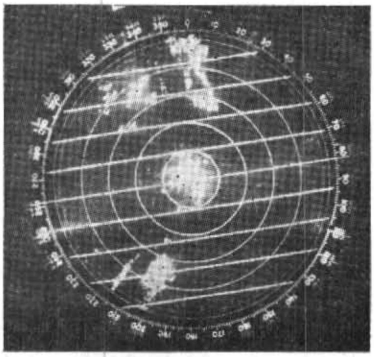
Fig. 2a. 7 February 1960



0750 IST Range 150 n. miles Elev. 1°

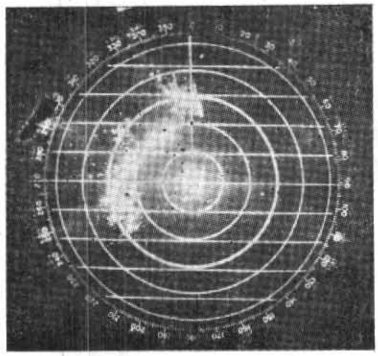
Fig. 2b. 16 February 1960

Fig. 2. Echoes due to super-refraction in fair weather



1800 IST Range 50 n.miles Elev. 1°

Fig. 2c . 27 April 1960



2030 IST Range 100 n. miles Elev. 1°

Fig. 2d. 29 April 1960

Fig. 2. Echoes due to super-refraction in fair weather

(*iii*) The same patterns could be seen on several different days.

(*iv*) Some, though not all, of the echoes could be definitely identified with the coast-line or other topographical features.

The normal ground clutter corresponding to normal propagation at 1° elevation of the antenna is shown in Fig. 1, and some cases of echoes due to superstandard propagation are shown in Fig. 2.

The chief features are—

(*i*) The frequent appearance of certain line of echoes which are not readily identifiable with any features on maps (Figs. 2a and 2c).

(*ii*) A large number of sharply defined echoes to the west and northwest mostly at places where there is high ground or small hills (Figs. 2a and 2b).

(*iii*) Parts of the coast-line in the north-east, but not necessarily the same part of the coast line appearing every time (see Figs. 2a and 2c).

Echoes to the west and northwest, *i.e.*, on the land side are the most common and these have occasionally extended to 120 miles. Echoes near the coast occur only in conditions of strong super-refraction and that almost always in the northeast direction.

3. The associated meteorological factors

Super-refraction is explained by the presence of favourable temperature and humidity gradients in the first few hundred or few thousand feet of the atmosphere. To detect such gradients it would only be necessary to make observations at close intervals. Such observations are not available in these cases and only the routine radiosonde data are available. The possibility of fitting in a temperature and humidity profile based on these data and eddy diffusivity theory as suggested by Booker (1948) has also been considered impracticable in the present case. Using the temperature and humidity values at the surface, 1000, 2000 and 3000 ft, the refractive modulus

$$M = (n - 1 + Z/a) \times 10^6$$

where n is the refractive index, Z is the height above ground and a is the effective earth's radius has been computed for each of these levels and a few typical profiles in the different seasons are shown in Fig. 3.

Under standard conditions, M increases with height at the rate of about 38 per 1000 ft and the broken straight lines in Fig. 3 show this slope. Wherever the slope of the M-profile is less steep than this, it shows a faster than normal increase of M with height and hence *substandard* conditions of propagation. Where the slope is steeper, propagation is superstandard. Where there is an M inversion, there is an actual duct formation.

In the profiles as plotted, the variations in the vital region of the first few hundred feet are smoothed out to some extent, and the profile is at best a broad indication of the general conditions—the only indication available in the absence of better data.

The winds at these levels are also plotted alongside the curves as these have been found to be useful in explaining some of the cases of super-refraction.

4. The monsoon season

In this season, *i.e.*, July to September the extension of seeing conditions is only over a small distance and the most distant echoes are only 30 to 40 n. miles away. The M-curves also indicate a nearly standard slope on most of the occasions of super-refraction. Except for two cases (for instance on 18 September 1959—see Fig. 3b) all the other have occurred in the evening or early night with the sea-breeze often present. The winds above 500 ft are in a *westerly* direction. Sea-breeze is not usually prominent in this season. But on days when it does establish itself, it is reasonable to expect that a temperature and humidity structure similar to that found by Hatcher and Sawyer exists, *i.e.*, at the lowest levels humidity falls and temperature rises gradually towards the west and the opposite gradient applies to the east of the station. And on the days under consideration convection has apparently not been much in evidence and vertical mixing is, therefore, not appreciable. A ray proceeding at grazing angle of incidence westwards, would therefore meet warmer and drier air as it progresses even though the *vertical* M-profile may not be particularly favourable. One can, therefore, expect a greater likelihood of the extension of seeing on the west than on the east. This conclusion agrees with the results actually obtained.

On occasions when super-refraction has occurred in the morning, there is an appreciably superstandard layer either from surface to 1000 ft or between 1000 and 2000 ft.

5. The post-monsoon season

In the first half of October, super-refraction occurred in the evening or early night on some days when winds above 500 ft were westerly. On the night of 11 October 1959, there was an M-inversion upto 1000 ft accompanied by easterly winds upto 1000 ft over which there were westerlies. The wind regime as already explained would aggravate super-refraction towards the west.

Echoes were seen upto 70 miles on the west on this occasion but none on the east. On the remaining occasions, no particularly favourable conditions could be detected but on these days super-refraction was not very extensive.

In the second half of October the prevailing wind changes to easterly, but super-refraction is observed *only* when the land-breeze has set in. Super-refraction is quite extensive and dense echoes are obtained. The same conditions are largely true of the occasions of super-refraction in winter, which are discussed below.

6. Winter

In January and February, supernormal propagation is very frequent in the mornings and later part of the night. Targets are seen to a considerable distance (in one case upto 120 miles on the west and northwest) on some occasions even in the evening and early hours of the night. In the mornings very often it is possible to see a part of the coastline and several echoes near the coast in the northeast, though the same part of the coastline is not necessarily seen on different days. It is noteworthy also that the coast to the east and southeast is not at all seen.

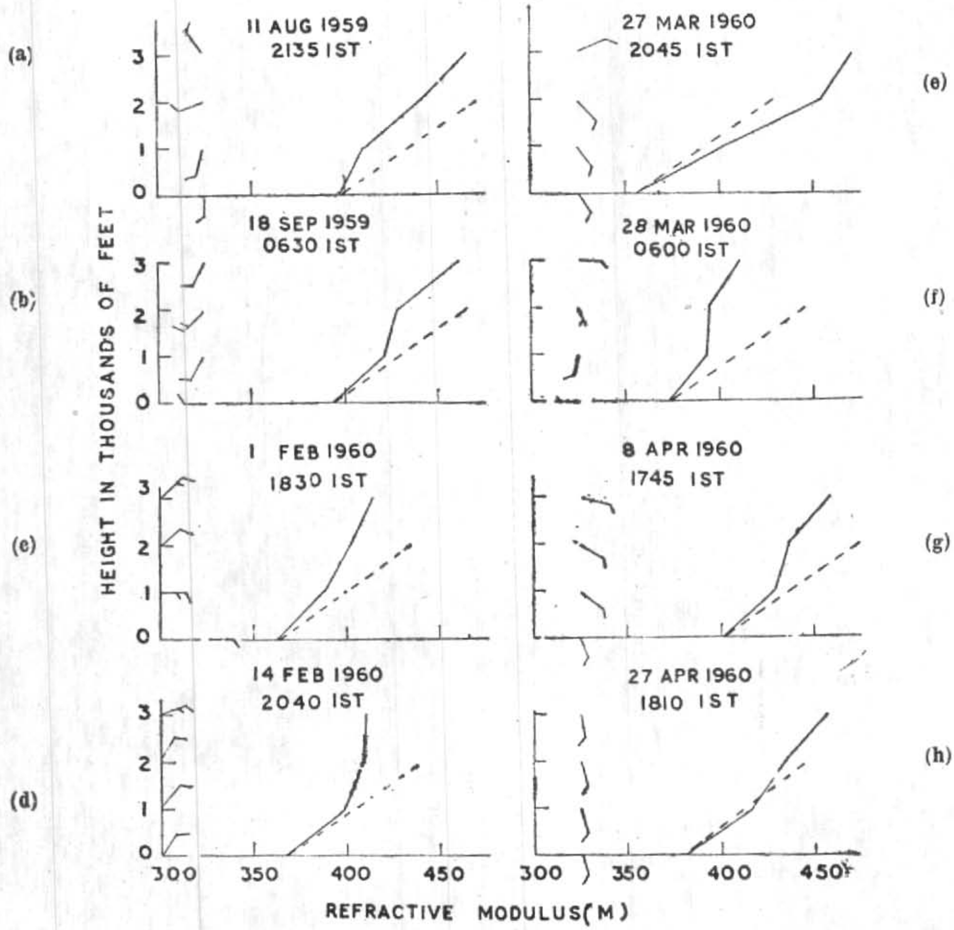


Fig. 3. Profiles of refractive modulus and wind

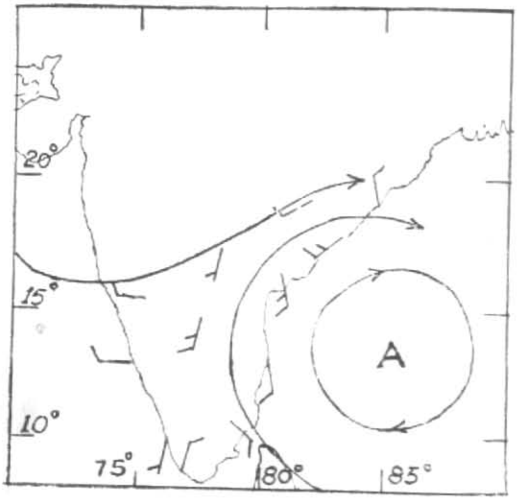


Fig. 4. Streamline (0·9 km a.s.l.) on 8 April 1960 at 0530 IST

In this season a ground inversion forms in the evening and deepens as the night advances. A steep lapse in humidity is also observed upto considerable heights. The humidity at the surface is often very high in the morning hours and thick mist has formed on some of the days. Extensive super-refraction is, therefore, not surprising. However the preference shown to certain direction may require some explanation.

Many of these cases are associated with land-breeze and in all cases the winds aloft are E-ly or NE-ly. Under such conditions the humidity at the lowest levels would probably be increasing gradually from W to E and temperature would also rise in the same direction. A ray proceeding in the westward direction has, therefore, a more favourable chance of super-refraction owing to the humidity gradient than a ray going eastwards. That echoes first appear on the west is, therefore, understandable. It would seem that as the superstandard conditions become more pronounced, the echoes spread out to the north and northeast. Why no echoes appear on the rest of the coast (southeast) is something that can, perhaps, be explained if a close mesh of observations of temperature and humidity is available.

7. Pre-monsoon season

The most extensive cases of super-refraction occur in the months of March and April and to a less extent in May. Super-refraction generally starts at 18 or 19 hrs in the evening and continues till about midnight and in some cases till next morning.

During the month of March, winds at the surface are light variable (SE to S-ly in the evening becoming W-ly by morning) while winds at levels immediately above are easterly to southeasterly with a general backing of wind with height. There is generally a fall in surface wind speed by 20 to 21 hrs, which is about the time when super-refraction starts in the month.

In the cases considered in the months of April, winds are generally southerly from surface to 3000 ft. However, the surface wind backs slightly to southeast in the afternoon owing to sea-breeze effect. There is a sharp increase in the humidity in the late afternoon/evening hours brought about, no doubt, by the sea-breeze. This results in a steep lapse of humidity with height at the lowest levels. It is also a feature of this month that a high is present at 3000—5000 ft above Madras, which may give rise to subsidence and consequently a favourable condition for super-refraction. Surface winds are, however, generally strong upto about 1800 hrs and, therefore, horizontal stratification is possible only after they die down. This explains the setting in of super-refractive conditions after about 1800 hrs. The features presented above are well illustrated during the periods 8 to 13 April and 29 April to 1 May 1960, when super-refraction was most marked. It will be seen from Table 1 and Fig. 4 that there was a well established anticyclonic circulation at 3000 and 5000 ft on 8th, 9th and 10th just to the east/northeast of Madras. This had, however, disappeared on the 11th and reappeared on 00 GMT chart of 13th. Super-refraction was well-marked from 8th to 12th in the evenings and nights.

TABLE 1

Synoptic features associated with marked super-refraction in April 1960

Date	Time of chart (IST)	Upper air circulation over Bay, close to Madras		Remarks relating to		Time of super-refraction observed (IST)
		3000 ft	5000 ft	Temperature profile over Madras	Humidity profile over Madras	
		Anticyclonic	Anticyclonic		Marked lapse in mixing ratio from 1000 to 3000 ft	1745—2330
	1730	Do.	Do.			
	2330	Do.	Do.			
9-4-60	0530	Do.	Do.			
	1730	Anticyclonic even from 2000ft	High displaced further to NE		Do.	1915—2330
	2330	Similar to 1730 IST				
10-4-60	0530	Anticyclonic	Anticyclonic			
	1730	Do.	Do.			1940—2330
	2330	Do.	Do.			
11-4-60	0530	High completely disappeared			Marked laspe upto 3000 ft	
	1730 } 2330 }	No High	High establishing	Temp. lapse upto 2000 ft	Lapse not marked	
12-4-60	0530	No High at 3000 or 5000 ft		Inversion 3000—5000 ft	Marked lapse of mixing ratio upto 5000 ft	1930—0630 of 13th
	1730	Do.		Stable lapse rate upto 3000 ft	Do.	
	2330	Do.				
13-4-60	0530	High from 2000 ft upwards		Inversion 3000-5000 ft		Upto 0630 of 13th
	1730	Similar to 0530 IST			No super-refraction in evening	
27-4-60	0530	High at 3000 and 5000 ft		..	..	1810—0903 of next day
	1730	Do.		Stable upto 3000 ft	Slight lapse	
28-4-60	0530	Anticyclonic	Anticyclonic	Inversion upto 2000 ft	Marked lapse upto 3000 ft	1715—0745 of next day
	1730	Do.	Do.	Not particularly favourable		
	2330	High to the interior over Coastal Andhra Pradesh				
29-4-60	0530	High at 3000 and 5000 ft		Shallow inversion 1000 to 2000 ft	Marked lapse of mixing ratio upto 2000 ft	1730 to 0820 of next day
	1730	Do.				

TABLE 2

Cases of abnormal propagation

Followed by mist/fog/haze commencing			Not followed by mist/fog/haze	Total
Before midnight and persisting	Just about midnight and persisting	At early morning and persisting		
14	4	1	7	26

TABLE 3

Cases of abnormal propagation not followed by mist/fog/haze

S. No.	Date	Duration (IST)	Remarks
1	19-20 Nov 1959	2020—0740	Long duration and commencing before midnight
2	24 Jan 1960	1730—2300	Relatively for short duration only and before midnight
3	27 Jan 1960	2000—2200	
4	28-29 Jan 1960	2100—2200 0400—0600	In early morning hours
5	1 Feb 1960	0330—0745	In early morning hours and forenoon
6	4 Feb 1960	1730—2000	As in S. No. 2
7	8 Feb 1960	2030—0730	As in S. No. 1

Similar synoptic conditions prevailed during the period 27 to 30 April. The T-ϕ grams of these dates also show a sharp lapse of humidity in the first 3000 ft and a stable lapse rate of temperature. The M-profiles for 8 and 27 April 1960 are presented in Figs. 3(g) and 3(h) respectively.

Fig. 5 shows the sharp rise in humidity in the evening and consequently large rise of the surface M-value in the same period.

8. Mist or fog formation in relation to super-refraction during winter

The radiation inversion and stable conditions referred to above are favourable to the formation of mist or fog. Appreciable super-refraction on winter nights can, therefore, be taken as a possible indirect indication of formation of mist in the morning (fog itself being very rare at Madras) even though at time of fog, super-refraction may again decrease owing to attenuation (De 1959). The reliability of this advance indication was tested by studying 27 occasions in the months of January and February and the results are given in Tables 2 and 3. There is one case of mist formation not preceded by abnormal propagation and as many as seven cases of super-refraction not followed by mist. But out of 16 days when super-refraction started well before midnight, and persisted most of the night, mist formed on the following morning on 14 days. There were four cases of mist, following super-refraction, starting at about midnight and one in which mist formed although propagation became abnormal only in the early morning hours.

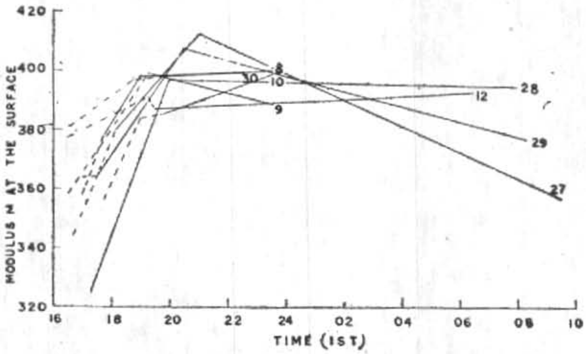


Fig. 5. Variation of M-value with time on various dates in April 1960]

The large increase in the evening is due to rapid rise in humidity. The full lines indicate periods of super-refraction and the broken lines periods preceding super-refraction

It would, therefore, appear that there is a very high probability of mist, if super-refraction starts early in the night and persists throughout the night.

9. Conclusion

Super-refraction phenomena are very pronounced during the months March—May and to a lesser extent during winter months. They also occur on a few occasions during the monsoon season when the sea-breeze establishes itself. They are associated with a high lapse of humidity and a stable temperature lapse rate in the first 2000-3000 ft. Presence of anticyclonic circulation between 3000-5000 ft in the neighbourhood of Madras especially favours the phenomenon during April—May. In winter there is a high probability of mist following in the early morning, if super-refraction starts early in the night and persists throughout the night.

10. Acknowledgement

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