SUPER REFRACTION IN SOUTH ARABIAN SEA

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ABSTRACT

The phenomenon of super refraction has been investigated in South Arabian Sea over a period of nearly two years from radars located at Cochin. From the observations made, the existence of a super-refracting layer seems to be well established during the premonsoon months from January to April each year. This is supported by the existence of M. Inversions computed from Radio Sonde data in the region. Duct heights of 135 feet have been estimated which can trap 1st and 2nd order modes in 3 and 10-cm bands.

Introduction

Super refraction has been observed over extensive areas of the Arabian Sea in centrimetric and metric bands during the last war. The intensity has been found to be most pronounced in the Northern half of the Arabian sea and seems to tail off Southwards. Radars at Cochin during the last war have not reported any super refraction over the sea at any time of the year. It was, therefore, considered desirable to study the phenomenon of super refraction over the sea at Cochin. Observations were started sometime in 1957 and from the data now available the existence of a super refracting layer seems to be well established in the pre-monsoon period from January to April each year.

Anomalous propagation at radar wave length arises from the existence near the surface of the earth of a duct capable of acting as a wave guide to long distances. This duct behaves like an efficient wave guide only for radio wave lengths less than a critical value which is determined by the height of the duct. Thus for a wave length of 3, 10 and 50 cm, a duct width of 20, 65 and 330 ft respectively is necessary for super refraction provided the antenna is located within the duct.

In the Northern Arabian sea super refraction is experienced during November to January although its intensity weakens during cold spells of the weather. During February to May its intensity increases tremendously and echoes from across the Arabian Coast have been observed at Bombay. Super refraction, however, collapses with the onset of the Southwest Monsoon when the radar performance of the stations returns to normal and remains so throughout the monsoon period. At Cochin the monsoon starts early in May and sporadic rains continue even late in October. From December to March the season is quite dry and calm and the wind directions are mostly North East. It is this part of the season which is most suitable for duct formation and in which long distance super refracting echoes have been noticed at Cochin.

Observations at Cochin

Radar observation of anomalous propagation at 10 cm were started in December 1957 and continued upto the onset of the monsoon in 1958 and again in the same period in 1958-59. There are a number of atolls in Maladiv group of islands in the bearing range 210°±3° from Cochin at a distance of 250 miles. These islands stretch nearly 470 miles in the north and south direction and 20 miles in width, but most of them are small low-lying islets surrounded by barrier reefs. A few atolls are big enough to give rise to marked land echoes on a 10 cm radar. A number of echoes from Maladiv group have been seen at this bearing on a PPI as well as on A-scope in the third sweep of Radar 293 at a distance of 365 to 390 miles as shown in Fig. 1 during intense super refracting conditions. Table 1 shows the number of echoes received per day, from the sea from this group of islands during December to March.

TABLE 1

Number of echoes per day observed at Cochin
December—March

Months	First Fortnight No. of echoes per day	Second Fortnight No. of echoes per day
Dec. 58	*Nil*	3
Jan. 59	6	5
Feb. 59	7	7
Mar. 59	7	5

N.B.—Observations were taken from 0700—0900 hrs.

Presence of anomalous condition was indicated by the presence of long distance land echoes beyond the normal range of the radars from seaward direction from Cochin. These echoes were characteristically different from those due to a moving ship or from clouds. They were persistent and showed a diurnal variation characteristic of the super refracting echoes as shown in Fig. 2. Cloud echoes were always distinguishable by their nature and movement and they were excluded from these observations. Echoes from Maladiv group of atolls in this range and bearing have been observed in premonsoon season in 1958 and 1959. They attain their maximum intensity during February-March and disappear at the onset of the monsoon early in May.

Observations of super refraction phenomenon was carried out on radar type 293 installed at N. D. School. It is a 10 cm radar with a fan shape beam 35° in the vertical and 2° in the horizontal. The pulse width is 1·9 micro seconds with a prf of 500. The radar is provided with a PPI and A—Scope and has a maximum range of 75 miles. The antenna is mounted at an angle of 15° to the horizontal and is located at a height of 80 ft above the sea level. The vertical width of the beam is such that a fraction of the beam energy can be intercepted when suitable ducts exist in the surrounding region over the sea. Regular observations have been carried out between 7 and 9 AM throughout December to April and on some occasions, records have been taken all round the clock and echo strengths in amplitude, bearing and range have been recorded every 15 minutes. These observations have also been repeated from radars available on board the ships of the Indian Fleet during February 1958. Whenever super refracting conditions were noticeable a check on the radar performance and the crystal current was also made. The performance figure of the radar was measured by the relation.

$$S_{db} = P + 20 \log A_{Sqft} - 40 \log R_{yds.}$$

where S is the signal in db above noise from a vessel within the radar horizon, A is the echoing area of the vessel in sq. ft. and R is the range in yards. For a known class of ship of the Indian Fleet which was observed at a distance of 8 nautical miles, the performance figure of the radar 293 was found to be 135, from a previous calibration of the A-Scope with a 10 cm calibrated signal generator. The performance of the radar fluctuated between 125 to 145. Super refractive echoes were found to be most prominent when the performance figure was above 135.

Meteorological Observations

The Radio Sonde data was obtained from the meteorological station at Trivandrum, for this period. Mostly this has been utilised for the calculation of the modified refractive index profile of the upper atmosphere upto 5000 ft. The M values have been calculated from 1000 mb to 850 mb levels. The M profiles are shown in Fig. 3 (A) and (B). During January, meteorological data was also collected on board INS Jamuna during a cruise from Cochin to Minicoy. Wet and dry bulb thermometer readings and wind directions were noted at the deck and the bridge levels.

Surface Based Duct

The M profiles in Fig. 3-B plotted from the Radio Sonde Data of Trinvandrum indicate the presence of M-inversions and surface based ducts. From the data obtained on board INS Jamuna on 6-1-59 the modified refractive index was calculated by the following equation[1].

$$M = \frac{79}{T}\left[p + \frac{4800e}{T}\right] + \frac{z}{a}\,10^6 \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where p=atmospheric pressure in mb,

T=temperature in °A,

e=vapour pressure in mb,

z=height in ft above surface level,

a=radius of earth in ft.

When the M values were calculated from the ship's observations, the formula (1) was altered to accommodate pressure variations between the deck and the bridge in the following form.

$$M = \frac{79}{T}\left[p + \frac{4800e}{T}\right] + 3{\cdot}8z \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where z is in 100 feet.

The *M* values calculated from ships observations are plotted in Fig. No. 4. The M values at 320 ft were taken from the radio sonde data at Trivandrum during the early morning hours when the ship's observations were also made. One can find the duct height and profile index from the type of M-slope of Fig. 4.

It has been shown[2] that

$$\frac{M - M_o}{h} + K_\infty \times 10^6 = \frac{d^{1-m}}{m} K_\infty\ 10^6\ h^{m-1} \quad .. \quad .. \quad (3)$$

where M = modified refractive index at height h

M_o = modified refractive index at the surface ($h=o$)

h = height above surface in feet

K_∞ = the curvature at a great height of a modified ray (assuming flat earth in radians per foot)

$= \frac{4}{5} K_e$ where k_e is the curvature of the earth $= -4 \times 10^{-8}$ rad/ft.

d = duct height in feet

m = profile index

Equation (3) can be written in the form of a straight line

$$\log y = \log A + b \log h \quad .. \quad .. \quad .. \quad .. \quad .. \quad (4)$$

where, $y = -\left[\frac{M - M_o}{h} + K_\infty\ 10^6\right]$

$b = m - 1.$

$A = -\frac{d^{1-m}}{m} \times 10^6 K_\infty$

It is possible to compute the values of y from M-values. When log y is plotted against log h, a sloping straight line can be drawn which nicely fits most of the observed values. From this straight line it is possible to find the proper value of "m" and duct height 'd'

The value of "m" (profile index) can be found from the slope of the line which has been drawn for the observations of Fig. 4.

$$m = 1 - \frac{\log y_1 - \log y_2}{\log h_2 - \log h_1} \quad .. \quad .. \quad .. \quad .. \quad (5)$$

when $h = 1$ ($\log h = 0$), $\log y = \log A$ or $y_o = A$

From this value of y_o it is possible to obtain the value for "d"

$$y_o = -\frac{d^{1-m}}{m} K_\infty\ 10^6 \quad .. \quad .. \quad .. \quad .. \quad (6)$$

$$\text{or } \log d = \frac{1}{1-m} \log \frac{m\, y_o}{-K_\infty\ 10^6} \quad .. \quad .. \quad .. \quad (7)$$

From the above formulas both "m" and "d" have been calculated for the surface based duct of fig. 4.

In this case, the value of m has been found to be 0·34 and the value of y_o = 3·04.

Using the above profile index and the value of y_0 the duct height d is found to be 135·7. Thus a surface based duct of approximately 136 feet is found to exist near Cochin. This is capable of entrapping first order modes in 3 and 10 cm band when antennas are suitably located in the duct.

Elevated Ducts

Fig. 2 (*a*) also indicates the persence of elevated *M* inversions giving rise to either elevated or surface based ducts which might be quite extensive. Table 2 shows the type of layers likely to exist for the observations made.

TABLE 2

Observed M-Inversions and Gradients

Months	Super standard layers from surface upto 5000 ft	Surface based M-Inversions	Surface based strong super standard layers	Elevated M-Inversions	Elevated strong super standard layers	Number of Observations
December 1958	3	*Nil*	1	*Nil*	1	5
January 1959	3	3	*Nil*	1	1	8
February 1959	3	1	2	1	1	8
March 1959	1	*Nil*	*Nil*	*Nil*	3	4
Total ..	10	4	3	2	6	25

It has been noted that even when the modified refractive index profile as calculated from the radio sonde data is only super-standard, long distance echoes are visible for some time in 10 cm band. It has not been possible to estimate the duct height and the extent of super-refracting layers due to lack of suitable radio meteorological data over the path of propagation. The radio sonde data from Trivandrum and radar observations made at Cochin have only established the fact that elevated ducts might be quite extensive during January to March in the sea near Cochin. Long distance VHF communication has also been picked up occasionally. The existance of super refracting layer may, therefore, be quite extensive than is normally expected.

Diurnal variations of echoes at Cochin

Fig. 2 and 5 show the ratio of the hourly mean value of the signal above noise observed on days when super refraction has been very prominent. It is interesting to note that peak intensities have occurred at about 0815 on most of the days when super refraction has been in existence. The intensity shows a secondary peak near about 1200 hrs before becoming normal at about 1700 hrs. The change in the corresponding modified refractive index profile from 0530 to 1730 hours is also shown on the same curve. Thus very close agreement seems to exist between the rise of echo intensities and the change in the refractive index profile from standard to abnormal.

Conclusions

The existence of super refracting layer over the sea near Cochin seems to be well established during the months of January to April from the radar data collected so far. This is also supported by the existence of M-inversions as computed from the available radio sonde data during this part of the year. The winds over the area are mostly East to North East. As this wind mostly travels over the land and after crossing the Western Ghats is dry when it moves over the sea, it creates conditions of humidity deficit which are conducive for the duct formation. Air subsiding from the anti-cyclonic region over the Deccan Plateau is also helpful in producing an air stream similar to North-east monsoon. Thus during the months of January to April the super refracting belt of the Northern-Arabian Sea extends South of Cochin. Observations on meter wave lengths are also being planned to observe the extent of the super refracting layers in this part of the Arabian Sea.

Acknowledgements

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References

1. D. Kerr—Propagation of Short Radio waves. (*Rad. Lab. Series* **13.**)
2. *SRDE REPORT No.* 1020.

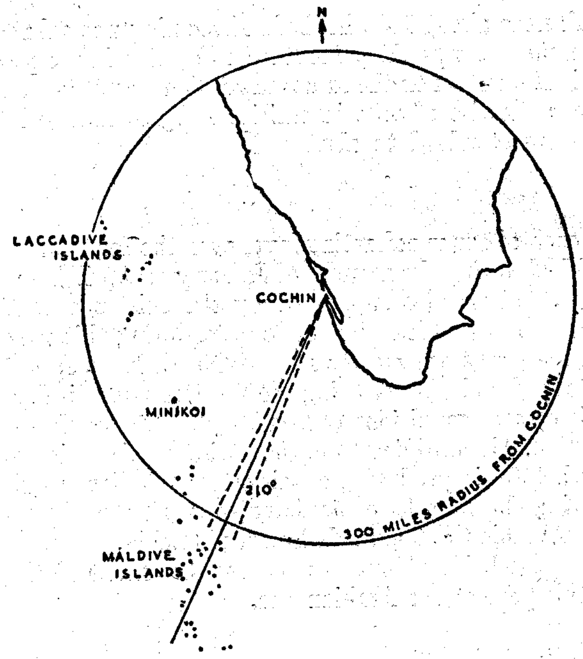

FIG. 1. Map of Cochin with Neighbouring Sea Area.

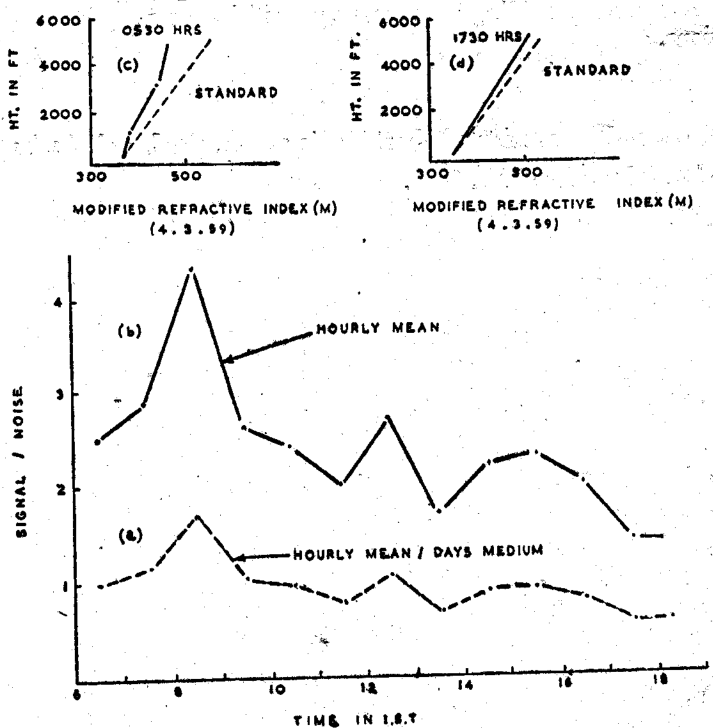

FIG. 2. Diurnal Variation of Echo Intensity.
(4-3-59)

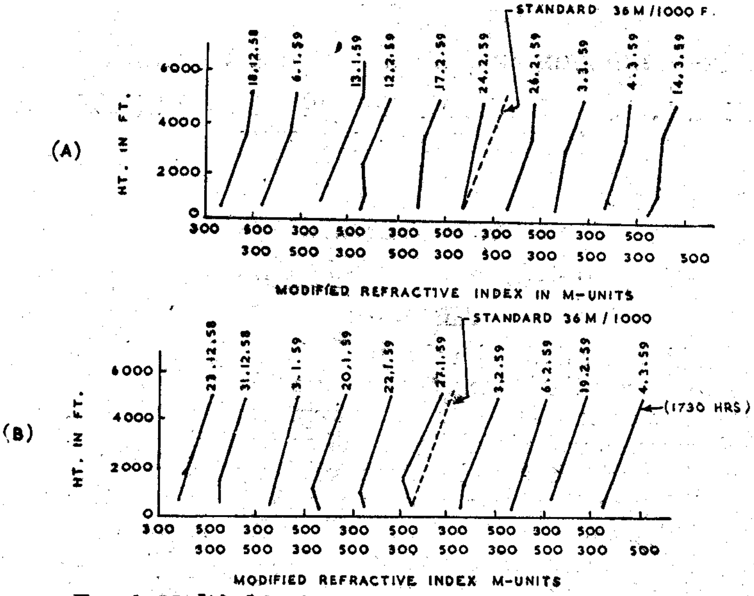

Fig. 3. Modified Refractive Index Profile at 0530 Hrs.

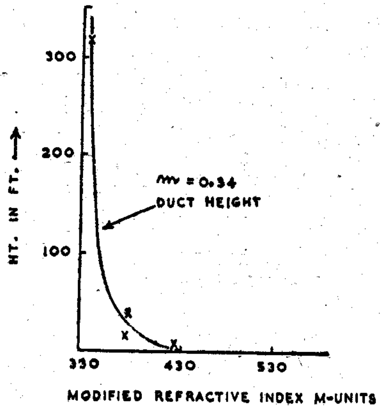

Fig. 4. Duct HT. & Profile Index.
(6-1-59)

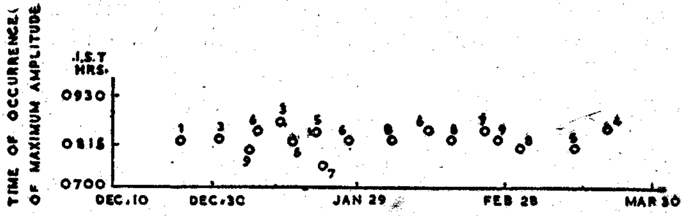

Fig. 5. Time of occurrence of Maximum Echo Amplitude.
N. B. :—Number Indicates Maximum Number of Echoes Seen.