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Anomalous propagation of centimetric waves associated with thunderstorms

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ABSTRACT. Two cases of anomalous propagation of centimetric waves after the occurrence of thunderstorms, observed with a 3·2 cm radar at Nagpur airport, are described and discussed in the light of the meteorological data available. The influence of various meteorological factors in the formation of ground ducts have been examined. It is shown that the anomalous propagation is caused by the diverging downdraft from the base of a thunderstorm, spreading cold moist air below the warm dry air.

1. Introduction

The anomalous propagation of centimetric radio waves is caused by the horizontal stratification of atmosphere, characterised by marked vertical variations in temperature and water vapour content in the lower levels (Appleton 1946). The appropriate conditions are the existence of a temperature inversion and a steep humidity lapse rate in the lowest layer of atmosphere of about 1 km thickness, which result in the sharp fall of radio refractive index with height. The anomalous propagation also occurs, although infrequently, in association with thunderstorms. Two such cases were observed in pre-monsoon thunderstorms over Nagpur with the help of a Storm Detection Radar (Decca type 41) situated at Nagpur Airport.

2. Super-refraction observed on 29 May 1962

At 1345 IST on 29th, a few scattered thunderstorm cells were observed towards northeast of the station, between 35° and 60° azimuth and at a distance 47 to 55 nautical miles. By 1500 IST these cells developed and aligned themselves in a broken line running from 360°/60 n.m. to 070°/47 n.m. The line then moved towards the station and by 1600 IST was within 20 n.m. of the station, extending from ESE/30 n.m. to NW/40 n.m. The line thunderstorms approached the station from the northeast at about 1635 IST. The first squall occurred at 1645 IST with a maximum speed of 64 km/hr and lasted till 1704 IST. Another squall occurred between 1715 and 1735 IST with the maximum wind speed of 64 km/hr. During the two squalls a sharp fall of surface temperature by 16°C and rise in humidity by 65 per cent took place. Rain occurred between 1710 and 2050 IST and a rainfall of 3·9 mm was recorded. The thunderstorm activity slightly weakened after 1755 IST and all precipitation echoes disappeared after 2050 IST.

The super-refraction echoes were first detected on radarscope at 1750 IST in the northeastern sector within a range of 40 n.m. as scattered dots lying side by side with the convective echoes. During the next one hour the super-refraction echoes spread all round the station, the significant ones lying between northwest and northeast at the range 20—40 n.m. By 1950 the super-refraction further intensified in the northeast sector and echoes began to appear towards north and northeast at 50—60 n.m., and also towards south up to 50 n.m. (Fig. 1 a). The maximum range of super-refraction was observed at 2045 IST when weak echoes were seen upto 80 n.m. towards the north and the south and beyond 60 n.m. towards east and west (Fig. 1b).

Subsequently the more distant super-refraction echoes began to disappear and by 2119 IST a major part of echoes beyond 40 n.m. had dissipated (Fig. 1 c). However, weak super-refraction echoes extending up to 80 n.m. could still be seen. After 2119 IST the nearer super-refraction echoes upto 25 n.m. range began to intensify again, as seen in the PPI photograph taken at 2145 IST (Fig. 1d). The super-refraction pattern underwent further change and except in the northern sector, the echoes beyond 20 n.m. disappeared at 2215 IST. Finally all the echoes disappeared at 2249 IST.

The routine radiosonde ascent taken at 1755 IST, which coincided with the occurrence of anomalous propagation showed a strong temperature inversion and large humidity lapse rate from ground upto 925-mb level.

3. Super-refraction observed on 2 June 1962

At 1220 IST of 2 June a few convective cells were detected in the radarscope towards southeast at the range of 20 to 50 n.m. By 1425 IST they intensified into a well developed group of thunderstorms extending from 100° to 190° in azimuth and 10 to 40 n.m. in range. Later the cells got aligned in a zigzag line oriented in the east-west direction, and came over the station from southeast at 1445 IST. Showers occurred between 1526 and 1600 IST and a rainfall of 5·7 mm was recorded. At 1550 IST a squall occurred with a maximum speed of 67 km/hr and lasted for 4 minutes. Between 1500 and 1600 IST, the period characterised by squall and strong gusty surface winds, the surface temperature fell by 12°C and humidity increased by 60 per cent. Thereafter, surface wind became light with occasional calm.

The cells began to dissipate after 1550 IST and thunderstorm at the station ended at 1620 IST. At about this time the super-refraction echoes appeared on the scope, extending the ground clutter in the east up to 30 n.m. (Fig. 2a). At 1700 IST the super-refraction also appeared towards the south as extension of ground echoes upto 25 n.m.,

TABLE 1

Meteorological data from the radiosonde ascent on 29 May 1962 at 1755 IST at Nagpur

Pressure (mb)	Height a.g.l. (m)	D.B. Temp. (°K)	Vapour pressure (mb)
967	0	298·0	27·0
925	400	304·6	14·9
900	645	303·7	15·3
850	1153	300·0	10·5
800	1684	294·4	11·1

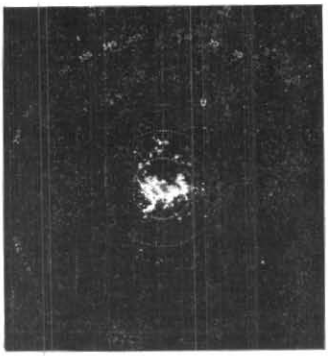
side by side with the decaying convective echoes (Fig. 2b). All the precipitation echoes vanished by 1740 IST and Fig. 2(c) shows the super-refraction pattern obtained at that time. On comparison of Fig. 2(c) with the permanent ground echoes (Fig. 2d) it may be seen that the super-refraction was extending upto 40 n.m. in east and southeast and up to 45 n.m. in south. The super-refraction echoes continued up to 2210 IST.

A temperature inversion, accompanied by steep fall in humidity, was observed from ground up to 900-mb level in the radiosonde ascent taken at 1641 IST.

4. Discussion

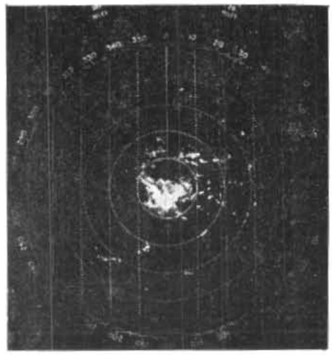
The echoes attributed to anomalous propagation appeared on the radarscope as extended ground coverage and showed no movement with time. Their characteristics were altogether different from precipitation echoes.

The radiosonde ascents, which were taken just after the appearance of super-refraction, confirmed the simultaneous occurrence of a temperature inversion and sharp fall in humidity with height at lower levels in both the cases. The radiosonde data of the evening of 29 May are given in Table 1 and corresponding vertical distributions of refractive



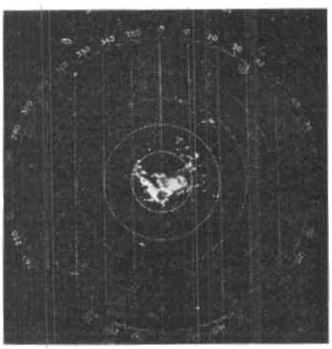
1950 20 1°

(a)



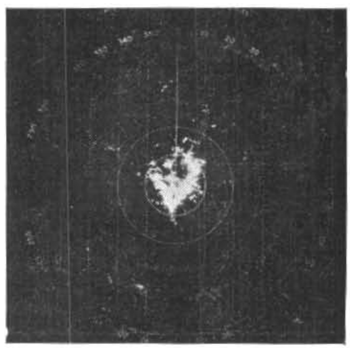
2045 20 1°

(b)



2119 20 1°

(c)

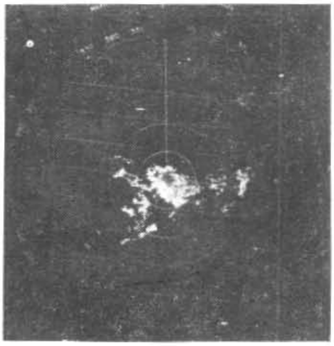


2145 20 1°

(d)

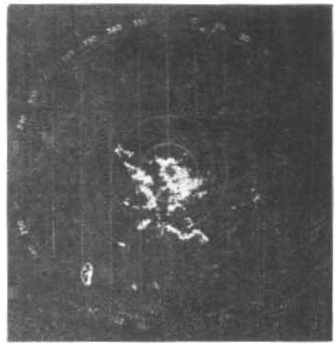
Fig. 1 (a, b, c, d). PPI photographs on 29 May 1962

(Figures at the bottom, from left to right, indicate time in IST, range rings in nautical miles and elevation in degrees respectively)



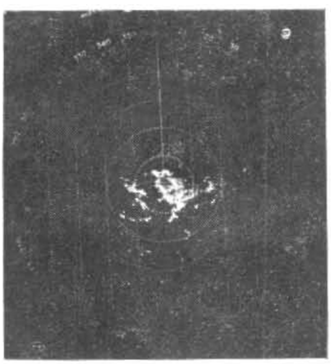
1610 10 1°

(a)



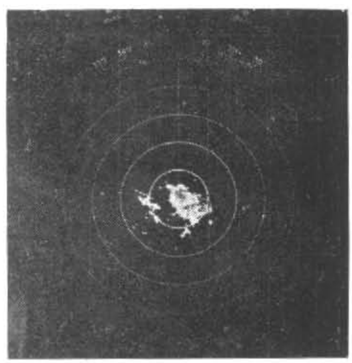
1700 10 1°

(b)



1740 10 1°

(c)



10 1°

(d)

Fig. 2 (a, b, c). PPI photographs on 2 June 1962
Fig. 2 (d). PPI photographs of permanent echoes

(Figures at the bottom indicate, from left to right, time in IST, range rings in nautical miles and elevation in degrees respectively)

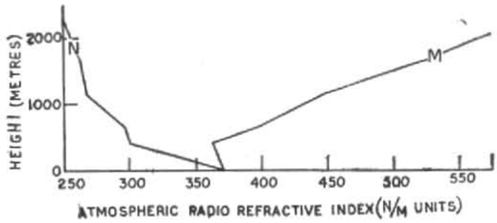


Fig. 3. Distribution of Refractive Index (N) and Modified Refractive Index (M) at Nagpur on 29 May 1962 at 1755 IST

index N and modified refractive index M are shown in Fig. 3. The M-inversion shows the existence of a ground duct upto 400 metres. The refractive index gradient within the duct was $-0\cdot18$ N units/metre which exceeds the critical value required for anomalous propagation.

On 29 May 1962, the super-refraction appeared at 1750 IST, when the surface wind speed was decreasing after the occurrence of two squalls. Before the squalls the air near the surface was warm and dry, at temperature 42°C and relative humidity 19 per cent. During the squalls the temperature fell sharply to 26°C and humidity rose to 84 per cent. The explanation offered is that during the squalls the downdrafts caused the cool and moist air, from the base of thunderstorm cells over the station, to spread rapidly over the ground displacing the relatively lighter warm air. Since this was caused by diverging downdrafts of violent thundersqualls, the whole process took a very short time and no large scale mixing between the warm and the cold air was possible except at the boundary of the two. A slight increase in surface temperatures after the squalls suggests that there could have been only slight mixing. With the cold moist air settling below the warm dry air, the temperature inversion and steep humidity lapse rate were built up. The conditions were then favourable for the occurrence of super-refraction.

On 2 June 1962, the super-refraction was observed when the surface wind had weakened, just after the squall had produced a favourable refractive index profile, and it persisted till the wind was light or calm. However, in the first case of 29 May 1962, the anomalous propagation was sustained with much stronger surface wind, reaching even 37 km/hr in gusts, while in the second case the phenomenon was observed till the wind was light or calm. It was also seen that the temperature inversion and humidity lapse rate built up in the first case were much stronger than in the second, possibly due to more vigorous thunderstorm activity, Hence, although strong surface wind might tend to destroy the favourable conditions because of turbulence, the super-refraction can be sustained by moderately strong wind in cases where the temperature inversion and humidity lapse rate are sufficiently strong.

Cases of super-refraction associated with thunderstorms have also been discussed by De (1959) and Mathur and Kulshrestha (1961).

5. Conclusion

The anomalous propagation of centimetric waves associated with thunderstorms occurs when the diverging downdraft from a thundersquall spreads cold moist air over the ground and below the warm dry air, thus forming a radio duct (Battan 1959). A calm wind after the squall may help in forming the ground duct and its continuance; but the duct may exist even with moderately strong surface wind, depending upon the strength of temperature inversion, humidity lapse rate and thickness of the duct. The duct may be eventually destroyed by turbulence; or aided by radiative cooling of earth's surface in case of thunderstorms taking place in the evening or night.

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