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On super-refraction after the passage of a thunderstorm

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ABSTRACT. A situation is described when the 3·2 cm high power radar at Safdarjung showed unusual ground coverage due to super-refraction near the earth's surface. It occurred after the passage of a frontal thunderstorm. Super-refraction is generally associated with stability in the atmosphere. A case is discussed in which super-refraction occurred in an atmosphere which sustained thunderstorm activity.

1. Introduction

In a paper by the senior author (see ref.), a reference was made to the occurrence of the phenomenon of super-refraction at New Delhi (Safdarjung) on the evening of 20 November 1957—a couple of hours after the passage of a thunderstorm. The phenomenon is described here in detail and an attempt has been made to provide an explanation for the same.

2. The synoptic situation

A day prior to the date in question, *i.e.*, on 19 November 1957, a western disturbance moved away across the extreme north of the country and a low pressure area which was affecting Punjab and neighbourhood was moving away eastward across Punjab-Kumaon hills. Rain and thunderstorm occurred locally in Jammu and Kashmir and at a few places in Punjab and West Rajasthan. On 20 November 1957, according to 0830 IST observations, thundershowers were fairly widespread in Jammu and Kashmir, Himachal Pradesh, the Punjab and west Uttar Pradesh. Scattered thundershowers were also reported in east Uttar Pradesh and west Rajasthan.

3. Factual description of the observations

At 1030 IST on 20 November 1957, the high power radar CPS-9 at the Weather Radar Unit, Safdarjung (India met. Dep. 1958) observed the disturbance located between 45 and 95 miles westsouthwest of Delhi. By 1240 IST, the scattered thunderstorm cells had aligned themselves into a line pattern and were only 25 miles from the station. The thunderstorm, extending from SSE to WNW, can be seen in Fig. 2. By 1310 IST, the thunderstorm became more intensified and precipitation extended to about 30,000 ft at a distance of 25 miles at 275° azimuth from the station (Fig. 3). The movement of the line of thunder cells was westerly and it was expected to pass over the station.

The thunderstorm came over Safdarjung, New Delhi at 1335 IST. The maximum wind speed was 45 miles per hour and the station recorded 33 cents (about 8 mm) of rain. There was a sudden change in the humidity and the temperature fell by about 16°F or 9°C. The records of self-recording instruments, *viz.*, anemograph, microbarograph, raingauge, hygrograph and thermograph for 20 November 1957 are shown in Fig. 1.

By 1408 IST, the main body of the thunderstorm had passed over the station and was moving away eastwards. The squall line was, however, maintaining its shape and general characteristics. Because of rain all round the station and consequent heavy attenuation, no further photographs were taken.

When the radar was operated again at about 1555 IST, there was no rain at the station and the thunderstorm had moved further eastwards. However, typical echoes were observed upto about 60 miles in the east and these appeared to be due to ground reflection of the radar beam. This was an abnormal observation because normally ground clutter echoes are observed upto about 17 miles only on this radar. This unusual ground coverage is shown in the two off-centre PPI photographs (Figs. 4 and 5). On increasing elevation from 0° to 2°, the clutters disappeared and instead we got the thunderstorm pattern again (Fig. 6).

By 1700 IST, these echoes began dissolving and Fig. 7 shows that by 1720 IST, the clutters could be seen to about less than 50 miles only. That the vertical heights of these particular echoes were inappreciable is clearly shown by the RHI photograph (Fig. 8) which also shows an abrupt 'cut-off' of such echoes at about 42 miles.

This pattern went on dissolving and by 1745 IST these particular echoes were confined to about 30 miles only (Fig. 9).

By about 1830 IST, this abnormal phenomenon had disappeared and we had the normal pattern again. The normal ground coverage pattern is shown in Fig. 10 wherein the clutters extend to about 20 miles only.

The very nature of this particular type of echoes, their fixed position with respect to time, and their inappreciable heights, clearly indicate that they are due to reflection of the radar beam by surface objects. However, surface objects at ranges of this order (60 miles) cannot be seen unless the beam follows a path near to the earth's surface. The echoes observed were thus obviously the result of super-refraction taking place at the time of observation because of the ducting of the radar beam to a distance of about 60 miles.

The unusually large ground coverage persisted for about an hour only and then the clutters at larger ranges began to disappear. Within next two hours, the normal ground clutters (upto 17 miles east of station) only were to be seen showing that what had been observed during the previous two hours was a transient phenomenon due to some abnormal propagation of the radar beam.

On raising the elevation of the antenna, the usual thunderstorm pattern was seen. This is exactly what was to be expected if it was a case of super-refraction. The ray, which appeared to be caught in a duct, was able to penetrate it when the elevation was raised above a critical angle. All these facts proved that what was observed was super-refraction or duct propagation.

4. Discussion and explanation

Super-refraction or duct propagation of radar beams is a well known and fairly well explained phenomenon (Booker 1951, Kerr 1951, Sheppard 1946). It is generally confined to a height of about 1000 ft or so above ground and is produced due to layers of rapid decrease, with elevation, of the index of refraction. In such layers, called ducts, unusually long ranges of radar detection may occur. These ducts are generally associated with temperature inversions where the water vapour content decreases rapidly with elevation, *i.e.*, where there is an abnormal moisture lapse rate. The direct effects of temperature distribution through these layers are of less importance than the moisture distribution. The dependency of the index of refraction on pressure may be neglected.

Generally speaking, such conditions as described above are associated with stability in the lower atmosphere, such as on a calm winter morning when the change in the temperature rate and moisture content is expected to be well pronounced. Such phenomena are well quoted in the available literature. The most intriguing feature to be considered in the present case, however, is how super-refraction occurs in an apparently unstable atmosphere associated with thunderstorms. The following explanation is offered.

Due to thunderstorm, there was rain. The evaporating rainfall and the cooling of the earth's surface by as much as about 10°C most probably created a temperature inversion and an abnormal moisture lapse rate.

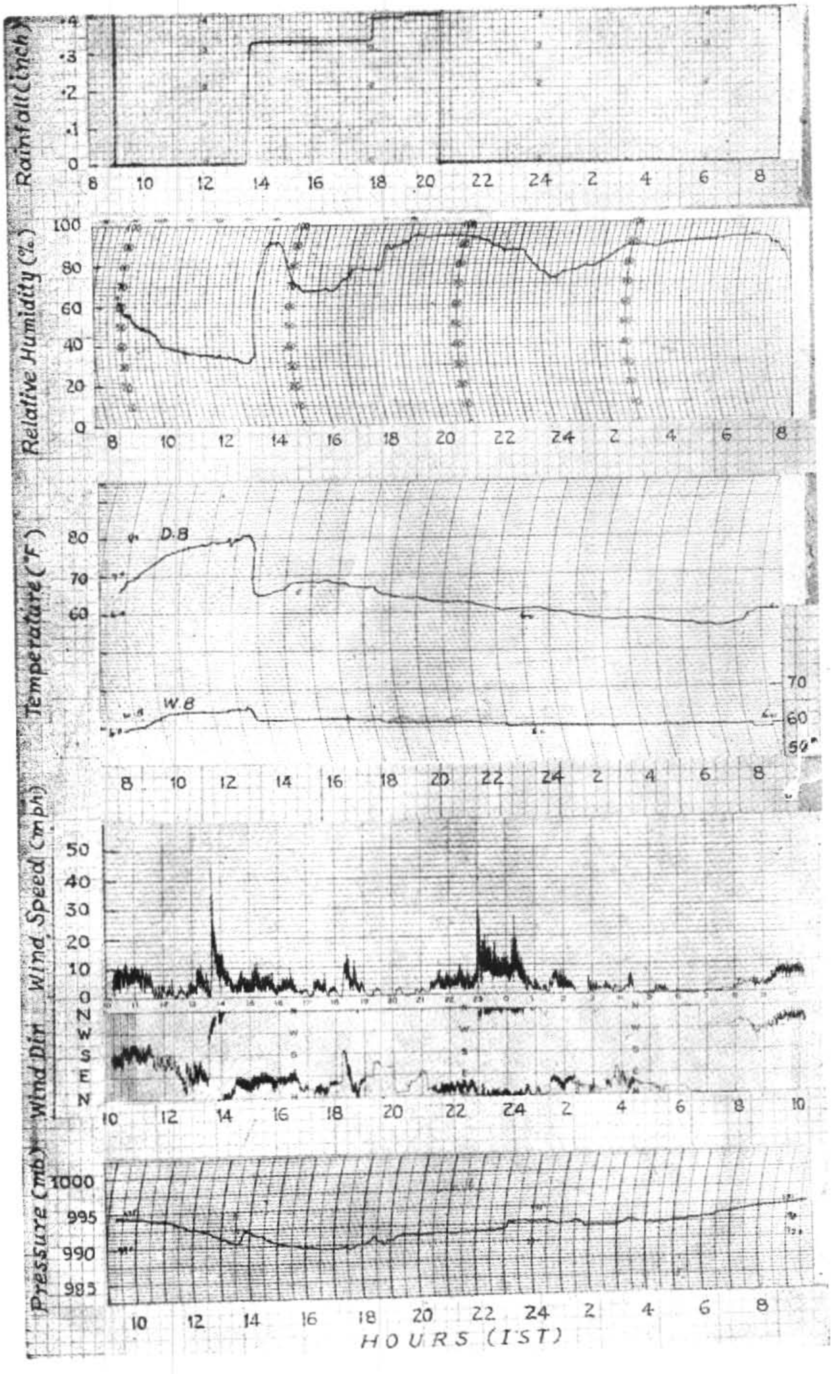
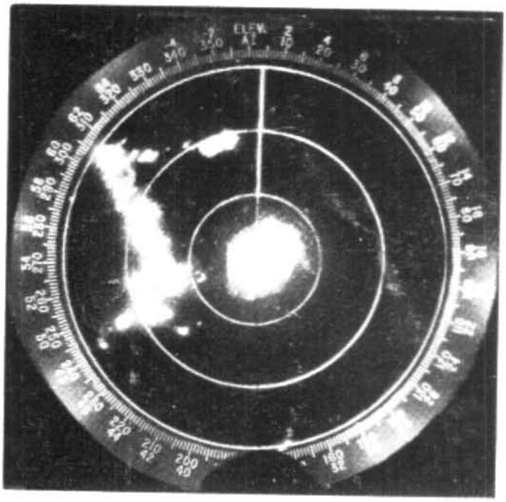
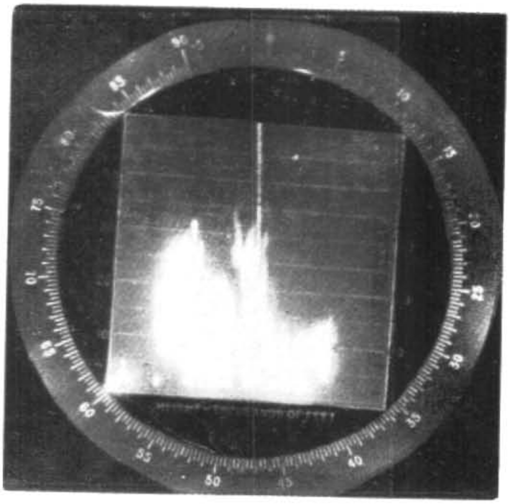


Fig. 1. Autographic records of New Delhi on 20 November 1957



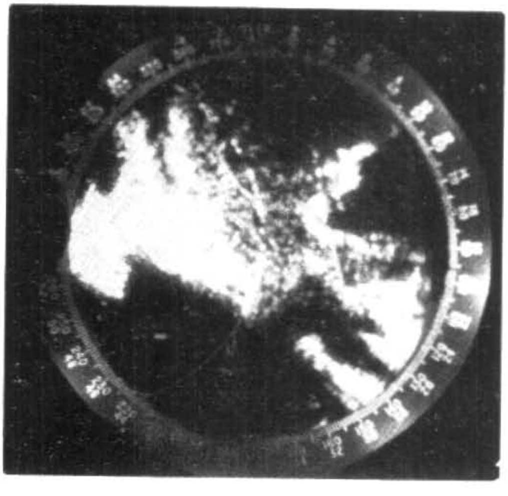
1240 IST Range 75 miles

Fig. 2



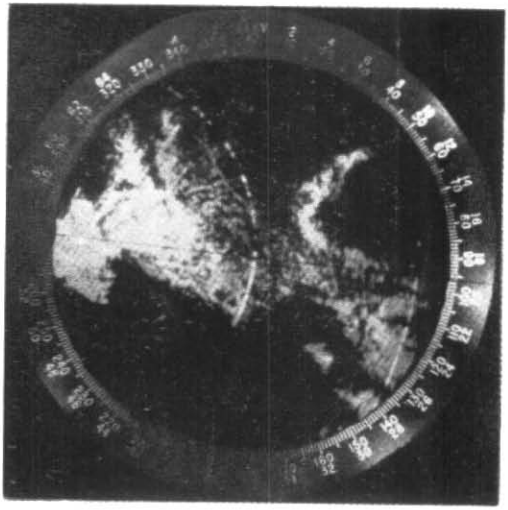
1310 IST Range 50 miles

Fig. 3



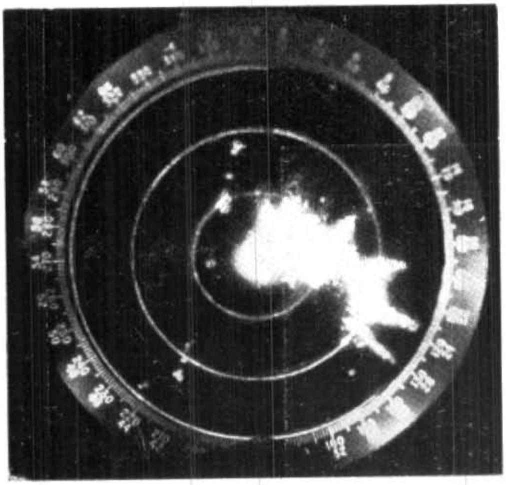
1625 IST Range 50 miles

Fig. 4



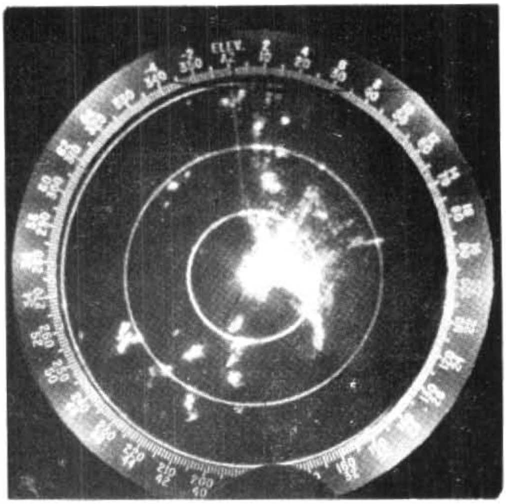
1630 IST Range 50 miles

Fig. 5



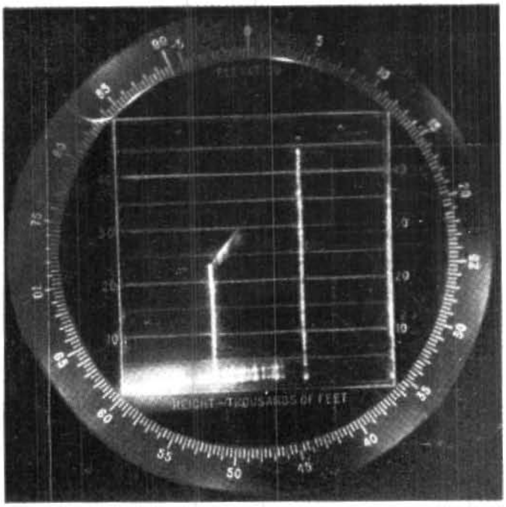
1635 IST Range 75 miles

Fig. 6



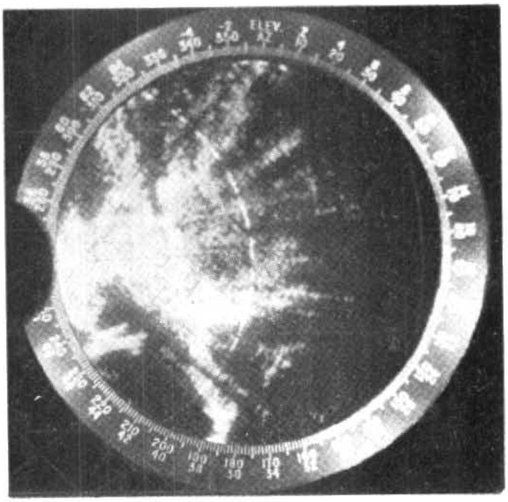
1720 IST Range 75 miles

Fig. 7



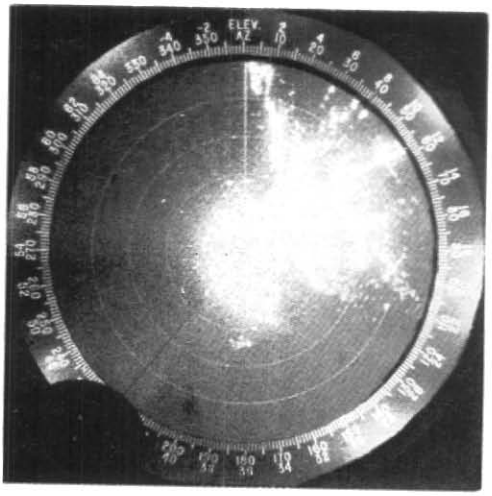
1725 IST Range 75 miles

Fig. 8



1745 IST Range 50 miles

Fig. 9



1830 IST Range 25 miles

Fig. 10

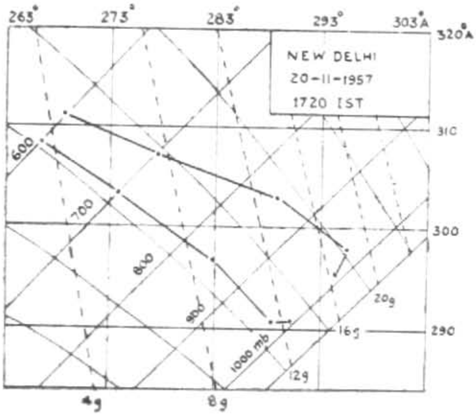


Fig. 11

The almost calm at the station combined with the overcast sky helped to delay the ground heating and consequent mixing. The abnormal moisture lapse rate, therefore, persisted for some time, and it was responsible for the unusual ground coverage. It happened in the direction of motion (eastward from the station) of the thunderstorm as naturally expected. As soon as there was slight rain at about 1810 IST and there was a rise in wind speed accompanied by a sudden shift in wind direction, the unusually "stable" conditions were disturbed due to mixing and the duct disappeared soon thereafter. Even if there would have been no rain, the abnormal propagation would have given place to normal 'line of sight' propagation as soon as the heating of earth's surface was sufficient to create enough mixing.

In a recent communication, De (1959) has discussed a similar occurrence at Dum Dum. According to him, "the downdraft from the thundersquall had brought cold and moist air to the surface and had well mixed the air near the ground. After the squall had passed over the station, the surface wind became light southerly and the air close to the ground became semi-stable. The temperature and humidity distribution was thus favourable for the formation of radioduct".

It is felt that unless there is almost calm wind at the station, such phenomemon is not likely to occur although the temperature and humidity distribution may be quite favourable. As can be seen from the anemogram, Delhi (Safdarjung) recorded almost calm at the time of occurrence of this phenomenon and super-refraction disappeared as soon as the wind speed rose to 10 mph. At this time there was a sudden shift in wind direction from northeast to south. Thus in the opinion of the authors, light wind at the station is a pre-requisite. De (1959) has not given the wind data in his paper and this point could not be examined in his case.

That there was a temperature inversion near the surface at about this period is shown by the 1720 IST radiosonde flight on 20 November 1957. A portion of the tephigram is shown in Fig. 11. However, the coarseness of the radiosonde data does not allow a quantitative calculation of the intensity of super-refraction to be made. Super-refraction phenomenon of the type as discussed in the paper is found to occur only rarely. During the period September 1957-February 1960, only this one instance could be noticed by the Safdarjung radar. It is thought that such phenomena are mostly associated with frontal thunderstorms which generally follow a certain sequence and the weather is more systematized. However, this is to be seen.

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DISCUSSION

Dr. P. Koteswaram said that such occurrences of super-refraction after passage of thunderstorm are not very unusual. It was observed on a few occasions at Dum Dum.

Shri S. M. Kulshrestha in reply said that one such instance has been referred to in the paper.

Gp. Capt. P. K. Sen Gupta mentioned that occurrence of such type of super-refraction after the passage of thunderstorm might be caused by many reasons and that apart from temperature, moisture and wind considerations there might be some other parameter affecting such occurrences.

Sq. Ldr. K. R. Saha emphasized the transient nature of this type of phenomenon as compared to the stable forms which are usually observed throughout the night due to nocturnal radiation and consequent inversions. He also mentioned the importance of wind in this respect which tends to wipe out the stratification observed.

Shri S. M. Kulshrestha replied that no doubt, wind considerations are important as pointed out in the paper but their contention was that the stratification would disappear due to normal ground heating and mixing even in case of light wind.

Dr. P. R. Pisharoty suggested that with the help of radar it will be worthwhile to make an attempt to divide area around each station into a number of zones and to study the number of thunderstorms passing through each zone.

Dr. U. K. Bose mentioned that this phenomenon of super-refraction over Indian region was observed during last war on a number of occasions when coastal lines of Arabia were seen in the radar located at Bombay. There is however, difference between this type of observation and the observation which has been mentioned just now, on account of its transient nature. In this connection, he also mentioned a recent paper under publication, in which the super-refraction phenomenon seems to be extended to the coastal line of Bengal from Dum Dum (De 1960, *Indian J. Met. Geophys.*, **11**, 4).

Shri S. M. Kulshrestha in reply said that a distinction has been made between the two types of super-refraction. That is why this super-refraction under unusual circumstances has been termed as abnormal super-refraction.