551·593 : 621·396·9(547)

Angels near Bombay

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(*Received 5 March 1962*)

ABSTRACT. "Angels", observed near Bombay during the past four years, with the 3-cm Weather Radar, are studied in this paper. It is seen that the distance of the zone of angel activity from the coast is influenced by the surface pressure and to a lesser extent by the surface temperature on land. It has been suggested that the regions of large refractive index gradients, formed by the subsidence of dry air to the lower moist levels in the sea breeze circulation, might be an angel source.

1. Introduction

Angels, the radar echoes from the regions of atmosphere apparently devoid of any particulate matter, are well known phenomena. Friend (1940) first observed such echoes and later a number of investigators who studied this phenomenon attributed the same to birds or to insect swarms. But this explanation had to be abandoned in the light of further investigations, which conclusively revealed that not all such echoes, could be due to birds and insects. The problem of enhancement of the radar cross-sections of the regions of the atmosphere from which these echoes arise, has been tackled only with limited success and it is now believed that the enhancement of the scattering cross-sections may be due to the presence of sharp refractive index gradients (not easily measurable on account of the limited resolving power of the available refractometers), over areas which may be large enough only to contain a few Fresnel Zones appropriate to the wavelength in use (Atlas 1960). Rai (1959, 1960) has studied the angels observed near Bombay. He has discussed the possibility of these echoes being due to sharp refractive index gradients occurring in either a large number of eddies in the sea-breeze front or in the horizontally stratified layers. The observed movement of the angels has been tentatively ascribed by Rai to the existence of shear-gravity waves in the stratified layers. The angel observations collected during the last four years' routine operation of the 3-cm radar* at Bombay have been studied in the present paper and a few interesting cases such as angels very near the coast, angels far away from the coast, angels occurring as an echo band oriented almost orthogonal to the coast etc have also been briefly presented. The distance of the zone of angel activity has been studied in relation to the surface pressure and the surface temperature on land. The location of the angel activity zone has also been examined in relation to the wind direction at the radar site. From these, the sea breeze circulation would appear to be mainly responsible for the formation of regions of sharp refractive index discontinuities which may serve as angel sources.

2. Observations

The angel echoes are generally observed to the west of Bombay coast (Fig. 1) during the period October to April or May. The layer of the angel activity is confined to a height upto 5000 ft above sea level. It may be mentioned here that these echoes are not observed along or to east of the coast. The echoes mainly occur on the warmer days in the afternoon and sometimes continue till late evening or night. Their intensity, shape,

*Decca Type-41, Wave length 3·2 cm, Peak power 20 KW, Pulse length 2·0 μ sec, P.R.F. 250 PPS, Horizontal beam width 0·75°, Vertical beam width 4·0°

distance from the coast and orientation are variable. 46 cases of angel activity were observed during the years 1958 to 1961. Simultaneous observations of clouds, wind direction and speed and the surface pressure and temperature at the time of observation of angels were also recorded and studied. A few more interesting cases are discussed in the following paragraphs.

Case I—Angel band perpendicular to the coast

On 1 October 1960, a few dot type echoes were observed to the west of the station in the afternoon. These later developed into well-marked angel bands (Fig. 2 a, 1732 IST). The PPI presentations at 1744 and 1836 IST were as in Figs. 2 (b) and 2(c). The echo disappeared at 1915 IST. The orientation of the angel bands in relation to the coast is a point of interest in these photographs.

Case II—Distant angel activity

On 2 October 1960 also, a few dot type echoes appeared to the west in the afternoon period and later developed into a zigzag band with non-uniform intensity (Figs. 3a to 3c). It is interesting to note that the zone of activity shifted westwards from about 40 miles at 2145 IST to 50 to 70 miles at 2306 IST (Figs. 3b and 3c). No activity was noticed after midnight.

Case III—Angel bands convex towards the coast

On the morning of 21 October 1960, some scattered angels appeared on the radarscope at a distance of about 10 to 20 nautical miles to the west of the coast. They persisted till evening when at 1740 IST they started orienting themselves in arcs somewhat convex towards the station (Fig. 4). The prominent echoes at 355° azimuth remained practically stationary unlike the angels to the west and northwest. The activity persisted upto 1810 IST.

Case IV—Angel band very near the coast

On 18 January 1961, a number of dot type echoes were present within 8 to 12 miles off-shore towards west which later oriented in the form of a N-S band. This band moved rapidly towards the coast and was at a distance of 6·1 n. miles at 1716 IST (Fig. 5, the second circle is the variable range marker at 6·1 n. miles). The N-S band then moved a little westward and finally disappeared.

Case V—Splitting angel echo bands

An intense wavy angel band oriented N-S appeared on the PPI on 27 February 1961 at 1400 IST (Fig. 6a). The band splitted into two, rejoined and also extended southward (Figs. 6b to 6e). The almost stationary echoes at 355° azimuth (Figs. 6c to 6e) are a noteworthy feature. At 1635 IST, the echo became imperceptible.

3. Discussion

The preferred time of angel activity, *i. e.*, afternoon to late evening, leads us to think that these angels might be associated with sea breeze circulation. At the same time, the fact that the angel echoes never cross or touch the coast line of Bombay shows that the activity might not be entirely due to the sea breeze front (*i.e.*, the region separating the land and sea air masses). The angel echoes in the form of lines nearly convex towards the station (Case III) show at the same time that all the angel echoes cannot be due to scattering of the radar energy from the horizontally stratified layers either, since the echoes so formed will orient themselves in a band more or less concave towards the station.

With and after the onset of sea breeze during the mid-day and afternoon period the moist air is drawn inland and a shallow radio duct is likely to form near the coast. For the sea breeze circulation to be complete, air returns from the land to sea at higher levels. If it be assumed that this air is relatively dry (which it most probably will be, being essentially of the land origin), then it can reasonably be thought that when this air subsides to the lower moist levels some distance off shore, it may create tongues of sharp refractive index discontinuities. These discontinuities may possess large radar scattering cross-section, and they may serve as angel sources. The likely presence of the shallow radio duct is further substantiated by the almost stationary echo to the north (355° azimuth) observed on many days of angel activity (Fig. 4, Figs. 6c to 6e).

The region of subsidence of the dry air returning from the land, which will now be the region of enhanced scattering cross-section, may occur near or far away from the coast depending upon the magnitude of the sea breeze circulation cell. This, in turn, depends upon the differences in the land and the sea pressures. Fig. 7 presents graphically the observed distance of the angel activity zone in relation to the surface pressure and temperature at about the time of echo occurrence. It can be seen from Fig. 7 that the distance of the angel activity zone does not vary so sensitively with the temperature. For a given temperature, however, it is seen that the lower values of the surface pressures are generally associated with relatively more distant angel activity.

According to the simplified theory of Humphreys (1940), the depth of the sea breeze h bears an inverse relationship to the surface pressure. The larger the h (*i.e.*, the lower the surface pressure), the more distant will be the zone of subsidence of the dry air (for off shore winds). This is qualitatively borne out by Fig. 7.

Table 1 is the contingency table drawn for the bearings of the region of angel activity and the corresponding prevailing wind directions. The more numerous occurrences of the angel activity zone in the sector 225°—360° for the wind direction, between 270°—315° further bring out the association of the angel activity zone with the sea breeze. Haurwitz (1947) has shown that the intensity of the sea breeze increases not only as long as the difference in temperature over the land and the water increases but it keeps growing until this difference disappears.

TABLE 1

Contingency table for wind directions against the zones of angel activity

Wind	ANGEL			
	NNW (315°-360°)	WNW (270°-315°)	WSW (225°-270°)	SSW (180°-225°)
NNW (315°—360°)	15	19	17	3
WNW (270°—315°)	25	36	30	8
WSW (225°—270°)	2	1	1	0
SSW (180°—225°)	1	0	0	0

According to Defant (1950) the phase delay between the occurrence of maximum difference in the land and sea surface temperatures and the maximum intensity of the sea breeze may vary from 1·4 to 4·7 hrs (the analysis by Haurwitz gives a value of 6 hours). It may thus be seen that the sea breeze circulation cell may continue to intensify and grow in size even after the epoch of maximum difference in the land and the sea surface temperatures. This may explain the observed westward movement of the angel activity zone in the evening on many occasions.

The occurrence of angel bands oriented east-west (a relatively rare case) is difficult to explain with the help of sea breeze circulation alone.

4. Conclusion

The data presented in this paper indicate that the sea breeze circulation plays an important role in the development of angel activity off Bombay. The refractive index discontinuities formed in the region where dry air subsides to the lower moist levels in the sea breeze circulation, would appear to be the cause of this phenomenon.

5. Acknowledgement

The authors wish to record their deep gratitude to Shri N. C. Rai Sircar for his kind interest in the work and encouragement. They are also thankful to the members of the staff in the Radar Unit for their cooperation in collecting the data.

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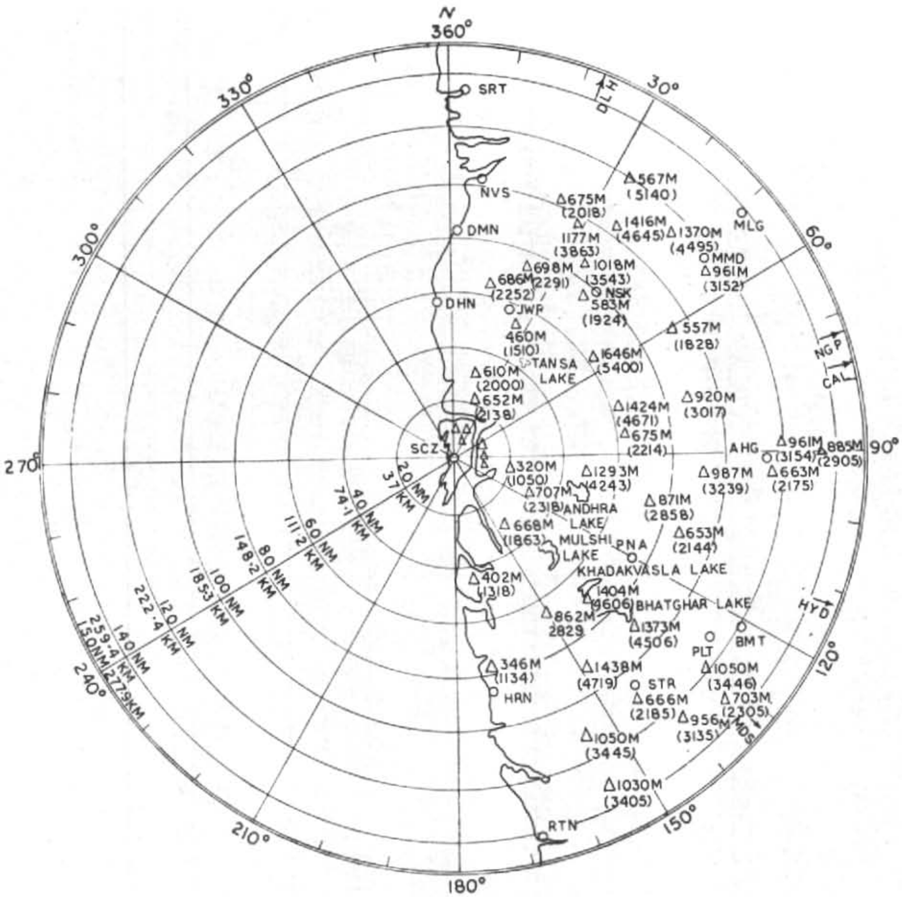


Fig. 1

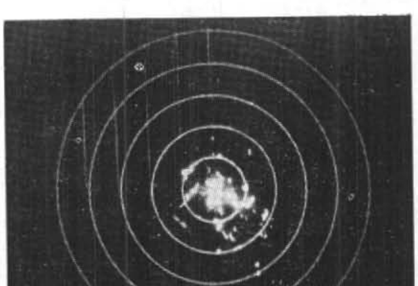
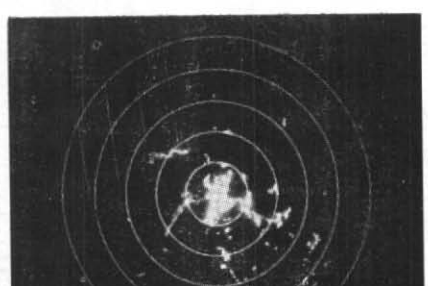


Fig. 2(a)



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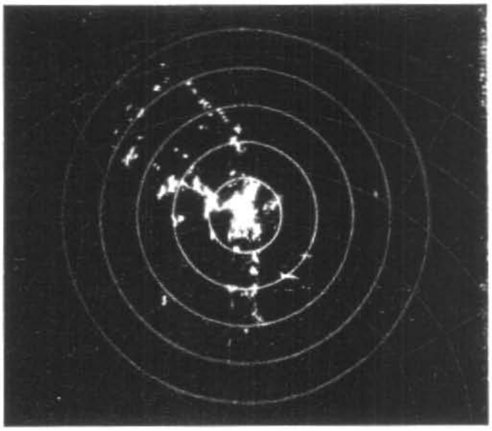

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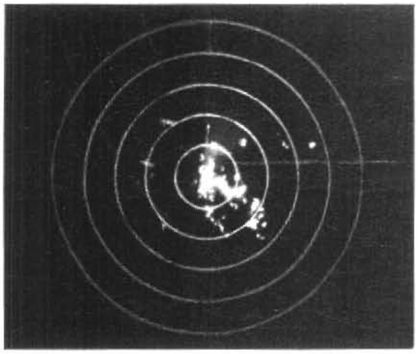

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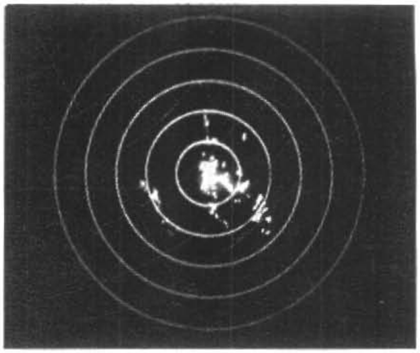

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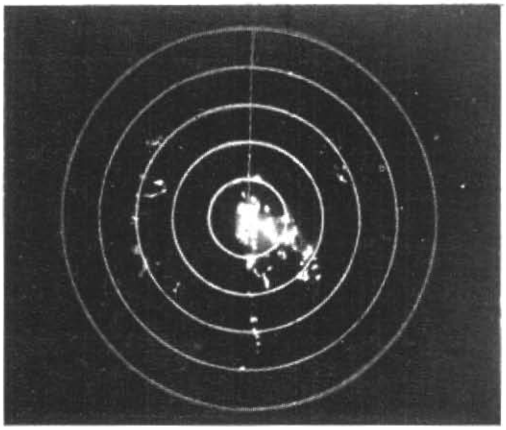

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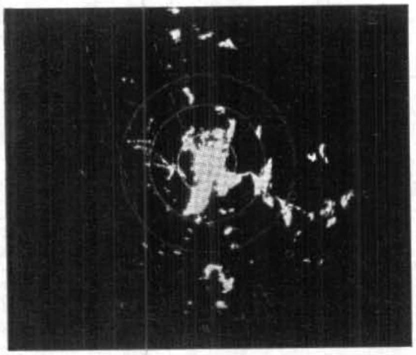


Fig. 4

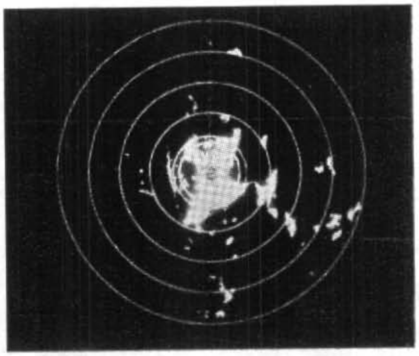
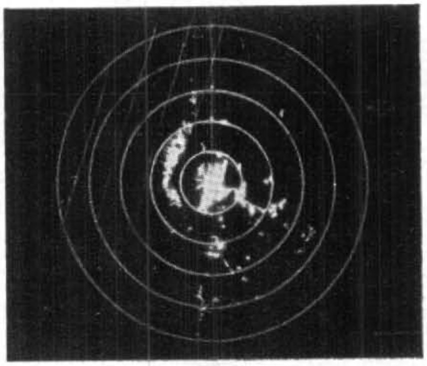


Fig. 5



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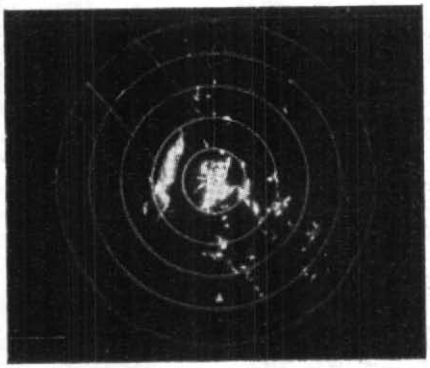
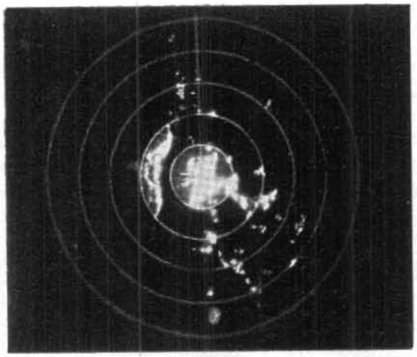


Fig. 6 (b)



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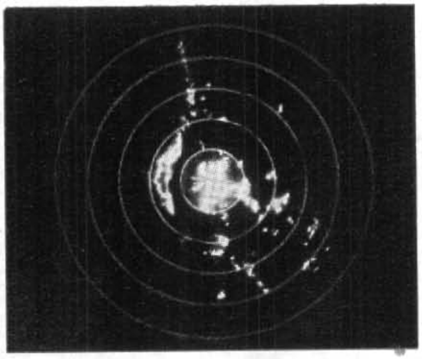

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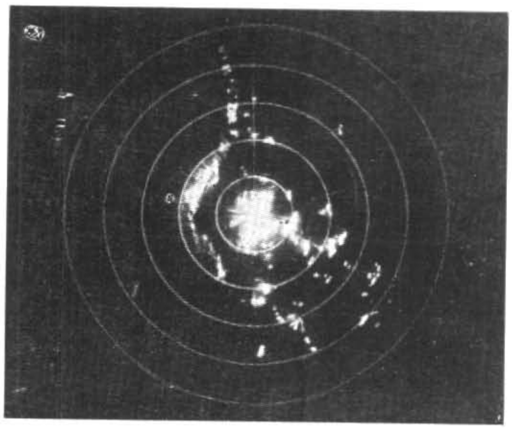

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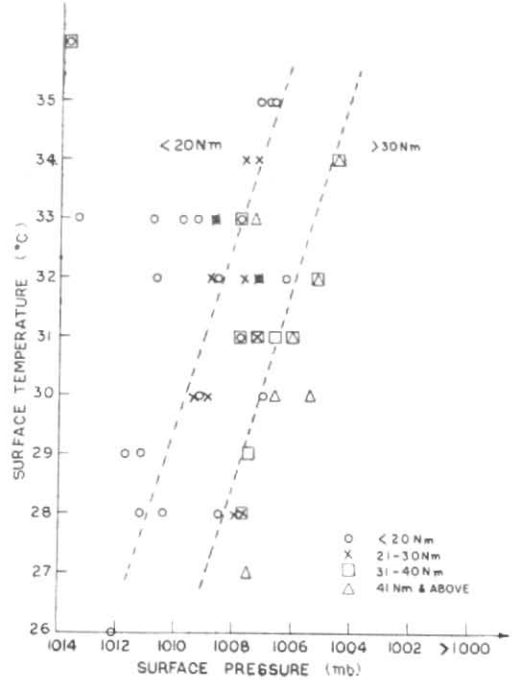
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X 21-30Nm
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△ 41 Nm & ABOVE

Fig. 7