TABLE 1

Mean values of diurnal range of temperature in the seventeen intervals of solar declination

Solar declination (degrees)	Date From	Date To	Mean (°F)	S.D. (°F)	Date From	Date To	Mean (°F)	S.D. (°F)
	Period I				**Period II**			
23	Dec 23	Jan 1	21·3	3·5	Jun 10	Jun 22	15·9	3·2
22	Jan 2	,, 10	19·4	4·9	,, 1	,, 9	16·6	3·8
21	,, 11	,, 16	21·3	5·4	,, 25	,, 31	17·7	3·7
20	,, 7	,, 21	23·4	5·7	,, 20	,, 24	16·5	5·1
19	,, 22	,, 25	21·6	3·6	,, 16	,, 19	20·6	5·1
18	,, 26	,, 29	21·1	4·9	,, 12	15	21·7	3·2
17	,, 30	Feb 2	23·7	6·1	,, 8	,, 11	21·7	3·0
16	Feb 3	,, 5	22·5	4·6	,, 4	,, 7	23·6	3·9
15	,, 6	,, 8	24·5	5·3	May 1	May 3	22·3	3·8
14	,, 9	,, 11	22·7	5·0	Apr 28	Apr 30	22·3	3·8
13	,, 12	,, 14	27·7	5·0	,, 25	,, 27	22·8	5·0
12	,, 15	,, 17	27·2	3·7	,, 22	,, 24	21·2	4·8
11	,, 18	,, 20	26·7	5·7	,, 19	,, 21	21·5	3·4
10	,, 21	,, 23	24·7	5·5	,, 16	,, 18	22·6	3·5
9	,, 24	,, 25	27·6	7·4	,, 13	,, 15	22·4	3·1
8	,, 26	,, 28	26·5	6·4	,, 11	,, 12	22·4	3·0
0–7	Mar 1	Mar 21	25·4	5·1	Mar 22	,, 12	23·4	3·6
	Period III				**Period IV**			
23	Jun 23	Jul 3	14·2	4·5	Dec 11	Dec 22	18·8	5·0
22	Jul 4	,, 12	14·5	4·1	,, 2	,, 10	19·7	6·2
21	,, 13	,, 18	15·8	3·5	Nov 26	,, 1	18·0	5·8
20	,, 19	,, 24	13·9	3·5	,, 21	Nov 25	16·2	5·3
19	,, 25	,, 28	14·2	3·5	,, 17	,, 20	15·[illegible]	4·4
18	,, 29	Aug 1	14·1	3·7	,, 13	,, 15	16·7	5·1
17	Aug 2	,, 5	13·6	3·2	,, 9	,, 12	18·6	6·0
16	,, 6	,, 8	14·9	2·7	,, 6	,, 8	18·9	5·7
15	,, 9	,, 12	15·9	3·8	,, 3	,, 5	16·3	2·2
14	,, 13	,, 15	16·1	3·3	Oct 31	,, 2	15·9	3·8
13	,, 16	,, 18	15·7	4·0	,, 28	Oct 30	17·4	4·2
12	,, 19	,, 21	16·1	3·2	,, 25	,, 27	17·6	4·2
11	,, 22	,, 24	15·7	2·4	,, 22	,, 24	16·7	3·7
10	,, 25	,, 27	17·1	2·0	,, 20	,, 21	15·7	2·2
9	,, 28	,, 30	16·1	2·2	,, 17	,, 19	15·9	3·1
8	,, 31	Sep 2	18·0	3·8	,, 13	,, 16	17·4	3·0
0–7	Sep 1	,, 23	18·2	3·8	Sep 24	,, 12	17·4	3·8

S.D.—Standard deviation

TABLE 2

Correlation coefficient (γ) of diurnal range of temperature between periods

Period	Period II	Period III	Period IV
I	0·51*	0·56*	—0·29
II		0·51*	—0·47
III			—0·22

* The values are significant for $P=0·05$

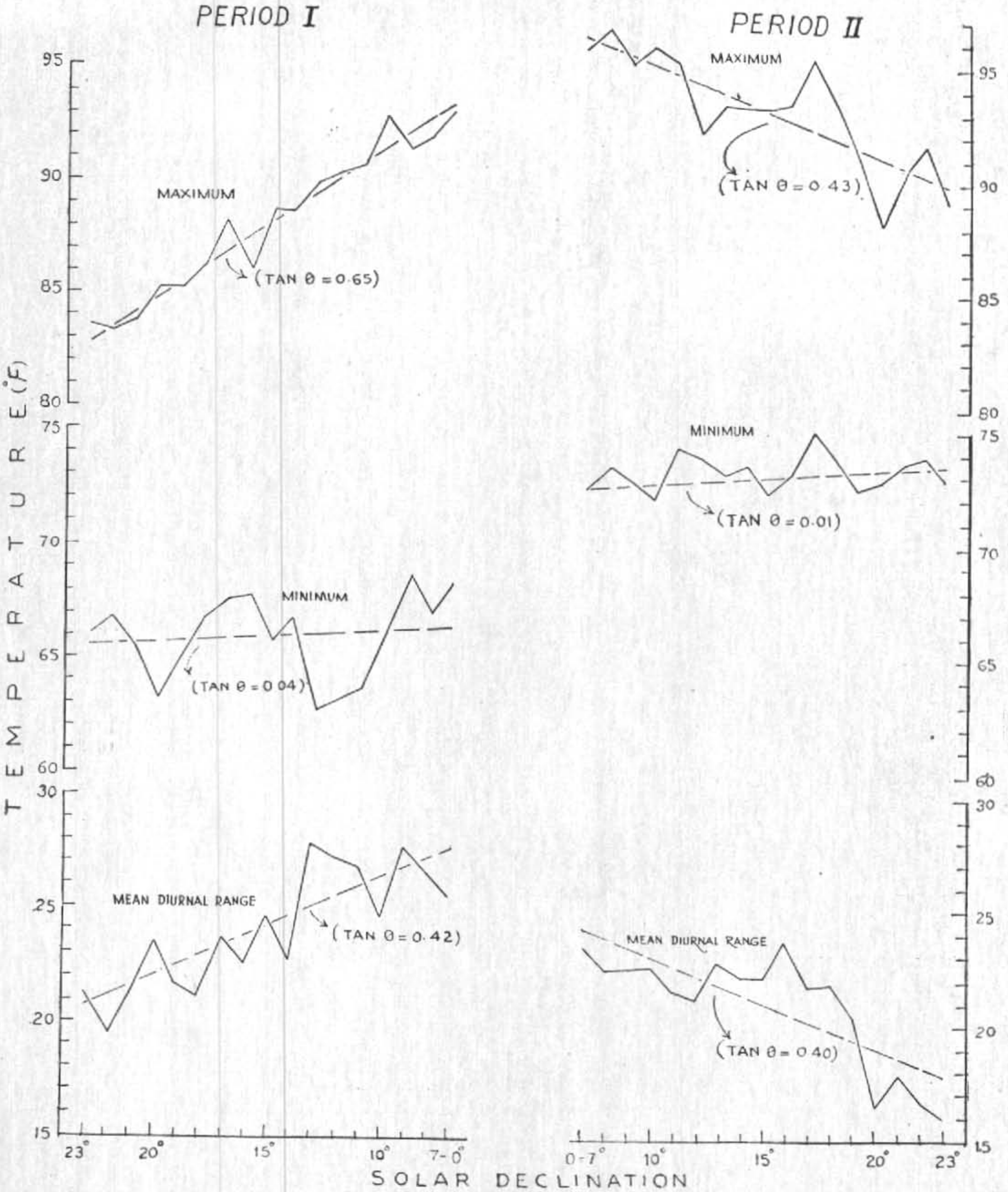


Fig. 1(a). Maximum and minimum temperatures and mean diurnal range of temperature at Coimbatore for the Periods I and II

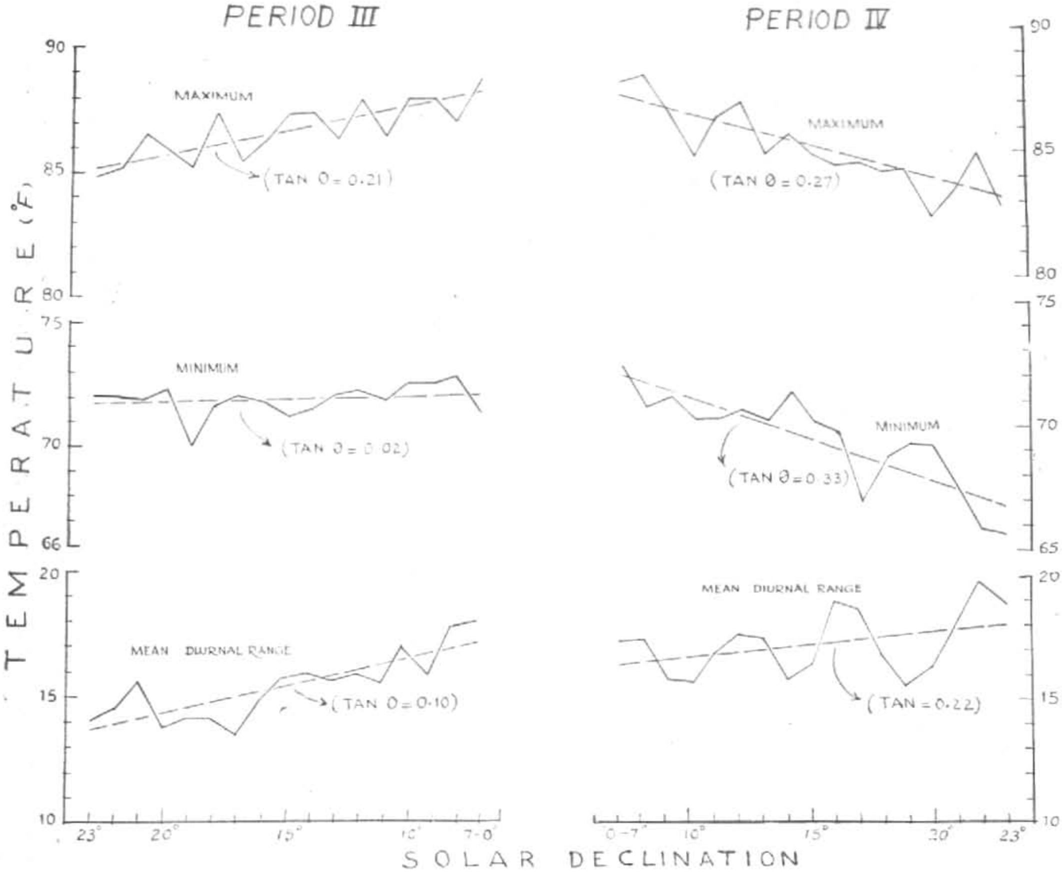


Fig. 1(b). Maximum and minimum temperatures and mean diurnal range of temperature at Coimbatore for the Periods III and IV

551·553·11 : 621·396·96

ANGEL OBSERVATION IN ASSOCIATION WITH SEA BREEZE

Radar angels in the form of dots have been observed on some occasions during the post-monsoon and winter periods on the PPI scope of a 3-cm radar Decca (Type 41) based at Bombay. The set characteristics are given in Table 1. These angel echoes appear as a number of small dots confined to one particular sector or quadrant mainly towards the west and are not evenly distributed around the station. The echoes are obtained generally upto 15 miles range with 0—2° aerial elevation, only with the longer pulse-length (2·0 μ sec). As this radar is provided with PPI display only, information regarding the vertical structure of the echoes cannot be obtained.

A particularly well marked echo pattern of dot-type occurred on 31 October 1958 just before the setting in of the sea breeze. These echoes just appeared at 1335 IST in the W-NW at range 5—12 miles and continued till 1406 IST. The echoes at longer ranges started disappearing first. The movement of the echoes was rather

TABLE 1

Wave-length	3·2 cm
Peak transmitted power	2×10^4 watts
Pulse length	0·2 μ sec 2·0 μ sec
Pulse repetition frequency	250
Horizontal beam width	0·75 degrees
Vertical beam width	4·0 ,,

erratic and it was difficult to find a particular dot persisting for more than one or two sweeps. The distribution of the dots was also random though in some of the photographs presented, there is an indication of certain orientation. Fig. 1 shows a set of photographs of the echoes taken during the period 1340 to 1412 IST. Photographs were taken as and when the echo pattern was changing and not at regular intervals. From 1400 IST onwards the number as well as intensity of the dots started decreasing and by 1412 IST no echo could be seen. The echoes were not tracked as in the case of sea breeze observation with 1·25 cm radar reported by Atlas (1953). It is, therefore, difficult to associate these with sea breeze front as such. The association of the echoes with the onset of the sea breeze is, however, unmistakable.

Fig. 2 gives the relevant portion of the day's anemogram. At 1415 IST the wind changed sharply from northeast to west-northwest. The temperatures and humidity graphs for the day are given in Fig. 3. Though there was not much fall in temperature, quite an appreciable shift in relative humidity occurred.

The dot-type angels observed with horizontal incidence have been reported and discussed by a number of workers in England and America (Plank 1956, Jones 1958). In about all these cases the echoes are explained as reflection from ground objects *via* some atmospheric inhomogeneity. In the present case, however, there being no ground objects to the west, the above explanation is not tenable. Keeping in

TABLE 2

T_1	T_2	q_1	q_2	$\triangle n$
305·8°A	304·1°A	9·4 gm/Kgm	12·8 gm/Kgm	25N

view that the echoes are observed at ranges near 10 miles with 0-2° aerial elevation, for an explanation of these echoes one has to look for some reflecting source in the lower atmospheric layers below 2—3000 ft. The nature and distribution of the echoes suggest a random distribution of such source elements within the area concerned. The simplest picture to visualise, is the existence of a large number of eddies. These eddies may be either air parcels of high humidity in a relatively dry environment or dry air parcels in a relatively humid environment. The portions of the radar beam incident on such eddies will be partly reflected back from the boundaries. The size and distribution of echoes so obtained will, therefore, depend upon the distribution of eddies and the refractive index difference between the eddies and the environment.

The occurrence of the echoes just before and their disappearance just after the onset of sea breeze may be explained by assuming that the eddy activity reaches the maximum before the setting in of the sea breeze and the eddies are destroyed, at least temporarily, by the sea breeze circulation.

The refractive index for microwave frequencies as given by the empirical equation

$$N = \left(n - 1\right)\times 10^6 = \frac{79}{T}\left(P + \frac{4800}{T}e\right)$$
$$\approx \frac{79}{T}P\left(1 + \frac{7\cdot 71}{T}q\right)$$

where N is the modified refractive index, n the refractive index, P the pressure, T the temperature, e the vapour pressure and q the specific humidity.

The temperature and specific humidity values before and after the sea breeze as derived from Fig. 3 are given in Table 2.

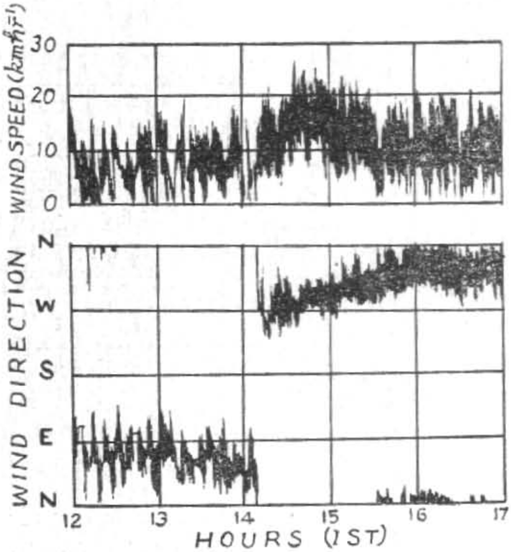


Fig. 2. Anemogram record of Santacruz on 31 October 1958

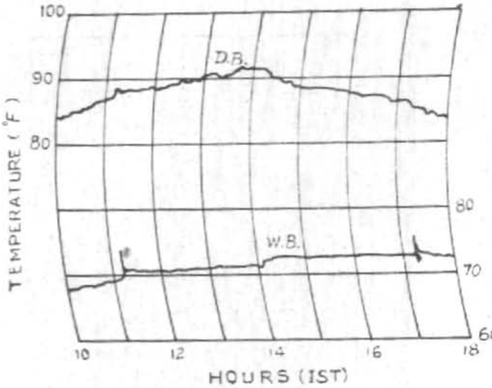


Fig. 3(a). Thermograph record of Santacruz on 31 October 1958

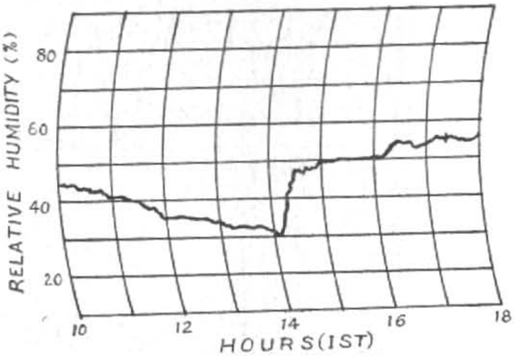


Fig. 3(b). Hygrograph record of Santacruz on 31 October 1958

Using the observed temperature and specific humidity changes, the refractive index change as computed from the above empirical equation is about $25N$ (taking $P \approx$ 1000 mb).

The refractive index difference across the front in case of the sea breeze angels observed by Atlas and co-workers was $30N$ as measured with a refractometer.

Assuming that the size of the air parcels concerned is very large compared with the wave-length ($a >> \lambda$) and that the refractive index difference between the eddies and environment is approximated by that across the 'front' for the portion of the beam normally incident on the air parcel, the problem is similar to that of vertical incidence. If we take the power reflectivity of these angel sources even as low as of the order of 10^{-13} and use the refractive index difference computed above, in order to get eflections at $\lambda = 3$ cm, the thickness of the layer across which this refractive index difference must exist is of the order of 10 cm. Whether such a sharp refractive gradient exists at the boundaries of the air parcels is yet to be known.

D. B. RAI

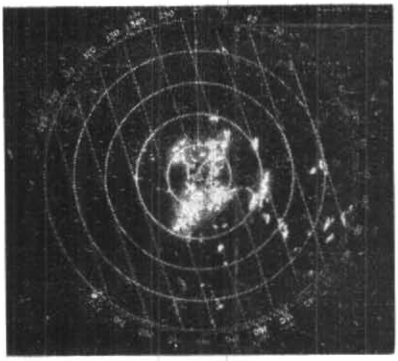
Meteorological Office,
Bombay
February 23, 1959

REFERENCES

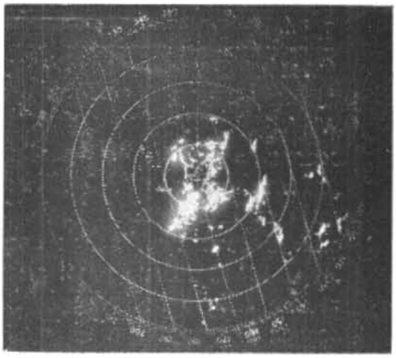
Atlas, D. *et al.* 1953 *Proc. Conf. Radio Met. Austin* Univ. Texas.

Plank, V. G. 1956 *Geophys. Res. Pap.*, 52, Air Force Cambridge Research Centre, Bedford, Mass.

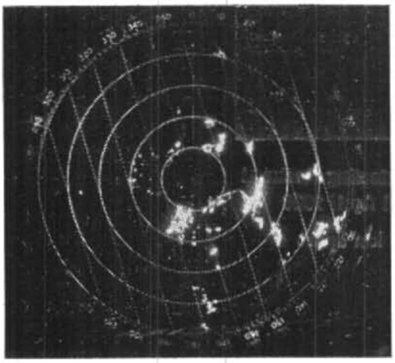
Jones, R. F. 1958 *Quart. J.R. met. Soc.*, **84**, p. 437.



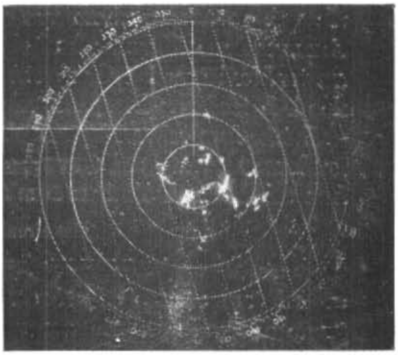
At 1340 IST



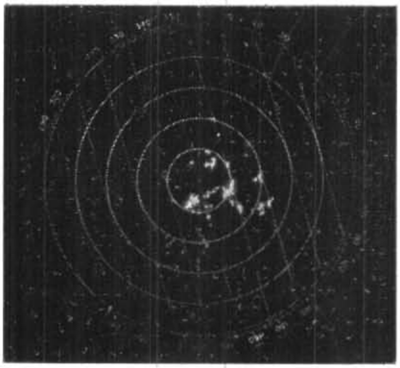
At 1343 IST



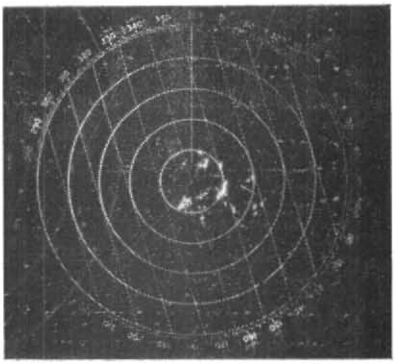
At 1352 IST



At 1355 IST



At 1403 IST



At 1412 IST

Fig. 1. Photographs of PPI scope showing the dot echoes during the period 1340–1412 IST on 31 October 1958

Observations were taken at 25 miles range with range markers at 5 miles interval upto 1352 IST, later at 50 miles range with range markers at 10 miles interval

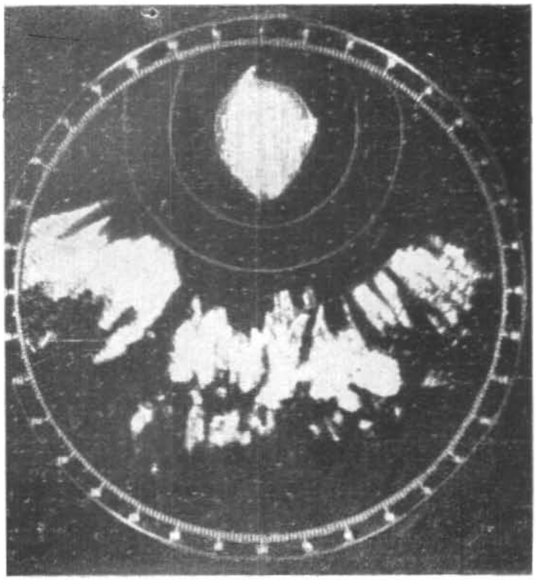


Fig. 1. PPI presentation of the Storm Detecting Radar at Dum Dum Airport at 1730 IST on 24 April 1959

The circular range markers are 20 km apart

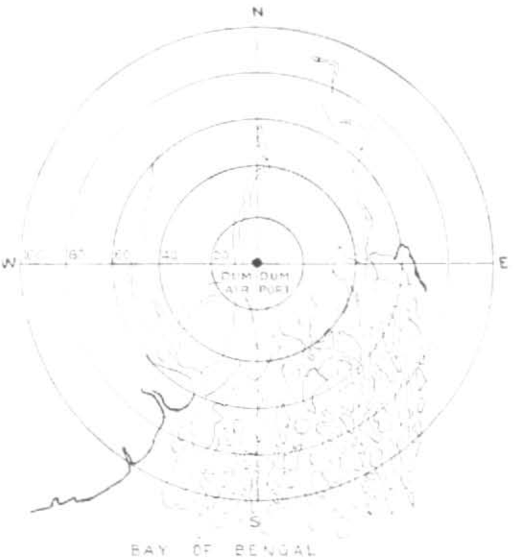


Fig. 2. A sketch showing the Bay Coast

The circular rings are 20 km apart