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The formation and structure of a rare fog at Jodhpur

D. VENKATESWARA RAO and A. K. MUKHERJEE

Meteorological Office, Jodhpur

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ABSTRACT. The meteorological conditions leading to the formation of a rare fog, which caused a spectacular lunar corona at Jodhpur in the early hours of 18 January 1957, have been investigated. The observed reversal of the surface wind just prior to the development of fog is explained.

The variation in the angular diameter of the red annulus of the lunar corona at different times showed that the fog was homogeneous soon after formation with a droplet diameter of 18·2 μ. It is shown from the changes in the chromatic structure of the corona that the drop size increased rapidly with the ageing of the fog but did not, however, exceed 50 μ before its dissipation.

1. Introduction

The phenomenon of fog is almost unknown at Jodhpur during the winter months. Solar or lunar coronas due to fog do not appear to have been reported in India. Yet a well formed lunar corona was produced by a thick fog at Jodhpur just before sunrise on 18 January 1957. As Rao and Banerji (1954) have shown, optical phenomena caused in the atmosphere are capable of yielding surprisingly useful information on the physical structure of the material particles responsible for their manifestation. It is the purpose of this note to analyse the meteorological conditions leading to the formation of this rare fog and to examine the light thrown on its structure by the coronal rings it produced.

2. The phenomenon observed

The atmosphere was clear with a visibility of 4 nautical miles till 0650 IST. There was *sudden* development of fog at 0700 IST with a sharp drop in the visibility to 1000 metres. The moon was nearly full and was at an altitude of 22° 46′ above the western horizon. The time of sunrise on this day was 0727 IST. The moon was noticed to have been encircled at 0700 IST by a bluish-white aureole fringed on the exterior by a reddish-brown ring. The rings were symmetrical around the exciting luminary.

The angular diameter of the outer edge of the ring was estimated to be about 6° 30′ at 0700 IST when the phenomenon first appeared. It was most distinct at 0712 IST when it was about 5° 30′ in outside diameter. By 0714 IST the fog attained its maximum thickness, visibility reducing below 100 metres. The red ring was observed to shrink and darken into reddish-brown on the outer margin and bluish on the inner edge, no other spectral colours being distinguishable in between. It disappeared together with the moon at 0715 IST when elevation of the moon was 20° 2′ above the horizon. The shrinkage of the angular dimension of the red ring was of the order of 30′ of arc at the time the phenomenon was lost to view.

The fog lasted till 0820 IST. A watch was kept for the appearance of a fog-bow after sunrise. No trace of it was, however, discernible.

3. The synoptic situation

A shallow land low appeared over north Gujarat and adjoining Rajasthan on the evening of 16 January 1957. It intensified slightly and moving eastnortheastwards lay over north Madhya Pradesh and adjoining Rajasthan on the evening of the next day. Under its influence, a small cyclonic circulation appeared between Jodhpur and Jaipur. It was shallow and extended upto

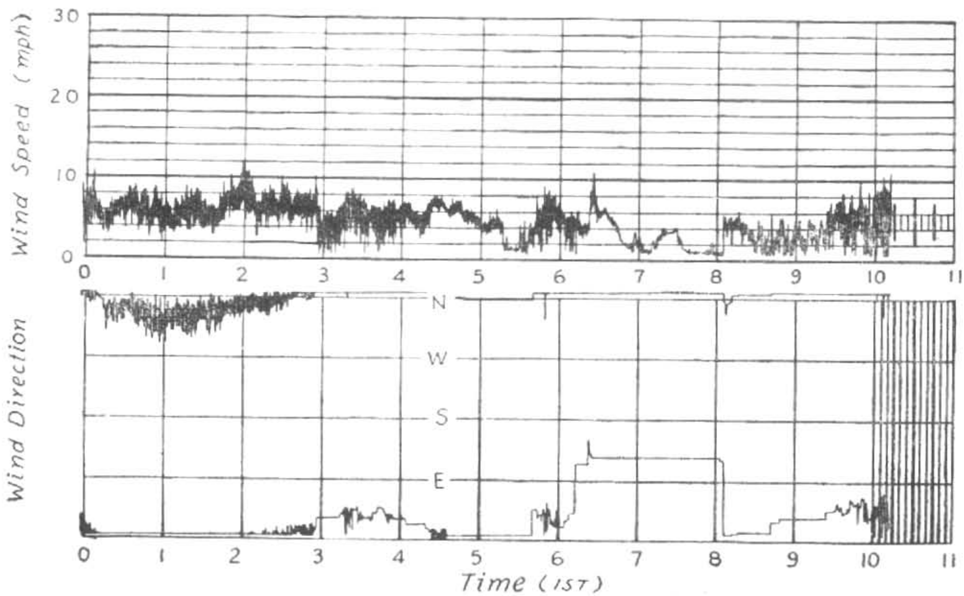

Fig. 1

1·5 km a.s.l. An anticyclone appeared over west Rajasthan and neighbourhood by 0830 IST of 18 January.

4. The local weather at Jodhpur

The local sky was cloudy on 17th morning but cleared towards midnight. Subsequently it remained practically clear till the fog developed. The dry bulb temperature fell to 53°F at 0405 IST on 18 January and remained so till 0620 IST. It later fell rapidly to 49·7° by 0715 IST, a drop of 2°F having occurred during 0620 to 0650 IST. It remained steady at about 50°F till 0815 IST after which the usual diurnal rise was registered. The surface wind was NNW, 5-10 knots, from the early afternoon of 17 January till 0615 IST of 18 January. It then shifted suddenly to southeast and weakened to 2-4 knots remaining so till 0810 IST. Later, it backed to the northeast and rose in speed to 8-12 knots.

No ground inversion was present on the morning of 18 January or earlier. At 0830 IST on 18 January, the temperature at 1 km was 49·5°F while the minimum temperature was only 49·7°F.

5. Discussion

5.1. *Suddenness in development and density of the fog*—The dew-point temperature at 2330 IST during the period 16-20 January ranged between 5 to 7°C on all days *except* on 17 January when it was 11°C. Further, there was steep radiational cooling due to the clearing of the sky after midnight, following a warm day. The temperature reached at 0630 IST on 1 January was 8°C as against the dew-point of 10·6°C. The suddenness of the formation of the fog appears, therefore, to be largely attributable to the steep radiational cooling of more than the required magnitude, which presumably attained its maximum just before sunrise, resulting in the vapour pressure in the atmosphere equalling or exceeding the equilibrium value by 0650 IST.

5.2. *The behaviour of the surface wind in relation to the density of the fog*—The anemogram of 18 January shows a reversal of wind direction from westnorthwest to southeast at 0615 IST (Fig.1). The reversed wind direction was maintained till 0810 IST, the northerly component having reasserted itself later.

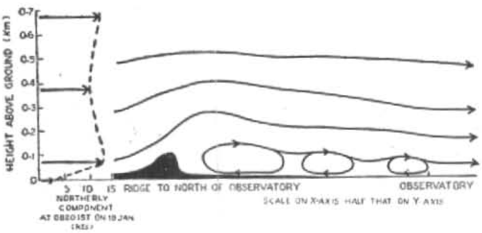

Fig. 2. Reversal of surface wind at observatory due to formation of stationary eddies

There is a straight ridge at a mean distance from the observatory of 1 mile 2 furlongs stretching from the northwest to the north with a height increasing from 207 feet at the northwestern end to 303 feet at the northern end. From this end onwards the ridge slopes away gently into the plains. The ridge facing the observatory is precipitously steep in the northwestern quadrant.

That even low hillocks can produce sizeable perturbations in the horizontal flow patterns of the upper air has been shown by Rao and Raghavan (1950) in respect of the airfield at Visakhapatnam. Forchtgott (Corby 1954) had found that organised flow patterns could be discerned only when there was stable or neutral stratification, the wind was roughly normal to the mountain ridge and the wind direction varied little with height. Corby has reproduced a diagram for determining the type of mountain air-flow after Forchtgott. It has been found from this diagram that the conditions at Jodhpur on the morning of 18 January were favourable for the development of standing eddies. In view of the stability of the ground layer and the presence of the ridge across the northerly winds, it appears likely that some stationary eddies with approximately horizontal axes had developed on the lee and extended beyond the observatory as illustrated in Fig. 2. Reverse flow up the lee slope appears to have been responsible for the observed wind reversal. The development of this eddy and the accompanying stirring of the stagnant saturated air appear to have played a significant part in the abrupt development and rapid intensification of the fog as early as 12 minutes before sunrise.

5.3. *The structure of the fog*—As already stated, well-defined diffraction rings were produced around the moon by the fog under study. The relationship between the diameter of cloud or fog droplets and the diffraction minima produced by them is given by the well-known equation

$$\sin\phi = (n + 0\cdot22)\ \frac{\lambda}{a} \qquad (1)$$

where ϕ is the angle at which the diffracted light is viewed off the transmitted beam, n is the order of the diffraction minimum for light of wave-length λ and a is the mean diameter of the droplets causing the phenomenon. The diameters of the fog droplets at 0700, 0712 and 0715 IST have been computed using equation (1). The results are given in Table 1.

The sudden chilling that led to the condensation of water vapour appears to have produced a multitude of small droplets of varying sizes leading to the appearance of an aureole. The average drop-size at the commencement of condensation was 15μ. The drop-size spectrum appears to have narrowed down rapidly until by 0712 IST, the corona presented well-defined red and blue annuli. The fog appears to have become practically homogeneous by this time with a drop-diameter of about 18μ. The subsequent darkening and loss of definition of the red ring and the reappearance of the aureole suggest rapid widening of the drop-size spectrum (Humphreys 1940).

The coronal structure and its variation thus lead to the following general inferences—

(*i*) When the aqueous tension in the atmosphere near the ground surpasses the equilibrium value, the sizes of the drops formed due to

TABLE 1

Variation with time of diameter of fog droplets

Time of observation (IST)	Description of observed corona	Surface wind		Temperature		Visibility (m)	Outer diam. of red ring	ϕ	Drop diameter (μ)
		Dir. (Deg.)	Speed (kts)	Dry bulb (°F)	Wet bulb (°F)				
0700	Bluish white aureole exteriorly fringed reddish brown	140	3	50·2	50·0	1000	6°30′	3° 0′	15·1
0712	Well defined corona with inner blue and outer red rings	140	2	49·8	49·8	450	5°30′	2°30′	18·2
0715	Aureole tinged bluish inside and reddish brown exteriorly	140	2	49·7	49·7	100	5° 0′	2°15′	20 2

condensation are dispersed over a wide spectrum.

(*ii*) As the fog so formed attains stability, the drop-size spectrum narrows down and the fog tends to become homogeneous.

(*iii*) Soon after the development of a homogeneous fog, the drop-size spectrum spreads out as more and more drops of varying sizes form due to subsequent condensation and growth by coalescence or collision and the fog once again becomes heterogeneous.

(*iv*) A homogeneous fog is only an early stage in a developing fog and this stage is of a relatively brief duration.

5.4. *Comparison with available details*—Haughton and Radford (George 1951) examined microscopically the drop-size in advection fogs on the Atlantic seaboard of the U.S.A. in an atmosphere uncontaminated by industrial pollution. They found that the drop size had an arithmetically mean diameter of 12μ. Mahrous (1954) reports from a study of sea fogs that generally speaking fog drops have diameters of between 16μ and 37μ in dense fogs with a visual range varying from 100–400 yards. The authors' results are in broad agreement with those of the above workers.

As already mentioned, no fog-bow made its appearance at about the time of sunrise (0727 IST) or later before the fog lifted off the ground *en masse* into stratus by 0830 IST. Johnson (1954) has shown that the drop diameter should be of the order of 50μ for the appearance of a mist or fog-bow. The results of the present study thus show that even after ageing, the fog drops did not reach diameters of 50μ and that they remained ranged between 20 and 50μ.

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