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Drop size distribution and liquid water in a winter fog at Delhi

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ABSTRACT. The note presents an account of measurements made of drop size distribution and liquid water in fog at various phases of its development and decay on one winter morning at Delhi. The general features observed are discussed briefly.

1. Introduction

On 16 December 1958 Delhi was in grip of persistent drifting type fog which lasted from early morning till about 1000 IST. Observations made on the day, at an open site on the ridge behind National Physical Laboratory, of size distributions of fog droplets and their variations with ageing of the fog are discussed briefly.

2. Technique of measurement

Glass slide ($\frac{1}{4}''$ by $3''$), having a thin uniform coating of magnesium oxide and mounted on a suitable holder, is ordinarily kept covered inside a casing. By pressing a lever arrangement the slide is made to come out of the cover and is exposed to fog for a short period of a few seconds. As one observer exposes the slide with its treated surface normal to the wind, a second observer notes the time of exposure on a stop watch and makes simultaneous observation of wind speed with a Casella air-meter. Noting of exposure time by a stop watch is sufficiently accurate for purposes of these measurements, as exposure in each case is made for at least 5 seconds. Speed of drift of fog on this day was high enough to cause impinging droplets to produce well-formed craters on magnesium oxide coating, and no external device for suction of fog air was necessary. Observations were made at intervals of about 15 minutes, beginning from 0730 IST till dissipation of the fog. Measurements of crater diameters were made with the help of a microscope, having a graticule fitted at the eye-piece, under magnification of 150, and the sizes so measured reduced to true drop diameters on the basis of calibration as by May (1950). For purposes of measurements, the slide was scanned along three horizontal strips near top, bottom and middle, the area scanned being such as contained at least 400 craters.

3. Results

Particulars regarding time of observation, period of exposure of slide and speed of wind, together with total concentration of droplets and liquid water in fog as calculated from drop size measurements, are given in Table 1. Histograms showing percentage of drops belonging to different size groups, based on 10 observations made during the period, are shown in Fig. 1. Fig. 2 shows variations in concentration of droplets and amount of liquid water at different epochs of observation. Corresponding changes in median volume diameter are plotted in Fig. 3.

4. Discussion

Fog droplets measured are seen to lie mostly in the diameter interval 10 μ to 50 μ, the median volume diameter (defined as that diameter above and below which liquid water content is the same) ranging from 25μ to 35μ. The largest drop recorded has a diameter of 85μ. Very small concentration of droplets of diameter less than 10μ is due apparently to rather low collection efficiency

TABLE 1

S. No.	Slide No.	Time (IST)	Exposure time (sec)	Average wind speed (m/s)	Concen-tration/c.c.	Liquid water content W (mg/m³)
1	3	0733	5·5	4·4	5·1	53
2	5	0739	5·2	5·3	3·7	48
3	7	0759	5·0	3·0	7·6	53
4	9	0815	5·2	3·6	5·1	42
5	11	0834	5·0	4·3	4·6	74
6	15	0851	5·0	3·7	2·4	38
7	17	0905	5·0	3·8	3·5	49
8	21	0925	10·2	4·6	0·63	6·2
9	24	0942	15·0	3·7	0·43	5·9
10	26	1000	60·0	5·2	0·05	0·62

of the catching device employed for purposes of the measurements. Observed drop concentration varies from the maximum 7·6/cc at 0800 IST to a much lower value at later dissipating stages of the fog. Liquid water content is highest, 74 mg/m³, at 0834 IST, falling rapidly to one tenth this value or less by 0925 IST as fog starts thinning out.

Considering data of similar observations made elsewhere by other workers, it is seen that Haughton and Radford (1938) in their measurements in fog on northeast coast of U.S.A. observed the median volume diameter to range from 26μ to 76μ and liquid water from 10 mg/m³ to 300 mg/m³. Kozima, Ono and Yamaji (1953) working on southeast coast of Hokkaido, Japan, observed considerable variations in microstructure of fog from one situation to another. While some of the fogs were found to be very rich in droplets of small sizes, others were composed of relatively large droplets, the mode diameter exceeding 20μ in many cases. Droplet concentrations as observed by them varied between 1 and 20/cc.

From Fig. 1 it is seen that, while at the initial stages concentration of droplets in the diameter range 9·5μ—19μ is nearly the same as in the range 19μ —28·5μ, concentration in the latter size group tends to predominate with ageing of the fog. This feature is probably due partly to growth of smaller droplets by progressive condensation and partly to loss in their number as a result of coalescence with drops of larger sizes. Rapid decrease of liquid water content towards end stages of fog is due obviously to rising ambient temperature and consequent evaporation of fog droplets. Rising trend of median volume diameter at dissipating stages of the fog, as shown in Fig. 3, may be explained as due to depletion at a greater rate of concentration of droplets of smaller sizes, by evaporation. Irregular variations observed in some instances in the drop size spectrum and associated parameters from one occasion of sampling to another may be accounted for as being due to differences in the life history of different parcels of the drifting type of fog, as in this case.

No reliable observation of temperature and humidity could be made at the observation site. Using data of the meteorological observatory at Safdarjung (direct distance about 4 miles), where there was also a similar development of fog on this morning, it is seen that the minimum temperature recorded in the early morning was 8·0°C, while the dew-point temperature at 0530 IST was 8·3°C. Using this observed depression of minimum temperature below dew point,

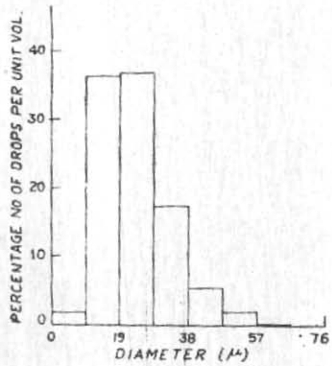

Fig. 1(a). 0733 IST
Conc. = 5·1/c.c., $W = 53$ mg/m³

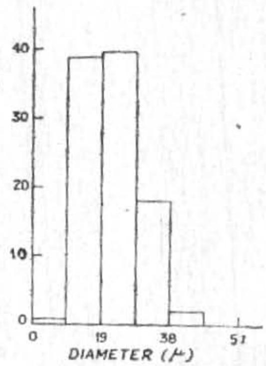

Fig. 1(b). 0739 IST
Conc. = 3·7/c.c., $W = 48$ mg/m³

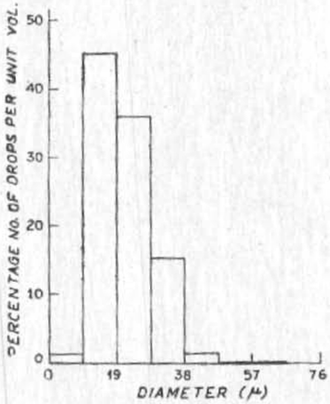

Fig. 1(c). 0759 IST
Conc. = 7·6/c.c., $W = 53$ mg/m³

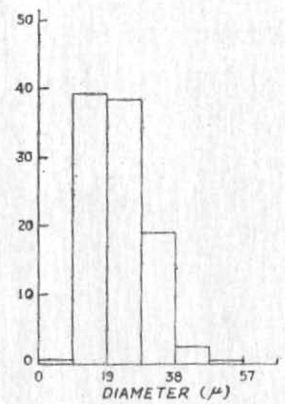

Fig. 1(d). 0815 IST
Conc. = 5·1/c.c., $W = 42$ mg/m³

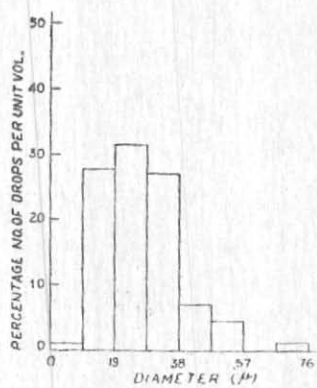

Fig. 1(e). 0834 IST
Conc. = 4·6/c.c., $W = 74$ mg/m³

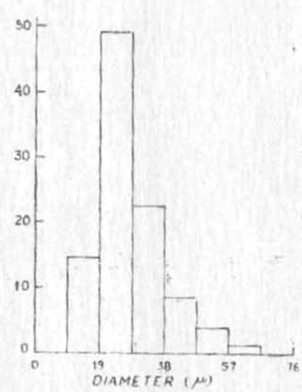

Fig. 1(f). 0851 IST
Conc. = 2·4/c.c., $W = 38$ mg/m³

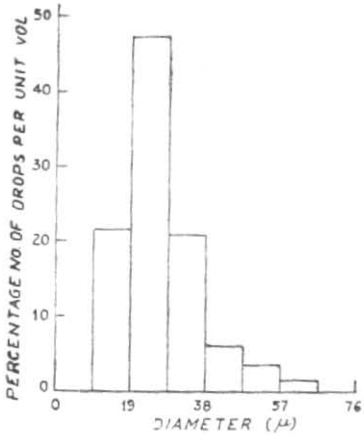

Fig. 1(g). 0905 IST
Conc.$=3\cdot5$/c.c., $W=49$ mg/m^3

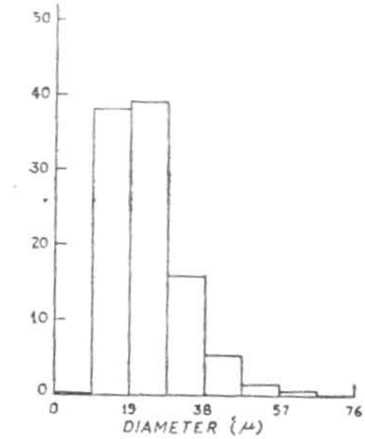

Fig. 1(h). 0925 IST
Conc.$=0\cdot63$/c.c., $W=6\cdot2$ mg/m^3

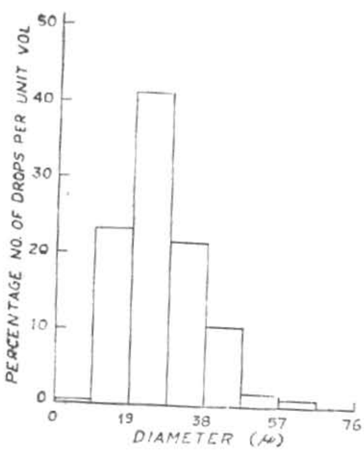

Fig. 1(i). 0942 IST
Conc.$=0\cdot43$/c.c., $W=5\cdot9$ mg/m^3

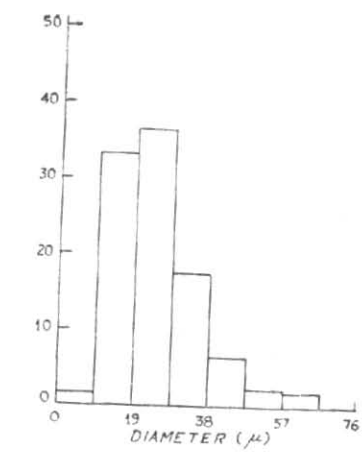

Fig. 1(j). 1000 IST
Conc.$=0\cdot05$/c.c., $W=0\cdot62$ mg/m^3

Fig. 1. Drop size distribution of fog at different epochs

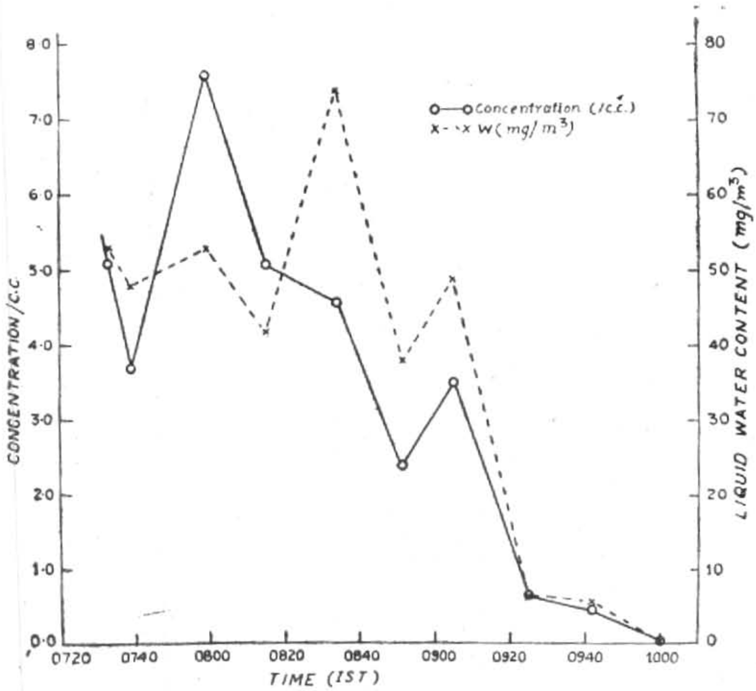

Fig. 2. Variation of concentration of droplets and liquid water content with time

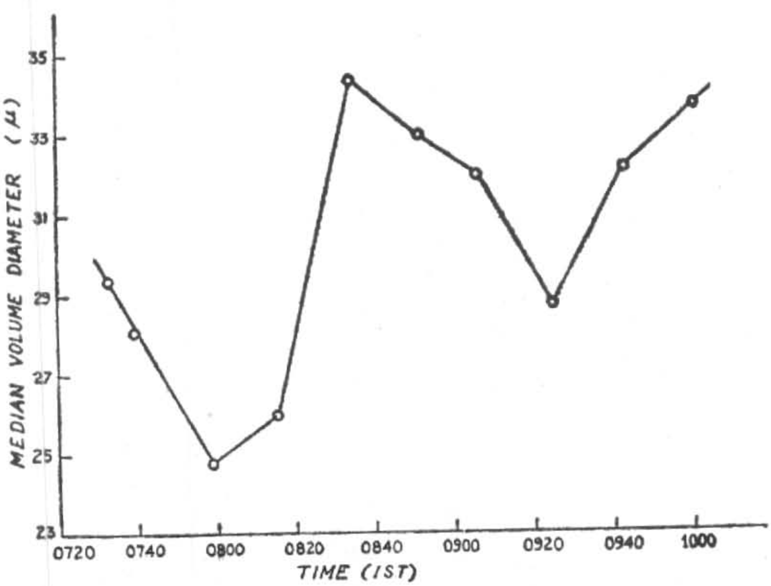

Fig. 3. Variation of median volume diameter with time

theoretically estimated liquid water in fog comes to about 170 mg/m³, which is comparable with the observed maximum liquid water content of 74 mg/m³ at 0834 hours.

On the basis of data collected, it may be possible to estimate how far the observed fog droplet sizes are explained by consideration of hygroscopic nuclei content of air. That fog often develops or persists in situations when relative humidity is below 100% suggests that hygroscopic nuclei probably play an important part in its development and subsequent life history. Assuming that fog droplets of sizes larger than 10μ diameter are results of condensation on hygroscopic nuclei, a rough estimate of average size of such nuclei can be made on the basis of observed liquid water content, if the chemical composition of hygroscopic particles is known. If we assume that hygroscopic nuclei in the lower air are mostly sodium chloride and that these grow by condensation till these are in equilibrium under condition of relative humidity 100%, the equilibrium radius r of a solution droplet, formed on a nucleus of mass m is given by (Best 1954)—

$$r = \sqrt{m/3P}$$

$$\text{where } P = \frac{4TM}{\rho R\theta}$$

and the symbols have the following meanings: T—Surface tension of water, M—Molecular weight of water, ρ—Density of solution droplet, R—Universal gas constant and θ—Absolute temperature. Now, using concentration 7·6/cc, and liquid water 53 mg/m³, ($=53\times10^{-9}$ gm/cc) as was observed at 0759 IST, we get—

$$53 \times 10^{-9} = \frac{4\pi}{3}\,(m/3P)^{\frac{3}{2}} \times 7\cdot6,$$

which gives the average mass of salt particle as $0\cdot95 \times 10^{-12}$ gm, and its average radius as 0.45μ. A droplet formed on a salt nucleus of this size would have a diameter of about 24μ in equilibrium under atmospheric humidity 100%, which is about the same as the median volume diameter of 25μ observed at 0759 IST. Concentration of 7·6/cc of hygroscopic particles of mean radius 0·45μ, as has been assumed, may not at all be an over-estimate. Observations by Dessens (1949) at stations well inland in France have shown average concentration of sea-salt nuclei of radii greater than 0·1μ to be about 100/cc and of those larger than 1μ about 1/cc.

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